INSURANCE AND THE NATURAL HAZARDS

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ABSTRACT

Natural hazards—floods, hurricanes, tornadoes, earthquakes, windstorms and hailstorms—cause considerable property damage in various parts of the world. In the United States, average annual damage resulting from these hazards is increasing rapidly. A large percentage of the damages occur as a result of infrequent, but severe, geophysical events (individual storms or earthquakes). If aggregate damage resulting from the event is exceptionally large, the event is called a natural disaster. The number of natural disasters in the United States is increasing each year. Resultant property losses are increasing even more rapidly. Increased density of properties susceptible to damage, increased value of these properties, and increased cost of repair have raised the probability of natural disaster occurrence in recent years even though the magnitude and character of the natural hazards have not changed.

Insurance is one means of protection against the natural hazards for fixed property. In this report, one-to-four family dwelling structures represent fixed property. To provide protection, two components of risk must be evaluated: (1) risk per individual structure and (2) risk of a large number of simultaneous losses—catastrophe potential. The latter component has attained added importance recently with the increased number and magnitude of natural disasters.

Information available for risk evaluation is (1) past damage experience; (2) data on the damage susceptibility of structures to be insured and the cost of repair; and (3) knowledge of physical characteristics of the natural hazards from the natural sciences. Damage experience results from the interaction of a natural hazard (frequency, location and severity of a geophysical event—storm, earthquake or flood) with characteristics and geographical distribution of exposed properties. Occasionally, interaction between the geophysical event and the distribution of properties leads to the creation of catastrophic losses resulting in a natural disaster. Evaluation of risk must be based either upon a retrospective or prospective measure of this damage experience.

Past damage experience, a retrospective measure of loss potential, is a poor measure of future risk because of (1) non-stationarity of property characteristics; (2) bias introduced by chance interactions of hazard and property array; and (3) by random occurrence (or non-occurrence) of a severe geophysical event during the short sampling period of years that is usually available for study. A pure extrapolation into the future of past loss experience, including the chance combinations of events that led to past natural disasters, does not provide a great amount of insight into the character of future risk.

What is needed is not actual damage that occurred as a result of past geophysical events, but damage resulting to the present distribution of properties from a recurrence of these past events. For example, to estimate future earthquake risk in California, emphasis should *not* be on what the 1906 San Francisco earthquake cost, but what it would cost if a comparable earthquake occurred today and affected the present type, distribution, and value of properties.

A supplementary approach to the use of loss experience (called Natural Hazard Simulation) is presented which provides a prospective measure of risk. A mathematical approximation of the natural hazard mechanism is constructed which artificially produces geophysical events that mathematically interact with a given geographical array of properties. Natural Hazard Simulation utilizes and ties together available pertinent information. Use of an electronic computer permits calculation of a large number of, say, 25-year sequences of synthetic loss experience which can be used to estimate the two measures of natural hazard risk. "Natural disasters" occur at irregular intervals in the simulation analysis when a severe geophysical event occurs near a center of population.

Using this approach, effects of a recurrence of past geophysical events or simulated future events upon present or hypothetical future distributions and types of properties can be estimated. It produces, in effect, a weighted measure of the many possible interactions between natural hazard and property array which, because of his short life span, man cannot afford to wait for nature to produce. Characteristics of an insurance operation needed to cover the hazard (rating, underwriting, claim settlement, loss reserving, and reinsurance) also are simulated.

Examples of the application of Natural Hazard Simulation to flood, earthquake, hurricane wind and tides, winter windstorm, and thunderstormspawned hazards (such as tornadoes, wind and hail hazard) are presented. Purpose of the application to flood hazard was to (1) estimate magnitude of the hazard to more than fifty-million dwelling structures in the United States for which very little damage experience was available and (2) determine characteristics of a joint Insurance Industry/Federal Government flood insurance program need to cover the hazard. Characteristics of a joint program were needed to establish relationships and financial arrangements between the Federal Government and the Insurance Industry. This work was done as consultants to the U.S. Department of Housing and Urban Development during development of a National Flood Insurance Program which is now operational. In this plan, the Federal Government assumes a portion of risk by acting as a reinsurer against excessive losses on industry's share of the Program.

An application of Natural Hazard Simulation to the earthquake hazard on the West Coast of the United States has been made. Examples of mathematically produced earthshock patterns are given. Correspondence between calculated and observed patterns is good. Measures of both components of risk are discussed for the present array of 625,000 dwellings in the San Francisco Metropolitan area when a recurrence of all earthquakes in the historical past (170 years) is used as a measure of earthquake hazard. A similar type of analysis also has been made for the Los Angeles Metropolitan area.

An application of the approach to the hurricane wind hazard is illustrated using computer printouts of the geographical pattern of highest wind expected during a hurricane's passage as obtained from the computerized mathematical model. Calculated patterns of wind speed severity provide realistic approximations of observed patterns. An example of the interaction between natural hazard and property array in producing a "natural disaster" is illustrated by calculating "loss experience" to dwelling properties in Louisiana from an intense hurricane whose path is successively changed relative to centers of population. The effect of changing the intensity of a hurricane upon resulting damage when the path is held constant is also shown. Both measures of hurricane wind risk—expected loss per exposure and catastrophe potential—are being estimated by developing "loss experience" to the present array of dwelling properties in the Gulf and Atlantic States based upon two measures of the magnitude of the hurricane wind hazard; namely, (1) a recurrence of hurricanes of various intensities and paths which have been recorded in the historical past and (2) a number of series of 25-year sequences of "synthetic loss experience" based upon computer simulation techniques.

An application of Natural Hazard Simulation to winter windstorm and thunderstorm-spawned tornadoes, wind, and hail in the Middle Western United States has been carried out for the first measure of risk. The mathematical model for obtaining a measure of catastrophe potential for these hazards is currently being developed. Future applications will include development of an integrated procedure for simulating "loss experience" from all of the natural hazards to a given array of structures in various geographical areas.

Natural hazard simulation offers a supplementary approach to the sole use of past loss experience for (1) estimating the two components of natural hazard risk and (2) developing characteristics of an insurance program needed to cover the natural hazards at a time when average annual property damages caused by natural hazards are increasing rapidly because of the increased number and magnitude of natural disasters.

RÉSUMÉ

L'assurance et les périls de nature

Les risques (hazards) naturels telles que les inondations, les ouragans, tourbillons, tornades et tremblements de terre etc. causent dans différentes parties du monde de dommages considérables aux propriétés et biens privés. Aux Etats-Unis, la moyenne annuelle de ces destructions augmente très vite. Bon nombre de celles-ci sont le résultat de très graves ravages géophysiques exceptionnels: tempêtes isolées ou tremblements de terre. Si le tôtal des dégâts entraînés par l'événement est très important, on parle d'un désastre naturel. Les pertes amenées par ces dégâts deviennent de plus en plus considérables d'autant plus qu'aux Etats Unis, le nombre de ces désastres augmente chaque année. L'accroissement des biens et la concentration toujours plus dense des propriétés exposées aux risques d'une part et l'augmentation des frais de réparations d'autre part, ont augmenté la probabilité de désastre naturel ces dernières années quoique l'ampleur et les caractéristiques du risque naturel n'aient pas changés.

L'assurance est une forme de protection des immeubles contres les risques (hazards) naturels. Dans ce rapport nous entendons par immeubles les maisons d'une à quatre familles. Afin de réaliser la protection contre ces risques, il faut évaluer ses deux composants c.à.d. 1e le risque par structure individuelle et 2e le risque de conflagration importante — la catastrophe en puissance. Ce dernier a pris récemment plus d'importance à cause de l'accroissement du nombre et de l'ampleur des désastres naturels.

Les informations valables et disponibles pour l'évaluation du risque sont: 1e les expériences obtenus pendant plusieurs périodes d'observation, 2e les renseignements sur la susceptibilité des dommages vu les constructions à assurer et les frais de réparations, 3e la connaissance des caractéristiques physiques de ces risques naturels par la contribution des sciences naturelles.

L'expérience s'établit par l'interaction de tous les éléments naturels du risque (fréquence, lieu, gravité) y comprises les caractéristiques et la répartition géographique des biens exposés.

L'interaction entre l'événement géographique et la répartition des biens peut occasionnellement donner lieu à des "dégâts catastrophiques" .Appelé ici désastre naturel. L'évaluation du risque doit être basé sur une mesure rétrospective ou prospective de cet expérience.

Une série de ravages dans le passé, aussi bien que la mesure rétrospective sont une pauvre mesure de perte potentielle pour un risque futur à cause 1e du caractère non-stable des propriétés, 2e du biais dû aux effets aléatoires du risque ± favorables et la répartition des propriétés donnée, 3e du hasard d'encourir un événement géographique pariculièrement rare et grave pendant la période relativement courte d'observation. On ne peut se porter garant de l'aspect future du risque en faisant une simple extrapolation, même en admettant les aspects aléatoires qui ont provoqué ces événements dans le passé. Nous n'apportons donc aucun intérêt aux dommages actuels, causés par ces événements géographiques du passé, mais bien à l'évolution des dommages en affectant la répartition actuelle des objets par une série d'événements développés dans le passé. Par exemple, le risque éventuel de tremblement de terre en Californie. Nous ne sommes nullement intéressés au coût du tremblement de terre de 1906 à San Francisco, mais ce qu'il coûterait si un tremblement de terre semblable se produisait aujourd'hui en fonction du type actuel de la répartition et de la valeur des biens.

Une "Approach" supplémentaire à l'usage de l'expérience de perte (appelée "Natural Hazard Simulation") a été élaborée. Elle permet la réalisation d'une mesure prospective du risque. Une approximation mathématique du mécanisme de risque naturel a été réalisée. Ainsi nous pouvons simuler les événements géophysiques alternant avec la répartition géographique des biens. N.H.S. utilise et réunit toutes les informations disponibles et pertinantes. L'usage d'un ordinateur électronique permet de calculer systématiquement les deux mesures stochastiques du risque naturel en utilisant des pertes artificielles obtenues au cours de séquences de 25-années d'expérience. On obtient les désastres naturels par simulation à intervalles irréguliers quand un événement géophysique très grave se produit près d'une centre de population.

En utilisant cette "approach" on arrive à estimer les effets obtenus lors de répétition d'événements du passé ou de simulation des ravages présent ou hypothétiques. Nous obtenons ainsi une mesure pondérée d'une multitude d'interactions possibles entre les risques naturels et les séries de répartition géographique des propriétés en tenant bien entendu compte du court espace de vie. Les caractéristiques d'une opération d'assurance nécessaire pour couvrir un risque (hazard) sont aussi envisagées (tarification, souscription, règlement du sinistre, établir des réserves pour les sinistres en suspens et réassurance).

Nous avons appliqué la technique du N.H.S. aux inondations, aux tremblements de terre, aux ouragans, aux raz de morée etc. Le but d'application, aux risque d'inondation était 1e d'estimer avec peu d'observation l'ampleur du risque pour plus de cinquante million d'immeubles aux Etats-Unis et 2e de déterminer les paramètres nécessaires d'un programme établi en commun par les industries des assurances et le gouvernement général. Pour faire face à de tels risques un programme en commun était nécessaire. Il était donc souhaitable de relever ses caractéristiques afin d'établir les relations nécessaires et de faciliter les arrangements financiers. Ce travail a été réalisé consultant au "V.S. Department of Housing and Urban Development", pendant le développement d'un programme national d'assurance inondation, qui est maintenant devenu opérationnel. Dans ce projet, le gouvernement général assume une partie du risque en agissant comme réassureur des pertes excessives à une note établie par les assureurs.

Une Application du N.H.S. au tremblement de terre a été effectuée pour la côte de l'Ouest des Etats-Unis, un modele mathématique, afin d'obtenir une mesure de risque éventuelle a été réalisé. La correspondance entre les modèles simulés et les observations est assez satisfaisante. Les deux variables de risque ont été discutés pour l'ordre actuel de 625.000 immeubles de San Francisco. A ce but on a soumis la métropole à une série de tous les tremblements de terre des 170 dernières années. Cette analyse a aussi été réalisé pour la métropole de Los Angeles.

On a appliqué le modèle au risque d'ouragan, de cyclone et de tourbillons divers. Pour cela on a fait une mise en page, par ordinateur, des caractéristiques géographiques du vent, supposé le plus grave, durant son passage. Le passage aussi a été simulé par ordinateur. Les modèles calculés pour différentes gravités de vent démontrent l'aspect réaliste vis-à-vis des modèles observés. Un exemple des conséquences des interactions entre les risques naturels et la répartition géographique des propriétés, pour les désastres naturels a été obtenu en effectuant "l'expérience de perte" pour les immeubles en Louisiane. La trafectoire du tourbillon a successivement été modifiée par rapport aux centres de population. L'effet de changement de l'intensité du tourbillon a été démontré en gardant le trajet constant. Les deux mesures de risque de tourbillon (perte causée par l'exposition et la catastrophe potentielle) ont été estimés en développant "l'expérience de perte" pour les ensembles d'immeubles actuels au "Gulf and Atlantic States". On a retenu deux hypothèses pour l'ampleur de vent 1e Une répétition de coups de vent de différentes intensités et directions recueillie pendant plusieurs années. 2e Un grand nombre de séries de 25 années d'expérience de perte synthétique basées sur les techniques de simulation d'un ordinateur.

Une application de simulation de risque naturel pour le tempête d'hiver et les tornades orageuses, les vents et les grêles en "The Middle Western United States" a été réalisée pour la première mesure du risque.

Le modèle mathématique pour obtenir une mesure de catastrophe potentielle en puissance pour ces risques est couramment développé.

Des applications ultérieures envisageront le développement d'une méthode, la simulation de l'expérience passée de tous les risques (hazards) naturels pour une "array" donnée de structures dans différents airs géographiques variées.

La simulation de risque naturel offre une approach supplémentaire pour le seul usage de "l'expérience de perte" afin d'estimer les deux composants de risque naturel et de développer les caractéristiques d'un programme d'assurance nécessaire pour couvrir ces risques à l'époque où la valeur moyenne annuelle des dégâts ainsi causés aux biens croît rapidement de par l'augmentation en nombre et l'amplitude des dits risques.

Property damage caused by the natural hazards

Land, oceans, and atmosphere comprise the natural environment of man. Usually this environment is tranquil. However, at unpredictable times and places, elements of the environment become hostile and present a threat to man and his possessions. These hostile events are the natural hazards—floods, hurricanes, tornadoes, earthquakes and hailstorms—which occur in many parts of the world (Exhibit 1). Type and severity varies markedly from one portion of the earth to another. In the United States, earthquakes occur in the Western States; hurricanes affect the Gulf and Atlantic coastlines; severe thunderstorms with accompanying tornadoes, hail and high wind are prevalent in the Middlewest; winter and spring windstorms affect the Midwestern and Northern states.

Dacy and Kunreuther (1969) have shown that nearly all sections of the United States are subject to significant property losses resulting from one or more of these hazards. Natural hazards have several unique characteristics that distinguish them from other hazards: (1) in any given area, the occurrence of a severe geophysical event is rare—a long past history is needed to include many past occurrences; (2) a large percentage of total property damage attributable to the natural hazards occurs as a result of these rare, but severe geophysical events. If aggregate damage resulting from the event is exceptionally large, the event is called a natural disaster.

The number of natural disasters is increasing each year in the United States and resulting property damage is increasing even more rapidly. The trend in average annual damage caused by the natural hazards, which includes the natural disasters, is steeply upward. Information in Dacy and Kunreuther's paper suggests that average annual property damage is currently more than $ 700,000,000 a year. In many years, property damage is less than

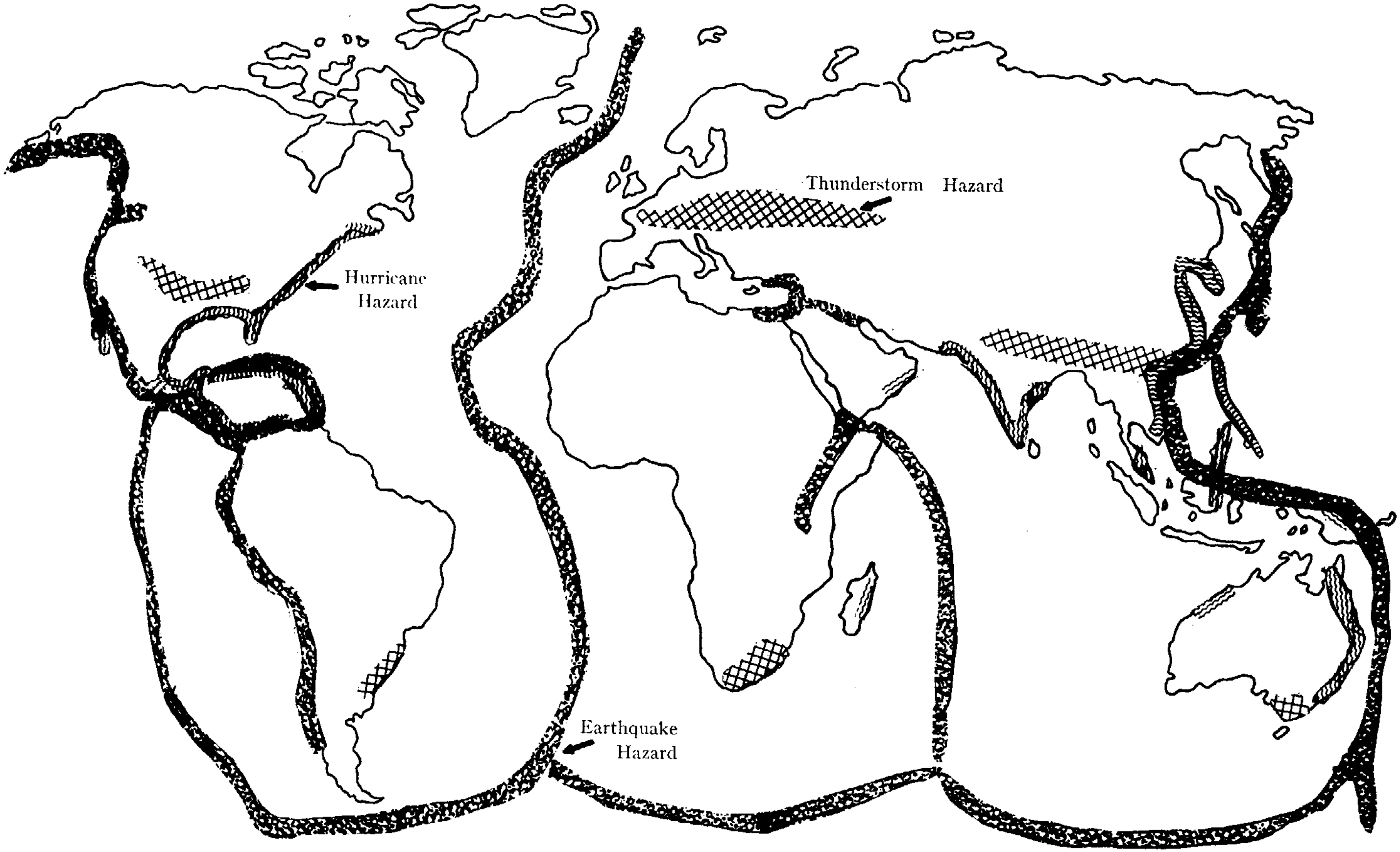

Exhibit 1. Areas prone to the destructive forces of Thunderstorms, Hurricanes, and Earthquakes.

the average. In some years, damage is much greater than the average. In 1965—the year of Hurricane Betsy—property damage resulting from all natural hazards is estimated to have exceeded 2.7 billion dollars. Maunder (1970) shows that the weather hazards alone (hurricanes, tornadoes, hailstorms and winter windstorm) exert a significant effect upon various economic activities in the United States. Floods and earthquakes can exert similar effects.

Insurance as a means of protection

Insurance is one means of protection against the natural hazards. Hendrick and Friedman (1965) estimate that insured property losses due to the weather hazards are averaging nearly one-half billion dollars a year. To provide protection, an evaluation of risk must be made. To evaluate risk, information is needed on the loss-producing characteristics of the hazard. Two components of risk must be evaluated. The first is expected loss-perindividual exposure. The second is a measure of the probability of simultaneous damage to a number of structures in an area—the catastrophe potential. The second measure is not important in many lines of insurance, but it is of increased importance in natural hazard coverages because of increasing numbers of natural disasters. With information on these two measures, decisions can be made regarding rating, underwriting, claim settlement, loss reserving and reinsuring of properties insured against these hazards.

Evaluation of Risk

Types of information available for risk evaluation are (1) past damage statistics; (2) data on the structure to be insured including its damage susceptibility; and (3) knowledge from the natural sciences—seismology, oceanography, meteorology and climatology.

Past damage experience, if taken by itself, is not a good measure of risk. Time changes over the years occur in:

1. type of construction;
2. susceptibility of structure to damage;
3. building codes;
4. kind and amount of insurance;
5. size and type of deductible;
6. cost of repair.

All of these factors help to make damage statistics inconsistent over a period of time so that it is not possible to compare damage statistics of 1970 with statistics of 50 years ago or even 10 years ago. The character of the natural hazards does not change with time, but property characteristics are rapidly changing. Damage experience is a resultant of an interaction of (1) the natural hazard (frequency and severity of geophysical events—storms, earthquakes, floods) with (2) the character and geographical distribution of insured properties. Identical aggregate damages can result from a severe storm over a sparsely-settled area and a moderate storm over a densely-populated area.

Occasionally, interaction between occurrence and magnitude of a geophysical event and the distribution of properties leads to the creation of catastrophic losses resulting in a natural disaster. A good example of interplay between the physical hazard and the geographical distribution of structures in causing a natural disaster was Hurricane Betsy in 1965. Hurricane Betsy was a severe storm, but not more severe than other storms that have occurred along the Gulf Coast. However, the path of the storm was optimal for producing a maximum amount of damage to property in the densely-populated areas of New Orleans. A difference of a few tens of miles to the east or west of its actual path, as Betsy moved inland, would have greatly reduced the resultant losses and downgraded the storm from being the most costly natural disaster in the United States to the present time with total property losses, insured and non-insured, of nearly one and one-half billion dollars.

To evaluate risk, it is desirable to consider the various possible interactions of natural hazard and property distribution—not only the chance interactions that happened to occur in the past as reflected by loss experience such as resulted from occurrence of a Hurricane Betsy. For the natural hazard risk evaluation, what is needed is not actual damage that occurred as a result of past geophysical events, but damage resulting to the present distribution of properties from a recurrence of these past events. To evaluate future risk, emphasis should *not* be on what the 1906 San Francisco earthquake cost, but on what it would cost if a comparable earthquake occurred today and affected the present distribution and value of properties. A pure extrapolation into the future of past loss experience and chance combinations of events that led to past natural disasters is not a good measure of future loss potential. However, man's life span is short and he cannot afford to wait for nature to produce all of the possible combinations of interactions between geophysical events and property distributions that lead to property damage and the occasional production of a natural disaster.

The purpose of this report is to outline a supplementary approach (called Natural Hazard Simulation) to the sole use of loss experience for evaluating magnitude of the natural hazards and for determining characteristics of an insurance operation needed to cover them. Natural Hazard Simulation artificially produces and measures the effect of various interactions between hazard and property distribution through (1) use of currently accepted knowledge in the physical sciences for defining physics of the natural hazard; (2) mathematical modeling of the hazard mechanism; (3) simulation of the interaction between hazard and property through use of an electronic computer which permits rapid calculation of a large number of long series of years of "synthetic loss experience" including production of "natural disasters". This approach utilizes other sources of pertinent information not directly extractable from past damage experience, ties this data together, and expresses implications of this integrated information in the context of an insurance operation needed to cover these hazards.

Natural hazards and loss experience

In order to explain the use of natural hazard simulation, a pictorial representation of the actual (but unknown) system by which nature produces loss experience from an interaction of natural hazard and property distribution is given by a block diagram in Exhibit 2a. This diagram stresses relationships between various pertinent factors: (1) Frequency of occurrence of the event (storm, earthquake, flood) at a given location (natural hazard); (2) severity of the event at the location (natural hazard); (3) concurrent severity in surrounding locations (natural hazard); (4) expected damage when an event of given severity occurs (loss function); (5) number, value and type of exposed properties in the affected area (property characteristics).

The block entitled "natural hazard" represents the physical mechanism which at irregular time intervals introduces an impulse (storm, earthquake, or flood) into the system. This mechanism determines frequency, severity and geographical extent of these impulses. The impulse acts upon various characteristics of properties (number, geographical distribution, value, type of construction) represented by the block entitled "property characteristics". Results of the interaction of natural hazard and property characteristics is the production of property damages designated by the "damage statistics" block. Extent of damage is governed by the "loss function" block which measures susceptibility of individual properties to damage. The loss function acts like a filter upon the hazard—property interaction. The amount of damping depends upon such things as resistance of the building to damage, inflationary cost of repair, quality of material and workmanship. The loss function determines (1) expected number of dwellings damaged during an event of given severity and (2) loss per damaged structure. The greater the susceptibility of the properties to damage, the less effective the "loss function" filter and the greater the magnitude of the "damage statistics". If an insurance program to cover the hazard is in existence, it represents a second filter on the damage statistics. Effects of such things as deductibles, amount of coverage, and underwriting can markedly alter the character of the resulting "loss experience" on insured properties as compared with "damage statistics" on all exposed properties. If an insurance filter is introduced, a "loss experience" block replaces the "damage statistic" block.

The arrows in Exhibit 2a designate direction in which the system operates. It is *not* reversible. It is not possible to start with loss experience accumulated over the period of time in which the system is in operation and move backward through the system in an attempt to reconstruct characteristics of the natural hazard mechanism. It is an irreversible process because, even though the natural hazard mechanism is not changing with time, "property characteristics"—the number and structural characteristics of exposed structures—are very rapidly changing in all sections of the United States. Susceptibility of these properties to damage and the cost of repair ("loss function") are also changing. Both "property characteristics" and "loss function" are highly dynamic and are nonstationary with time.

Expected-loss-per-individual exposure

The first component of risk (expected-loss-per-individual exposure) can be represented by the block diagram in Exhibit 2a if the "property characteristics" block represents only a single dwelling-type structure. For purposes of this report, the effect of natural hazards upon fixed properties (namely, dwelling units housing one to four families) will be discussed. Natural hazard simulation is based on a mathematical approximation of each of the blocks in Exhibit 2a. With these approximations, which are denoted by circular areas in Exhibit 2b, artificially generated impulses (storms and earthquakes) can be carried through the system mathematically. Output of the simulation is a "synthetic loss experience" which ideally provides a realistic approximation to actual loss experience as produced by nature which is depicted by the block diagram in Exhibit 2a.

In the mathematical approximation, impulses from the "natural hazard" component act upon the unit structure. The impulse could be an earthshock from the earthquake hazard or a period of high wind if the hurricane hazard is being considered. Frequency and magnitude of these impulses are determined solely by physical characteristics of the hazard in a geographical area. Past loss experience is used only indirectly. It is used in constructing the "loss function" which determines susceptibility of the structure to damage from an impulse of given severity. Damageability depends upon such things as type and quality of construction. Form of the severity measure of the impulse is determined by the loss function. For instance, speed of the peak gust of wind can be used as an index of severity for the hurricane hazard; hailstone size, duration of hailfall, and if wind-driven for the hail hazard; proximity to path for the tornado hazard; earthshock severity for the earthquake hazard; and depth of water above floor level for the flood hazard.

Evaluation of the first component of risk (expected-loss-per-exposure) has been made for a number of hazards and regions using Natural Hazard Simulation. For instance, the hailstorm hazard in Texas (Friedman 1965) and the hurricane wind hazard in Louisiana

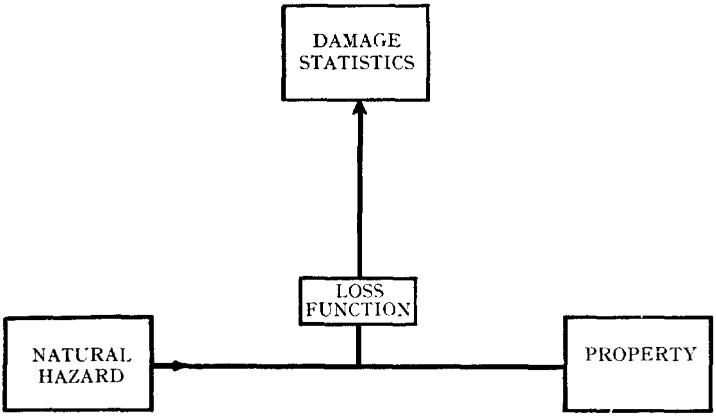

Exhibit 2a. Actual (but unknown) system by which natural hazards become damage producers to fixed property.

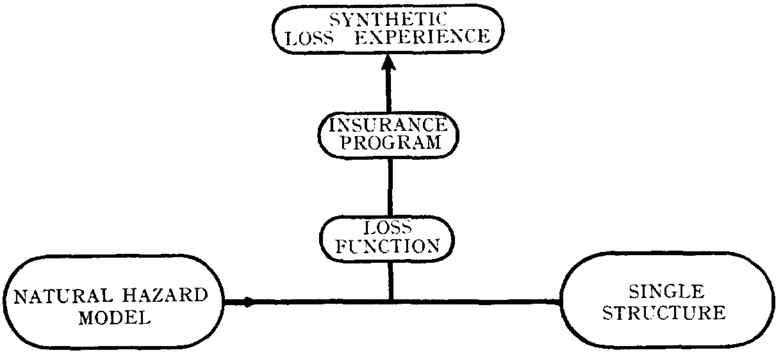

Exhibit 2b. Mathematical approximation of the actual system (Exhibit 2a) which is constructed to estimate the first component of risk—potential loss per individual structure.

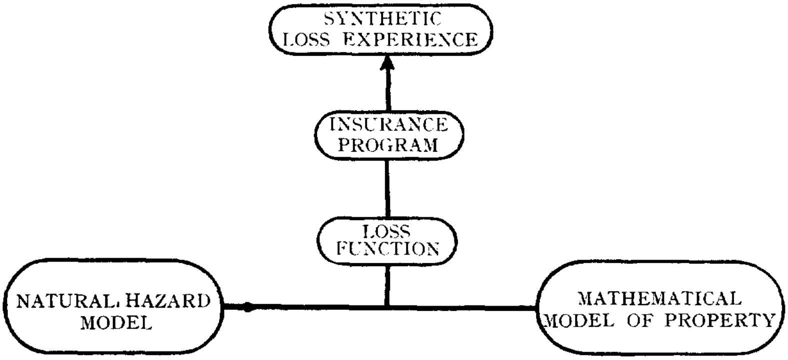

Exhibit 2c. Mathematical approximation of the actual system (Exhibit 2a) which is constructed to estimate the second component of risk—catastrophe potential. The first component also can be estimated from output of this model.

(Friedman and Kong 1966). Another example is given in Exhibit 3a which represents a pattern of pure premium isolines that has been obtained as a measure of expected-loss-per-unit-dwelling in the Midwestern section of the United States. The Midwest is subjected to a number of thunderstorm-spawned weather hazards—tornadoes, wind and hail. A mathematical model was constructed to approximate the natural hazard mechanism in various parts of the Midwest for each of the component hazards. Using past loss experience, a loss function was established for the unit dwelling which converts measures of severity of the various hazards (tornadoes, hail, thunderstorm winds) into resultant damage to dwellings. An insurance operation was approximated by assuming certain values of liability and deductible. Inasmuch as characteristics of the unit dwelling were held constant, the "loss experience" was developed solely on the basis of an application of output of the natural hazard mechanism applied to the nonchanging dwelling structure. On the basis of this measure of the natural hazards magnitude, central sections of the Middlewest—areas within Oklahoma, Kansas and Nebraska—have the highest loss potential for individual dwellings due to the weather hazard (Friedman and Shortell 1967).

Catastrophe Potential

If natural hazards behaved like most other hazards, the pattern given in Exhibit 3a would be a sufficient measure of loss potential on which insurance operation decisions could be based. However, increased density of properties susceptible to damage; increased value of these properties; and increased cost of repair have raised the probability of natural disaster occurrence in recent years and the need to evaluate catastrophe potential. The first component of risk is not a good measure of the second component—catastrophe potential. An example of the lack of geographical correspondence between the loss potential-per-individual-risk and catastrophe potential is graphically illustrated in Exhibit 3b. The location of catastrophic weather-associated losses (one million dollars or more in damages to insured properties caused by a single severe weather event) have been plotted on the pattern of pure premium for individual structure loss potential given in Exhibit 3a. Information on these catastrophes is based upon annual tabulations issued by the

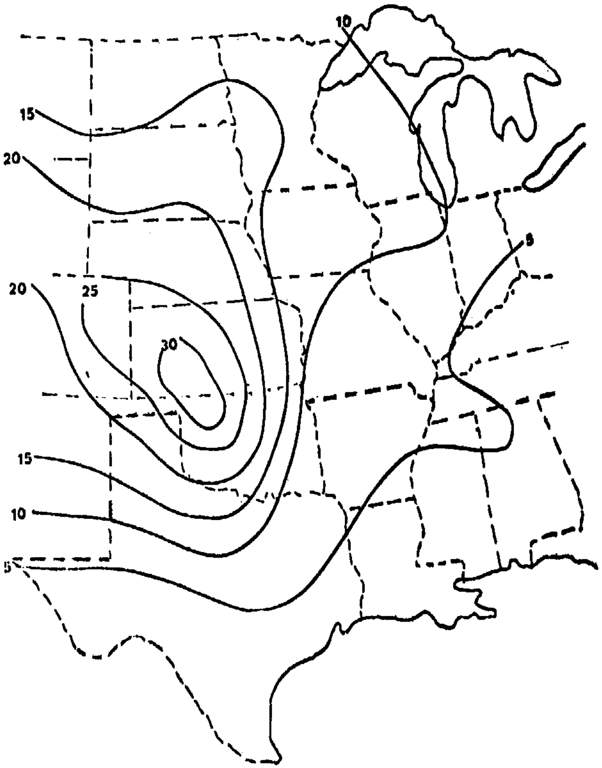

Exhibit 3a. Estimate of pure premium rate needed to cover the first component of natural hazard risk: expected average annual loss per dwelling based on Natural Hazard Simulation. Hazards include tornado, hail, thunderstorm wind, winter and spring (non-thunderstorm) windstorms.

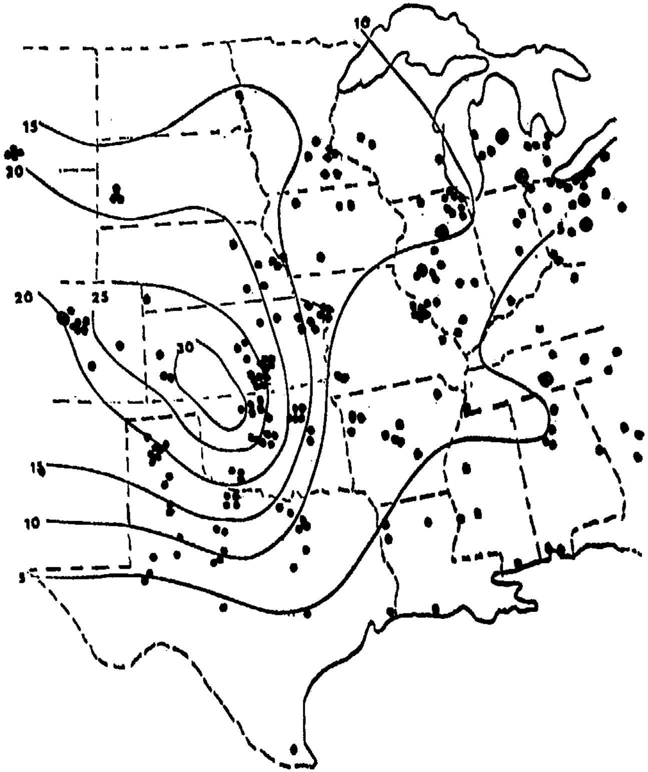

Exhibit 3b. Location of catastrophes caused by natural hazards during past twenty years plotted on the premium pattern given in Exhibit 3a. Losses exceeding one million dollars caused by a single geophysical event have been coded as a catastrophe by the National Board of Fire Underwriters and more recently by the National Insurance Actuarial and Statistical Association. The U.S. Department of Commerce publication "Storm Data" was used to pinpoint location of severest damage. Encircled dots represent area of greatest damage from winter windstorms.

National Board of Fire Underwriters—National Insurance Actuarial and Statistical Association for the past twenty years.

An inspection of Exhibit 3b shows that catastrophes (natural disasters) are not concentrated in Oklahoma and Kansas where severe weather events are most frequent. Instead, the locations are spread eastward into the Mississippi and Ohio River valleys where density of exposed properties is much greater than in the Great Plains States. The occasional occurrence of a severe weather event in densely populated areas quite frequently leads to the production of a great many simultaneous losses—hence, creation of a natural disaster. In the thinly populated Great Plains region, the much more frequent storms have a lesser probability of hitting a densely populated area which is needed to produce a natural disaster. Consequently, the geographical distribution of exposed properties is needed, in addition to the spatial distribution of the natural hazard, in order to determine catastrophe potential. A simple measure of dwelling structure density in the United States is given by the population density map in Exhibit 4. Number and magnitude of natural disasters will increase as population density increases. Interaction of the location and spatial extent of a natural-hazard event with the geographical distribution of properties determines the frequency and magnitude of resulting natural disasters. No matter how *severe* a storm may be, it is not a *damaging* storm unless the affected area contains damage-susceptible properties.

To approximate occurrence of simultaneous multiple losses (catastrophe potential) of Midwestern weather hazards in the future, the mathematical models given in Exhibit 2b must be expanded to produce geographical patterns of severity using the "natural hazard" mechanism and the unit dwelling concept in "property characteristics" must be expanded to obtain a measure of the geographical distribution of exposed properties. Refer to Exhibit 2c. In Natural Hazard Simulation, an impulse (geophysical event) takes the form of a geographical pattern of severity which is applied, mathematically, to a given geographical array of structures. The severity pattern is calculated using pertinent information pertaining to location, path, and intensity of the geophysical event. For the earthquake hazard, basic information is location, depth, and magnitude of an earthquake. For the hurricane hazard, pertinent infor-

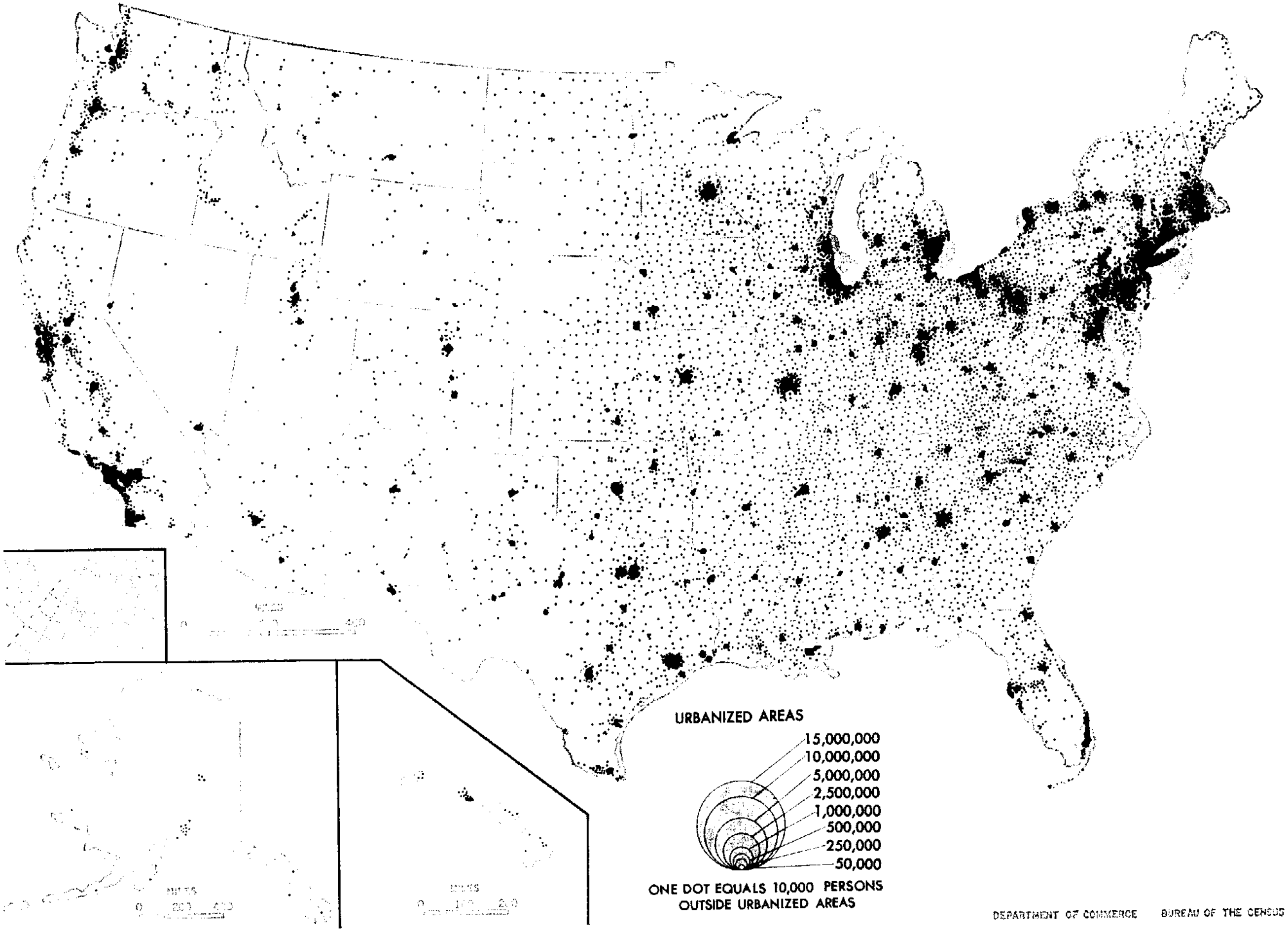

Exhibit 4. Population density based on the 1960 Census.

mation would be hurricane intensity (lowest sea level barometric pressure); direction and curvature of the storm's path; storm size; and speed. The interrelated basic information also can be generated using past frequencies and simulation techniques.

Method of Analysis

The massive computational task of approximating the natural hazard—structual damage system shown in Exhibit 2c requires the use of an electronic computer. Using a Fortran program on the IBM 360-65 computer, "property characteristics" are provided for at each of 90,000 grid points—which represent contiguous United States (excluding Alaska and Hawaii). Each point represents an area of about 30 square miles. Information on number, value and other characteristics of dwelling properties can be stored in the computer for each of these grid areas. This latest version of a Natural Hazard Simulation program is still being tested. For test purposes, information based upon U.S. Census data has been put in the computer file for (1) the Gulf and South Atlantic states to be used in studying the hurricane hazard and (2) California to be used in studying the earthquake hazard.

Computer simulation techniques are utilized in order to produce the irregular impulses in time, space, and intensity (occurrence of a storm or earthquake of given magnitudes in various geophysical areas). Severity of the geophysical event is calculated for each grid point in the affected area which is a very small fraction of the 90,000 possible grid areas. Severity is converted into a measure of loss experience using the "loss function" filter and the hypothesized "insurance coverage" filter depicted in Exhibit 2c. Output is synthetic loss experience in terms of (1) number of dwellings affected and (2) expected total damage for each grid area and for the entire group of affected grid areas. In addition, a plot of the calculated geographical pattern of the event's severity is printed out. Examples of these computer plotted patterns are given in Exhibits 6, 7, 9-11, 13-16.

The purpose of each application of Natural Hazard Simulation establishes the scope, scale, and detail required. Scale has ranged from a macroanalysis of the inland flood hazard to the more than fifty million dwellings spread unevenly over 3,000,000 square miles in contiguous United States to a microanalysis of the earthquake hazard to slightly more than one hundred thousand dwellings located within the 45 square mile area of the City of San Francisco. One hundred and thirty grid areas of one-third of a square mile each were used in the San Francisco study. The 90,000 grid areas (of slightly more than 30 square miles each) which are being used to represent the United States provide sufficient detail for a macroanalysis of large-scale geophysical event severity patterns. These 90,000 grid areas each represent a one-tenth of a degree of latitude and longitude grid. Convergence of the meridians is accounted for in the analysis. Much finer detail given by smaller grid areas are required for many applications.

The Natural Hazard Simulation approach given in Exhibit 2c has been used as a basis for estimating the two components of risk: (1) expected loss per risk and (2) catastrophe potential for various natural hazards in different sections of the United States. Synthetic loss experience of current or hypothesized future geographical distributions of properties were obtained by using either a recurrence of geophysical events recorded in the historical past or by simulating long sequences of occurrences based upon past frequency and severity characteristics of the event. Some of these applications are discussed in the following sections.

Applications

Coastal Flooding—The purpose of this application was to estimate magnitude of the coastal flood hazard to dwelling properties in the United States for which very little actual loss experience was available. Both components of risk were estimated. An initial study (Friedman 1965) was prepared for the National All Industry Flood Insurance Committee which was studying feasibility of flood insurance. A second study was subsequently made for the United States Department of Housing and Urban Development (Friedman and Roy 1966) during development of the National Flood Insurance Program which is now operational. Coastal flooding was defined to include tidal inundation and wave wash from hurricanes along the Gulf and East Coasts of the United States and from severe winter storms along the Middle Atlantic and New England Seacoasts.

A mathematical representation of the hazard was constructed by relating the intensity of coastal floods to the frequency, severity, path of hurricanes and severe winter storms. Storm surge was simulated in each of sixty-four equally spaced coastal strips covering the Gulf and Atlantic coastlines from Brownsville, Texas to Portland, Maine. Magnitude of the surge was obtained by incorporating effects of a number of factors, such as hurricane intensity, wind pattern, speed, coastline orientation and character of the ocean bottom along the shore. Large local variations can occur in the magnitude of storm surge. These local effects were included along with effects of coastal storm barriers when information was available. Storm surge occurrences were based upon the historical record of hurricane occurrences. Frequency of "simulated" hurricanes of various intensities and paths were made consistent with frequency of actual hurricane occurrences in the past 80 years by using simulation techniques.

Verification of the storm surge simulations were made by comparing calculated with actual storm tide measurements. Thousands of "years" of loss experience were simulated. A large number of natural disasters resulted from the chance positioning of a severe hurricane near a highly populated section of coastline during the simulated time sequences.

Property characteristics were obtained by mapping elevation contours along the Gulf and Atlantic coastlines and estimating the number of dwellings within each elevation contour. Six severity zones were defined, based upon elevation, after accounting for the effect of the astronomical tide. Number and value of dwellings in the six severity zones were estimated for each of the sixty-four coastal strips.

A loss function relating water depth to damage was constructed based upon U.S. Corps of Engineers Studies. Greater damage was anticipated in coastal flooding than in inland flooding because, for a given depth of water, there are additional damaging effects of wave action and salt water.

Expected loss per dwelling was computed as a pure premium (rate per dollar of liability) for dwellings in each of the six severity zones and sixty-four coastal sectors. Refer to Exhibit 5. Considerable information on catastrophe potential was obtained by studying "natural disasters" that occurred periodically over simulated spans

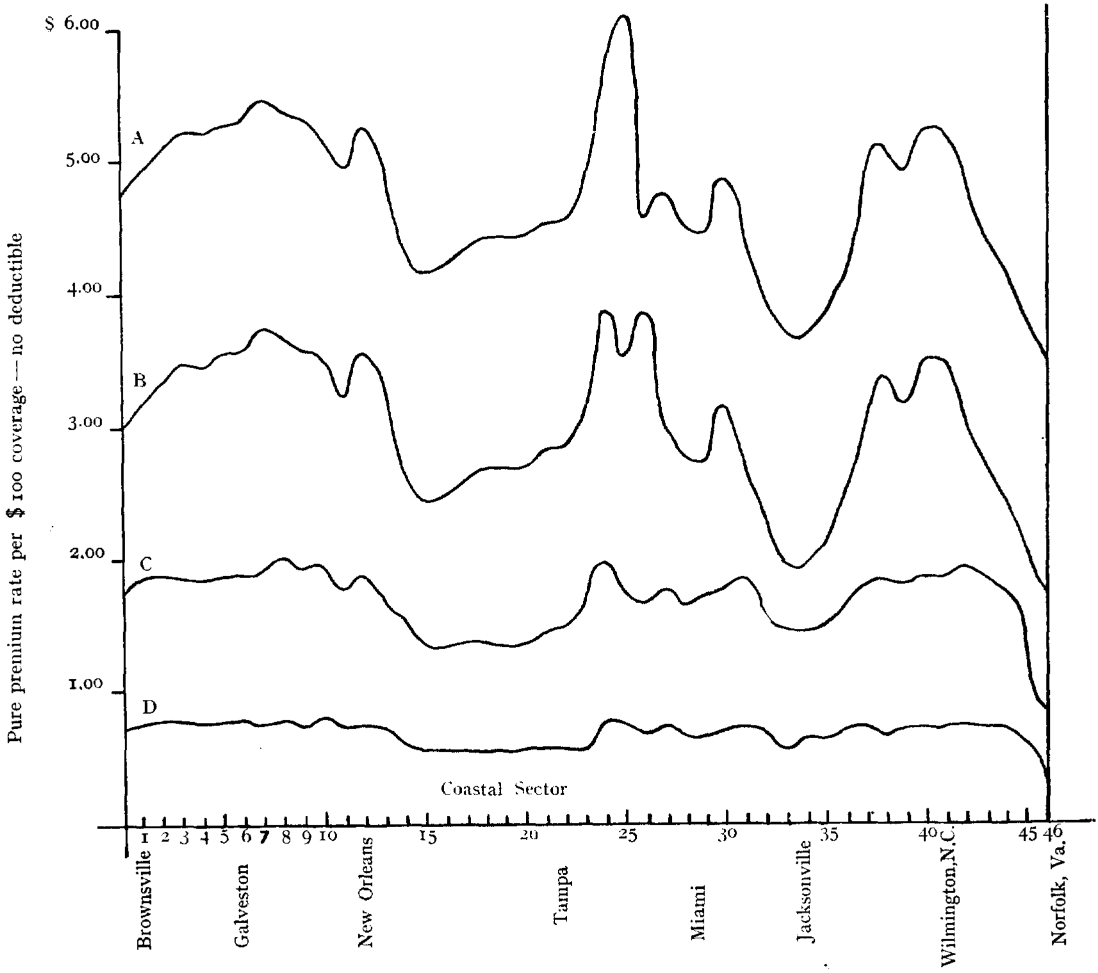

Exhibit 5. Measure of first component of risk for dwelling structures due to coastal flooding hazard along Gulf and East Coasts of the United States. Natural Hazard Simulation was used to obtain these measures for each of a number of flood hazard zones defined by the return period of floods. Premium rate is dependent upon, among other things: (1) hurricane severity and orientation which determines depth of the flood when an event occurs and (2) loss function. Flood hazard zones are:

Hazard Zone A — flood return period less than 5 years
Hazard Zone B — flood return period between 5 and 10 years
Hazard Zone C — flood return period between 10 to 25 years
Hazard Zone D — flood return period between 25 and 50 years

of years. Number of dwellings affected and amount of damage was obtained for each catastrophic occurrence. Occasionally, more than one "natural disaster" occurred in a single year. On the other hand, in many years, aggregate damage from coastal flooding was minimal.

Inland Flooding—This study was done concurrently with the coastal flooding study. The purpose was to determine the magnitude of non-coastal flood hazard to dwelling properties in the United States. Mathematical representation for the inland flooding hazard was based upon flood intensity measured by depth which was simulated for each of six severity zones in 1010 urban areas. The loss function (depth-damage) curve was based upon data gathered by the U.S. Corps of Engineers and property characteristics were obtained by estimating the number and value of dwellings in each flood severity zone.

Output of the inland flood model was similar to the coastal model output including "loss experience" summarized by (1) city size and (2) flood severity zone. Tabulated items included (1) simulated frequency of floods by intensity category; (2) number of dwellings exposed; (3) number of dwellings damaged; (4) total amount of damage; (5) damage per dollar of liability; (6) premium income; (7) pure premium required to cover losses (risk per individual dwelling). Experience on dwelling structure and dwelling contents was simulated separately.

In both inland and coastal flood studies the effects of various factors were simulated: (1) correlation of floods between cites; (2) correlation of damage from year to year; (3) type and size of deductible; (4) subsidies; (5) flood plain zoning; (6) market growth; (7) mixture of coastal and inland exposures; (8) excess loss point for Federal Government reinsurance based upon frequency and magnitude of "natural disaster" occurrences; (9) size of initial and loss reserve funds. For excess loss reinsurance, the premium needed to cover catastrophic losses in a single year or series of high-loss years was calculated. The reinsurance rate was found to be highly dependent upon the relative mix of inland flood plain and coastal flood plain structures covered by a flood program.

Verification of the reasonableness of the simulation model output was made as often as actual information became available. Representativeness of the inland flood model was independently checked by (Schaake and Fiering 1967) who used a somewhat different approach and who concluded that the Natural Hazard Simulation approach produced realistic results.

Simulation of a National Flood Insurance Program operated jointly by the insurance industry and the Federal Government was made using Natural Hazard Simulation to help establish relationships and financial arrangements between the Government and insurance industry under various possible plans. One of these plans has been approved by Congress and is currently being implemented.

Earthquake—Natural Hazard Simulation has been applied to the earthquake hazard (Friedman 1970). The purpose was to determine if there was sufficient pertinent information available in seismology to permit construction of a mathematical approximation of the earthquake hazard to dwelling structures. It was found that a mathematical representation could be constructed using a continuous index paralleling the Modified Mercalli scale to estimate earthshock intensity. Secondary local effects such as fire, tidal wave, and landslides were not included. A model for generating geographical patterns of earthshock intensity was obtained by incorporating effects of the following influencing factors:

1. magnitude of the earthquake
2. distance from the center of the earthquake
3. orientation of the locality relative to the fault line
4. depth of earthshock
5. duration of earthshock
6. geology of intervening area
7. local ground conditions

Local ground condition is an extremely important factor which is difficult to properly quantify. For test purposes, a rough index was used to represent ground conditions in each grid area—one tenth of a degree latitude-longitude square (about 6 miles by 6 miles)—in California. Refer to Exhibit 6a which is essentially a quantification of Richter's qualitative description of ground conditions in California (Richter 1959).

One output of the computer model is a printout of a computed geographical pattern of earthshock intensity based upon input

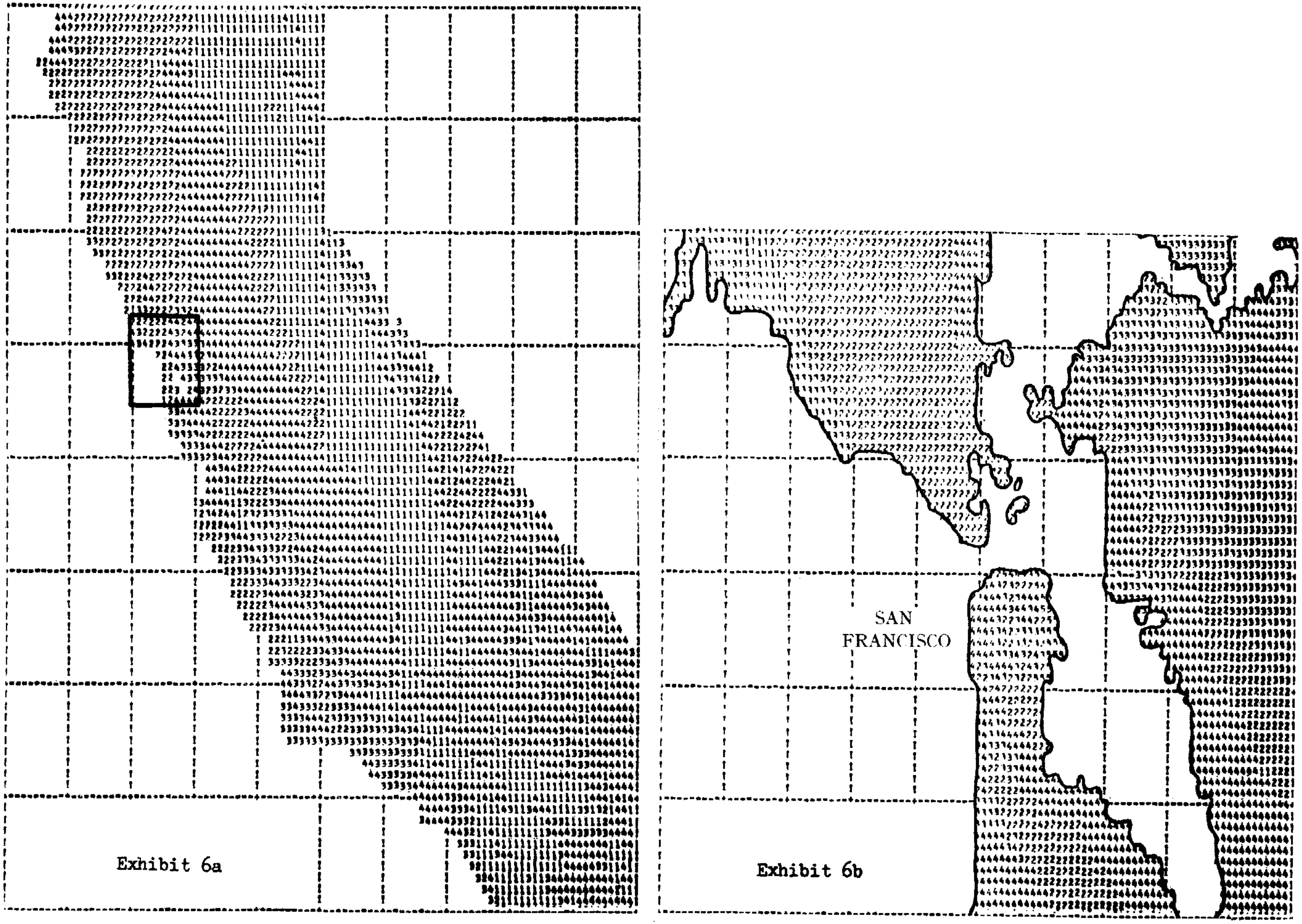

Exhibit 6. Index of local ground condition used in the Natural Hazard Simulator for the earthquake hazard in California. Exhibit 6a represents an index for grid areas of about 36 square miles for the entire State. Exhibit 6b provides 100 times greater detail for San Francisco and vicinity with an index for each 0.4 of a square mile.

Exhibit 7. Observed and calculated intensity patterns of the 1906 San Francisco earthquake.

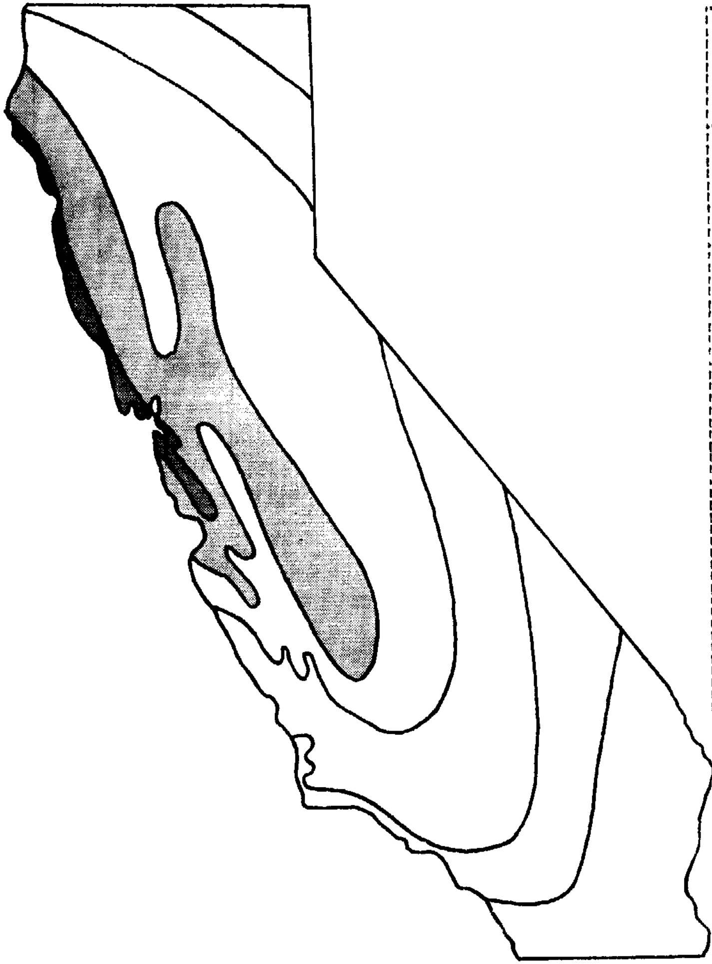

Exhibit 7a. Observed intensity pattern (Rossi-Forel units) Refer to page 477 of Richter's *Elementary Seismology*.

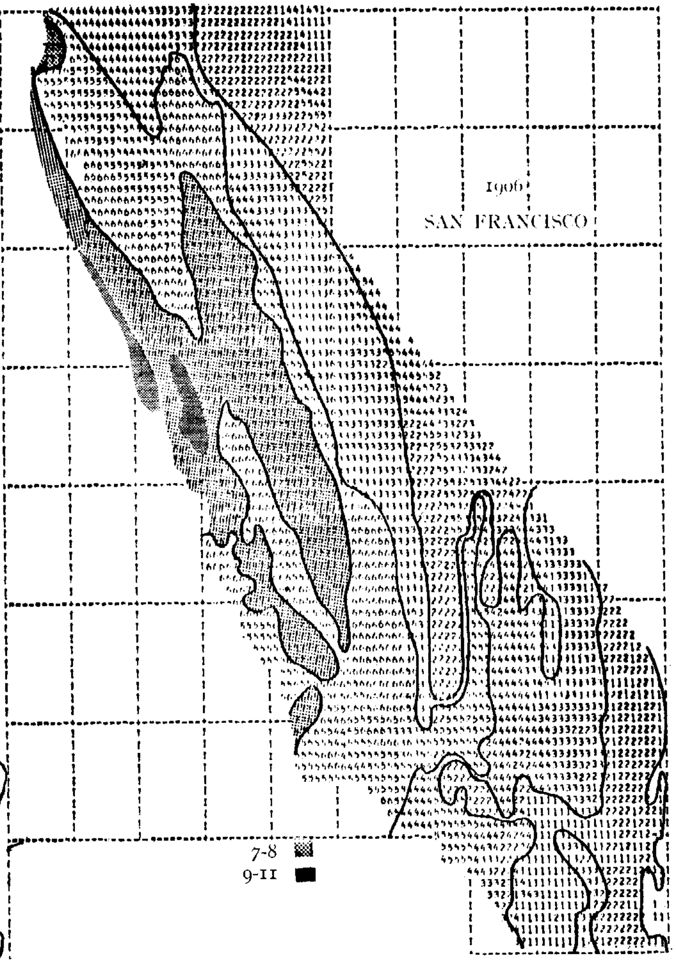

Exhibit 7b. Calculated intensity pattern (Modified Mercalli units).

information on magnitude, depth, and location of the source of the earthquake. A number of validity tests have been made including comparison of the observed earthshock pattern associated with the 1906 San Francisco earthquake (Exhibit 7a) with the calculated pattern (Exhibit 7b). Both patterns show the effect of local ground condition with an extension of the area of severe earthshock into the Great Valley of California. Although the observed pattern is in different intensity units (Rossi-Forel), the shape of the simulated pattern closely duplicates the observed pattern. Simulated contours of intensity are much more irregular in shape than observed contours but some of the smoothness may be due to lack of data in interior sections of California at the time of the 1906 earthquake.

To test effect of grid size, the City of San Francisco was subdivided into grid areas of 1/3 of a square mile (1/100 of a degree of latitude and longitude). A local ground condition index was assigned to each grid area (Refer to Exhibit 6b). This provided 100 times more detail than was obtained using the 36 square mile grid (Exhibit 6a). Eighty moderate or strong earthquakes affected San Francisco in the past 170 years (1800-1969). Earthshock patterns were computed for each of these earthquakes by inputing only magnitude and location of these past earthquakes. Because ground conditions vary considerably in the City of San Francisco, output of the model indicated a range of earthshock intensities within the City resulting from each simulated quake. On the other hand, a single value was usually published to represent observed intensity during past earthquakes in San Francisco. This was probably always the greatest intensity observed within the city. Observed intensities were available for 60 of the 80 earthquakes that affected San Francisco in historical times. A comparison of the calculated range of intensities with the observed value is tabulated in Exhibit 8 which provides a measure of the mathematical model's ability to produce realistic earthshock intensities. Table 1 summaries these data by giving the number of times that observed intensity was within the simulated range. Of the 60 observations, 46 of the observed intensities (77 percent) were within the simulated range. Correspondence between simulated and observed intensities is greatest when observed intensities are large enough to produce structural damage. The threshold intensity for production of

Exhibit 8.

Summary of Information on Eighty-three Earthquakes that Affected the San Francisco Bay Area in Historic Times.

Epicenter Intensity of These Earthquakes was at least VI on the Modified Mercalli Scale.

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
						Coordinates of Epicenter			
Number	Epicenter Intensity (Modified Mercalli)	Date Of Occurrence		Description of Epicenter Location	Approximate Distance Of Epicenter From Center of San Francisco (miles)	Latitude °North	Longitude °West	Range of Computed Intensities Grid Points Representing San Francisco	Actual Reported Intensity For San Francisco*
1	11.0	1906	Apr 18	NW of San Francisco	30 NW	38.0	123.0	8-10	8
2	11.0	1952	Jul 21	Kern County	270 SE	35.0	119.0	1-3	4
3	10.5	1872	Mar 26	Owens Valley	260 ESE	36.5	118.0	NF**	NF
4	10.5	1857	Jan 9	Fort Tejon	270 SE	35.0	119.0	4-7	5***
5	10.0	1954	Dec 16	Dixie Valley Nevada	250 ENE	39.3	118.2	NF-1	1-3
6	10.0	1932	Dec 20	Western Nevada	260 ENE	38.7	117.8	2-5	2
7	10.0	1915	Oct 2	Pleasant Valley, Nevada	310 NE	40.5	117.5	2-4	< 5
8	10.0	1838	Jun -	San Francisco	20 SSW	37.5	122.5	7-9	7
9	9.5	1868	Oct 21	Hayward	30 SE	37.5	122.0	6-9	8
10	9.5	1836	Jun 10	San Francisco	30 NE	38.0	122.0	6-8	-****
11	9.0	1954	Aug 24	East of Fallon, Nevada	240 ENE	39.6	118.5	2-4	4
12	9.0	1954	Jul 6	East of Fallon, Nevada	240 ENE	39.4	118.5	1-4	4
13	9.0	1922	Mar 10	Cholame Valley	180 SE	35.8	120.3	2-5	-
14	9.0	1892	Apr 21	Winters	60 NNE	38.5	122.0	4-7	5
15	9.0	1892	Apr 19	Vacaville	60 NNE	38.5	122.0	5-7	5
16	9.0	1869	Dec 27	California-Nevada	180 NE	39.5	120.0	2-4	5***
17	8.5	1898	Apr 14	Mendocino County	120 NW	39.0	124.0	3-6	4
18	8.5	1865	Oct 8	Santa Cruz Mountains	60 SSE	37.0	122.0	4-7	7
19	8.5	1865	Oct 1	Fort Humboldt	250 NW	41.0	124.5	NF	-
20	8.0	1934	Jun 7	Parkfield	170 SE	35.9	120.5	1-2	NF
21	8.0	1926	Oct 22	Monterey Bay	70 SSE	36.8	122.0	4-7	5
22	8.0	1897	Jun 20	Near Hollister	70 SE	37.0	121.5	3-6	4
23	8.0	1861	Jul 3	Contra Costa County	30 SE	37.5	122.0	4-7	5
24	8.0	1858	Nov 26	San Jose	30 SE	37.5	122.0	4-7	6
25	7.5	1911	Jul 1	Central California	60 SSE	37.0	122.0	4-6	5
26	7.5	1902	May 19	Elmira	60 NNE	38.5	122.0	2-5	4
27	7.5	1899	Jul 6	Watsonville	70 SE	37.0	121.5	3-6	3
28	7.5	1891	Oct 11	Napa County	60 N	38.5	122.5	3-6	4
29	7.5	1885	Apr 11	Monterey County	140 SE	36.0	121.0	2-5	3
30	7.5	1868	Sep 26	Ukiah	90 NNW	39.0	123.0	2-4	-
31	7.5	1856	Feb 15	San Francisco	20 S	37.5	122.5	4-7	7
32	7.0	1963	Sep 14	Near Chittenden	80 SE	36.8	121.6	NF	5
33	7.0	1961	Apr 8	S of Hollister	90 SE	36.7	121.3	1-2	5
34	7.0	1957	Mar 22	E of Mussel Rock	10 SSW	37.7	122.5	5-7	7
35	7.0	1955	Oct 23	Near Concord	30 NE	38.0	122.1	3-6	6
36	7.0	1955	Sep 4	E of San Jose	50 SE	37.4	121.8	3-6	5
37	7.0	1949	Mar 9	Hollister	80 SE	37.0	121.5	2-5	6
38	7.0	1948	Dec 31	Near Hollister	80 SE	36.9	121.6	NF-1	5
39	7.0	1939	Jun 24	Near Hollister	90 SE	36.8	121.4	NF-2	2
40	7.0	1933	May 16	Niles Canyon	30 NE	38.0	122.0	3-6	5
41	7.0	1916	Aug 6	Paicines	120 SE	36.5	121.0	1-4	2
42	7.0	1914	Nov 8	Santa Cruz Mountains	60 SSE	37.0	122.0	3-6	3
43	7.0	1903	Aug 2	Santa Clara	30 SE	37.5	122.0	4-7	5
44	7.0	1903	Jun 11	Central California	30 SE	37.5	122.0	4-7	6
45	7.0	1899	Oct 12	Santa Rosa	50 N	38.5	122.5	2-5	-
46	7.0	1899	Apr 30	Watsonville	70 SE	37.0	121.5	2-5	-
47	7.0	1898	Mar 30	Mare Island	30 ENE	38.0	122.0	3-6	6
48	7.0	1893	Aug 9	Santa Rosa	50 N	38.5	122.5	2-5	> 1
49	7.0	1890	Apr 24	Monterey Bay	70 SE	37.0	121.5	1-4	4
50	7.0	1889	Jul 31	San Francisco Bay	30 SE	37.5	122.0	3-6	6
51	7.0	1889	May 19	Collinsville	30 NNE	38.0	122.0	3-6	4
52	7.0	1888	Nov 18	Oakland	20 S	37.5	122.5	3-6	-
53	7.0	1888	Feb 29	Petaluma	20 N	38.0	122.5	4-7	5
54	7.0	1885	Mar 30	SE of Hollister	120 SE	36.5	121.0	NF-1	-
55	7.0	1881	Apr 10	Modesto	80 E	38.0	121.0	2-5	4
56	7.0	1865	Mar 8	Sonoma County	50 N	38.5	122.5	2-5	4
57	7.0	1852	Nov 24	San Francisco	20 S	37.5	122.5	3-6	-
58	7.0	1808	Jun 21	San Francisco	20 N	38.0	122.5	4-7	-
59	7.0	1800	Oct 11	San Juan Bautista	80 SE	37.0	121.5	1-4	-
60	6.5	1937	Mar 8	Near Berkeley	20 E	37.8	122.2	3-6	5
61	6.0	1963	Jun 7	Near Antioch	40 ENE	38.0	121.8	NF-1	4
62	6.0	1963	May 22	West Central California	40 SSE	37.3	122.2	NF-1	4
63	6.0	1958	Dec 11	San Francisco	10 SSW	37.7	122.5	4-6	-
64	6.0	1958	Oct 30	NE of San Jose	40 SE	37.5	121.8	NF-1	-
65	6.0	1957	Mar 23	W of Daly City	10 SSW	37.7	122.5	3-6	6
66	6.0	1956	Apr 4	Near Saint Helena	50 N	38.5	122.5	NF-2	1-3
67	6.0	1954	Dec 16	E of San Leandro	20 E	37.7	122.1	3-6	4
68	6.0	1951	Jul 23	Berkeley Hills	10 NE	37.9	122.3	3-6	5
69	6.0	1951	Jan 25	San Francisco Bay	20 ENE	37.8	122.2	3-6	-
70	6.0	1949	Jun 9	E of San Jose	60 SE	37.4	121.6	1-4	5
71	6.0	1947	Jun 22	Gilroy	60 SE	37.0	121.8	1-2	6
72	6.0	1945	Aug 27	San Jose	50 SE	37.3	121.8	2-5	5
73	6.0	1943	Oct 25	NW of Mt. Hamilton	50 SE	37.4	121.7	2-6	5
74	6.0	1927	May 28	Near San Jose	50 SE	37.3	121.8	NF-2	3
75	6.0	1927	Feb 15	Near Santa Cruz	60 SSE	37.0	122.0	2-5	-
76	6.0	1926	Jul 25	Near Idria	140 SE	36.5	120.5	NF	-
77	6.0	1915	Oct 7	Piedmont	30 SE	37.5	122.0	2-5	4
78	6.0	1906	May 1	Guerneville	60 NNW	38.5	123.0	NF-1	-
79	6.0	1899	Jun 1	San Francisco	20 S	37.5	122.5	2-5	4
80	6.0	1891	Jun 2	Mount Hamilton	50 ESE	37.5	121.5	NF-1	2
81	6.0	1883	Mar 30	Hollister	70 SE	37.0	121.5	NF	4
82	6.0	1864	Mar 5	San Francisco	20 S	37.5	122.5	2-5	4
83	6.0	1851	May -	San Francisco	20 S	37.5	122.5	2-5	5

* Reported intensities using the Rossi-Forel Scale were converted to an equivalent Modi rcalli intensity before tabulation in Table 1.

** NF represents Not Felt

*** intensity level reported for Sacramento

**** - (dash) indicates reported intensity not given in source material.

Earthquakes # 3, 19, 76 not felt in San Francisco and were not included in the analysis.

dwelling damage is about V on the Modified Mercalli scale. Results of these comparisons indicate that the mathematical model can produce realistic estimates of the earthshock intensity pattern when only location and intensity of an earthquake's epicenter is known.

TABLE I

Number of times reported intensity was within the range of simulated intensities in the City of San Francisco based upon 60 earthquakes that occurred between 1800 and 1969.

Reported intensity in San Francisco (Modified Mercalli)	Number of Earthquakes	Number of times reported intensity is within range of simulated intensities	Percentage
VII or greater	6	6	100%
VI	8	7	88
V	18	14	78
IV	18	14	78
III or less	10	5	50
Total	60	46	77%

The model provided useful results for all 80 earthquakes including those not associated with the San Andreas fault zone. Epicenter distance ranged from over 250 miles away for intense earthquakes (Modified Mercalli XI) in Central Nevada to a few miles away for moderate earthquakes (epicenter intensity of VI). Exhibit 9a is an example of the observed earthshock pattern of a moderate earthquake. This earthquake occurred near St. Helena, California in April 1956. The center of the earthquake was far enough away so that San Francisco was on the fringe of the isoseismal pattern. Exhibit 9b represents the simulated isoseismal pattern on the detailed grid. Correspondence between simulated and observed patterns is good.

Before damage statistics could be simulated, assumptions had to be made regarding characteristics and geographical spread of structures to be insured. For the test application, it was assumed that all dwelling properties were covered by insurance. Number and value of single-unit dwellings were obtained from U.S. Census Tract data. On the detailed grid, for the City of San Francisco,

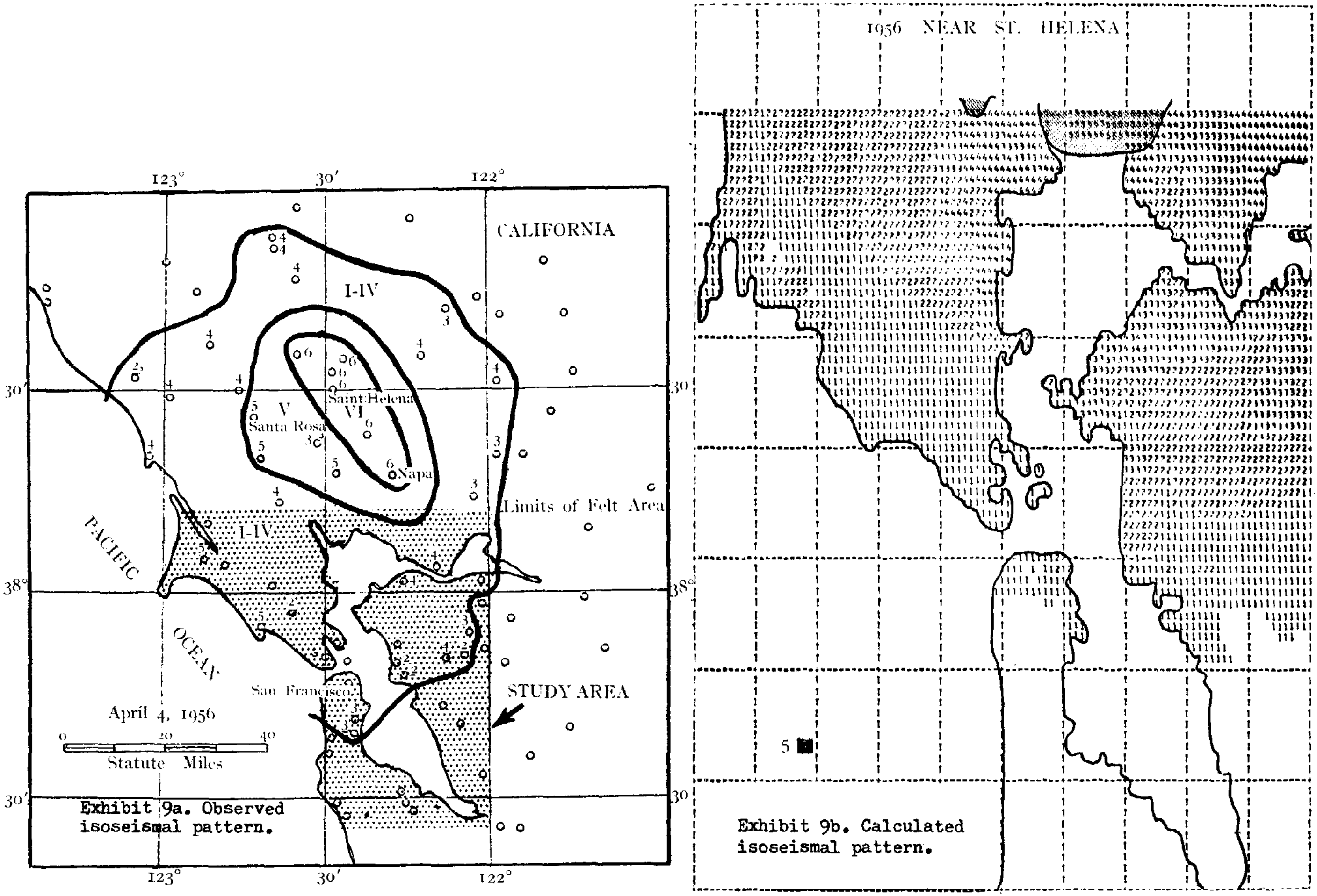

Exhibit 9a. Observed isoseismal pattern.

Exhibit 9b. Calculated isoseismal pattern.

Exhibit 9. Observed and calculated isoseismal pattern (Modified Mercalli intensity units) of a moderate earthquake at Saint Helena, California in April 1956. Calculated pattern (Exhibit 9b) is for the stippled section designated "Study Area" in Exhibit 9a.

110,000 dwellings were assigned among the 130 grid areas—each grid area representing 1/3 of a square mile. On the large grid, for Metropolitan San Francisco, 625,000 dwellings were assigned to 130 grid areas—each grid area representing 36 square miles. No attempt was made, because of lack of data, to determine type of structure such as frame versus brick.

A damage function, relating simulated earthshock intensity to (1) number of dwellings damaged and (2) amount of loss per damaged dwelling in each grid area was developed based on information from the 1933 Long Beach, 1952 Kern County, and 1957 San Francisco earthquakes. No insurance deductible was assumed in the test program. Provision also has been made to include the effect of aftershocks following a major earthquake.

Simulation of the intensity pattern and calculation of damage information for each earthquake requires less than 30 seconds on an IBM 360 electronic computer.

Output for each grid area includes:

1. Simulated intensity.
2. Number of dwellings in grid area.
3. Number damaged.
4. Value-at-risk per dwelling in grid area.
5. Percent of value-at-risk lost on each damaged dwelling.
6. Loss per damage dwelling.
7. Total damage in each grid area.
8. Accumulated damage over past earthquakes.

Table 2 gives average annual damage-per-dwelling (first component of risk) based on a recurrence of earthquakes that originally occurred in each of eight 20-year periods. Data was based upon simulated damages to the 1960 distribution and value of 110,000 dwellings in the City of San Francisco. The need to have a long record to estimate the magnitude of the earthquake hazard is

Exhibit 10. Example of changes in size and shape of computed earthshock patterns as affected by changes in magnitude (Richter Scale) of the earthquake. Depth and geographical location of the earthquake source is held constant (15 kilometers located at San Francisco). To increase clarity of calculated patterns on the computer printouts which have been drastically reduced in size, two modifications have been made; namely, (1) a line has been drawn enclosing areas in which the earthquake is computed to be perceptible and (2) areas in which intensity was calculated to exceed Modified Mercalli 5 (treshold of structural damage) have been stipled.

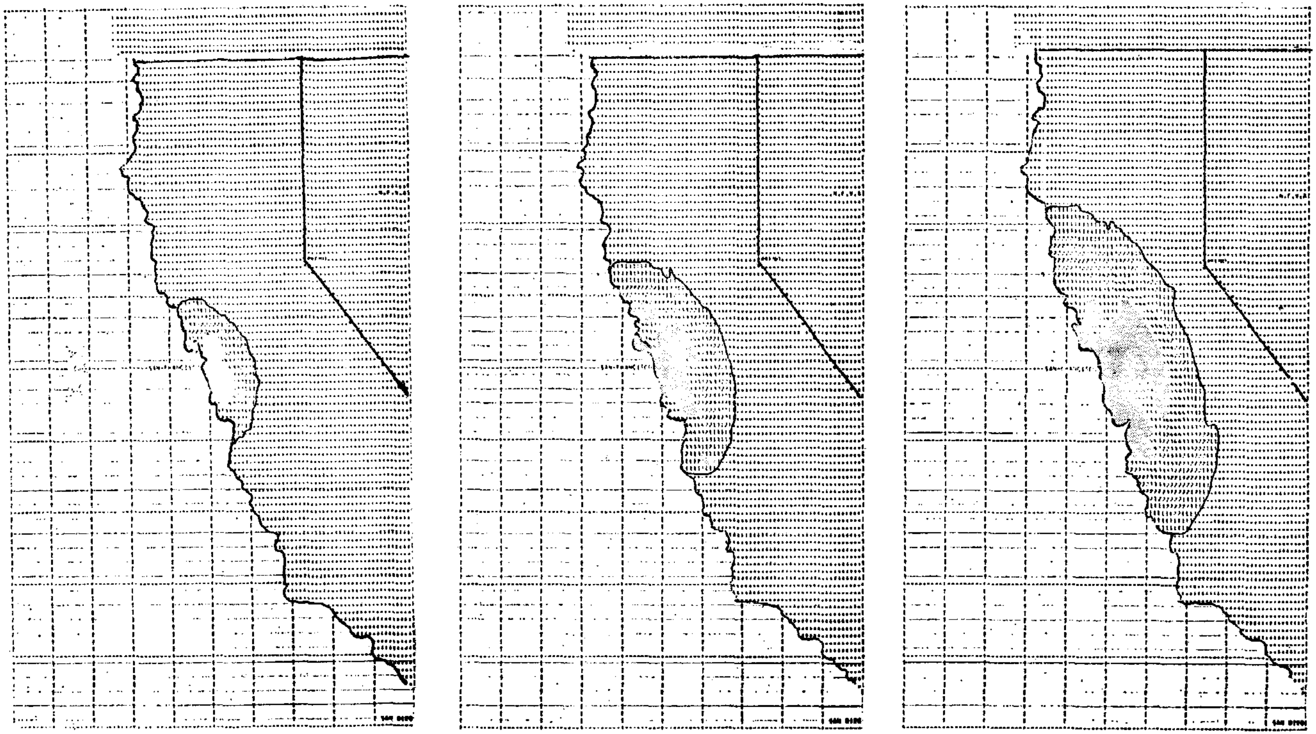

Exhibit 10a. Richter magnitude 5.0 earthquake centered at San Francisco.

Exhibit 10b. Richter magnitude 5.5 earthquake centered at San Francisco.

Exhibit 10c. Richter magnitude 6.0 earthquake centered at San Francisco.

Exhibit 10. (continued) Examples of changes in size and shape of computed earthshock patterns when magnitude (Richter Scale) is changed while depth and location of earthquake source is not changed. Computed patterns are dependent upon availability of the index of local ground condition which has been estimated only for the State of California. Therefore, computed intensity patterns do not extend eastward into the State of Nevada or northward into the State of Oregon.

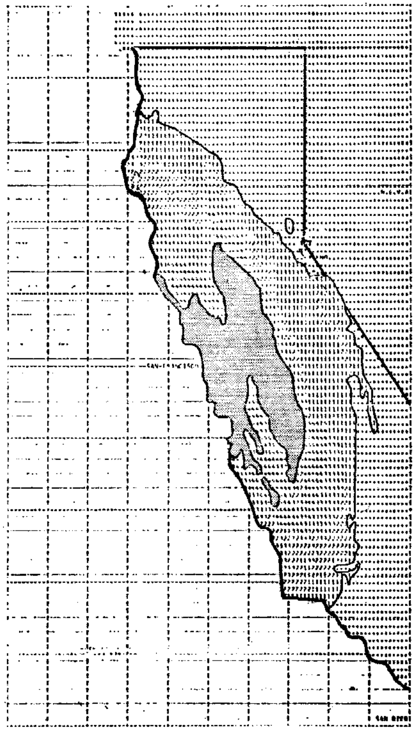

Exhibit 10d. Richter magnitude 6.5 earthquake centered at San Francisco.

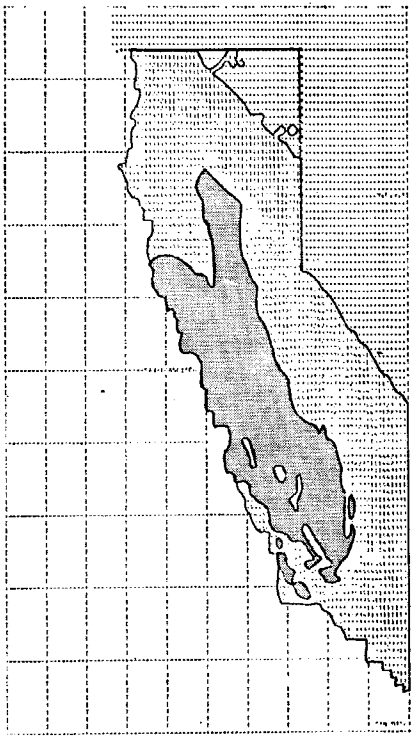

Exhibit 10e. Richter magnitude 7.0 earthquake centered at San Francisco.

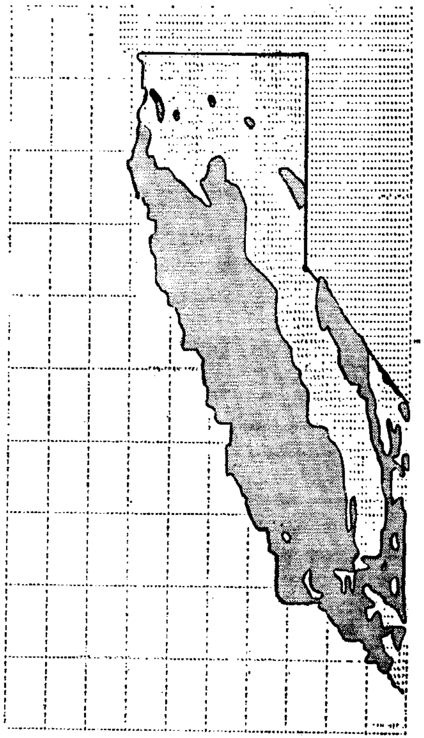

Exhibit 10f. Richter magnitude 7.5 earthquake centered at San Francisco

emphasized in Table 2. Estimates of average annual damage vary from an annual damage of 30 cents per dwelling if the 20-year period from 1928 to 1947 is used to estimate the long-term expected average annual damage to $ 80 per dwelling if the 20-year period from 1888 to 1907 is used. Damage in the 1928 to 1947 period underestimates the magnitude of the hazard by a multiple of 60, while damage in the 1888 to 1907 period overestimates the magnitude of the hazard by a multiple of 4. The long-term average annual damage-per-dwelling is nearly $ 20 per dwelling if recurrence of all earthquakes that occurred during the 168-year period is used.

TABLE 2

Average annual damage-per-dwelling to the 1960 distribution and value of dwelling properties based on simulated losses associated with recurrence of earthquakes that originally occurred in each 20-year period.

20-year period		Average annual damage-per-dwelling in the City of San Francisco
1948-1967		$ 4.20
1928-1947		,, .30
1908-1927		,, 1.60
1888-1907		,, 79.90
1868-1887		,, 19.00
1848-1867		,, 10.20
1828-1847		,, 48.70
1808-1827		,, .60
	168-year period	$ 19.70

If annual damages each year exactly equaled the long-term average annual expected damage, actuaries would need only the expected value of annual damages to approximate risk. However, annual damages vary greatly from year to year so that a measure of catastrophe potential also is needed. Fifty-four of the 80 simulated earthquakes described earlier were strong enough to cause structural damage in San Francisco. Thirty of the 54 damaging earthquakes, when taken together, account for only one percent of the accumulated damages resulting from a recurrence of all damaging earthquakes. On the other hand, catastrophe potential is closely tied to the four most damaging earthquakes which account for

85 percent of the total accumulated "damages" from all earthquakes since 1800 in the City of San Francisco:

	City	Metropolitan area including city
1906 earthquake	44%	33%
1838 earthquake	24%	21%
1868 earthquake	12%	17%
1836 earthquake	6%	13%
Total	86%	84%

The 1906 earthquake would have accounted for 44 percent of the accumulated damage in the City of San Francisco and 33 percent of accumulated damage in the entire metropolitan area. Most of the simulated earthquake-caused losses result from the rare situation in which an intense earthquake occurs near the heavily-populated San Francisco area. The average return period of these natural disaster producers is about 40 years; although, actually, 2 occurred within 2 years of one another and 3 of the 4 within a period of 32 years.

Table 3 illustrates the effect that a rare, but damaging earthquake can have upon an insurance operation. If the long-term average annual damage-per-dwelling of about $ 20 were used to estimate the magnitude of the hazard (based on 168 years of experience), average damage-per-dwelling resulting from the 1906 earthquake would be 73 times larger. It would take 73 years of

TABLE 3

Total simulated damage-per-dwelling resulting from recurrence of a single catastrophic earthquake expressed as a mutliple of he average annual damage-per-dwelling in the City of San Francisco.

Recurrence of a comparable earthquake	Multiple of average annual damage-per-dwelling based on past 168 years	Multiple of average annual damage-per dwelling based on most recent 20-year period
1906	73 times	339 times
1838	40 times	184 times
1868	19 times	90 times
1836	10 times	45 times

average annual damage-per-dwelling to equal damages incurred in a single earthquake. The multiple would be much larger if the long-term average annual damage-per-dwelling had been estimated from the most recent 20-year period ($ 4 per dwelling). In this case, the multiple would have been 339 times.

A similar type of analysis has been performed for the City of Los Angeles using a recurrence of all moderate and severe earthquakes that were located close enough to affect the Los Angeles area in the historical past as a measure of the long-term earthquake hazard. A large grid area (1/10 degree latitude and longitude areas of 36 square miles) was used.

Utility of computer simulation as a means of analyzing physical aspects of the earthquake hazard is illustrated in Exhibit 10 which approximates changes in the geographical pattern of earthshock severity when magnitude of an earthquake is increased. It is assumed that the earthquake was centered near San Francisco at 15 kilometers below the earth's surface. Simulated size and shape of the earthshock severity pattern is given for various values of Richter magnitude ranging from 5 through 7.5. A line has been drawn on the computer printout to enclose areas where earthshock from the quake was perceptible (intensity 1 or greater). Areas affected by intensity 5 or greater have been stippled. An earthshock intensity of 5 is the damage threshold for dwelling structures. It is noted that the geographical area of intense earthshock increases rapidly as magnitude of the earthquake is increased. Irregularity in shape of the patterns emphasize the importance of local ground conditions in determining earthshock severity. Notable research relating the character of local ground conditions to earthshock severity is being conducted at several research institutions. It is hoped the results of this work can eventually be incorporated into the Natural Hazard Simulator.

The effect of geographic location upon size and shape of the earthshock severity pattern is illustrated in Exhibits 11 a-d in which magnitude and depth of the earthquake is held constant (Richter magnitude 6.0 and 15 kilometers, respectively) while the position of the quake's center is varied along the San Andreas fault zone. Pronounced differences in pattern size and shape are due, among other things, to geographical variations in ground conditions.

Exhibit 11. Examples of changes in size and shape of computed earthshock patterns as affected by changes in the location of the earthquake source. Depth and magnitude are held constant at 15 kilometers and Richter 6.0 respectively. To increase clarity of the computed patterns three modifications have been made to the computer printouts: (1) a line has been drawn enclosing areas in which the earthquake is computed to be perceptible; (2) areas in which intensity was calculated to exceed Modified Mercalli 5 (threshold of structural damage) have been stippled; and (3) the outline of the State of California has been darkened for easier identification.

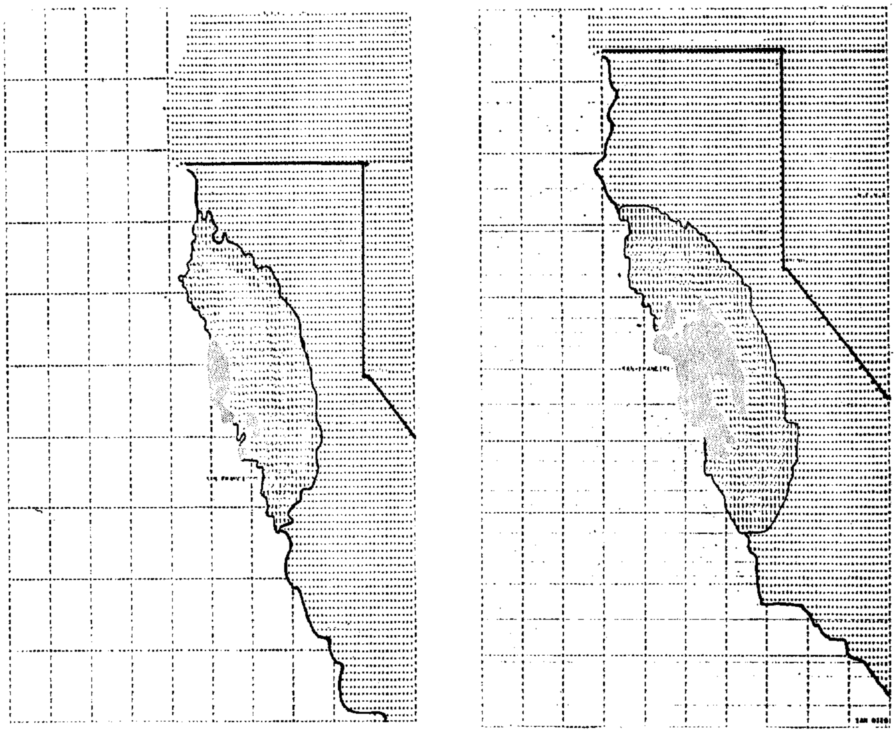

Exhibit 11a. Richter magnitude 6.0 earthquake centered 100 miles North-Northwest of San Francisco.

Exhibit 11b. Richter magnitude 6.0 earthquake centered at San Francisco.

Exhibit 11. (continued) Examples of changes in size and shape of computed earthshock patterns as affected by changes in the location of the earthquake source. Depth and magnitude are held constant at 15 kilometers and Richter 6.0 respectively. To increase clarity of the computed patterns three modifications have been made to the computer printout: (1) a line has been drawn enclosing areas in which the earthquake is computed to be perceptible; (2) areas in which intensity was calculated to exceed Modified Mercalli 5 (threshold of structural damage) have been stippled; and (3) the outline of the State of California has been darkened for easier identification.

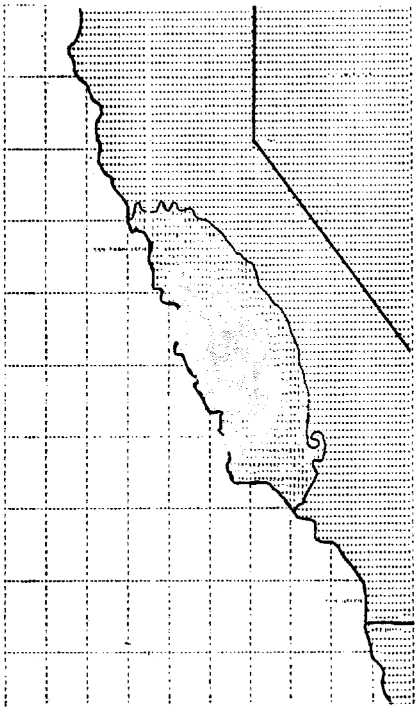

Exhibit 11c. Richter magnitude 6.0 earthquake centered 100 miles South-Southeast of San Francisco.

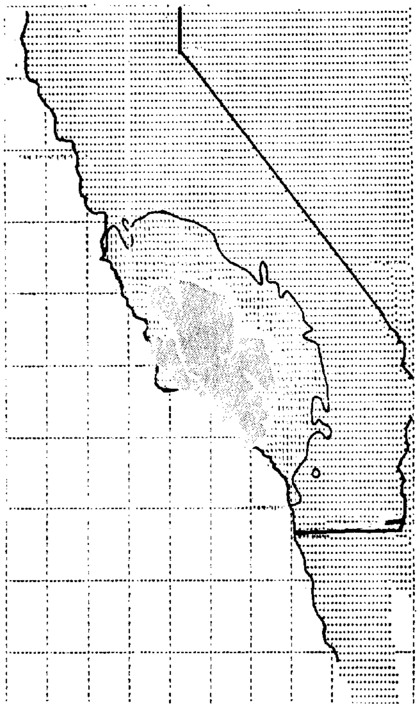

Exhibit 11d. Richter magnitude 6.0 earthquake centered 200 miles South-Southeast of San Francisco.

Repeated interactions of earthshock severity patterns, similar to those given in Exhibits 10 and 11, with the geographical array and density of fixed properties in California determines magnitude of the catastrophe potential. Exhibit 12, which depicts population density, provides a proxy view of the spatial distribution of properties in California on which output of the earthquake hazard mechanism must act.

Objectives of future studies will be (1) development of a more meaningful index for local ground conditions and measure of earthshock intensity; (2) development of a procedure for studying the earthquake hazard to non-dwelling type structures; (3) simulation of loss experience to properties using different sets of assumptions regarding frequency and magnitude of future earthquakes.

Recent reports on status of earthquake research in the United States by the National Research Council (1969); the National Academy of Engineering (1969); and Housner (1967) emphasize the need for research in (1) frequency of occurrence, (2) spatial distribution of earthquake motions as affected by magnitude, distance, local geology and soil properties and (3) subsequent development of seismic zoning maps. Urgency of the need is shown by the fact that "no matter how difficult it is to produce an accurate or even meaningful seismic zoning map, it must be remembered that such maps are absolutely essential in the implementation of effective earthquake-resistant building codes. If good modern maps are not available, the engineer is forced to rely on old inadequate ones". A seismic risk map was published recently by the U.S. Coast and Geodetic Survey (Algermissen 1969); but, risk as defined on the map is given in terms not directly applicable to an insurance operation. Natural Hazard Simulation can possibly contribute to these research objectives by providing an input to construction of a seismic risk mapping, in an insurance context, as expressed in terms of the two components of risk.

Hurricanes—Dacy and Kunreuther (1969) list the fifteen most damaging natural disasters during the years 1954 through 1965 in the United States. Six of these were hurricanes which accounted for over fifty percent of the total damages.

The hurricane hazard can be separated into two parts: (1) wind and (2) tidal inundation and wave wash. The tidal inundation and

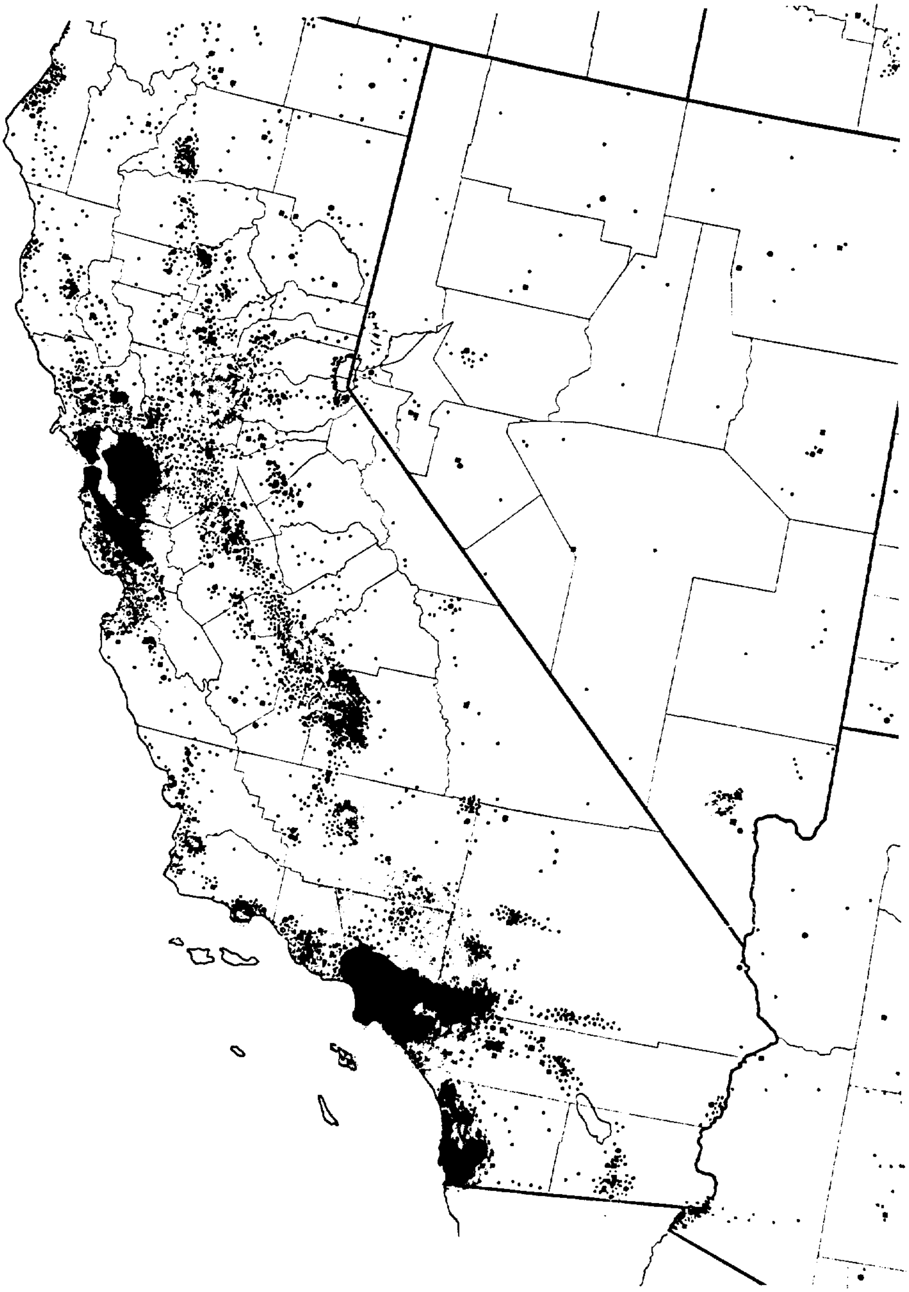

Exhibit 12. Population density of California based on the 1960 Census.

wave wash hazard was approximated on a broad scale during the flood insurance simulation studies mentioned previously. Currently, a mathematical model is being developed to approximate the hurricane wind hazard. The purpose is to estimate (1) potential loss per individual property in various sections of the Gulf and Atlantic Seaboard and (2) risk of simultaneous multiple losses (catastrophe potential) in these areas. An estimate of the potential loss per individual property using this approach has been used in a number of successful rate filings (Friedman 1966, refer to reference 16 and 17). An estimate of catastrophe potential of the hurricane hazard in New England was recently studied using Natural Hazard Simulation in which recurrence of the 1938 Hurricane and its damaging effect upon the present distribution of properties in New England was simulated (Kong and Shortell 1968).

A mathematical model for specifying the severity pattern of a hurricane's wind field as it moves inland has been constructed to include effect of the following physical characteristics of the tropical cyclone (Friedman 1961, 1964, 1966):

1. Storm intensity as measured by the minimum sea level pressure at the storm center.
2. Path of the storm as indicated by direction and curvature of the track as the hurricane nears the coastline and passes inland.
3. Speed of the storm as measured by movement of the storm's center.
   Storm speed can distort the wind field by increasing speeds to the right of the storm path (looking in the direction toward which the storm is moving) and reducing speeds on the left-hand side.
4. Size of the storm. Geographical extent and storm intensity are not directly correlated.
5. Decrease in wind speed as the hurricane moves inland because its source of energy (warm ocean waters) is no longer available and also because there is a reduction in wind speed caused by the frictional effect of land-based obstructions.
6. Stage of development of the hurricane as it moves onshore.
   Highest winds usually occur in the eye wall in the right-hand quadrant. Intensity of these winds is directly related to stage of development of the hurricane (developing, mature, decaying).

7. Inherent gustiness of hurricane winds.
8. Effect of differences in land roughness (urban versus suburban exposures) upon resultant wind speeds.

Size and shape of patterns of peak wind speeds associated with a hurricane's passage are dependent upon these factors. To verify reasonableness of computed patterns, input conditions representing a number of past hurricanes were used to compute the wind patterns which were compared with observed patterns. The degree of correspondence between calculated and observed was more than adequate for purpose of the study. Paths of past hurricanes along the Gulf and East Coasts have ranged from those that parallel the shoreline to those that move inland on a track normal to the coastline. Examples of observed and calculated wind fields for these extreme paths are given in Exhibit 13*). Hurricane Flossy skirted the Gulf coastline in 1956. A year later Hurricane Audrey moved inland on a course nearly perpendicular to the same stretch of coastline. The Natural Hazard Simulation provides a reasonable approximation of the observed wind fields.

Hurricane Diane was a typical storm on the East Coast of the United States. It moved on a curved path through South and North Carolina in the fall of 1955. Exhibit 14a gives the computed wind pattern which is a reasonable facsimile of the observed pattern. Exhibits 14b-d illustrate the effect of increasing the hurricane's intensity upon the wind pattern. Intensity of Hurricane Diane was increased in the model by reducing the sea-level pressure at the storm's center by successive increments of one-half inch of mercury and horizontal extent of the storm was permitted to increase. Resulting peak wind patterns show a rapid increase in severity of the storm. Inasmuch as loss functions relating wind speed to structural damage are non-linear, the more intense version of the hurricane (Exhibit 14d) will produce a disproportionately large amount of damage as compared with a similar type of hurricane of somewhat lesser intensity.

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*) Examples of computer derived wind speed patterns given in this report do not include the effects of item #7 (Inherent gustiness of hurricane winds) and item #8 (Differences in land roughness upon resultant wind speed). The capacity for incorporating these items has been built into the computer program; but, has not, as yet, been utilized.

Exhibit 13. Observed and calculated geographical pattern of highest wind associated with movement of Hurricane Flossy along the Gulf Coast in 1956.

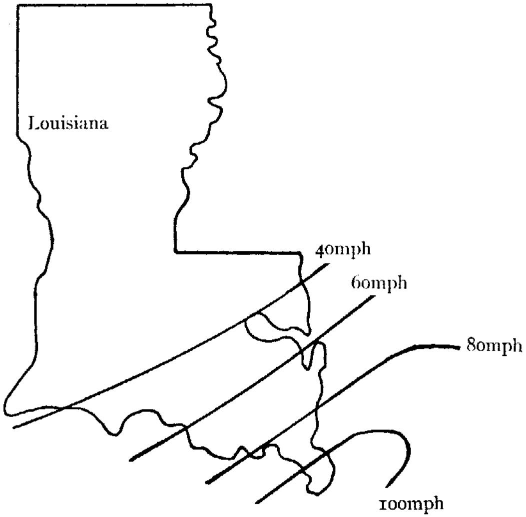

Exhibit 13a. Observed pattern of peak wind gust based upon observations tabulated in the U.S. Department of Commerce publication *Climatological Data Annual issue*—1956 (Vol. 7, No. 13) Superintendent of Documents, Washington, D.C.

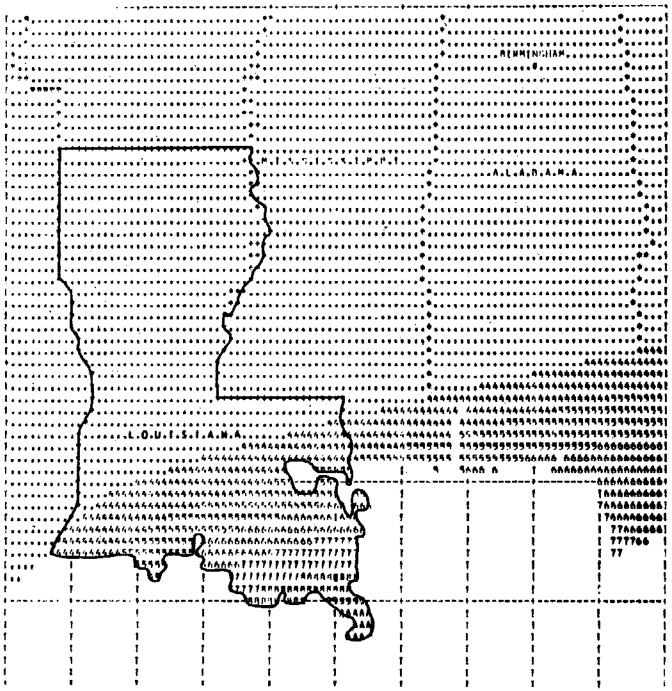

Exhibit 13b. Computed pattern of highest winds. The digit given at each grid point in the affected area represents a wind speed interval. For instance, the digit 5 denotes a wind speed between 50 to 59 miles per hour. For speed intervals above 100 miles per hour, an alphabetic designation is used. The letter A represents the interval from 100 to 109 miles per hour. The State of Louisiana has been outlined on the printout.

Exhibit 13. (continued) Observed and calculated geographical pattern of highest wind associated with passage of Hurricane Audrey across the Gulf Coastline in 1957.

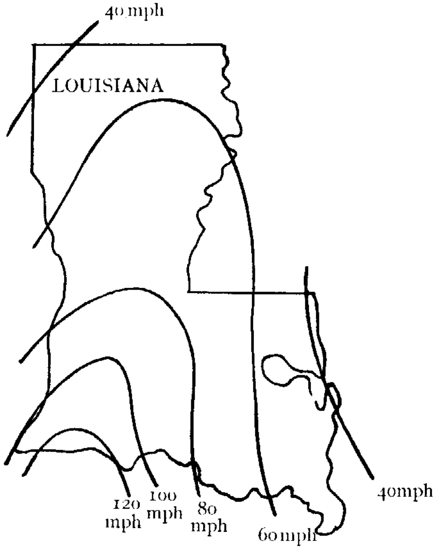

Exhibit 13c. Observed pattern of peak wind gust based upon observations tabulated in the U.S. Department of Commerce publication *Climatological Data Annual Issue*—1957 (Vol 8, No. 13) Superintendent of Documents, Washington, D.C.

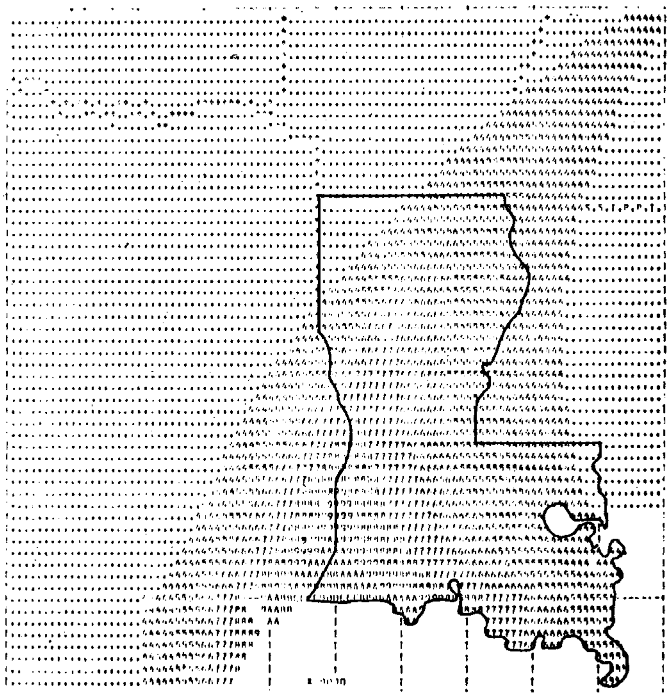

Exhibit 13d. Computed pattern of highest wind. The digit given at each grid point in the affected area represents a wind speed interval. For instance, the digit 5 denotes a wind speed between 50 and 59 miles per hour. For speed intervals above 100 miles per hour, an alphabetic designation is used. The letter A represents the interval from 100 to 109 miles per hour. The State of Louisiana has been outlined on the printout.

Exhibit 14. Computer printout of the pattern of highest wind associated with hurricanes of selected intensities that follow the same path as Hurricane Diane followed through the Carolinas in 1955. Storm size allowed to vary with storm intensity.

Exhibit 14a. Hurricane with an intensity of *29.00* inches (lowest sea level pressure) which follows the path of Hurricane Diane.

Exhibit 14b. Hurricane with an intensity of *28.50* inches (lowest sea level pressure) which follows the path of Hurricane Diane.

Exhibit 14. (continued) Computer printout of the pattern of highest wind associated with hurricanes of selected intensities that follow the same path as Hurricane Diane followed through the Carolinas in 1955.

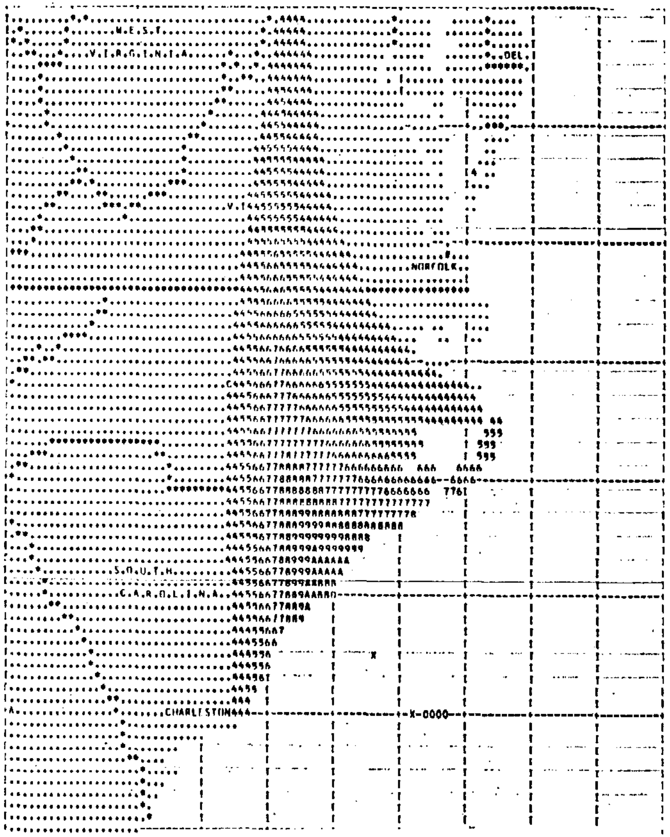

Exhibit 14c. Hurricane with an intensity of *28.00* inches (lowest sea level pressure) which follows the path of Hurricane Diane.

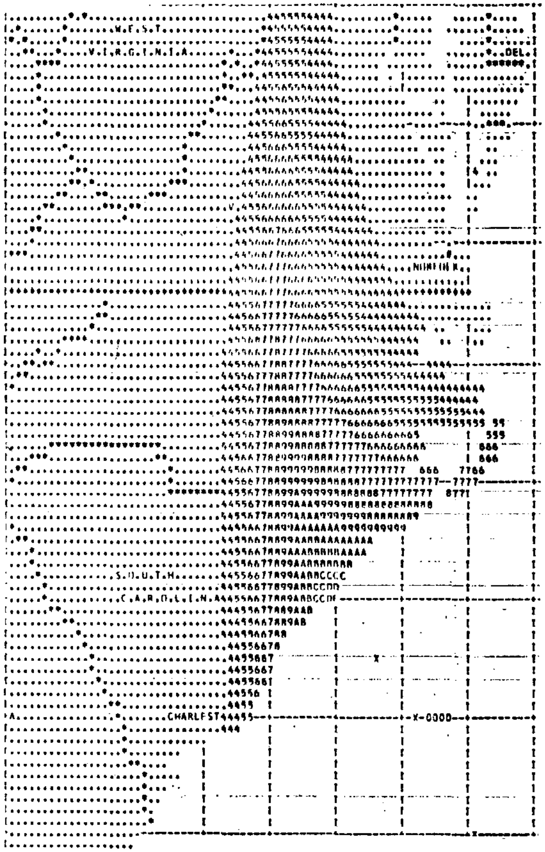

Exhibit 14d. Hurricane with an intensity of *27.50* inches (lowest sea level pressure) which follows the path of Hurricane Diane.

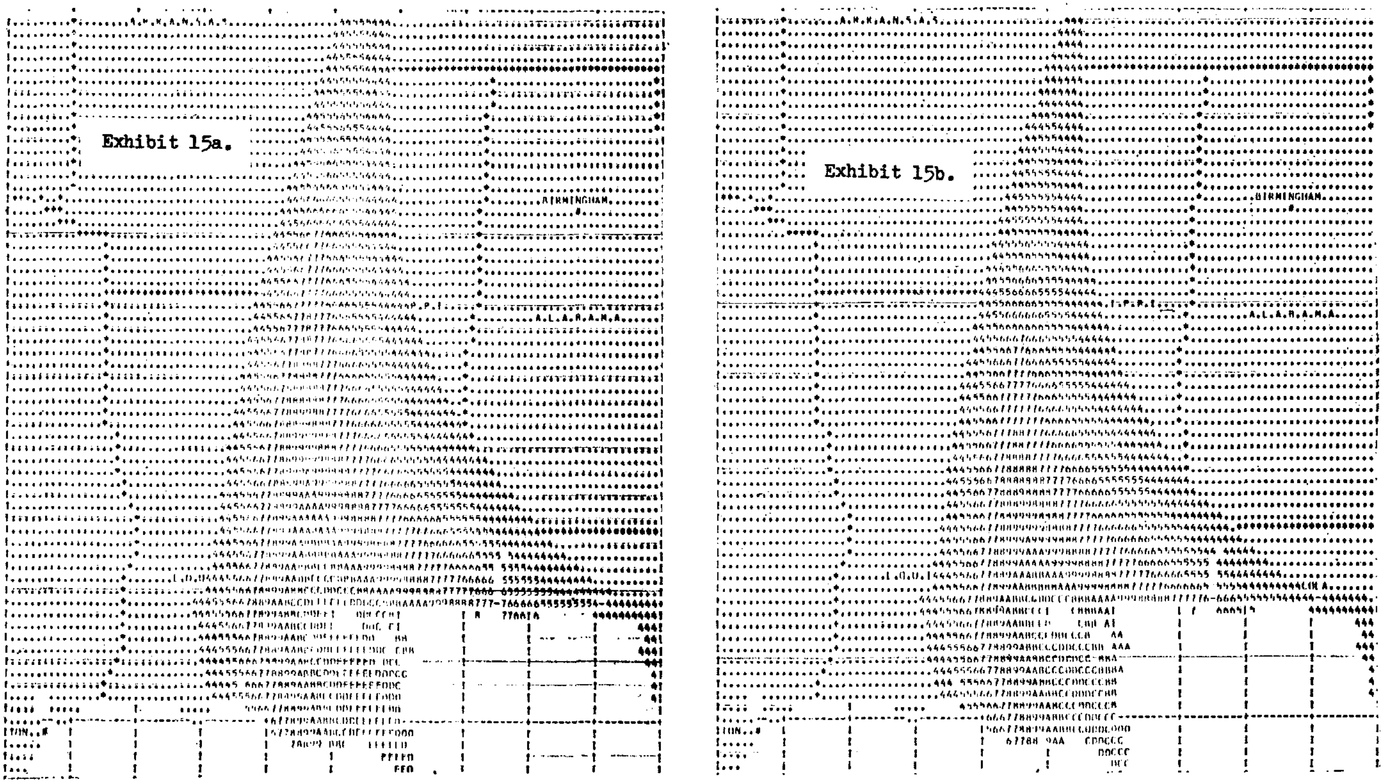

Exhibit 15. Computer printout of the pattern of highest wind associated with the simulated passage of hurricanes of selected intensities which follow the same path that carries the storm directly over New Orleans. "Damage" to dwelling structures varies from 8 million dollars resulting from a storm with an intensity of 29.00 inches (lowest sea-level pressure) to 205 million dollars for a storm with an intensity of 27.50 inch central pressure. In this example, storm size allowed to vary according to storm intensity. Exhibit 15a: Computed pattern of highest wind speed resulting from passage of a hurricane with a landfall intensity of *27.50* inches on a path that carries it over New Orleans. Exhibit 15b: Computed pattern of highest wind speed resulting from passage of a hurricane with a landfall pressure of *28.00* inches on a path that carries it over New Orleans.

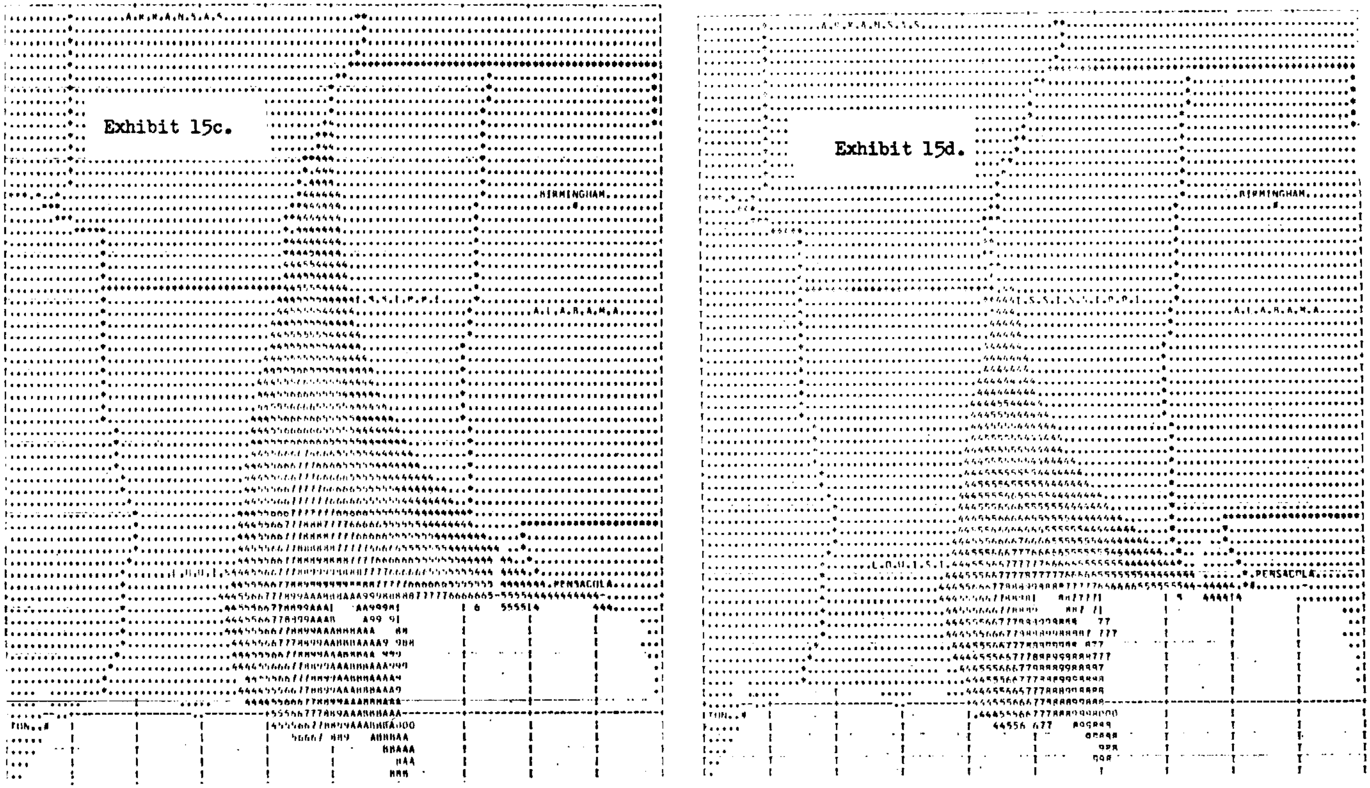

Exhibit 15. (continued) Computer printout of the pattern of highest wind associated with the simulated passage of hurricanes of selected intensities which follow a path that carry the storms directly over New Orleans. Resulting "damage" to dwelling structures varied from 8 million dollars from a storm with an intensity of 29.00 inch lowest sea-level pressure to 205 million dollars from a storm with a 27.50 inch lowest sea-level pressure. Storm size changes relative to that of 27.50 inch hurricane. Exhibit 15c: computed pattern of highest wind speed resulting from passage of a hurricane with a landfall pressure of *28.50* inches on a path that carries it over New Orleans. Exhibit 15d: computed pattern of highest wind speed resulting from passage of a hurricane with a landfall pressure of *29.00* inches on a path that carries it over New Orleans.

A quantitative estimate of the effect of changing hurricane intensity (as measured by sea-level pressure) upon aggregate damage to an exposed geographical array of dwellings can be made using the simulation approach. Location and value of over 500,000 dwelling structures in the state of Louisiana, based upon U.S. Census Data, have been assigned to the 1300 grid areas (6 miles: by 6 miles square) which represent the State in the computer. A hurricane with a path that would carry it directly over the New Orleans Metropolitan area is mathematically applied to these properties for each of five different storm intensities. Computed peak wind patterns are given in Exhibits 15a-d. Table 4 contains pertinent "damage statistics" resulting from the five passes.

TABLE 4

*"Damage statistics" to Louisiana dwelling properties resulting from a hurricane which passes over the New Orleans Metropolitan area at each of five different intensities *). See Exhibit 15.*

Hurricane Intensity Lowest sea level pressure (Inches of mercury)	Number of Louisiana dwellings in areas with winds of 40 miles per hour or more	Aggregate computed damage based upon wind severity acting on number and value of dwellings in each grid area
27.50	318,000	$ 205,000,000
28.00	297,000	,, 90,000,000
28.50	275,000	,, 31,000,000
29.00	252,000	,, 8,000,000
29.50	226,000	,, 1,000,000

Importance of the rare, but extreme storm as a major damage producer is stressed in Table 4—extreme storms produce a disproportionately large share of hurricane-caused damages. The possible impact of hurricane modification—Project Stormfury (1970) of the U.S. Department of Commerce—on damage reduction

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*) By contrast, there were 254,000 dwelling structures affected by computed winds of 40 miles per hour or more during Hurricane Flossy (Exhibit 13b). Computed aggregate damage was $ 1,500,000. A total of 427,000 dwellings were computed to have experienced winds of 40 miles per hour or more during Hurricane Audrey (Exhibit 13d) with computed "damages" of $ 3,600,000.

could be quite large it reducing a hurricane's intensity by a relatively small amount results in a disproportionate reduction in wind-caused losses. Peak wind speed in New Orleans is calculated at 160 miles per hour for the most intense storm (Exhibit 15a) and 80 miles per hour for the least intense version of the hurricane.

Effect of interaction between geographical distribution of a geophysical event and exposed properties in producing a natural disaster, mentioned previously, can be illustrated by comparing aggregate damage to Louisiana dwelling properties when the path of a storm of given intensity is changed relative to the center of population. Exhibit 16 is the computed wind pattern of a hurricane with a central atmospheric pressure of 27.50 inches of mercury with an identical storm path placed 1° and 2° degrees of longitude west of the path through New Orleans and 1° degree east (about 60 miles) of the original path over New Orleans. Table 5 provides "damage statistics" resulting from these four "occurrences". Exhibits 16a-d give resultant peak wind patterns.

TABLE 5

"Damage statistics" to Louisiana dwelling properties resulting from a hurricane of given intensity (central pressure of 27.50 inches of mercury) which has landfall at each of four different locations. Refer to Exhibit 16.

Location of Landfall relative to New Orleans	Number of Louisiana dwellings in areas with winds of 40 miles per hour or more	Aggregate computed damage based upon wind severity acting on number and value of dwellings in each grid area
60 miles east of New Orleans	237,000	$ 44,000,000
Position storm over City	318,000	,, 205,000,000
60 miles west of New Orleans	410,000	,, 103,000,000
120 miles west of New Orleans	445,000	,, 71,000,000

Degree of dependence of resultant damage totals upon the complex interplay of geophysical severity pattern and geographical array of damage-susceptible structures is shown in Table 5. The magnitude of a natural disaster is extremely sensitive to chance positioning of the severity pattern in relation to the particular distribution of property in any given region.

Future work on the hurricane hazard will include an evaluation

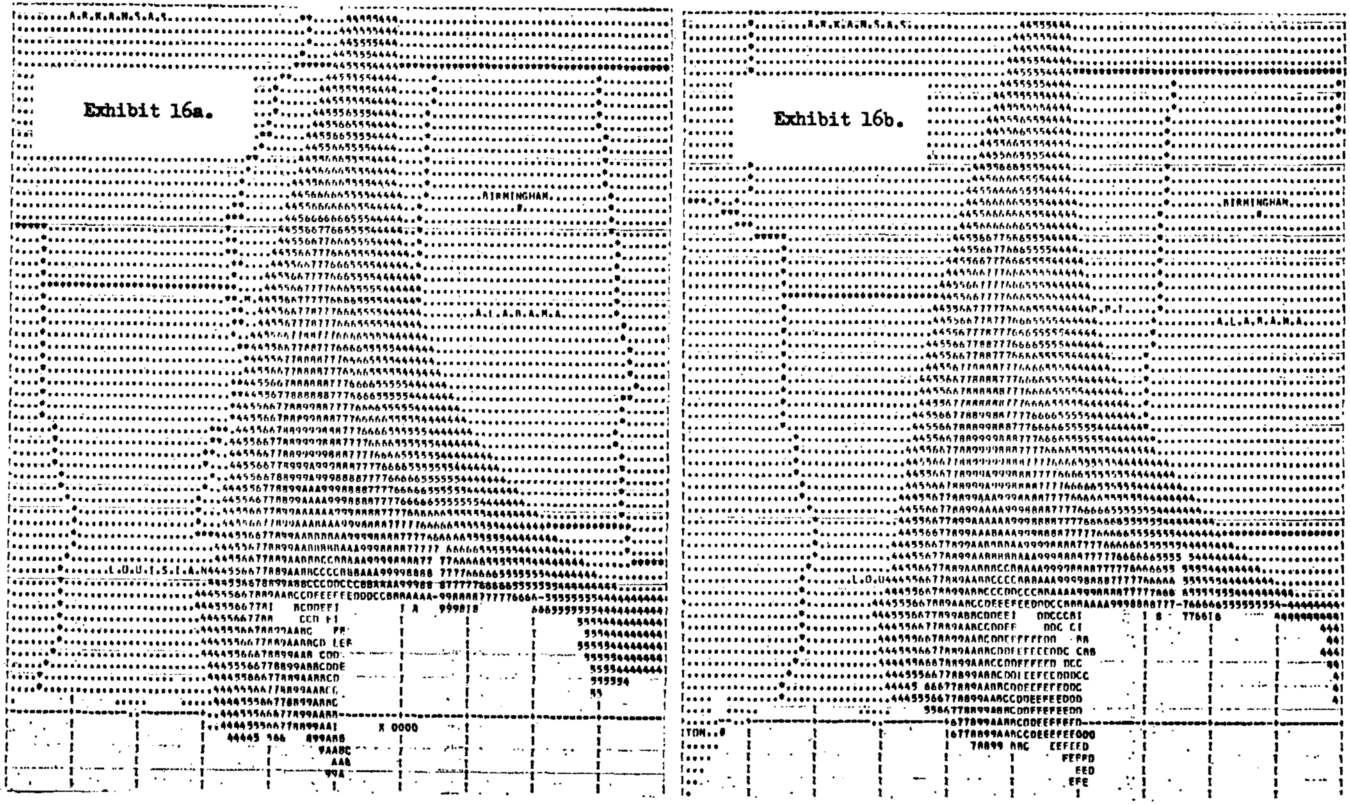

Exhibit 16. Example of effect of interaction of geographical severity pattern of a geophysical event with the distribution of properties upon magnitude of the resulting "natural disaster". Four storms of identical (severe) intensity and size are mathematically moved across the State of Louisiana from four different landfall positions. The resulting patterns of highest winds are given in Exhibits 16a-d. Resultant "damage" to Louisiana dwellings varies from 45 million dollars produced by the severity pattern in Exhibit 16a to 205 million dollars produced by the wind severity pattern of a storm that moves directly over New Orleans. Exhibit 16a depicts the highest wind pattern of a severe hurricane with a landfall *60 miles east of New Orleans.* Exhibit 16b gives the wind pattern of an identical hurricane of severe intensity which has a landfall that carries it over New Orleans.

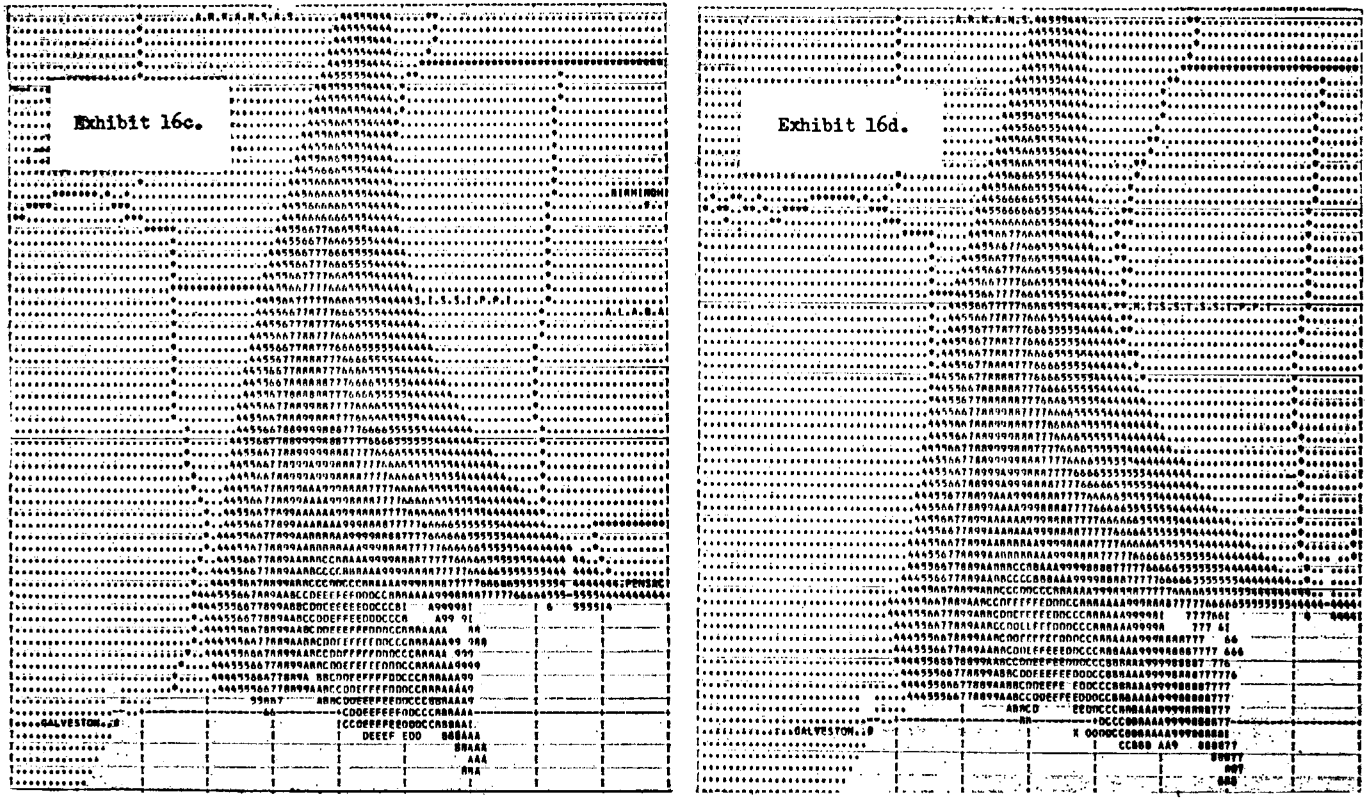

Exhibit 16. (continued) Example of effect of interaction of geographical severity pattern of a geophysical event with the distribution of properties upon magnitude of the resulting "natural disaster". Four storms of identical intensity and size are mathematically moved across the State of Louisiana from four different landfall positions. Resulting patterns of highest winds are given in Exhibit 16a-d. Resultant "damage" to Louisiana dwelling properties calculated at 105 million dollars if the storm moved onshore 60 miles west of New Orleans and 70 million if the storm came ashore 120 miles west of New Orleans. Exhibit 16c shows the wind pattern for a hurricane identical to the storm represented in Exhibit 16b but with a landfall *60 miles west of New Orleans.* Exhibit 16d represents the wind pattern for a hurricane identical to the storm given in Exhibit 16b but with a landfall *120 miles west of New Orleans.*

of the two components of risk for the hurricane wind hazard in various sections of the Gulf and East Coasts of the United States using (1) a recurrence of past hurricanes as a measure of the hurricane wind hazard and (2) a large number of simulated 25-year sequences of "synthetic loss experience" as a measure of the hazard. Another objective is to combine the hurricane wind and tidal inundation hazard mechanisms into a single mathematical model.

Thunderstorm byproducts—tornadoes, wind and hail

Work has been done on an evaluation of the first component of risk as mentioned previously. Construction of a mathematical model for approximating the severity pattern of the thunderstorm-spawned hazards to use in evaluating catastrophe potential has been started.

Widespread winter and spring windstorms

Some work has been done in determining the first component of risk for non-thunderstorm windstorms. Construction of a model for evaluating catastrophe potential has not begun.

Integrated effect of all Natural Hazards

Expansion of the system in order to simulate the integrated effect of all of the natural hazards on given geographical arrays of structures can be made after mathematical modeling of the individual hazards has been accomplished.

Summary and Conclusion

Floods, hurricanes, tornadoes, earthquakes, windstorms and hailstorms—the natural hazards—are causing increasing amounts of property damage in the United States. A large percentage of these damages occur as a result of infrequent, but severe, geophysical events (storm or earthquakes) that are located in or near populated areas. If aggregate losses are great, the event is called a natural disaster. The number and magnitude of natural disasters in the United States, are both trending upward.

Insurance is one means of covering the natural hazards. To provide this protection, two components of risk must be evaluated:

The first is risk-per-individual-structure; the second is risk of a large number of simultaneous losses—the catastrophe potential. The latter component of risk has attained added importance with the increased number and size of recent natural disasters.

Past loss experience, taken by itself, does not provide a good measure of either risk component. On a relative basis, loss experience provides a better measure of the risk-per-individual-structure than the catastrophe potential on which it gives very little insight.

A supplementary approach (Natural Hazards Simulation) is presented which provides measures of both risk components. Of especial interest is its measure of catastrophe potential. Various tests and applications of the approach suggest that it provides meaningful estimates of natural hazard risk. It is based upon a considerable amount of additional information not inherently contained in loss statistics. Natural Hazards Simulation supplies a means of tying together unconnected bits and pieces of pertinent information currently available from a number of different sources and translates the result into an insurance context. Output of the procedure provides a means of obtaining an up-to-date understanding of the physical character of the natural hazards including (1) how the system of interactions of these hazards with a geographical array of exposed properties results in production of property damage; (2) how this interaction can occasionally result in the creation of a natural disaster of catastrophic proportions; and (3) how to provide, if possible, a more efficient workable insurance program to cover these hazards. High-speed electronic computer capacity permits this type of analysis.

The purpose of Natural Hazards Simulation is *not* to compete with experts in various related fields by attempting to create new knowledge in their fields, but to (1) take knowledge currently accepted by these experts in their field of specialization; (2) interweave this knowledge with that from other sources into a construction of a mathematical approximation of the actual system by which natural hazards become damage producers to fixed property; and (3) interpret output of this mathematical system in terms of the characteristics of an insurance operation needed to cover the natural hazards.

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