EARTHQUAKE ENGINEERING
AS AN AID TO INSURABILITY

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ABSTRACT

This paper outlines the physical factors that a major insurer
considers significant to insurability of structures in earthquake zones
and specifies in some detail the type of construction and engineering
documentation that will aid an earthquake insurability evaluation on the
part of major insurers.

The scope of evaluation includes:

Micro-regionalization
Soils Reports
Earthquake design factors and codes

Course of construction
inspection
Instrumentation

The subject of evaluation is largely applicable to all types of
construction, but high-rise reinforced concrete is given as a basic
example.

FORWARD

The key to better analysis for earthquake insurance parallels the
better earthquake engineering facilities now available.

The development of an attitude that structures must be earthquake
engineered rather than subjected to earthquake code factors in their
design promotes a higher degree of reliability in earthquake resistant
construction and allows for appropriate economies through application of
structural dynamics.

In attempting to develop data for insurance purposes, the designer
should be aware that the earthquake insurer as mentioned in this paper is
a phantom. The insurer is not one person but many, and at times he may
seem to not exist. Conversely the insurer is aware that the earthquake
engineer is a phantom and that he will not be dealing with any one person,
but again it will be many of several disciplines and more often than not,
finding any resemblance to an earthquake engineer on a specific structure
will be difficult if not impossible.

The insurer in this presentation assumes the role of investor, and
problems are considered from the viewpoint of the various allies of the
insurer, namely owner, mortgager, government administrator, property
manager or banker, all of whom may have a common cause - the longevity
of structures.

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Referring to Figure 1, a graph has been prepared that offers to the insurer a first approximation that he can apply along with considerable judgment of the equivalent building site accelerations that will compensate for the usually unavailable probability maps or regionalized seismological and geological data.

Figure 1 is based on recent work of two independent seismologists, one William K. Cloud (Reference 1) who has based his attenuation curve on data for 19 recent earthquakes (Figure 2), and the recent seismological work of W. G. Milne (Reference 2).

Referring to Figure 1, the curve A-B represents Cloud's compilations of recent earthquakes which shows coincidence with Milne's work for various magnitudes using the formula as shown in Figure 1.

Steinbrugge and Bush (Reference 3) have indicated that "the distance that the structure is from a fault on which an earthquake occurs is not as important as a proper earthquake resistant design of the foundation and superstructure", indicating the need "for verification through the use of strong motion instruments".

We have located the "threshold of damage" at magnitude 4 as a straight line in Figure 1, and have a rough approximation of a range of damagability for earthquakes of various magnitudes where the attenuated acceleration curves cross this line. Within that range we do not attempt to attenuate for distance for known or suspect poor foundation conditions on specific structures, however, attenuation of acceleration for known good foundations and construction is an important part of our analysis.

THE RESPONSE TRIANGLE

The problem from the viewpoint of the investor is to answer the question "How can important structures be earthquake engineered and what kind of economics is involved?".

A device using a triangle plotted on logarithmic paper to show the investor how the art of earthquake engineering integrates or combines many sciences to produce structural resistance to forces of the probable earthquake is presented. The design criteria of this device requires that the following be considered:

(a)   The design of the device is such that it is qualitatively accurate, commensurate with our best knowledge of the science's today.

(b)   It must present a clear-cut answer to the non-technical reader and its configuration be such that it presents the perspective and emphasis of the majority of practitioners of the art of earthquake engineering and correctly depicts the disciplines of the various contributing sciences.

(c)   It must be self-destroying if incomplete.

Referring to Figure 3 the base, line A-B, of the triangle represents the earth's sciences. A complete report covering the seismic factors and soil factors are a necessity for all important structures, and practically as well as symbolically it is the foundation for any earthquake engineering that is to be performed. The line representing earth sciences therefore coincides with the line depicting an earthquake producing a magnitude on the "threshold of damage". This indicates the necessity for inclusion of the documentary geology and soils reports on all important structures involving even exposures to low magnitude damaging earthquakes.

Next described in Figure 3 is a line B-C depicting structural engineering. The proportioning of this line will vary somewhat with the type of structure and the allowable calculated risk taken by the designer. Structures for example where economics allow for no damage even in severe earthquakes, would require a different breakdown of structural engineering methods.

The closing line A-C of the triangle in Figure 3 depicts construction inspection and like the application of the structural engineering, requirements increase directly with the increase of earthquake magnitude and with the extent of structural engineering services.

Continuing to refer to Figure 3 it may be observed that force equivalents in the form of accelerations at the epicenter and at the site are located on the left, and code and design accelerations are located on the right.

This allows a quick plotting of the magnitude at epicenter and a comparison with attenuated accelerations which can be located on the response triangle. Reference to the response triangle later in this paper will indicate one of many possible uses whereby a comparison to probable forces can be compared graphically with the designer's intent to resist these forces and an indication of the insurer's evaluation of engineering services can be shown. The comparison of acceleration forces and the design structural resistance can show either reserve strength or underdesign, or as is often the case the extent of the designer's "calculated risk".

The response triangle quantitatively will be as sophisticated as the input, for example it will reflect the accuracy or lack of accuracy of the assumed acceleration forces at the site and the consideration that a given code has for dynamic factors. It is not impossible that its use can be extended into spectrum analysis using a series of plotted triangles. However, most codes can be reduced to a single component maximum acceleration in terms of gravity, and hopefully in the single response stage this will serve to promptly illustrate the majority of ratios of input acceleration to the accelerations the buildings are calculated to withstand.

The engineering services (refer to Line O-C, Figure 3) are graded by the insurer on the basis of documentation available for earth sciences, structural engineering and inspections briefly outlined on the following pages. Those items marked with an asterisk are suggested minimum requirements, and are applicable to reinforced concrete construction which is used as a working example.

EARTH SCIENCES - DOCUMENTATION *

(a)   Provide earthquake zone and micro regionalization of area or
applicable engineering geologist's report stating general area foundation.

        (i)   Granitic, mesozoic sediments, or metamorphics;
        (ii)   Tertiary sediments and volcanics;
        (iii)   Quarternary, consolidated;
        (iv)   Quarternary alluvium, sand dunes, or landslide area.

(b)   Provide specific building foundation information at site:

        (i)   Rock;
        (ii)   Firm natural ground;
        (iii)   Alluvial (loose);
        (iv)   Littoral (natural shore line);
        (v)   Mixed soils;
        (vi)   Filled ground - recommend and have performed as
                 necessary applicable soils test.

(c)   State the seismic probability, i.e. the peak acceleration
force occurring once in 100 years for a specific area. If this value is
not available suggest application of the acceleration values as indicated
in Figure 1 using the nearest maximum earthquake epicenter.

(d)   Provide recommendations for soil compaction and soil inspec-
tion if area requires filling or if unusual sub-soil conditions require
spread foundations, pilings or rafts, tie-ins, batter piling, etc. or if
geology and soils report indicate the probability of earthquake triggered
liquefaction of soils.

STRUCTURAL ENGINEERING - REQUIREMENT FOR INSURER'S REVIEW

(a)   The following factors should be considered:

* Calculation of Base Shear   * Distribution of Base Shear
  Use of Building   * Regional Seismic Zoning
* Foundation Soils Conditions   * Type of Structure
  Vertical Seismic Force   * Seismic Forces for Attachments
* Overturning Moment   (parapets, chimneys, towers)
* Torsional Forces   Drift Limitation
  Separation of Buildings   Allowable Stresses
  Ductility Factor

*(b)   Correlate foundation factor, i.e. the dynamics of ground
motion due to soils type at site, with design acceleration.

*(c)   Indicate material strength requirements, i.e. concrete and
steel.

(d)   Designate structural components designed within elastic limits
and within inelastic limits.

(e)   Indicate method used of detailing for ductility and containment.

(f)   Indicate application of building period and assumed deflection of various stories.

(g)   Indicate method of checking deflection and ductility at each floor level.

*(h)   Estimate damage in dollars or as a percentage of building cost, designating non-structural components and structural components for:

(i)   Earthquake force expressed as maximum acceleration percentage of gravity for once in 100 years at site;

(ii)   Design earthquake force acceleration expressed in percentage gravity.

COURSE OF CONSTRUCTION INSPECTION - SERVICES AND DOCUMENTATION

*(a)   Testing soils under foundations (bearing) immediately prior to construction.

(b)   The inspector must be constantly present at the project during all phases of the work: formwork, placement of reinforcement, placement of concrete and curing requiring continuous inspection.

*(c)   Since the quality of the concrete, anchorage positioning of the reinforcement, adequate strength and stability of the formwork and proper finishing and curing are of paramount importance and the specifications intend that all process involved shall be adequate, the inspector must be sure that compliance with the specifications is complete.

*(d)   The inspector must make sure that laboratory certificates are at the project for all materials required to be laboratory tested before they are incorporated in the work.

*(e)   The inspector should make sure that forms are in proper alignment unyielding and of adequate strength.

*(f)   The placement of reinforcement should be checked with the details on the drawings.

*(g)   Compaction by tamping or vibration must be thorough so that dense concrete is produced. Care must be taken to avoid harmful excessive vibration.

*(h)   Curing processes or methods must comply with the specifications.

EARTHQUAKE ENGINEERING DOCUMENTS

These report guidelines to be prepared by the earthquake consultant are designed to assist the insurer in his appraisal of grading of the degree of earthquake engineering services used on a given project, and to form the background material for application of earthquake forces equated to "as built" earthquake resistance. These values are plotted on the response triangle and ultimately develop into earthquake damage probability estimates.

RESPONSE TRIANGLE (FIGURE 3) - ELASTIC RANGE ILLUSTRATIONS

The problem from an insurer's viewpoint might be resolved in the following illustrative example. First consider the building designed for a seismic force compatible with the estimated effective forces at the site, and with no deficiencies in the engineering documents.

In this instance the building is on good ground so that the force used allows for attenuation of the epicentral force according to Figure 1, or 20% g at 25 miles results in 10% g at the site.

Therefore 10% g is plotted on the left side of the triangle in Figure 3 designated (X site). It will be noted that this is equal to the code design also shown as 10% g on the triangle as (X code design) on the right side, and this therefore indicates there is adequate resistance to survive the once in 100 year earthquake used in this example. Later examples will reveal how deficiencies in engineering services downgrade the code design.

The amount subject to a loss would be 1.5 million dollars or the cost of the 25 story reinforced concrete apartment house used as an example. Due to the confidence the insurer has in the earthquake design analysis, he believes on the basis of documentation and the extent of engineering services that the structure will survive with only minimum plaster cracking and that the P.M.L.[II] would not exceed 5% which is equal to the standard minimum deductible incorporated in most earthquake policies.

Secondly consider the same building using only minimum code requirements and a failing to keep documentation of significant structural foundations and construction features so that the insurer would have little reason to have confidence that the building was properly constructed.

Reference to Figure 3 will show:

(a) The unknown soil and foundation conditions automatically require application of the epicentral rather than the attenuated earthquake force. Therefore, the 20% g rather than 10% g is used, placing the construction in a category where elastic response design is not generally economical.

[II] The nomenclature that the insurer uses in estimating damage potential is the term "probable maximum loss" (P.M.L.). The P.M.L. is a loss estimate applying a judgment factor to the total cost of the exposed structure or structures.

(b)   The code design % g is downgraded because of the deficiencies and documentation of the engineering services relative to foundations, structures, and inspections. In this case 50% services was estimated because of a combination of the lack of course of construction foundation, and construction inspection reports. The distance represented logarithmically indicated from X' to 100% (Line A) was deducted from the code design to obtain the "as built" resistance. The total under-design is indicated by Line B in as much as the "as built" design is considerably below the estimated earthquake forces at the site the probability of earthquake damage is considerably increased, for example, the probability of an earthquake in the $6\frac{1}{2}$% g range is 62 times more likely than in the 20% g range for which this project should be designed, according to annual earthquake statistics (Reference 4).

The insurer looks at the high incidence of poor construction that has been revealed in past earthquakes when construction has not been under surveillance of a well engineered independent inspection system provided by the investor. Therefore in making the loss analysis he would assume unless interim earthquake experience proved otherwise, that the P.M.L. on the basis that the building's construction was poorly supervised and was therefore not capable of withstanding the design lateral forces. Judgment factors would enter into the estimate but a 75% to 100% P.M.L. would be the likely first approximation based on the response triangle, or stated in dollars the P.M.L. would be $1 million dollars to a total loss. This P.M.L. and the high probability of a loss would make the economics of insurability reflect adversely both for the insurer and the investor.

The investor should compare the economics of saving perhaps .05 cents per square foot or one half of 1% or in this case $7500.00 for additional required engineering and inspection costs. Construction costs would not necessarily increase, however, the additional construction costs, if any, could be calculated for a specific building by the earthquake engineer in making an economical comparison.

For example in this structure which would cost approximately $1.5 million dollars, normal engineering with code provisions for earthquake and some inspection would cost .11 cents per square foot in a selected North American City. If continuous inspections were required and if the earthquake load capacity check-ups and additional information that is advocated in this paper were used, it would cost an additional .05 cents per square foot for that same City.

It will be shown in another example later on how "as built" earthquake design accelerations located in a higher range than the maximum earthquake forces anticipated once in 100 years drastically lessen the damage probability and improves earthquake underwriting considerations.

It is also necessary to consider the building in more severe earthquakes than this previous example and the nature of the construction as documented becomes more and more important when the design is in the inelastic range insofar as the insurer's determination of acceptability of risks in high seismic zones is concerned.

RESPONSE TRIANGLE (FIGURE 3) - INELASTIC RANGE ILLUSTRATIONS

Assuming as before a 25 story reinforced concrete high-rise apartment structure in a higher earthquake zone than given in the first example, costing approximately $1.5 million dollars. In this case the probable seismic forces estimated at the site were considerably higher than the 10% g lateral force. The ground accelerations assumed were above those economically practical to design for within the elastic range.

In this case even when the buildings are of good design and construction and with adequate documentation for all phases of design, construction and inspection, the investor or his insurer would assume a higher degree of non-structural damage if the earthquakes approach the design earthquake range.

See Figure 3. Assume 20% g at the site based on allowable attenuation from 35% g to 20% g at 25 miles according to Figure 1. Also assume no downgrading of code design in as much as there are no engineering documentation deficiencies, and allow 50% g code design (design in ductile range). The plotting on the response triangle (Figure 3) would show (Y) 50% g code design which is greater than 20% g force at site by 30% g represented by Line C. This would roughly improve odds of structural damage to odds of once in 500 years (Reference 4).

The probable loss estimate would again be based on judgment factors applicable to the specific building, however, assuming this to be 10% or approximately $150,000.00 for an earthquake that would be predicted to occur only once in 100 years, then the investor and insurer would share this loss on an approximately equal basis considering a 5% deductible. This loss would appear to fall in the category of a calculated risk by the designer, however, the probability still exists of higher seismic forces occurring that could do structural damage, but the odds have improved for investor and insurer.

Now as a final example, the same building is considered where deficiencies existed in the documentation of foundation, structural and inspection services. Referring again to Figure 3, the site forces require that 35% g at the epicenter (Y') be plotted because of the unknown foundation conditions. Furthermore, the engineering service documentation was such that documentation of foundations, designs and inspections were inadequate. Specifically continuous inspection at the site was lacking and downgrading resulted because 20% engineering services were estimated as shown on Figure 3 at Y'. The downgrading is indicated by Line D and was deducted from the code design to obtain the "as built" design which is approximately 17% g being considerably below the contemplated value of 35% g for a once in 100 year maximum acceleration force. The probability of an earthquake in the $17\frac{1}{2}$% g range based on annual statistics (Reference 4) would appear to be 46 times greater than in the 35% g range so that the vulnerability to damage as far as the underwriter or investor is concerned, has shown an alarming rate of increase.

The P.M.L. estimate therefore would be 100% of the building cost or even greater depending on existence of demolition and clean-up insurance.

It appears obvious that the economies of insurability have become adverse for the insurer with the inadequacies encountered and that there would be reason for the investor to consider the cost for adequate engineering, construction and inspection.

Approximate estimates of additional engineering and inspection obtained in the field would not exceed one half of 1% to 2% of the total cost. Analysis of course would have to be made to determine how the more desirable engineering design would effect costs. Generally experience has indicated this to be an expenditure of conservative percentage.

INSTRUMENTATION - AN AID TO THE INSURER

A major factor that will help insurers in their evaluation of the extent of structural earthquake resistivity and in their estimate of the extent of damage potential of new and old buildings, is the compliance with the Pacific Coast Uniform Building Codes requirement for the installation of accelographs in high-rise buildings.

Accelographs and other strong motion indicators, as well as foundation instruments such as slope indicators on side hill areas and ground water indicators, will do much to add to the adequacy of supervision during construction or on locations of questionable foundations.

THE ROLE OF THE INSURER

The role of the insurer should be clear. He is, particularly in the case of being an earthquake insurer of common type structures as indicated in this paper, basically interested in determining whether he wants to invest his company's resources behind the earthquake damage probabilities of a specific structure for an already established earthquake insurance rate in accordance with well established policy forms.

Such excellent rating organizations in North America as the Pacific Rating Bureau are influential rate-wise on the Pacific Rim of the United States including Alaska. The Canadian Underwriters' Association likewise has broad rating making authority from its member insurers throughout Canada.

The insurer, however, is much like the banker who even with interest rates set, must determine on the individual merits of each investment its acceptability. The acceptability for earthquake insurance purposes of specific risks is distinctly the insurer's responsibility just as the earthquake engineer has a distinct choice of accepting clients and a suming the responsibility of designing a building that will survive ear i-quakes. Each have their proviso that the assumption of these respon ibi-lities in the case of the banker, insurer or engineer involves favorable rather than adverse economics insofar as their participation is concerned in a given project.

The insurer as depicted here who becomes involved in the technology of earthquakes does so basically for the following purposes:

(a) Short Range:

    (i) To review individual risks in a knowledgeable manner preferably in close liaison with owners and their engineers prior to construction so that his company will be aware of loss probabilities and so that insurance can be arranged on a favorable economic prognosis.

(b) Long Range:

    (i) Promote building codes, standards, modes of design and encourage a close liaison with competent professional soils and structural engineering firms, and encourage full-time field inspection of projects.

    (ii) Attempt to assist engineering consultants in compiling persuasive documentation prior to and during construction that will be helpful in placing earthquake insurance.

    (iii) To refrain from being very much persuaded by engineers that a building merely incorporating the earthquake provisions of a code is a utopian example of an earthquake resistive structure.

CONCLUSIONS

The response triangle and the background data furnished by the earthquake engineer provides for the insurer and/or investor for specific structures a quantitative analysis of assumed earthquake forces and earthquake resistances, and it provides a qualitative analysis of engineering services based on documentation of the extent and quality of earth, structural and inspectional sciences.

The response triangle fulfills the requirements of the criteria set for it and graphically depicts the advantageous position of the insurer or investor with proportionately high levels of earthquake engineering and quality control under a variety of circumstances.
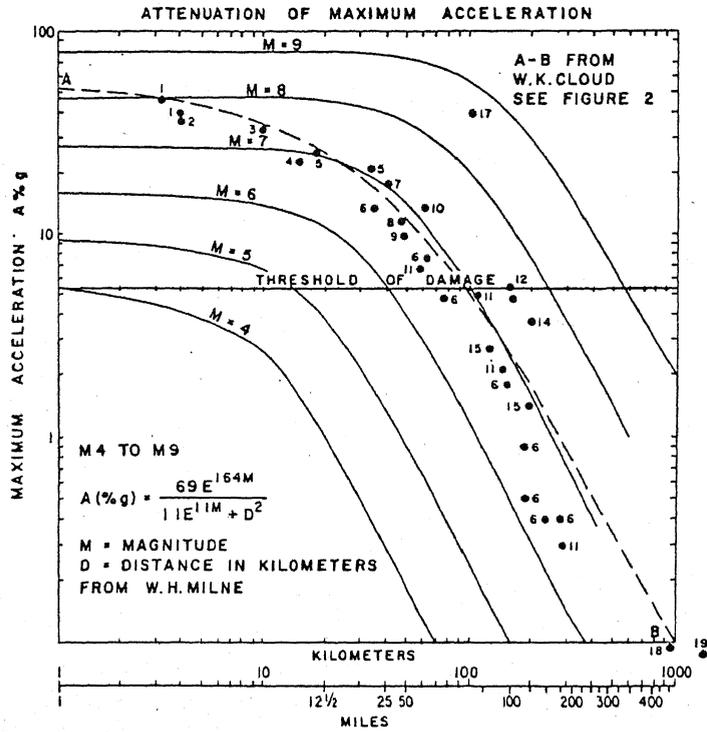
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3. STEINBRUGGE, K.V., AND BUSH, V.R., "EARTHQUAKE EXPERIENCE IN NORTH AMERICA 1950 - 1959", PROCEEDINGS OF THE SECOND WORLD CONFERENCE ON EARTHQUAKE ENGINEERING, JAPAN 1960, VOL.1, P. 381.

4. GUTENBERG, BENO, AND RICHTER, C.F., "SEISMICITY OF THE EARTH AND ASSOCIATED PHENOMENA", PRINCETON, PRINCETON UNIVERSITY PRESS, 1949.

EARTHQUAKES DURING WHICH THE PLOTTED ACCELERATIONS WERE RECORDED [III]

1.	PARKFIELD, CALIFORNIA	27 JUNE 1966	(M-5.5)
2.	ELCENTRO, CALIFORNIA	18 MAY 1941	(M-7.1)
3.	PUGET SOUND, WASHINGTON	13 APRIL 1949	(M-7.1)
4.	EUREKA, CALIFORNIA	31 DEC. 1954	(M-6.6)
5.	LONG BEACH, CALIFORNIA	10 MARCH 1933	(M-6.2)
6.	KERN COUNTY, CALIFORNIA	21 JULY 1952	(M-7.6)
7.	ELCENTRO, CALIFORNIA	30 DEC. 1939	(M-6.5)
8.	LOGAN, UTAH	30 AUG. 1962	(M-5.7)
9.	PORTLAND, OREGON	6 NOV. 1962	(M-4.8)
10.	SANTIAGO, CHILE	13 SEPT. 1945	(M-7.1)
11.	HEDGEN LAKE, MONTANA	17 AUG. 1959	(M-7.1)
12.	SAN JOSE, COSTA RICA	5 OCT. 1950	(M-7.7)
13.	MEXICO CITY, MEXICO	11 MAY 1960	(M-7.2)
14.	GUATEMALA	23 OCT. 1950	(M-7.3)
15.	SAN JOSE, COSTA RICA	18 NOV. 1945	(M-7.0)
16.	BISHOP, CALIFORNIA	10 APRIL 1947	(M-6.4)
17.	LIMA, PERU	17 OCT. 1966	(M-7.5)
18.	LITUYA BAY, ALASKA	10 JULY 1958	(M-7.8)
19.	PRINCE WILLIAM SOUND, ALASKA	27 MARCH 1964	(M-8.3)

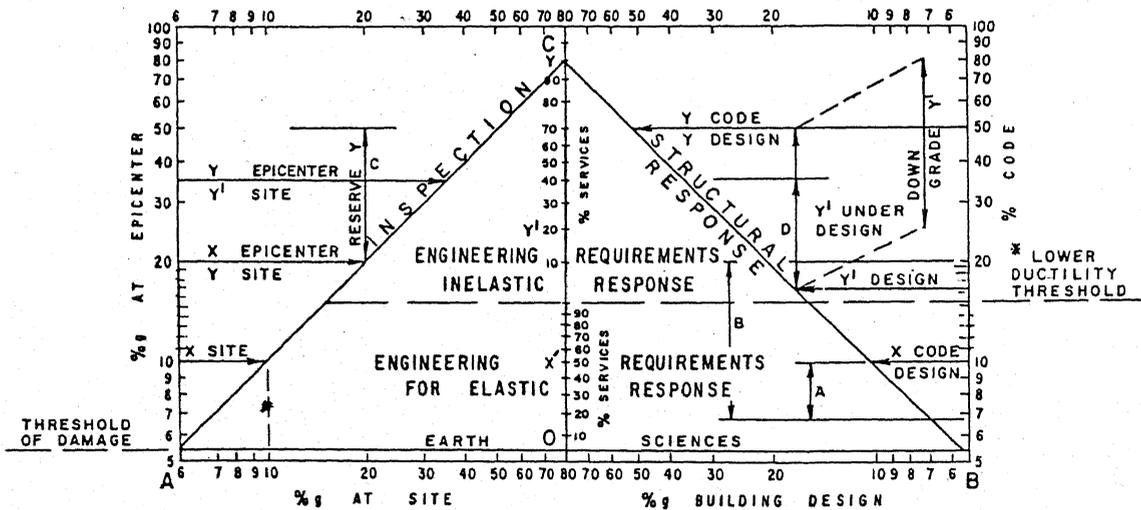FIGURE 2

[III] CLOUD, WILLIAM K., "STRONG-MOTION SEISMOGRAPH RECORDS", STATE OF THE ART SYMPOSIUM, FEBRUARY 5-6, 1968.

ATTENUATION OF MAXIMUM ACCELERATION

A-B FROM
W.K.CLOUD
SEE FIGURE 2

$$A(\%g) = \frac{69\,E^{164M}}{11\,E^{11M} + D^2}$$

M = MAGNITUDE
D = DISTANCE IN KILOMETERS
FROM W.H.MILNE

M 4 TO M9

F ALBERTI 1968   FIGURE I.

FROM FIGURE I   FOR CASE X
20% g AT EPICENTER AT 25 MILES 10%g

FOR CASE Y
35% g AT EPICENTER AT 25 MILES 20%g

* FOR   SPECIFIC   DESIGN

EPICENTRAL %g USED FOR
POOR OR UNKNOWN
FOUNDATIONS

FIGURE 3

RESPONSE TRIANGLE FOR INSURANCE ESTIMATES

F.ALBERTI 1968