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INCIDENT LOSSES: IDENTIFICATION AND EVALUATION METHODS TO BE EMPLOYED

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Descriptions of the possible consequences of earthquake action on a building subject to some design decision are provided. These descriptions are structured so as to help in the selection of optimum seismic design criteria. The magnitude of each incident loss may or may not be closely correlated to the state of the damaged building. Some losses may be related to or even dependent upon the physical damage state, others may be more closely related to the maximum acceleration experienced, while others may be related to the interstory drift. Since these three characteristics can be affected by changing the design strategy, it is desirable to study the possibility of eliminating or minimizing the incident losses by changing the design strategy. The incident losses are perceived to be: repair estimate and supervision; property devaluation after repairs; loss of tenants; loss of business; loss of man-hours in restoring the order; loss of man-hours due to repairing operations; discomfort caused by building motion and noise caused by quake; life toll and injury; physical damage to buildings contents; rescue operations; traffic congestion; and impact on local economy. They are categorized according to who feels the impact of the loss, the owner, the occupant, or the public.

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INCIDENT LOSSES: IDENTIFICATION AND EVALUATION METHODS TO BE EMPLOYED

I. Introduction

In general, severe earthquake action upon a building results in physical damages, that is, damage to structural and/or non-structural elements in the building. In addition to the physical damages, other losses are incurred as a result of the earthquake. These losses take the form of physical damage to building contents, business interruption, lives lost, injuries suffered, time spent in cleanup, time spent in restoring order to the building contents, rescue activities, etc. These "non-physical" losses resulting from the earthquake incident will be referred to as incident losses.

The physical damages are tangible in that descriptions of damaged buildings have been documented and records of repairs made do exist. A study of the physical damages in the San Fernando area due to the February 9, 1971 earthquake is near completion: the cost of physical damages being defined as the repair cost ratio. (re., Progress Report: "Informal Summary of Status and Plans at End of First Year," R. V. Whitman)

While the physical damages are tangible and the costs readily evaluated, the incident losses may be intangible and far more difficult to evaluate. It is the purpose of the present study to identify the incident losses and develop methods of evaluating them. The reasons for undertaking such a study are to provide descriptions of the possible consequences, both direct and indirect, of earthquake action on a building subject to some design decision; and to structure this description in such a manner as to help in the decision-making process to select optimum seismic design criteria.

II. Scope of the Study

The scope of this phase of the Optimum Seismic Protection Project consists of the following tasks:

1. To identify and enumerate the incident losses to each concerned party, that is, to the building owner, to the building occupants, and to the public.
2. To establish measurements for each incident loss.
3. To study the possibility of eliminating or minimizing the incident loss by changing the design strategy.
4. To establish methods of transferring the measurements of the incident losses onto a common scale and incorporating them into the optimization process already being used in minimizing the total expected costs.

In identifying and enumerating the incident losses to each concerned party, we define explicitly what we want to evaluate. From the manner in which each loss is distributed among the building owner, the building occupant, and the public, we can decide the extent of the evaluation process used.

Due to the diverse characteristics of the incident losses, the evaluation process used in measuring the incident losses may differ for each loss. The choice of evaluation process will depend primarily upon the availability of data that is useful in measuring the specific incident loss. As a result, the units of measurement for the incident losses may be different for different incident losses. For example, we may measure loss of business in units of "dollars per day", while we may measure life toll in units of "lives lost".

The magnitude of each incident loss may or may not be closely correlated to the state of the damaged building. Some losses may be related to or even dependent upon the physical damage state, others may be more closely related to the maximum acceleration experienced, while others may be related to the interstory drift. Since these three characteristics can be affected by changing the design strategy, it is desirable to study the possibility of eliminating or minimizing the incident losses by changing the design strategy.

Since the units of measurement used in evaluating the incident losses may differ, we need a method of transferring all of the measurements into some common units. For example, a possible common unit is the dollar, since a decision-maker may prefer to consider problems in economic terms. Also, by using dollar values, the measurements of the incident losses can be converted into a ratio to construction cost and incorporated directly into the optimization process being used at present in minimizing the total of initial and expected physical costs. This simple economic view has many serious limitations, however, particularly if losses are large, or difficult to evaluate (e.g., loss of business or prestige), or if human suffering is involved. Therefore, more general approaches to preference and utility measurement are also being pursued.

III. Categorization of the incident losses and discussion of scope of study

At present, we perceive the incident losses to consist of those enumerated in tables I, II, and III categorized according to who feels the impact of the loss: the owner, the occupant, or the public. Also tabulated are our present estimates of what each loss is most closely related to, its sensitivity to design change, and the anticipated units of measurement. The estimates are in many cases very tentative and subject to change. One purpose of this interim report is to stimulate discussion about these values.

TABLE I

INCIDENT LOSSES TO THE BUILDING OWNER

INCIDENT LOSS	MOST CLOSELY RELATED TO			CAN BE AFFECTED BY DESIGN?	ANTICIPATED UNITS OF MEASUREMENT
	INTERSTORY DISPLACEMENT	MAXIMUM ACCELERATION	PHYSICAL DAMAGE STATE		
REPAIR ESTIMATE AND SUPERVISION			✓	YES	5% OF THE REPAIRING FEE
PROPERTY DEVALUATION AFTER REPAIRS			✓	YES	DEVALUATION RATIO IS PROPORTIONAL TO DAMAGE RATIO
LOSS OF TENANTS			✓	YES	(1) RENTAL INCOME CAN BE EXPRESSED AS % OF BUILDING VALUE (2) THE LOSS LEVEL MAY BE REPRESENTED BY THE TIME REQUIRED FOR RESTORING THE RENTAL INCOME

TABLE II

INCIDENT LOSSES TO THE BUILDING OCCUPANT

INCIDENT LOSS	CLOSELY RELATED TO		PHYSICAL DAMAGE STATE	CAN BE AFFECTED BY DESIGN?	ANTICIPATED UNITS OF MEASUREMENT
	INTERSTORY DISPLACEMENT	MAXIMUM ACCELERATION			
Loss of Business			✓	Yes	$/day
Loss of Man-Hours In Restoring The Order		✓		Maybe Maximum Drift Criteria will Control Maximum Acceleration	Man-Hours/100 sq.ft.
Loss of Man-Hours Due to Repairing Operations			✓	Yes	Man-Hours/100 sq.ft.
Discomfort Caused by Building Motion and Noise Caused by Quake.		✓		No, Except In High Damage Site	Fraction Of - People Uncomfortable / People Perceiving
Life Toll and Injury			✓	Yes	Lives Lost No. of Severe Injuries No. of Minor Injuries
Physical Damage To Buildings Contents (furniture, etc.)		✓		Yes	$/unit area

TABLE III

INCIDENT LOSSES TO THE PUBLIC

INCIDENT LOSS	CLOSELY RELATED TO		PHYSICAL DAMAGE STATE	CAN BE AFFECTED BY DESIGN?	ANTICIPATED UNITS OF MEASUREMENT
	INTERSTORY DISPLACEMENT	MAXIMUM ACCELERATION			
RESCUE OPERATIONS			✓	YES	$/Unit Area Spent On Assisting Victims Of Earthquake.
TRAFFIC CONGESTION			✓	YES	?(May not be Significant at Level of Single Building Design)
IMPACT ON LOCAL ECONOMY (Loss of jobs, emigration from earthquake area)			✓	YES	Local Growth Rate Index
LIFE TOLL & INJURY			✓	YES	Lives Lost No. of Severe Injuries No. of Minor Injuries

III. Description of Damage States

In the study of physical damages caused by earthquakes, a thorough review was made of about ten buildings for which Ayres, Cohen, and Hayakawa had collected detailed damage information (internal report in preparation). By comparing the description of physical damage with the repair cost, the physical damage was categorized into 9 damage states and the corresponding repair cost ratios, including the lower bounds, upper bounds and mean value, were defined.

Since some incident losses can be approximately related to the physical damage state, it was decided to undertake a study to determine more specifically the extent of the incident losses occurring in each physical damage state. A search through available literature was made in order to select photographs depicting all degrees of damage occurring as a result of earthquake action. A total of about 120 photographs were reproduced from the literature and indexed according to the source used and the building name, if noted in the text. This collection was divided into two groups according to type of damage: building damages and incident damages. Those from the building damage group were then classified into physical damage states strictly according to the damage depicted in the photograph as compared to the descriptions of physical damage states. Subsequently, the same photographs were categorized into physical damage states according to the verbal descriptions of damage to the buildings which the photographs depicted as a cross-check to ensure proper classification. In almost all instances, the damage state to which a photograph was assigned in the first run corresponded to or was less severe than the damage state that actually existed in the building. For example, in the first run a photograph of the Hill Building, Anchorage, Alaska, depicted a beam suffering substantial damage and apparently requiring replacement. As a result the photograph was classified as damage state 5. In the subsequent search of the literature, damages throughout the building were severe enough to classify the Hill Building as being in damage state 6. The reason for such inconsistencies is the fact that a photograph cannot tell the real story about the entire building, but can give an idea of only local damages. For the photographs subject to this inconsistency, the damage state to which it was assigned was adjusted depending on the nature and degree of damage depicted. Thus, the two approaches, when combined, yielded a reliable set of photographs depicting damage to the building, according to physical damage state.

The group of photographs illustrating incident damages were first classified by type of damages: damage to lights, damage to suspended acoustic ceilings, disruption of furniture and shelf contents, and accessibility of exits via stairways. Each type of incident damage was further divided into degree of damage. For example, the degrees of damage to lights ranged from disturbance of the light shades to the failure of light brackets resulting in all the lights falling to the floor. Next, through the index of photographs, each photograph was identified with a building and its given damage state. Thus the distribution of incident damage according to physical damage state was established.

From review of this photographic survey of the physical damage states, a more descriptive explanation of the damage states has been made and follows.

DAMAGE STATE DESCRIPTIONS

DAMAGE STATE	
1.	Minor non-structural damage - a few walls and partitions cracked, incidental mechanical & electrical damage. Minor shelf upset (less than half the shelf contents fall onto the floor). Light fixtures still in place - some shades disturbed, hangers bent.
2.	Localized non-structural damage - more extensive cracking (but still not widespread); possibly damage to elevators and/or other mechanical/electrical components. Large portion of shelf contents fall onto floor. Light fixtures shaken until some hangers break, some lights are left dangling from ceiling (but not fallen to floor). Several ceiling panels disturbed or fallen - plaster cracked.
3.	Widespread non-structural damage - possibly a few beams and columns cracked, although not noticeable. Shelves & bookcases overturned, desks slid across floor, small objects tossed about. Light fixtures same as 2. Most ceiling panels disturbed or fallen to the floor, several hangers broken or buckled. Exit stairways become littered with plaster chips.
4.	Minor structural damage - obvious cracking or yielding in a few structural members; substantial non-structural damage with widespread cracking. Most, or all, light fixture hangers broken - lights are shattered on the floor. Exit stairways are heavily littered with broken plaster, concrete blocks, and tiles.
5.	Substantial structural damage requiring repair or replacement of some structural members; associated extensive non-structural damage. Most ceiling panel hangers bent, buckled, or broken with most panels fallen to floor. Exit stairways may become completely buried by fallen partition walls.
6.	Major structural damage requiring repair or replacement of many structural members; associated non-structural damage requiring repairs to major portion of interior; building vacated during repairs.
7.	Building condemned
8.	Collapse

For the purposes of presentation, the 120 photographs that were collected have been edited to include a sufficient number to indicate representative degrees of damage and placed (with captions) in an album according to damage state. Also, for the purposes of explicitly describing, for a building, what might be expected to happen during an earthquake, what dangers exist for the occupants, and what the post-earthquake activities are, a scenario of each damage state has been drawn up. This scenario and verbal description, combined with the photo survey, will provide a basis for describing and assessing incident losses that are related to the physical damage state. A copy of the scenarios is appended to this report.

IV. Approximate Dollar Costs of Incident Losses

Approximate dollar costs of the incident losses, according to building function will be assigned and inserted in the table shown on the following page. In most cases the dollar estimate will be based if possible on statistics of average incomes, business receipts, etc., and on knowledge of the overall consequences of building damages from earthquakes. At present, there is not sufficient data to assign values to all of the incident losses in the table.

A discussion of the variables expected to be encountered in evaluating each incident loss follows the table.

DOLLAR ESTIMATES OF INCIDENT LOSSES IN {OFFICE BLDGS. / APARTMENT BLDGS. / HOSPITALS}

	INCIDENT LOSS	DAMAGE STATE 0	1	2	3	4	5	6	7	8
TO BUILDING OWNER	REPAIR ESTIMATE AND SUPERVISION									
	PROPERTY DEVALUATION AFTER REPAIRS									
	LOSS OF TENANTS									
	LOSS OF BUSINESS									
TO BUILDING OCCUPANTS	LOSS OF MAN-HOURS IN RESTORING ORDER									
	LOSS OF MAN-HOURS DUE TO REPAIR OPERATIONS									
	DISCOMFORT CAUSED BY BUILDING MOTION & NOISE CAUSED BY QUAKE									
	PHYSICAL DAMAGE TO BUILDING CONTENTS (FURNITURE, ETC.)									
TO THE PUBLIC	RESCUE OPERATIONS									
	TRAFFIC CONGESTION									
	IMPACT ON LOCAL ECONOMY									
TO ALL	LIFE TOLL AND INJURY									

Repair supervision—Repair estimates will probably cost the building owner a percentage of the actual repair cost. Therefore the cost of the repair estimate is expected to increase with increasing damage state and not to depend on building function. However, the cost to have the repair operations supervised may depend on building functions: while repair operations can continue almost unrestricted in office buildings and apartment buildings, close supervision will be required in hospitals so as to cause minimum disturbance. The closer the supervision required, the greater the cost. Values may not become significant until damage state 3.

Property devaluation after repairs—Since the assessed value of a building after repairs is usually identical to its assessed value before the earthquake, the actual economic value of the building is restored by the repair process. So, for low damage states, this incident loss does not exist.

However, if the building has suffered appreciable damage, or if it suffered more severe damages than nearby buildings, people may be inclined to feel this building is not as safe as others. As a result, renting space in this building is not so desirable as in nearby buildings. Thus the building is, in effect, devalued. This incident loss is quite intangible and may be more important in apartment buildings where the occupants are seeking a safe building, than in office buildings. Loss will not be felt until the building reaches a damage state for which people begin to doubt the safe performance of the building.

Loss of Tenants—If a building suffers only slight damages, the occupants probably view the risks involved in staying there as being very small. But if a building suffers heavy damages, the occupants may view the increased risks as unacceptable and decide to move to another building (provided there are others which appear safer). Loss of a tenant results in lost rental income to the owner. The magnitude of the loss will vary with building function, as the effective rent per unit area of floor varies for office buildings, apartment buildings, and hospitals. Losses are expected to increase with higher damage states (increasing risks), and are expected not to occur at all for low damage states (where the perceived risks are acceptable).

Loss of business—When damage is severe enough to cause temporary closing of the building, the building is said to be out of function. When out of function, no activities are carried on and income or benefits derived from use of the building are prevented. In office buildings, the result is loss of work days and can be related to the business receipts normally received for a day's work. In apartment buildings, the benefits of shelter are deprived and the occupants are forced to relocate temporarily. In hospitals, the loss will be a combination of the above two, in addition to the prevention of health and medical services to the community. It can be seen that the loss of "business" would be greatest for hospitals and perhaps least for owners of apartment buildings. Also, the cost of lost business, beginning at about damage state 5, will increase with damage state, since the length of time the building is closed for inspection and/or repairs increases with damage state.

Loss of man-hours in restoring order—Beginning in damage state 1, the contents of a building will suffer varying degrees of disruption, as demonstrated in earlier descriptions. So, with increasing damage state, the degree of disruption increases and the time required to put things back in place increases. From the incident loss photographs (described above), Terry Sun (of Ayres, Cohen and Hayakawa) who has experience in making repair estimates of earthquake damaged buildings, provided estimates of man-hours per unit area required to return the area shown in a photo to its pre-earthquake condition. This information permitted the assignment of time estimates for restoring the order to the building. The cost to the occupants to restore the order depends upon the hourly rate of the person involved, which in turn depends upon the building function. It is expected that the cost of restoring order in an apartment building (where the tenants straighten up) will be relatively small, while it may become quite appreciable in hospitals and office buildings (where perhaps only professionals can return their books to the proper shelves).

Loss of man-hours due to repair operations—Once a building suffers physical damage, it is necessary to bring in workmen or contractors to make repairs. The length of time they are in the building depends on the severity and extent of damage (damage state). If repairs are made at a time when the occupants are not present, there will be no loss of man-hours. However, if it is necessary to make repairs while the building is occupied, the normal activities of the occupants will be interfered with or altogether halted. Thus there will be a loss of man hours, the cost of which depends upon the value assigned to the activities normally carried on, which varies with building function.

Discomfort caused by building motion and noise— When a building is shaken by an earthquake it will experience varying degrees of motion. Also, noises from the motion of structural and nonstructural elements in the building can be heard. These events appear to be related to the maximum acceleration and not necessarily to damage state or building function. Evaluation of the anxiety felt will obviously have to take the form of interviews with people to get their opinions on this topic.

In low activity rate areas, anxiety will probably not be important compared to other incident losses due to the infrequency of occurrence of earthquake action on the building. Also, in buildings with high damage, anxiety due to motion and noise will probably be insignificant compared to the anxiety caused by observance of the extensive physical damage. So, it appears that the circumstances in which discomfort may become important will be in buildings suffering light damages in high activity rate areas.

Rescue operations— For lightly damaged buildings, no rescue operations are likely to occur. However, for buildings suffering partial or complete collapse, rescue activities are likely to ensue. The extent of the rescue operation will depend on the number of occupants trapped or missing. The probability of the occupants' escaping depends on their perception of the dangers and their ability to evacuate the building quickly. Thus, for office buildings, most of the occupants being healthy and perceptive will probably escape; for apartment buildings, children may not be aware of the danger and, not knowing what to do, may inhibit evacuation; and for hospitals, many bed-ridden patients may be unable to move themselves at all. So the extent (and consequently, the cost) of rescue activities will depend on building function, being most costly for hospitals.

Traffic congestion—Under severe damages to a building, debris may fall into the streets and cause traffic blockage. If the earthquake is of high intensity, many people who are at work may decide to leave work and drive home to see if their families are safe. Or, if the building has collapsed or catches fire, fire department, police department, and rescue personnel may be occupying the streets surrounding the building. Traffic congestion will result, perhaps reducing the effectiveness of emergency operations. The implications of such possibilities have not yet been fully explored: it is still to be decided if this incident loss will be evaluated in the first stages of this study.

Impact on local economy—Should building damage be so severe as to cause a large number of occupants to move out, and should a large number of buildings be severely damaged, then the loss of these tenants may cause a severe blow to the local economy. For example, many people may move to a nearby city which they consider "safe". The result is a decrease in the number of worker-consumers and a resulting drop in local economy. Also, who the "tenant" is affects the magnitude of the impact. If a corporation moves its headquarters to an office building in another city, a large loss in revenue will be felt; but if a number of families migrate to an apartment building in a nearby city, the impact would not be so great. Therefore building function should again be considered in evaluating the incident loss.

The study will review several of the approaches that have been proposed or used by public decision-making bodies when human injuries and lives are unavoidably involved in the balance. These include, for example, methods which, in more or less complex ways, assign an economic value to the price the public is or "should be" prepared to pay to save an arbitrary human life. While such studies and their design implications represent information that might have some influence on a decision-maker's preferences and utilities, it is not planned to recommend that they be used directly as the basis for decision making.

Note: While most of the above incident losses can be evaluated according to the damage state of a given building, three of them (rescue operations, traffic congestion, and effect on local economy) will depend to a greater extent on the damages to all buildings in the area. Since the behavior ofthe majority of buildings is affected by the intensity of the earthquake, it appears that it will be more logical to evaluate these three incident losses according to intensity. For a given intensity, buildings in the area will be in varying damage states, but it is anticipated that most buildings will fall within a range of some "representative" damage state for this intensity. So, evaluation of rescue operations, traffic congestion, and effect on local economy will be done for a "representative" damage state, that is, assuming all buildings suffer the same degree of damage.

V. Incorporation of Incident Losses into the Optimization Process Presently being Used in Minimizing the Physical Costs.

It is expected that one output of this study will be values of the incident losses expressed in terms of dollars per unit area of floor for each damage state. These figures will be "typical" figures expected to be encountered. Therefore, they can be multiplied by a "typical" ratio of gross floor area per initial construction cost to yield an incident loss ratio, similar to the repair cost ratio presently being used. In this form, the incident losses can be incorporated directly into the optimization process as the physical costs are now.

In addition to providing information for use in the optimization process, this study will provide the decision-maker with information that might be useful to him. It is anticipated that this information be presented by describing states in multiple-objective terms.

One form of output will provide a set of consistent descriptions of the incident losses, by damage state, as they would be directly perceived. This information will probably be expressed in terms of the units of measurement used in evaluating each incident loss. Thus, the decision-maker is provided with estimates of the expected values of life toll, days of business interruption, man-hours to clean up, etc., and who feels the impact of each loss.

Next, estimates of the expected values of the incident losses will be weighted in order to facilitate comparison of the impacts of the losses. The output will be expressed in terms of expected equivalent monetary costs of the incident losses, with the valuation procedures explicitly stated for the conversion of each loss.

Finally, the consistent set of descriptions of incident losses by damage state will be used in assessing involved people's preferences over the range of losses. From these preference functions, utilities will be determined for the various consequences that can result from a design decision and the decision-maker can better understand the utilities of the options available to him.

In conclusion, the decision-maker will be provided with information expressed in multiple-objective terms. He has the choice of using whatever forms of the output he prefers in his analysis of the problem. For example, he may disagree with this study's estimations of monetary costs of some incident losses, in which case he has the option of considering the incident loss in its directly-perceived form or of inserting his own valuation procedure for assigning a monetary cost. As a result, the decision-maker can choose those forms of the output he considers the most applicable measures of the incident losses.