INSTITUTE OF ACTUARIES

CATASTROPHE STUDY GROUP

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Definition of Catastrophe

We took as our definition:

> "A single event which occurs relatively infrequently but which
> involves multiple claims totalling very large amounts of loss."

A catastrophe can arise from either natural phenomena or man-made hazards.

Examples of natural phenomena are:

(a) Earthquake and volcano including resulting fire damage.
(b) Windstorm including tornado.
(c) Avalanche.
(d) Inundation.
(e) Forest or bush fires.

and man-made hazards are:

(a) Explosion including nuclear fission.
(b) Failure of materials or construction.
(c) Conflagration (due for example to overcrowding or inadequate
    fire fighting.
(d) Pollution.
(e) Aviation hazards.

It was decided to concentrate our efforts initially on earthquake,
windstorm and inundation.   Three separate reports on our progress are attached
to this introduction.

The Actuarial Problem

Basically the problems of rating and reserving are common, but before any
calculations can be made an appreciation of the cause of the catastrophe
and the likely effect on property is required.   The reports cover much
of this aspect.   It will be seen, not surprisingly, that the main
difficulty rests in estimating frequency.   Underwriters can estimate the
probable maximum loss any one property, or any one location for catastrophes
of a given severity.   Thus the difficulty to be overcome is to find the
frequency distribution of events by severity.

For example for Los Angeles   earthquakes it might be reasonable to use

Intensity on MM Scale	Frequency per annum
VI	0.1667
VII	0.0455
VIII	0.0182
IX	0.0034

(MM.V is unlikely to do significant damage)

To each frequency an expected loss can be assigned.   Thus by multiplication and addition the net risk premium is indicated.

Reserving raises both actuarial and non-actuarial questions.

Actuarially, given the frequency and damage distributions for a particular location the reserve needed to cover the writing of the business can be calculated by the usual statistical methods.   In the case of multiple locations such as arise for an international insurer, this approach is not practicable. Even if it is possible to translate the data into mathematical expressions for the distributions the manipulation of the convolutions is a formidable mathematical task.   Hence in practice a suitable way is by computer simulation over a fairly long notional exposure period.

The non-actuarial problems are associated with local supervisory authority requirements and are to some extent political.   For example if an earthquake reserve is set up in the accounts it may grow to what appears to be a large fund before being called upon for a claim.   A prospective take-over might be induced at the sight of so much money apparently not being used.

In practice there has been a tendency in some cases to forget the need for catastrophe premiums to be separated and they have been treated as ordinary premiums e.g. in the fire account when no catastrophe occurs the account looks more healthy.

American accounting for catastrophes

The Financial Accounting Standards Board in the U.S.A. has ruled as to when contingency reserves may be maintained as such and specified certain rules. Insurance and reinsurance companies do not satisfy these rules and therefore for trading periods beginning after 30th June 1975 insurance catastrophe reserves cannot be shown as such.   The reserves must therefore be held in the shareholders' funds where externally they lose their identity.

Taxation.

Transfers to catastrophe/contingency reserves in most countries are treated for taxation purposes as non-revenue items and attract no tax relief. There are exceptions but in these cases limitations are usually applied either by amount (e.g. Finland) or by class of business (e.g. E.E.C. proposal).

Conclusion

There is clearly a very great deal of difficulty to be overcome in the writing of catastrophe covers but as far as rating and reserving are concerned the actuary can play a part.   It would be wise to recognise that it is only a part; the assistance of geologists, meteorologists etc. must be sought and above all the actuary must work with and for the underwriter.

CATASTROPHE STUDY GROUP - FLOODING.

1. One of the catastrophes which the Study Group considered warranting attention was that of flooding. The purpose of this note is purely to give a progress report on what we have done in connection with this particular catastrophe.

2. First, a search was made of actuarial transactions published in recent years. The papers traced which appeared of relevant interest included the following:

   Proceedings Casualty Actuarial Society. Vol.L14, 1972
   Actuarial Applications in Catastrophe Reinsurance by LeRoy J. Simion.

   In this paper a study is made of some of the implied actuarial relationships involved with a mathematical model as an aid to the maintenance of logical consistency with various reinsurance quotations.

   ASTIN Bulletin Vol.VII, Part 1, 1972
   Insurance and the Natural Hazards by D.G. Friedman.

   In this report it is mentioned that to provide insurance protection against the natural hazards two components of risk must be evaluated: (i) Risk per individual structure and (2) risk of a large number of simultaneous losses, i.e. catastrophe potential.

   It is suggested that retrospective measure of loss potential is a poor measure of future risk because of (1) changing characteristics of property, (2) bias introduced by chance interactions of hazard and property array, and (3) random occurrence (or non-occurrence) of a severe geophysical event during the short sampling period of years that is usually available for study.

   Friedman therefore presents a prospective measure of risk (called Natural Hazard Simulation) in which a mathematical approximation of the natural hazard mechanism is constructed which artificially produces geophysical events which interact mathematically with a given geographical array of properties. Use of a computer permits calculation of a large number of, say, 25 year sequences of synthetic loss experiences which it is claimed can be used to estimate the two measures of natural hazard risk.

   Using Friedman's 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. Characteristics of an insurance operation needed to cover the hazard are also simulated.

   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 programme need to cover the hazard. The programme is now operational; the Federal Government assumes a portion of risk by acting as reinsurer against excessive losses on industry's share of the programme.

   Journal of Risk and Insurance. Vols.2 & 3 of 1973.
   A Theory of Capacity and the Insurance of Catastrophe Risks by J.M. Stone.

   A theory of capacity is developed and examined for its implications regarding insurance industry structure, the theory being applied to a number of specific examples to illustrate the proper response of insurance to requests for unusual high peril coverages and marked phenomena within an impact of aggregate capacity.

3. It was then thought desirable to make further searches outside actuarial
   circles. A visit was therefore made to the Meteorological Office Library.

   From this source two papers which appeared of relevant interest were traced,
   both from the Association Internationale D'Hydrologie Scientifique.

   Efficiency of the Estimation of Floods with a given return period by
   Z. Kaczmarek, 1957.

   A maximal annual stream flow with a given return period Q.max.(T) is
   generally dependent on a certain number of parameters estimated in
   various ways from an N-term random sample. The value of Q.max.(T) is
   thus an estimate of the real flood recurring once in T years in an infinite
   statistical population of maximal flows.

   In order to determine the efficiency of the estimation Kaczmarek
   worked out asymptotic distributions of the estimated Q.max(T) for the
   distribution function F(Q.max.) defined by the Foster and Gumbel methods
   and the log normal method. He introduced the notion of confidence
   intervals of the estimate giving a rational basis for the determination
   of the safety factor, dependent on the required confidence coefficient
   The considered confidence interval on the flow Q.max(T) essentially
   differs from the control interval used by Gumbel which interval
   characterised only the deviation of an individual n'th element in an
   ordered N year observation sequence.

   Numerical examples illustrate the application of the formulae deduced
   permitting a comparison of the efficiency of the estimate Q.max (T) as
   determined by different methods.

   Probable Floods Curve as Function of Regional Parameters by J.Lambor,1957.

   Lambor's approach, which is concerned with river flooding, centres
   round the equation:

   $$Q = A \log^{\wedge} N + BN + C$$

   Where Q is the flood discharge in cubic metres per second which occurs
   once in N years on average; A, B, & C are regional parameters.
   $\wedge$ depends on the character of the river, the characteristics of the basin
   and the size of the drainage.

4. At this stage of the research it was considered that something more
   specific and of direct relevance to the United Kingdom was desirable.
   A number of enquiries of British Scientific organisations therefore were
   made and by a process of trial and elimination those which appeared
   potentially valuable to the research project in hand were ascertained.

   Three contacts have proved extremely valuable, namely:

   Middlesex Polytechnic, Flood Hazard Research Project.
   Institute of Hydrology
   Local Government Operational Research Unit.

   Much has been most usefully published by these organisation such as
   "The Economics of Flood Alleviation" in which Report the aim is to
   provide a fuller understanding of the economic consequences of river
   flooding and of their relevance to flood alleviation measures. Flood
   losses are classified according to the different classes of victim,
   e.g. property owners, agriculturists etc. with an indication of how each
   type of risk should be assessed. This loss information is combined with
   information on frequencies of floods of various magnitudes to derive
   the future benefits to be expected from providing different levels of
   protection.

Also there has been published by the Natural Environment Research Council a Flood Studies Report which reflects a most thorough investigation relative to the British Isles.

The basic data collated and used during the investigation is presented and summarised (in Vol.4) and comprises lists of gauging stations and their gradings and catchment characteristis, flood statistics, the basic peak flow records for 530 stations with historical records where these were found, and summaries of 1,500 events used in catchment response studies.

The hydrological studies (Vol 1) deal in a refined manner with items such as statistical flood frequency analysis, methods of extension of short records, estimation of flood peaks and flood volume (The writer found it of interest that the various statistical techniques utilised included Gumbel's method referred to in Kaczmarek's paper).

Very extensive rainfall records are available in the British Isles and these are exploited in the meteorological studies (Vol 2); statistical and physical studies of rainfall depth, duration, and return period are made for point and area rainfall everywhere in the British Isles. It is considered that the rainfall statistics can be used to compute the probabilities and the characteristics of flooding on different time and space scales.

Maps illustrating Vols. 1 & 2 are contained in Vol.5.

Vol.3 of the Report is valuably concerned with the choice and comparison of flood routing methods and the theory and strategy of flood routing.

5. Tentative Conclusion.

The relevant data available certainly as far as the British Isles are concered, is extensive. Moreover the related statistical techniques which have been developed are impressive.

It is tentatively concluded that a basis is in being upon which the actuary can build if faced with specific insurance problems related to flooding catastrophes.

L.G.G.T.

29th July, 1975.

1. Introduction

1.1. The purpose of this study is to find suitable actuarial and statistical techniques that may be used to assist in making the insurance against the effects of tropical cyclones a viable proposition. To do this it is necessary not only to examine the type and standard of data available but also to obtain a basic understanding of the tropical cyclone as an atmospheric phenomenon with its many destructive and disastrous effects.

1.2. "Tropical Cyclone" is a general term used to describe cyclonic circulations originating in the tropics and can be classified by varying degrees of intensity into four sub-divisions: (i) Tropical Disturbance, (ii) Tropical Depression, (iii) Tropical Storm, (iv) Hurricane.

The former two, being the least intense, are of little or no concern as they would rarely result in losses. Where a tropical cyclone has highest wind speeds between 39 and 73 m.p.h. it is classified as a Tropical storm, and where highest wind speeds exceed 73 m.p.h. it is termed a Hurricane. (In some areas the terms Cyclone and Typhoon are used). The Tropical storm, although potentially dangerous, is unlikely to have such a catastrophic effect as the hurricane and so in the following we will restrict ourselves to this final category.

1.3. Data relating to tropical cyclones in some regions goes back as far as 1871 but clearly the standard of atmospheric recording has changed substantially since then and so it is rare for the data for a region to be consistent over the whole period of observation.

Many precautions are now being taken to protect communities from the catastrophic effects of hurricanes, both by environmental planning and regulations and by the use of suitable warning systems; but while cities still exist in hurricane regions there is an important part to play for the insurer in protecting those communities.

2. Formation of a hurricane and its subsequent movement

2.1. There is still no exact understanding as to why a hurricane forms but there seem to be several essential conditions for its generation namely:

(i) Sea temperature of at least $26°C$;
(ii) A deep, moist, unstable layer of air ;
(iii) A weak, cyclonic circulation;
(iv) The air moving on a curved path;
(v) A variation of wind direction with height.

These conditions usually only exist in tropical regions between $5°$ and $20°$ latitude from the equator.

2.2. The view is currently held that hurricanes can be regarded as atmospheric heat engines being briefly described in the following manner. Low level air begins to flow into an existing cyclonic disturbance reinforcing the circulation. Diverging air at upper levels over the low level cyclonic convergence sets up a vertical circulation. A large amount of latent heat energy is released as water vapour in the ascending air flow cools, reaches saturation and condenses and this serves to drive the wind system.

High altitude winds act as an exhaust system releasing the ascending
air and preventing the cyclone from filling up. The air, once
released from the system, enters a high altitude anti-cyclone and is
transported away from the cyclonic spiral before sinking. The
intensity that a hurricane attains is thought to be determined by
the interaction of the high and low altitude winds in that if the
rate of convergence of air at low levels is greater than the rate
of release at the upper end of the spiral, the cyclone will fill and
die out. If the reverse is true the vertical circulation will
intensify.

2.3. Hurricanes, after formation, move generally with a speed of less than
20 m.p.h. The path taken can be very erratic but in general is
parabolic in shape; in the Northern Hemisphere movement is usually
west to north west until recurving to the north east, and in the
Southern Hemisphere is usually west to south west until recurving
to the south east. On crossing land, the intensity of the
hurricane will decrease very rapidly as there is insufficient
moisture to fuel the system. The intensity also decreases as the
track extends into higher latitudes where the water temperature is
lower.

2.4. The cyclonic circulation of a hurricane can extend over an area of
400 miles diameter. In general, the centre (or eye) of the storm will
be of 20-30 miles diameter; this is an area of calm where winds are
usually less than 15 m.p.h. Within a radius of 60 miles from the
centre winds will have reached hurricane force (74 m.p.h. or more)
and velocities exceeding 100 m.p.h. are often experienced; this
is the area of the most intense winds. The wind strength then gradually
decreases to gale force about 150 miles from the centre.

3. Effects of a hurricane

3.1. Most of the damage resulting from a hurricane is caused by wind,
rain and storm surge, the most destructive of these being the
storm surge.

3.2. As winds increase, the pressure exerted on a building increases
with the square of the wind velocity, so hurricane force winds
clearly exert tremendous pressures on structures and cause failure
where the design and standard of building is inadequate. A wind
velocity of 100 m.p.h. exerts a pressure of approximately 35lbs/
sq.ft., and this increases to nearly 80lbs/sq.ft. for a wind
velocity of 150 m.p.h. These hurricane force winds can sometimes
lead to structural failure as a result of the inverse effect where
the atmospheric pressure outside a closed building is reduced such
that the normal pressure inside causes an explosion. Structural
failure can also be caused by the oscillation sometimes produced
in tall buildings. Wind driven debris is yet another hazard which
may cause human injury as well as property damage. It must be
remembered that wind speeds are never constant and gusts will
occur up to 1½ times the mean speed.

3.3. Floods produced by rainfall are more destructive than the winds of
a hurricane. Precipitation of 20 inches in two days is not
uncommon and normal drainage cannot adequately cope with this.
Mountainous areas are particularly prone to this type of flood.

3.4. The most destructive effect of a hurricane is the storm surge which
floods low lying coastal areas and produces the effect of a tidal
wave when it is forced up narrow channels such as rivers. As the
storm centre crosses the continental shelf the mean water level
may rise 15 feet or more. In addition, below the centre of the
storm the low atmospheric pressure draws the water level upwards,
and behind the centre hurricane force winds depress the mean level;
this produces very strong currents. The storm surge, combined
with wind driven waves of 50 feet or more and the normal astronomical
tides can cause very severe flooding. The presence of water on
the land causes severe damage in itself, but the destruction is

intensified by the pounding of the waves on structures and by the erosion of foundations by the very strong current set up by the storm surge.

3.5. As well as property damage, the loss of life from a hurricane can be very high, particularly as a result of the flooding due to storm surge: Asia is an area particularly exposed to this phenomenon. The only way to reduce life losses of such catastrophic proportions is by timely evacuation of the exposed area, and this can only be achieved if an adequate warning system is in force.

3.6. Damage caused by all the above can be reduced by the enforcement of stringent design and building regulations and by ensuring that all possible precautions against flooding are taken.

4. Premiums

4.1. The procedure required to rate tropical cyclones is essentially a standard approach in that the frequency of occurrence and expected losses resulting are used to find a basic risk premium which should then be suitably loaded for fluctuation and expenses etc.

4.2. The data available is not always of the best quality and so a considerable amount of judgment is required to obtain the desired results. For most areas at risk there is data available to show the annual frequencies of tropical cyclones and the tracks they are likely to take. Some such data, in particular for the North Atlantic and for Australia, is very detailed showing, for example, frequencies of tropical cyclones passing through specified longitude-latitude squares, or within a certain radius of a location , or crossing segments of the coastline. Other areas are not so well documented. The main problem arises in ascertaining which of the tropical cyclones are potentially damaging (i.e. of high intensity) and the extent of the damage that would result.

4.3. The term "tropical cyclone" is usually used to describe a cyclonic disturbance which can vary in intensity from a tropical disturbance to a hurricane, as was described in 1.2. In most of the available data, tropical cyclones falling into classifications other than the most intense are included, i.e. the data frequently includes tropical storms as well as hurricanes, so some method of identifying the damaging tropical cyclones is required. It must also be remembered that the extent of damage is not only a function of the intensity of the cyclone but also a function of the radius within which the eye of the storm passes a location.

4.4. One method of measuring the intensity is by the atmospheric pressure at the eye of the storm which is very low relative to the normal pressure for the area; another is by the highest wind speeds recorded. But even when such measures are given (and that is not always) there is little information available at present to indicate the relationship between them and the resulting damage in the area. Clearly wind speed can be related to the wind damage to certain types of structure, but as was discussed in Section 3, it is the sea and rain, not the wind, that pose the biggest threat and frequently cause the most damage.

4.5. As the volume of sound data is built up it should prove easier to make realistic assessments of the relative frequencies of damaging tropical cyclones. In the meantime however one must make use of all the available historical data on the occurrence of losses from tropical cyclones, and by comparing the frequency of these losses (and any information on the intensity of the cyclones which caused them) with the data relating to all the tropical cyclones in the area make some judgment as to the likely frequency of damaging cyclones. A loss distribution given that damage occurs must then be obtained not only from the historical data available, which generally gives losses as a percentage of sums insured, but

also from consideration of the local conditions of the area.   It
must be remembered that the intensity of the tropical cyclones
occurring is not the only relevant factor in assessing the damage
potential of a location, the geographical features as well as the
normal factors such as standard of buildings and cyclone-precaution
measures implemented must also be taken into consideration.   In
order to obtain the most realistic results in this sphere,
consultation with underwriters and engineers is essential.   Such
consultations will assist in providing a premium rating structure,
based on the general analysis described above, to take account of
the type and standard of construction as well as the location of
buildings insured.

4.6. One further word of caution is required as to the credibility of
the data used for analysis; different periods of observation
provide data of varying credibility but it is not necessarily the
long periods that provide the most credible figures.   Where long
periods are shown it is often the case that methods and reliability
of recording have changed substantially through time, for example
in some areas sudden increases in frequency are shown which can
often be attributed to changed standards of recording e.g. radar
storm location rather than a change of atmospheric conditions.
Another problem is that the definition of a tropical cyclone,
and hence which cyclonic disturbances are documented, can change
through time.

5. Reserving

5.1. When insuring against losses due to tropical cyclones substantial
claims do not necessarily arise in a region every year so it is
essential that the premiums for this hazard collected each year,
and not paid out in claims, are either not classed as profit
or are regarded as non-distributable.   In this way it can be hoped
that when a large loss does arise, funds will be available to pay
for it.   If this is not done the insurer could be in financial
difficulty when the really big claim occurs.

5.2. If a company only writes business in one hurricane region, it is
possible to estimate claims distributions as described in Section
4.5. (although possibly very crude) and hence calculate the
reserves required for the portfolio using relatively simple
techniques.   If a world-wide portfolio is held the possibility
of accumulation of losses by the occurrence of catastrophes in
more than one region in a year must be considered.   To establish
a world-wide reserve usually requires the convolution of the claims
distributions for each location, but this would introduce a
mathematical sophistication which poor quality data does not justify.
A computer simulation is therefore the most appropriate method at
this stage.

5.3. Having estimated suitable frequency parameters from the data and
resulting damage parameters from the loss distributions, events
can be simulated for each location at risk and hence the losses
and their potential world-wide accumulation can be examined.
Assumptions as to the likelihood of one tropical cyclone affecting
more than one of the specified locations at risk must be made and
the input parameters adjusted accordingly.   An important
advantage of the use of simulation techniques in this context is
that the consequences of a change in the initial assumptions as to
frequency and damage levels can be monitored simply by changing
the input parameters.   Where the quality and credibility of the
data is poor it would be unrealistic to assume that any one set of
parameters obtained is absolutely correct.   It would therefore be
appropriate to obtain confidence intervals for the parameters,
examine the outcomes of a variety of possible combinations, and
base the estimate of reserve levels required on the set of results
obtained.

5.4. If any information is received relating to changes in local
conditions, such as a change in building regulations or the

implementation of flood precaution measures, then with the guidance of underwriters and engineers an estimate can be made as to the likely effect on the losses as a percentage of sums insured. It is then only a simple matter to change the simulation parameters and hence estimate the effects on the required reserve levels.

5.5. Assuming that the loss distributions are constructed on a gross basis, then any reinsurance arrangements or compulsory deductibles can be superimposed on the simulated losses and adjustments to the reserve levels made accordingly.

5.6. In view of the data upon which the above simulation must be based a relatively simple model would not be out of place. Random number simulation (as this is) is a very simple but powerful tool in circumstances where there are a large number of unknowns, but as with all statistical techniques the results must be interpreted with appropriate care.

6. Some Practical Insurance Problems

6.1. The premium rates which the foregoing analysis is likely to provide would generally be found to be above that which could normally be charged. One method of overcoming this would be to spread the load over all policyholders by a compulsory addition to premiums, but it is unlikely that this would be acceptable. The only method therefore of providing a feasible insurance scheme against tropical cyclones is to accept some form of outside intervention.

6.2. In the U.S.A. the Department of Housing and Urban Development (commonly known as HUD) has a scheme for insurance against losses to domestic property due to tropical cyclones. To qualify for the government scheme, the community must comply with federal regulations of land use and control for precaution against the effect of tropical cyclones. A pool of insurance companies provide cover and receive premiums from the public at a rate laid down by the government which in general will be less than the actuarial rate required. A federal payment is then made to the insurance companies to make up the difference between the rate charged and the actuarial rate required; this payment can sometimes be as much as 90% of the actuarial rate. In addition to the premium rate subsidy, the government provides excess of loss reinsurance protection for the pool.

An alternative to these payments would be for the government to give the insurance companies protection by means of stop loss reinsurance. Such methods of outside intervention are socially justifiable because the load is spread across the whole of the population rather than only a small subsection.

6.3. In an expanding economy insurance companies will also increase their business but extreme caution should be exercised when such an increase could lead to losses of catastrophic proportions. Losses from tropical cyclones can be immense, as has been demonstrated in the past, and so every care should be taken to ensure that all reasonable precautions are taken by the insured , that adequate premiums are generated either directly or via an industrial or government scheme and that these premiums are accumulated in years where losses are small. Only if these things are done is insurance against tropical cyclones likely to be a viable proposition.

P.B. Rawlins
I.I.D., July 1975.

1. Introduction.

1.1. Our purpose is to discover methods by which actuarial and statistical techniques may be used to assist underwriters and those concerned with the reserve situation when part of an insurance company's portfolio is exposed to earthquake risks. We do not pretend to be qualified as underwriters, engineers or seismologists, but a purely statistical approach is not feasible on a subject of this nature, and so a certain amount of study and enquiry was necessary on specialist lines in order that reasoned judgements could be made.

1.2. Our main concern is with damage likely to be caused to property covered by Fire Department policies. However, liabilities will also arise under life, personal accident, workers compensation, motor, marine (hull and cargo), and aviation (aircraft on the ground) policies. We have in the main restricted our investigation to the possibilities of earthquake shock damage. Although the risk of fire following could, of course, greatly increase a catastrophic loss, we consider that local conditions as to firefighting, civil order etc. in the confusion following an earthquake are too variable and difficult to judge to lead to credible analysis using statistical methods. Similar difficulties would apply to tidal waves, major landslides and other secondary effects of earthquakes.

1.3. In the past there have been many very large earthquakes and some have had catastrophic effects. But others have fortunately occurred in regions where there were no concentrations of property to be damaged or lives to be lost. Thus, since the size of an earthquake could until this century only be judged by the damage it caused in populated areas, our knowledge of historical events in some regions is severely restricted. The first instrumental measurement of distant earthquakes was in 1889 and the development of more sensitive seismometers has been continuing since then.

2. Causes of Earthquakes.

2.1. At present scientists cannot claim to fully understand the causes of earthquakes, although much research is being carried out around the world and our knowledge on this subject is increasing.

2.2. The theory of Plate Tectonics is now generally accepted as explaining why earthquakes occur mainly in active belts. According to this theory the outer shell of the earth is formed of a number of semi-rigid interlocking plates. These plates fit very closely together but are subject to forces from within the earth causing them to move relative to each other. This movement is not smooth or continuous. Due to friction between the rough edges of the plates there is a tendency for the rocks to stick, sometimes for long periods, until such pressure has built up that a jerk suddenly occurs to release the accumulated strain.

2.3. The earthquake belts of the world follow the edges of the plates forming the earth's surface. The nature of the earthquake activity occurring in a particular section of a belt depends on the type of relative motion of the plates in that region. (i.e. on whether motion towards each other, away from each other or past each other in the direction of the boundary predominates).

3. Measurement of earthquakes.

3.1. Magnitude and the Richter Scale.

Magnitude (M) is usually expressed according to the Richter Scale. This is an objective measurement of the size of the earthquake calculated from the amplitude of traces registered on seismometers and can be regarded as a measure of the energy (E) released. M and Log E are linearly related.

3.2. The depth of focus and location of the epicentre (point on the earth's surface directly above the focus) are calculated using the time taken by the various types of shock wave to reach the recording stations. It is now possible to obtain reasonably accurate instrumental measurements of magnitude, depth and location for most earthquakes from the network of seismometers operating around the world.

3.3. Intensity of damage and the Modified Mercalli Scale.

The intensity is a subjective measurement of the severity of an earthquake in terms of the actual observable effects it has on a region. Many scales of intensity have been developed and used to describe events in different parts of the world. One of the most widely used is the Modified Mercalli Scale (a copy of which is attached as an Appendix).

4. Effects of earthquakes.

4.1. It is now apparent that the effect of an earthquake on a particular structure depends on various factors, the most important being:-

(a) concerning the earthquake,
   (i)   its magnitude;
   (ii) the depth of its focus;
   (iii) the distance and direction of the epicentre from the structure;
   (iv) the period of shaking caused.

(b) concerning the structure;
   (i)   the type and standard of design and construction;
   (ii) the type of subsoil under the structure and its surroundings, particularly in the direction of the epicentre.

4.2. Various formulae have been developed by which the intensity likely to be felt in an area as a result of an earthquake occurring with known magnitude, depth and epicentral location can be estimated. Adjustments to the basic formulae are required to allow for different subsoil conditions. Intensities felt in areas of substandard subsoil (such as unconsolidated soil, reclaimed land, soil with a high water level or thick alluvium) may be up to 3 classes higher than those experienced on neighbouring areas of rock.

4.3. In general it may be said that severe shallow earthquakes (i.e. with focus less than 25 miles deep) cause most damage to property as the resulting shock waves run near the surface of the earth and can be destructive over a reasonably wide area (depending on the actual magnitude of the event and the subsoils of the region). If a severe earthquake originates at great depth (i.e. with focus more than 180 miles deep) then the area in which comparable destruction occurs would be relatively small, but the shock would be felt at low intensities over a much wider area (than for a shallow event) extending for perhaps hundreds of miles.

4.4. The increasing number of high rise buildings being constructed in earthquake prone areas causes another problem. We have very little evidence of the effects of past earthquakes on this type of structure. It appears that tall buildings, if well designed and well built, can survive with only superficial damage many events which are destructive to other buildings around them. However, a special danger exists when the shock waves received activate a natural resonance in the high rise structures. It seems that this may occur as a result of prolonged shaking by a near quake or of waves being received from a severe distant quake at depth. As far as we know there are no intensity scales designed to deal specifically with the effects on these high buildings.

5. Insurance problems and current methods.

5.1. The type of analysis chosen must depend on the nature of the problems to be solved in each case. The method of analysis will depend to a large extent on the standard and detail of the information available and on the availability of a computer.

5.2. Traditional methods of obtaining premium rates appear to be based mainly on the highest intensity of damage experienced in the past, together with estimated return periods of such damaging events. Seismic zoning maps are produced for many countries showing the highest intensities ever reported in each area. The basis for calculating return periods is often ill-defined. There is little scope for precision and results are obviously biased by the reliance on the past interactions of natural events with distributions of property. The allowance for damage resulting from more frequent but less intense events is usually calculated on a very arbitrary basis. Market forces have in many areas eroded these premium rates. Discounts are usually granted for superior types of construction, but as the earthquake risk is often written in conjunction with a fire policy, the earthquake rating may be biased by the fire rating although a good fire risk is not necessarily a good earthquake risk and vice versa. Variation of rating according to subsoil conditions is virtually unknown.

5.3. The nature of this type of risk i.e. potentially very large losses occurring very infrequently, is such that premiums received in years where no losses occur should not be regarded as profit and so available for other purposes. It has happened that earthquake premiums have been used to reduce losses resulting from inadequate fire premiums. Obviously some form of reserve should be built up in order that the insurer can meet his liabilities when they arise. However, there are only a few countries (e.g. Finland) where limited build-up of catastrophe reserves from pre-tax profits is permitted. There are arguments as to whether or not reserves for catastrophe should be identified as such in a company's accounts or just accumulated as part of the general surplus, even if the attitude of the tax authorities could be changed.

5.4. It is obvious that the statistician cannot replace the engineer or the underwriter in arriving at a suitable premium rate for a risk. However we can hope to provide information to assist in this task.

6. The use of a computer to simulate the amount of damage caused to a given distribution of properties by earthquakes of given magnitude and location.

6.1. A project of this nature was described by Dr. D.G. Friedman in his paper "Insurance and the Natural Hazards" ASTIN Bulletin Vol.V11,Part I. His method was to divide the area of interest by a grid and input to the computer for each subdivision - an index for ground conditions (fixed by geological findings); the number of dwellings and an

average value at risk appropriate for that area (could be fixed
by using the results of a recent census or varied to allow for
possible future developments). The computer was programmed to
compute simulated results of an earthquake occurring at a specified
point with specified magnitude, giving those results in the form of
intensity felt, number of dwellings damaged and average percent of value
at risk lost on each of the damaged dwellings for each subdivision and
hence the total amounts of damage caused.

6.2. This model is sophisticated in many respects. Detailed investigation
is required to decide on accurate indices representing geological
conditions in each subdivision. The methods used to estimate suitable
intensities felt in each subdivision from the parameters input for the
event, allowing for the different ground conditions through which the
shock waves would have to pass, must be complicated. The
accuracy of this section of the calculations has been checked by inputting
the data of large historical events and comparing the simulated intensities
with those actually reported. In this sort of comparison, it must be
remembered that those historical reports often contain a certain amount
of bias. Until relatively recent events it is rare for a full pattern
of observed intensities arising from an earthquake to be available.
For events of early this century there are often only a few reports available
for each earthquake and some of these may only quote the most dramatic
destruction, which may have been due to poor building anyway rather
than high intensity. For events before 1850, little can be gained from
the few reports available for most regions as buildings were so different
and observations usually isolated to a few civilised areas.

6.3. At the time the paper was written, the calculation of damage resulting
from a certain intensity being felt in a subdivision was very much
simplified by the assumptions that only dwellings need be considered and
that all dwellings within a subdivision were identical and damage amounts
could be estimated reasonably accurately by fixing only two figures
representing percentage number of dwellings damaged and percentage of
value lost. It is probable that little adaption of the model would be
required for various different types and values of buildings within each
subdivision to be taken into account.

6.4. This model requires specific information to be input for each event
and then the resulting damage is simulated. There is no provision for
the simulation of the event data. By considering the losses caused to
present day (or postulated) exposures by historical events, this
information from the past can be made more meaningful, but is still not a
very credible guide to future events and the losses which they will
cause. This model will probably be of most use in demonstrating where
a company's exposure is accumulating to an undesirable extent.
Estimated maximum losses and probable maximum losses could be calculated
and suitable exposure limits set for each area and reinsurance arranged.

7. Calculating probabilities for the occurrence of damaging earthquakes.

7.1. Great progress has apparently been made in recent years in the field of
predicting the time, place and size of earthquakes, but a lot more work
is required before full credibility can be placed in the predictions.
There is also research into controlling the size of earthquakes in
particularly active areas. It will be interesting to see how work of
this nature will affect the insurance industry. However, until it is
possible to ascertain information about future events, premiums
will have to be based on probable frequencies in each area.

7.2. Our researches indicate that different types of seismic activity occur
in different areas, and that it is possible to divide the earthquake
bands of the world into regions in which seismic conditions can be

regarded as homogeneous. Each of these regions can then be investigated separately. The location of geological features including known faultlines should be noted, together with all available instrumental evidence on past earthquakes. From this information deductions can be made, using a combination of seismology and statistics, to estimate the probable frequency of events of different ranges of magnitude and depth in each subdivision of the region (using a grid system as in paras:6).

8. Premiums and Reserves.

8.1. From the probable frequency of different types of earthquake occurring in each subdivision, estimates can be made (using the formulae referred to in para.4.2) of the probable frequency of events being felt in each subdivision at each damaging level of intensity. These esimates can be compared with historical records of the events felt in important locations, although the inaccuracies likely to arise in resports (as noted above para.6.2) and variations to be expected from a relatively small number of observations should be borne in mind. By applying knowledge of the types of property insured in each subdivision with judgement as to the level of damage likely to be caused to each type when subjected to each level of intensity, suitable premium rates may be deduced. Provided sufficiently detailed information is available, a rating system according to type and standard of construction and the local subsoil can be devised. Alternatively, provided that some judgement as to future mixes of business by type and area can be made, a simplified system for rating, on similar lines to the present system, may be calculated.

8.2. A computer program may be designed to estimate the reserves required by a company writing a portfolio of earthquake business around the world. It is necessary to consider that the world may be divided into zones such that seismic events in one zone are independent of events in all other zones. Obviously the division into zones must be based on the location of the earthquake bands of the world, but the spread of the company's business may also influence the boundaries chosen. Each zone can then be split into subdivisions as before. The type of data to be input for each subdivision must depend on the degree of detail in the information available and the sophistication built into the program.

8.3. When only a minimum of data is available, a fairly simple program may be used to give a reasonable idea of the size of reserves required. Suppose that only basic information is available centrally on the risks underwritten, such as total sums insured within fairly large subdivisions such as entire cities, and only a general outline of the mix of types of risks and level of building standards etc. for each subdivision (as appears to be the case for many companies at present). In this case, after reviewing the effects of past events in an area and considering the opinions of seismic engineers etc. it should be possible to decide on fairly general descriptions of claims distributions (claims expressed as percentage of sums insured) to be expected for each intensity as felt at the centre, or other suitable point, of each subdivision. The parameters of these distributions can be input to the computer. Provided that these concentrations of risk are sufficiently far apart that each event can only cause damaging intensities to be felt in one subdivision, the probable frequency of events giving rise to damaging intensities at each concentration can be input (cf.para.8.1.) If there is a possibility of large events affecting more than one subdivision then some allowance must be made by adapting the basic data input and/or introducing the possibility of such dependence into the program and/or manual adjustment of the results. Using a random number generator, the computer can then be used to simulate events for each subdivision over a series of periods. For each subdivision - for each period, a decision as to whether or not an earthquake occurs affecting that subdivision is made (by including warning and after shocks with their major shock,

it is reasonable to assume that no more than one ~~separate~~ event will affect any subdivision in one period, such as a year); if such an event is generated, the supposed intensity at which it is felt is decided and then a suitable claim amount arrived at by selecting a value from the relevant claim distribution and applying it to the amount exposed in the subdivision. Comparison of total premiums with total claims over many periods can then be made and estimates of reserves required calculated.

8.4. Obviously if a company were only involved in one or two independent areas, it would be possible to calculate reserves by manual algebraic means using the data assumed above. But the usual type of worldwide portfolio would require the manual calculations to involve multiple convolutions and so can be dealt with much more suitably by the computer methods. Also, once the computer system has been set up, the program may easily be run with amended data so that the effects of changed underwriting policy, or growth of business in certain areas, or different levels and types of reinsurance may be judged.

8.5. If very detailed information were available on all aspects of the problem a very sophisticated system could be constructed, on the lines of Friedman's model but which would start by simulating earthquakes according to the calculated probabilities of events occurring in each subdivision and then compute the claims arising. Although this would be a very interesting exercise, it is debatable whether the vast additional labour would give comparable improvement in the actual conclusions reached. We must recognize that man's knowledge of seismic events is relatively limited and the formulae on which any mathematical model must be built are only approximate, so that sophisticated computing techniques may be out of place here.

8.6. It is highly likely that many companies are not at present able to collate the data on their exposures in the detail required for any but the most simple analysis. In view of the nature of this type of business, which could easily prove to be catastrophic for some insurance companies as well as for the areas devastated by the earthquake, it seems essential that all companies pay great attention to monitoring their exposures in future. Reinsurers are particularly aware of their lack of information until after an event. It is also important that realistic premiums are received and some means found of ensuring that funds may be allowed to accumulate to meet the very large claims when they arise.

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