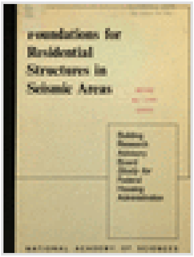

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FOUNDATIONS FOR RESIDENTIAL STRUCTURES IN SEISMIC AREAS

Prepared by

A Special Advisory Committee

of the

BUILDING RESEARCH ADVISORY BOARD

Division of Engineering—National Research Council

for the

FEDERAL HOUSING ADMINISTRATION

National Academy of Sciences
Washington, D. C.
1969

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FOREWORD

This report was prepared by a Special Advisory Committee of the Building Research Advisory Board, appointed by the Chairman of BRAB with the approval of the Chairman of the NRC Division of Engineering and the President of the National Academy of Sciences. It has been reviewed, accepted, and approved for transmittal to the Federal Housing Administration by a Review Subcommittee of the Board, acting on behalf of the Board.

The Board appreciates the contribution that Committee members have made through their study and the preparation of this report, and takes this opportunity to express gratitude for the effort entailed. An expression of appreciation is also due to all those who gave assistance to the Committee through either correspondence or personal contact.

ROBINSON NEWCOMB, Chairman
Building Research Advisory Board

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I
INTRODUCTION

1.0 STATEMENT OF THE PROBLEM

Under contract between the Federal Housing Administration and the National Academy of Sciences, the Building Research Advisory Board undertook to:

> Determine and evaluate the factors which must be considered in the use of deep foundations (piles, caissons, needle piles) in seismic areas.

The Special Advisory Committee appointed by the Chairman of BRAB to accept responsibility for this study elected to add shallow foundations to its charge, because, in its view, many of the considerations are applicable regardless of depth of foundation.

2.0 BACKGROUND

FHA has long recognized the lack of specificity in its Minimum Property Requirements and/or evaluation procedures in respect to foundations for multi-family structures in seismic areas. However, only in the past few years has the number of applications for FHA mortgage insurance on such properties reached a level that justified more detailed treatment.

Initially, FHA sought the assistance of the BRAB Technical Studies Advisory Committee (TSAC) concerning a particular aspect of one type of foundation, i.e., friction-type piles. FHA concern was whether seismic movement might cause a loss of friction between soil and pile, thus reducing load-carrying capacity. If such were the case, its evaluation procedures would need to be changed.

It was surmised by TSAC that, although this might be the case over a small section of the pile, other pile sections were likely to become more tightly wedged, offsetting any loss of friction and perhaps even increasing load-carrying capacity. This discussion led both TSAC and FHA into an overall evaluation of FHA requirements and evaluative procedures for foundations in seismic areas, and to the conclusion that pile foundations of other types should be studied as well, i.e., needle, end-bearing, and caisson types, in the interest of bringing to bear the best and most recent knowledge.

The study from which this report evolved was thus recommended to FHA by TSAC, and FHA, in turn, initiated the request to the Academy for the study.

3.0 REPORT ORGANIZATION

This report is divided into three principal sections: Section I, this Introduction; Section II, Recommendations of the Special Advisory Committee; and Section III, Supporting Information.

II
RECOMMENDATIONS

Much remains unknown about the precise nature, probability of occurrence, and likely magnitude of earthquakes; the precise manner in which seismic waves, produced by energy release during the process known to geologists as "faulting," travel through various rocks and soils; and the precise manner in which various rocks, soils, and buildings respond to and interact with one another when subjected to vibratory motion. However, sufficient knowledge has been gained from theoretical and applied research and from observation to permit stating of the important cause-and-effect relationships and identification of many if not all of the manifestations of seismic action of importance to building site selection and building foundation design.

In faulting--i.e., the sudden differential movement of two or more of the masses of rock making up the earth's crust--enormous amounts of energy are often released. This energy release results in two principal phenomena: Vibrations in the rock and soil mass, and actual cleavage and rupture of the rock and soil.

The vibrations radiate from the area of origin as longitudinal and shear waves. The frequency spectrum which results contains both high- and low-frequency elements. The high frequencies are attenuated more than the low as the waves move away from the area of origination; however, the rate of attenuation is least in hard rock and greatest in soft and low-density soils. Thus, it can be concluded that, at points close to the area of origin, the amount of high frequency vibration will be much greater than at distant points, and that buildings on rock will receive more high-frequency energy than buildings on soft and compressible soils, all other factors being constant. Further, due to the principles of "impedance matching," flexible building structures will be affected most by the low-frequency vibrations while high-frequency vibrations will transfer maximum energy to stiff structures.

Cleavage and rupture of the rock and soil are usually localized and, therefore, are usually a factor only in locating a building--i.e., it is not economically feasible to design a building to withstand seismic forces resulting from a fault displacement when the plane of the fault passes through the building.

Seismic energy release manifests itself in the following principal ways:

a. Building acceptance of some of the energy from vibrating ground in accordance with the impedance match, causing vertical and horizontal movements of the building and resulting in redistribution of loads on the foundation as well as in stresses in the superstructure.

b. A range of weak-soil effects, e.g.,

soil deflection resulting in direct and often differential loads on foundations from different soil strata

horizontal, vertical, or inclined soil compression resulting in tension cracking at the ground surface, area subsidence, loss of foundation support, or all three

soil liquefaction, resulting in loss of foundation support and/or additional vertical loads on pile foundations from loss of strength of upper soil strata

landslides due to shear failure or liquefaction, resulting in structure displacement.

It is not possible to evaluate the importance of these factors except in the context of a given site and building. Nevertheless, it is possible to make recommendations of a general nature regarding where and where not to build and what conditions to watch out for, as well as recommendations regarding investigative procedures which will ensure that sources of problems will be identified and that actions will be taken either to avoid or to design against possible resulting effects.

1.0 RECOMMENDATIONS

1.1 General

1.1.1 Each site and building should be considered to be unique in character and to require independent analysis and treatment.

1.1.2 No structure should be located directly over (i.e., above or on line with) an active or potentially active fault.

1.1.3 When tall, flexible structures are located in a region of active or potentially active faults, sites consisting of bedrock or firm soil generally should be selected in preference to those consisting of "weak" soils, even when the weak-soil sites are farther away from the active or potentially active faults.

1.1.4 For purposes of site evaluation and building design, the following soils should be classified as weak and considered critical:[1]

a. loose sand and gravel mixtures

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[1] See Appendix B for consistency definitions.

b. loose and medium fine sands

c. organic and inorganic silts of all consistencies, particularly soft and medium silts

d. soft clays and sensitive clays of medium consistency.

1.1.5 If sites with critical soils must be utilized, foundations should be carried to a depth below these soils; or critical strata should be removed and replaced or adequately densified prior to founding of structures; or the stiffness of the proposed structure should be modified accordingly.

1.1.6 When foundations, particularly piers and piles, are carried below critical soils, design should be such as to accommodate amplification of ground motion which may vary with differences in soil strata.

1.1.7 Irrespective of foundation type planned or soil type(s) involved, a slope stability evaluation[1] should be required for any site containing or located near a significant slope.

1.1.8 Design of the total system should be made the joint concern of foundation engineer, structural and other specialty engineers, and architect.

1.2 Investigative Procedures

Investigative and evaluative procedures should be prescribed by FHA to ensure identification and treatment of all significant factors.

1.2.1 At the outset of any building project, assurance should be provided, to the satisfaction of FHA, that provision has been made for complete collaboration at two levels--within the professional design team (comprising the foundation engineer; the structural, mechanical/electrical, and other specialty engineers; and the architect) and between the design team and the owner and mortgage insurer--to the end of establishing agreement on site suitability, on the adequacy of site improvement, structure design, and construction supervision, and on overall building performance objectives.

1.2.2 In ascertaining site suitability, the foundation engineer, in collaboration with other members of the design team, should take (and FHA should require) the following steps in addition to those normally conducted for the same purpose in nonseismic regions:

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[1] Building Research Advisory Board. Slope Protection for Residential Developments. Prepared as a service of the National Academy of Sciences for the Federal Housing Administration. National Academy of Sciences—National Research Council Publication.

a. Evaluation of seismicity of the general region and the immediate site area, from all available information and data concerning geologic history and current conditions, including geologic origin of rock and overburden material, position of known or inferred active or potentially active faults, presence of any overburden discontinuities or nonconformities, and earthquake history

b. Carrying out of sufficient surface and subsurface site explorations to permit verification of the items in a above, to make possible a quantitative evaluation of foundation materials and of the foundation problems which must be resolved, and to permit an assessment of seismic excitations which likely will be transmitted to any buildings constructed on the proposed or potential site

c. Preparation of a preliminary report encompassing the material called for in a and b above and containing recommendations, first, as to site suitability in general, and, second, in the event that the site is deemed suitable for building, concerning the types of building (in particular, types of foundation) which could appropriately be accommodated.

1.2.3 Once a site has been deemed suitable, the foundation engineer, in collaboration with other members of the design team, should take (and FHA should require) the following steps necessary for adequate building design:

a. Preparation of a general description of the proposed building(s), including foundation plans, extent and depth of subsurface construction, magnitude and distribution of loads to be transmitted by the foundations, and any assumptions as to vibrations or maximum deformations for which the structures must be designed

b. Planning and conduct of detailed subsurface explorations (further described in Section III of this report), and, on the basis of exploration findings, preparation of

   1. topographic sections on which all pertinent topographic and exploratory data are recorded

   2. details on ground-water levels and any special ground-water conditions encountered

   3. details on strata of critical soil identified, i.e., any soils of the type referred to in 1.1.4 above, the presence of which may result in inadequate or sudden loss of support, detrimental settlement, or slope failure

   4. summaries of soil test results, along with applications of soil test data in analyses for safe bearing capacities, lateral earth pressures, slope stability, and the like, plus

appended details, such as descriptions of any nonstandard test procedures and apparatus used.

c. Development of recommendations concerning foundation type and/or site improvements which are believed suitable, covering

   1. types of foundation, together with all pertinent information regarding excitations, soil loadings, soil support capabilities, and the like needed for detailed structure design--including items requiring special care in design, such as horizontal shear forces which must be transferred from foundation soil to structures; needed modifications of vertical load capacity of soils under dynamic or transient loads, excavation, stabilization, and dewatering; and need for specialized supervision by the foundation engineer during construction

   2. alternative types of site improvement and/or foundation which can be considered, in particular. Foundations treated in respect to improvements of critical soil strata by excavation and replacement, compaction, drainage, preconsolidation, and associated processes, with advantages, disadvantages, and risks involved in each case.

d. Development of recommendations regarding appurtenant structures on the site, e.g.,

   1. needed flexibility in utility lines, particularly at building/ground interfaces

   2. needed "tie-down" of bouyant structures below the surface of any water table.

e. Preparation and submission of a final report encompassing the above, the information presented in the preliminary report (per 1.2.2 above), plus any other data considered pertinent, and including a summary placing emphasis on all factors deemed of particular importance to safe and adequate design.

2.0 RESEARCH RECOMMENDATION

To improve or achieve greater assurance in present-day exploration, evaluation, and design techniques, additional information is needed regarding many aspects of earthquake-induced ground motion; also, regarding interactions among ground, foundations, and superstructure under seismic loading.

In particular, the following should be sought:

a. Data and information regarding ground movement at different depths in different materials--including information on subsurface conditions at existing strong-motion stations of the U. S. Coast and Geodetic Survey, and new information from strong-motion measuring equipment placed at the surface and at various depths at selected locations

b. Practical structural design methods which utilize strong-motion data and which permit variations in design based on expected ground behavior

c. Compilations of information on the seismicity of earthquake-active geographic regions for which such compilations do not now exist but within or immediately adjacent to which there is a possibility that building may occur--e.g., geology of the region, character and location of faults, nature and effect of soil deposits (such as the Richter micro-regionalization maps).[1] and earthquake history

d. Information concerning

   dynamic effects on soils which lead to substantial reduction in soil shear strength

   the mechanics of energy dissipation and damping in soils reactions of a pile and/or a pile system, and of basement walls, to seismic loadings as ascertained by instrumentation, plus observations on and evaluation of the interaction of piles within a pile group under dynamic loading

   the likelihood of occurrence, and the mechanics, of large-area consolidation of surface layers of soil under seismic loading.

e. Further information on the dynamic interaction of soils, foundation systems, and superstructure, and the effects of such interaction on stress and distortion in the superstructure. Exact cause(s), and development of criteria for improved means of prevention or control, of earthquake-induced landslides

f. Means for predicting changes in structure loads on supporting soil under dynamic conditions

g. An evaluation of the behavior of soil structures--e.g., earth fills--under dynamic conditions, perhaps using full-scale simulation tests (involving, for example, chemical or nuclear explosives) as a data source

h. Improved techniques for testing and evaluating potentially critical foundation soils to ascertain significant performance properties.

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[1] See Appendix D.

III
SUPPORTING INFORMATION

Presented in Section II were the principal manifestations of seismic energy release affecting building design; general recommendations, concerning building in seismic areas in consequence of these manifestations; and recommended procedural requirements for ensuring professional attention, and adequacy of site exploration and evaluation, reporting, and construction supervision. What follows is information to augment those recommendations and to aid in developing greater understanding of the problems involved.

1.0 FACTORS AFFECTING BUILDING IN SEISMIC AREAS

There are numerous possible cause-and-effect relationships which must be established in evaluating building sites and considered in preparing recommendations for site improvement, building design, or both.

1.1 Ground Motion

In the current state of knowledge, it is not possible to anticipate accurately whether faulting will occur or, in the event of occurrence, where the hypocenter and epicenter will be situated and what will be the probable extent and duration of occurrence. Further, since longitudinal and transverse vibratory motions proceeding from the hypocenter traverse materials which possess neither homogeneity nor definable geometric form, the possibilities concerning wave amplification and damping at a particular site are, for practical purposes, unpredictable. Both theoretical and applied research, and field observations, however, have led to several significant generalizations.

First, seismic waves will have more high-frequency components near the faulting. Second, in passing from underlying rock up through weaker soil strata, seismic waves can become amplified. Finally, vertical soil accelerations are not likely to exceed gravity loads in tall buildings.

From these generalizations, it may be concluded that short, stiff buildings, i.e., those having short natural periods, are most susceptible to damage if founded on rock close to an active fault, where wave frequencies are apt to be highest and thus high-frequency resonance is likeliest to occur. On the other hand, tall, flexible structures, i.e., those having long natural periods, are most susceptible to damage if founded on deep, weak soils--even at a considerable distance from an active fault--where wave frequencies are apt to be lower and thus low-frequency resonance is likeliest to occur. Furthermore, amplified ground motion is most likely under these latter conditions and at such locations.

Thus, for tall, flexible structures, sites having firm soil or rock at shallow depth are recommended as preferable over ones having weak soils, even if the latter are at a substantially greater distance from a fault. And, even though for any structure a site with rock or firm soils is preferred under normal conditions, a caution sign must be raised concerning such sites near active faults when short, stiff structures are the intended construction.

Ideal or even good sites are relatively rare in seismic areas; therefore, it can be expected that weak-soil sites will of necessity need to be used, or more appropriately, need to be made suitable by improvement of the site itself, by selection and design of an appropriate foundation/superstructure system, or by both. Therefore, it is necessary to understand both soil response and the structure effects which can be induced by soil response.

1.2 Soil Response

Apart from the relationship between site and structure type cited immediately above--which deals principally with the impact of resonant vibrations of ground and structure--there are other important soil response factors which must be considered in selecting a building site, and particularly in site improvement and structure design, when conditions are less than ideal.

First there is the matter of ground rupture, i.e., the fissuring which can emanate from the fault line and which may occur directly above the fault, in line with the fault, or radiating upward from the fault, depending upon the angle of geologic cleavage and the soil structure above. Actual ground cleavage due to fault movement can also occur and will generally be on a direct line with the fault. It is principally for this reason that building over active or potentially active faults is not recommended.

Next is the matter of soil properties and strength, both under normal conditions and during seismic disturbances. It is known that the strength of certain soils can be impaired by seismic loadings, with resultant effect on structures. The existence of such soils, which have been identified in Section II (1.1.4) as critical, must be ascertained, at whatever depth. Generally, if the Standard Penetration Test (ASTM D 1586)[1] reveals a resistance of greater than 25 blows per foot, soil strength probably will not be significantly impaired by seismic loading. Weak soils, however, can be affected in the following ways:

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[1] ASTM Designation 1586, Penetration Test and Split-Barrell Sampling of Soils.

1. Compression and/or Subsidence (large-area compression). Soil--particularly loose sands and gravels, and soft and medium silts and clays, above the water table--may be compressed in any direction, If compression is horizontal under vibratory motion, tension cracks may appear at the ground surface; if vertical, soil support can be lost and settlement can occur. Settlement can also result from soil compression produced by rocking action of a structure.

2. Soil Liquefaction. Under severe vibration in the presence of water, certain loose soils can suddenly liquefy and act much like quicksand. Obviously, any such phenomenon occurring beneath foundations would cause a sudden loss of support. Settlement of soils above the liquefied zone could impose additional loads (over and above those of the superstructure) on foundations which pass through the liquefied soil strata.

   As pointed out earlier, shock waves radiating from a zone of disturbance have a spectrum of relatively high-frequency, low-amplitude movements. As these waves transfer from rock to overlying soils, the high frequencies will be attenuated so that low frequencies predominate. Furthermore, the amplitude of motion may be magnified and the accelerations changed. Under certain conditions, frequencies of 1/2 to 5 cycles per second can occur. The resulting soil particle agitation, up and down or back and forth, can be such as to put these particles in a constant state of motion. This can occur with silts and loose sands and gravels below the water table. The result may be liquefaction of the soil. Footings, piers, or piles supported by such soils would settle.

3. Soil Deflection. When soils are stratified and it becomes necessary to support foundations below weak strata, there is the likelihood that additional, essentially horizontal, loads will be imposed on these foundations if differences in deformation of the various strata in response to ground shaking occur.

4. Soil Sliding. Landslides, small or large, are essentially the result of soil failure by shear. The result, of course, can be structure displacement and even collapse. Soft silts and clays, and other weak soils as well, on or near a slope are particularly susceptible to sliding.

This critical importance of site stability prompted the recommendation that a slope stability evaluation be made whenever significant slopes are involved, even though only certain soils are likely to be critical.

During site exploration and evaluation, it will be necessary to determine the above cause-and-effect relationships. This will entail an evaluation of seismicity of the region and the site, an evaluation of soils, preparation of site improvement recommendations and recommendations as to building types and structure-design value assumptions.

2.0 SITE SELECTION AND EVALUATION

The principal purpose of preliminary site explorations should be to make possible the rendering of a decision regarding acceptability or unacceptability of sites for development and building. If acceptance is indicated, explorations should also be adequate to permit a pre-preliminary determination of whether the proposed types of structure can be accommodated, or of what types of structure are most suitable.

The final site exploration should be designed to obtain design data, i.e., data which will be needed for developing a program of site improvement and for setting of building (foundation and superstructure) design assumptions.

Principal among the items to be considered in the exploratory process are those which follow.

2.1 Area Seismicity

Active faults and potentially active faults should be defined to include any known fault which is believed likely to move during the life of a structure; however, since the location of all faults is by no means known and movement cannot be predicted, a degree of risk will always be present.

Therefore, evaluating the seismicity of an area means that the likelihood, frequency, and magnitude of seismic activity must be assessed for the area as a whole, and for the particular site in question and the structures to be placed on that site as well.

A thorough review should be included of available information and data regarding existing geologic conditions and history--for example, width and composition of shear zone along fault; weak-gouge materials in faulted zones; ancient or recent landslides; adverse bedding planes; weak seams in rock or at rock/overburden interfaces; amount, depth, and source of ground water, and pressures exerted by such ground water.

If available, seismic probability maps can be of great help, first as an indication of the degree of exploration needed, and second as a means of ascertaining at least some of what is already known about an area.

Typical examples of the above are the zone map contained in the Uniform Building Code,[1] and the map provided by the U. S. Coast and Geodetic Survey on which are recorded known significant earthquake occurrences.[2] In addition, "seismic regionalization maps," as defined by C. F. Richter,[3]

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[1] See Ref. 2, Appendix A, also Appendix C.

[2] See Ref. 9, also discussions in Appendix E.

[3] See Ref. 10, 11, 12, 13, also Appendix E.

are available for limited areas. Further, there are maps of California on which are recorded known faults,[1] and a map by the California Department of Water Resources on which earthquake epicenters as well as faults are recorded.[2]

In some areas it may be necessary even to study newspaper files in order to gain insight into seismic history.

And, when all available sources of information and data have been exhausted, it will be necessary to develop a program of needed off- and on-site investigations to obtain data adequate for this seismicity evaluation and for preliminary and detailed site evaluation.

2.2 Soil Evaluation

The objectives of on-site exploration are:

In preliminary explorations, to determine general stratification and character of subsurface materials with accuracy suitable for engineering planning purposes

In final explorations, to determine subsurface conditions at specific structure locations in detail sufficient for selection of economical types of foundation, design of safe foundations, and preparation of quantity takeoffs and cost estimates.

1. General. There are no standard tests that will permit prediction of the response of foundation soils to earthquake shocks. Nevertheless, information can be obtained both in the field and in the laboratory to assist in the evaluation of the probable behavior of certain soils, particularly those referred to herein as critical.

   Standard soils investigations, particularly field identification and classification of soils per se, determination of water table, and the standard penetration test in granular or dense soils and unconfined compression tests in cohesive soils, should be routine. Where soft sensitive silts and clays are identified, undisturbed sampling (with thin-walled tube samplers or by hand-cut blocks), and, where further visual evidence is needed, hand-dug test pits or bucket-auger holes should be added to the routine investigational procedure.

   In addition to standard determinations of grain size, water content, Atterberg limits, shear strength in both undisturbed and remolded states, and relative density, special laboratory tests have been mentioned as being desirable in evaluating critical soils. These would be applicable where there is likelihood of a decrease in strength, an increase in compressibility, or liquefaction.

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[1] See Ref. 7, Appendix A, and Appendix E; see also Appendix D, where Fig. 2, 3, and 4 from Richter show this mapping technique (with excerpts from Richter to show limitations).

[2] See Ref. 11

Such tests might include laboratory determination of the dynamic moduli of deformation, ascertained by subjecting cylindrical specimens to axial and torsional vibrations and recording the frequency at which resonance occurs; also, repetitive cyclic loading tests, carefully performed to establish the correlation between strength and number of cycles of stress for a particular soil. In addition, it has been suggested (Ref. 6, p. 24) that soil which is supporting a foundation is subject during an earthquake to static stress together with superimposed pulses, and both test equipment and a test procedure have been proposed for evaluation of soil specimens under simulated earthquake loading for this and similar purposes.

Seismic geophysical investigations are helpful in evaluating the elastic response of certain soils to low-intensity shocks. For higher levels of intensity, the determination of the shear modulus by means of in-place field vibration tests provides useful information.

2. Extent of Explorations. The areal extent and depth of explorations must be adequate for locating and delineating subsurface strata unsuitable or unsafe for support of foundation loads, such as those previously cited as critical--i.e., compressible soils which could be the source of large settlements, weak materials which could create instability of foundations of slopes, loose fine sands and silts subject to substantial loss in strength or to liquefaction. The number, depth, and types of exploration boring or pit should be based on the nature of the proposed project, and on the seismicity evaluation--i.e., the geology of the area, specific geologic conditions of the site, and data from other explorations and construction experience in the vicinity; in fact, area geology and data from prior explorations are considered essential to planning the type and extent of exploration appropriate for a particular development.

3. Layout of Borings. Table 1 (following) contains suggested guides for the spacing of test borings. These guides, however, are a statement of general principles for planning of explorations and are not intended to cover the details that would actually be needed for specific sites and structures.

   Preliminary Borings - For large sites, preliminary borings should be plotted to produce an overall subsurface survey. Locations should be adequate in number and so situated as to indicate expected significant variations in the geologic structure or subsurface profile; for example, locations in valley bottoms and/or on top of high areas may be more indicative of critical conditions than those following a rigid geometric pattern.

   Final Borings - Final borings should be so plotted that geologic sections may be determined at the most useful orientations. Planning should be for a selected sequence; boring logs should be evaluated as received and related to a picture of subsoil conditions,

TABLE 1
PLAN OF EXPLORATION

Topic of Investigation	Boring layout
New site of wide extent	Space preliminary borings so that area encompassed by any 4 borings includes approximately 10% of total area. In detailed exploration, add borings to establish geologic sections at the most useful orientations.
Development of site on soft compressible strata	Space borings 100 to 500 ft o.c. in both directions at possible building locations. The wider spacing may be appropriate if correlation of important strata is reasonably good or if provision is made for additional evaluation during construction. Add intermediate borings when actual building sites are set.
Large, heavily loaded structure	Space borings approximately 100 ft o.c. in both directions, including borings at proposed exterior foundation walls, machinery rooms, and elevator pits; establish geologic sections at the most useful orientations.
Lightly loaded structure of large area	Execute minimum of 4 borings, one at each corner, plus intermediate borings at interior foundations sufficient to define subsoil profile.
Isolated rigid foundation 2,500 to 10,000 sq ft in area	Execute minimum of 3 borings around perimeter; add interior borings on basis of initial results.

TABLE 1 (Continued)

Isolated rigid foundation less than 2,500 sq ft in area	Execute minimum of 2 borings (at opposite corners); add more for erratic conditions if such are revealed.
Slope stability, deep cuts, high embankments	Execute 3 to 5 borings on a line in the critical direction to establish geologic sections for analysis (number of geologic sections required to depend on extent of stability problem); for an active slide, place at least one boring upslope of the sliding area.

Notes:

a. Where features such as cavities in limestone or fractures and joint zones in bedrock are being investigated, wash borings or rotary borings without sample recovery, or soundings and probings, may need to be spaced as close together as 10 ft when beneath footings or other significantly loaded areas.

b. Sufficient preliminary dry-sample borings should be made to determine most representative locations for undisturbed-sample borings. Where detailed settlement, stability, or seepage analyses are required, a minimum of one boring to obtain undisturbed samples of critical strata should be included.

c. Inclined borings may be required in special cases when surface obstructions prevent use of vertical holes, or when subsurface irregularities such as buried channels, cavities, or fault zones are to be investigated.

d. In certain geologic locations, test pits, trenches, or shafts may be required. This procedure is useful where slope evaluation is to be performed and where weathered material is exposed. Problems frequently are encountered where the depth to rock is slight, where there is colluvial material, or where soil is above the water table.

so that intermediate borings may be added or relocated in areas which prove critical. Borings on hillsides and at edges of fills should establish geologic sections necessary for stability analyses.

4. Depth of Test Borings. The depth of borings which will be required will depend to a considerable extent on the sizes and types of proposed structure, but will also be controlled to a substantial degree by the character and sequence of subsurface strata. In general, however, borings should extend into a hard, noncompressible or geologically persistent stratum; for general guides concerning appropriate boring depths, Table 2 (following) has been provided. During final exploration, at least one boring should extend well below the zone involved in any apparent stability, settlement, or seepage problem, to determine whether unusual conditions may exist at greater depth.

   Ground Water Observation - In boreholes for ground water observation, the casing should be in tight contact with hole walls and capped, and, if necessary, protected by a concrete encasement at the ground surface.

   Observation of water conditions in various strata may be required to evaluate conditions of artesian water pressure, perched water, and the like.

5. Covering and Backfilling. Borings made in foundation areas which eventually will be excavated below ground water, or where artesian pressures are encountered, must be plugged or grouted unless used for continuing water-level observations.

   All borings should be protected and covered until backfilled.

6. Miscellaneous. Borings in potentially compressible fine-grained strata of great thickness should extend to depth where stress from superimposed loads is so small that corresponding consolidation will not significantly influence surface settlements.

   Where stiff or compact soils are encountered at shallow depths, one or more borings should extend through this material to a depth where the presence of an underlying weaker stratum--should such a compressible stratum exist--cannot affect stability or settlement.

   If bedrock surface is to be determined and character and general location of rock are known, borings should extend 2 feet (or more if indicated by the geology of the region) into sound, unweathered rock. Where the character of rock is not known or where boulders or irregularly weathered material overlaps bedrock, a 10-foot core should be drilled into sound rock, with one or two selected borings reaching 20 feet. In cavernous limestone, borings should extend through strata suspected of containing solution channels or until the depth of sound rock is sufficient to carry foundation loads (angle borings, 35 to 40 degrees off vertical, are frequently necessary for locating of solution channels).

TABLE 2
DEPTH OF EXPLORATION

Topic of Investigation	Depth of Borings
Large structure with separate, closely spaced footings	To where increase in vertical stress for combined foundations is less than 10% of effective overburden stress; generally, borings should extend no less than 30 ft below deepest part of foundation unless rock is encountered at a shallower depth.
Isolated rigid foundations	To where vertical stress decreases to 10% of bearing pressure; generally, borings should extend no less than 30 ft below deepest part of foundation unless rock is encountered at a shallower depth.
Slope stability	Below any active or potential failure surface and into hard stratum, or to a depth for which failure is unlikely because of geometry of cross-section.
Deep cuts	Between 3/4 of and the full base width of narrow cuts below base of cut. Where cut is above ground water in stable materials, depth of 4 to 8 ft below base may suffice. Where base of cut is below ground water, determine extent of pervious strata below.
High embankments	Between 1/2 and 1 1/4 times the horizontal length of side slope in relatively homogeneous foundation; however, where deep or irregular soft strata are encountered, to hard materials.

7. Split-Barrel Dry Sampling and Penetration Resistance. The equipment and procedures for securing representative dry samples of soil and for determining standard penetration resistance are described in detail in ASTM D1586. To the procedures described therein, it should be added that the boring hole must, at all times, be kept filled with water or drilling fluid to a level above the natural ground-water level. Particular attention also must be given to avoiding a lowering of the water level in the drill hole during removal of drilling rods and tools prior to sampling. The split-barrel portion of the sampler preferably should be 20 inches long. When penetration resistance is greater than 30 blows per foot, however, a 12-inch minimum length of drive after seating is acceptable.

   For exploratory borings, the split-barrel procedure should be employed for securing representative dry samples, and standard penetration resistance should be determined for all samples and subsurface strata. On those projects where more extensive subsurface investigation is called for, established procedures for measurement of static penetration resistance using sampling tools of other types may be acceptable and desirable.

   In locations potentially subject to severe seismic disturbance, particular attention must be given to strata of subsurface materials which may be subject to liquefaction or substantial loss in strength under the effects of repeated shock or vibratory loadings. Not all such materials have been identified. However, all cohesionless granular soils with a standard penetration resistance of less than 10 blows per foot, as well as soft clays and soft organic silts on or forming slopes, at the face of cuts, or placed as fills at the edge of natural slopes and in ravines, are potentially dangerous in seismic areas. The contact zone between overburden or colluvium and top of rock may be especially weak and warrants special attention. All such soils and conditions should be the subject of special study by the foundation engineering consultant.

8. Requirements for Sampling Program. The number, type, and distribution of required samples depend on the arrangement of the strata and on the use to be made of the samples.

   Representative Dry Samples - Such samples are generally obtained at vertical intervals no less than 5 feet o.c. and at every change in strata, except in extensive strata of strongly homogeneous character, such as deep marine sediments.

   Undisturbed Samples - Recovery of undisturbed samples may be preceded by dry-sample borings to determine thickness and extent of critical strata. The number and spacing of undisturbed samples required will depend entirely on the specific design problems, and may range from only one or two from a boring to a practically continuous section from a boring in a critical stratum.

9. Obtaining Undisturbed Samples. Several types of drilling equipment currently available permit alternate taking of dry and undisturbed samples. Thus, a separate operation for dry-sample borings is not necessarily required.

   Supervision - Recovery of undisturbed samples is a specialized operation which should be supervised by an experienced soil engineer or geologist rather than a driller.

   Specifications - Any or all of the requirements which follow should be included in specifications for borings:

   a. Sampling devices--In general, use should be made of one of the stationary piston-type samplers, having a sampling tube of 2-inch or larger inside diameter (ID).

      For soils containing a significant amount of coarse gravel, shells, or other materials which may interfere with or damage the tube cutting edge, a thin tube of ID greater than 2 inches, or hardened cutting bits, should be used.

      For hard clays, use should be made of the nonpiston Shelby tube sampler with thin tube of ID greater than 2 inches.

   b. Sampling tubes--Brass, hard aluminum, or steel tubes, kept clean and smooth.

2.3 Design Information and Data

Once a site has been deemed suitable, and all relevant site exploration data have been collected, it remains to evaluate these data and to recommend site improvements, structure design parameters, or both.

1. Site Stability. Of first importance to project designers will be overall site stability--existing and attainable. The report of the foundation engineer, then, should contain a thorough treatment of site development proposals--e.g., cuts and fills to be made, soil density modifications to be effected, and changes in surface drainage patterns and ground-water conditions. These proposals should be presented in relation to possible or proposed structures, i.e., with drawings showing structure types and locations, together with load-carrying capacities of foundation soils and loads to be transmitted by structure(s) to the soil.

2. Foundations. Next, an analysis of proposed foundation systems, or recommended and alternative foundation systems, should be presented. In this regard, the following considerations are representative:

   Spread Footings - Where soil materials are weak and compressible, or apt to liquefy during seismic activity, spread footings should not be used lest severe settlement or differential settlement occur.

If, however, existing soil materials can be adequately improved, or removed and replaced with a well compacted fill of selected material, spread footings could comprise an acceptable foundation type.

Mats - Where spread footings are determined to be inadequate, mat foundations--which are better able to spread loads--could prove an adequate foundation type provided that such foundations do not rest on soils which can liquefy or which are subject to a high degree of strength loss during seismic activity.

Piles - Where neither spread footings nor mats are suitable, piles--whether driven, drilled, or cast in-place with or without bells--must have sufficient length to penetrate through soils which may liquefy or lose strength during seismic activity, and must be able to develop full design capacity in the lower firm stratum or rock, through either friction or end-bearing, or both.

It should be recognized that piles may be subjected to significant flexural strains under seismic loading after having been passed through soil layers of significantly different properties. Factors which should be considered in flexural design of piles include pile stiffness, soil reactions, and bending moments developed in individual piles. Reinforcing steel may be needed in concrete piles to resist bending moments. Also, pile caps will need to be tied together when either soft soil or soft fill underlies the pile cap; and such ties, when placed on soft soils, will themselves need to be designed to support their own weight plus superimposed loads, i.e., to withstand, at ultimate strength, forces which are expected as a result of interaction among footings, walls, and soil. In some instances, reinforced concrete slabs dowelled into grade beams and pile caps can be designed to function adequately as ties as well as floor slabs.

For short-time seismic loading, an increase in allowable soil stress may be permitted for some good foundation materials; however, horizontal resistance should be conservatively estimated in relation to relative deformation of the structure and to the confining and underlying materials, and such stress increases should be justified by the foundation engineer.

In load testing of piles, no special procedural requirements need be imposed for seismic areas.

3. Structure Design Parameters. An analysis of soil and structure vibrating periods should be made. The ultimate superstructure foundation system design must then be cross-checked with established site characteristics to ensure a completely compatible design.

4. Professional Collaboration and Inspection. Effective collaboration among all members of the building design and building ownership

teams is perhaps the most effective means for ensuring technical adequacy and satisfactory performance.

The foundation engineer, the structural, mechanical and other specialty engineers, the architect(s), owner, and insurer must work together effectively to achieve common agreement upon, and understanding of the expected behavior of the structure--i.e., foundation and superstructure as an integrated system. Much can be accomplished, for example, by arranging to have the foundation engineer review design concepts, and preliminary and final contract documents, including drawings and specifications.

This concept of collaboration can and should be applied to the construction phase as well, through provision for an adequate level of inspection of excavation and foundation construction by the foundation engineer. In some instances, an adequate level of inspection could be achieved by no more than one or two site visits; in others, involving detailed site exploration plus geologic mapping of subsurface formations, fault zones, and the like, full-time on-site inspection throughout the construction process could be needed.

5. Miscellaneous. Although not a part of the building or buildings on a site, appurtenant surface and subsurface structures are nevertheless important to overall project performance. For example, as indicated in the recommendations, utility lines can be particularly sensitive to ground motion and should be provided with flexible joints at points where accommodation to movement is needed, particularly at points of passage through foundations walls, floor slabs, and the like. Gas mains, high-pressure steam and water lines, and similarly hazardous carriers should not be allowed to pass beneath buildings and should be given special care to prevent rupture.

   Also, certain buried utility structures may become buoyant if the soil around or above liquefies under seismic action. At any location where liquefaction is a real possibility, care should be taken that buried structures are heavy enough or are tied down to underlying firm soil or rock.

3.0 SUMMATION

A substantial amount of research and development activity is currently in progress in an effort to improve techniques for testing and evaluating significant properties of what have been described in this report as critical foundation soils. If significant improvements are to be made in the design and performance of structures for the vast amount of building envisaged even for the remaining decades of this century, this work will need to be supported to a far greater extent than it is now or has been in the past.

Even with the existing limitations, current effort does offer near-term promise of improvements in respect to both testing and design methods. In fact, it would appear unwise for FHA to standardize such methods at this time, or to accept the standards of others, as a long-term solution to its needs. A position of flexibility in acceptance procedures at this time would permit FHA to respond quickly to the results of on-going research and development. In the final analysis, requirement for and reliance upon overall professional competence is the best assurance of good practice.

However, in the interest of sound acceptance procedures, FHA should consider the creation for its own use of guides to evaluation based upon the recommendations of this report. This might well also be made available to those seeking FHA mortgage insurance, for assistance in anticipating FHA needs. Further, FHA should consider creation of a consulting board to assist in the review of newly evolved methods and procedures whenever such are offered as changes to the suggested guides. Such a board could also assist in the formulation and review of specific technical studies which will be needed eventually to evolve the desired standards.

APPENDIX A
REFERENCES

1. California Department of Water Resources Bulletin No. 116-Z, "Faults and Earthquake Epicenters in California" (January 1964).

2. Gutenberg, B. "Effects of Ground on Earthquake Motion," Bull. Seis. Soc. Am., Vol. 47, No. 3 (July 1957), pp. 221-250.

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5. Soil Mechanics, Foundations and Earth Structures, Navy Design Manual NAVDOCKS DM-7, Department of the Navy, Naval Facilities Engineering Command, Washington, D. C. (November 1961).

6. Parmalee, R. A., Penzien, J., Scheffey, C. F., Seed, H. B., and Thiers, G. R. "Seismic Effects on Structures Supported on Piles Extending Through Deep Sensitive Clays," SESM 64-2, Institute of Engineering Research, University of California, Berkeley (August 1964).

7. Richter, C. F. "Seismic Regionalization," Bull. Seis. Soc. Am., Vol. 49, No. 2 (April 1959), pp. 123-162.

8. Seed, H. B., and Chan, C. K. Strength of Clays Under Simulated Earthquake Loading Conditions. Soil Mechanics and Bituminous Materials Research Laboratory, University of California.

9. Uniform Building Code of the International Conference of Building Officials.

10. U. S. Department of Commerce Coast and Geodetic Survey Publication No. 41-1, "Earthquake History of the United States Part I" (1965).

11. U. S. Department of Commerce Coast and Geodetic Survey Publication No. 41-2, "Earthquake Investigations in the Western United States (1931-1964)."

12. U. S. Department of Commerce Coast and Geodetic Survey Special Publication No. 254, "Principle Underlying the Interpretation of Seismograms," Washington, D. C. (1960).

13. U. S. Department of Commerce Coast and Geodetic Survey, "Earthquake Risk in the United States," Bull. Seis. Soc. Am., Vol. 42 (1952), p. 110.

APPENDIX B
SOIL CONSISTENCY AND DENSITY

TABLE 1
CONSISTENCY OF UNDISTURBED COHESIVE SOILS[1]

Consistency	q_u (tsf)[2]	Field Guide[3]
Very soft	0.25	Core (height = twice diameter), sags under own weight
Soft	0.25 - 0.50	Can be pinched in two between thumb and forefinger
Medium	0.50 - 1.00	Can be imprinted easily with fingers
Stiff	1.00 - 2.00	Can be imprinted with considerable pressure from fingers
Very stiff	2.00 - 4.00	Can barely be imprinted by pressure from fingers
Hard	4.00	Cannot be imprinted by fingers

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[1] See Ref. 4, Appendix A, for source.

[2] q_u = unconfined compressive strength.

[3] These field guides are only an indication of the consistency of soils as described in the left-hand column. The values of q_u are given as the basic values of consistency by which field guide classification can be verified. The values obtained from the field guide are not to be used for design without laboratory verification. Unconfined compressive strength is not synonymous with ultimate bearing capacity.

TABLE 2
RELATIVE DENSITY OF COHESIONLESS SOILS

Term	Field Guide[1]	Blows Per Foot[a]
Very loose	---	0 - 4
Loose	Easily penetrated with 1/2-in. reinforcing rod pushed by hand	5 - 10
Medium	Easily penetrated with 1/2-in. reinforcing rod driven with 5-lb. hammer	11-- 30
Dense	Penetrated 12 in. with 1/2-in. reinforcing rod driven with 5-lb. hammer	31 - 50
Very dense	Penetrated only a few inches with 1/2-in. reinforcing rod driven with 5-lb. hammer	50

[1] These field guides are given only as an example of one of numerous simple field procedures in current use for indicating density. Many other procedures are equally good, and this column is not intended to establish a preferred method. The results of the penetration test, as shown in blows per foot, are widely accepted as a standard for the terms shown.

[a] Blows as measured with sampler of 2-in. OD and 1-3/8-in. ID, driven 1 ft. by 140-lb. hammer falling 30 inches. See Tentative Method for Penetration Test and Split-Barrel Sampling of Soils, ASTM Designation D1586-58T (or most recent edition). It should be borne in mind that the number of blows per foot required at any given depth is influenced not only by the density of the soil, but also by its gradation (coarseness), the depth, elevation of the water table above the point at which the measurement is taken, and the weight of the drill rod.

APPENDIX C

LOCATING OF STRUCTURES IN FAULT AREAS

(from Gutenberg, "Effects of Ground on Earthquake Motion."[1])

CONCLUSIONS

In a discussion of potential effects of earthquakes on structures, findings of the present investigation and results concerning effects of local geology on wave propagation should be combined with results reported by engineers concerning vibrations of structures. It follows, for example, from the present investigation that, generally, shaking is relatively strong where the ground-water table is close to the surface. In addition, in the epicentral area of minor shocks prevailing periods of about 1/4 sec or less may be expected to produce relatively heavy shaking at sites where thin alluvium covers solid rock. As the magnitude of the shocks increases, periods of 1/2 to 3/4 sec play a greater role, and sites on thick alluvium must be expected to undergo relatively heavy shaking. Since ratios between the amplitudes on alluvium to those on rock may be as great as 10 or more, the resulting acceleration may show a similar ratio between a site on "poor" ground and one on crystalline rock. Figure 24 [of the quoted paper] indicates that even in a major earthquake the acceleration on crystalline rock usually remains well below g, but that it may exceed g on "poor" ground.

Relatively long-lasting shaking may be expected in areas with thick alluvial cover; on water-saturated ground, waves having periods of a fraction of a second produce prolonged shaking. Near the coast, areas with thick alluvium and shallow water table show such large short-period continuous unrest that only low-magnification instruments can be used for investigation of ground effects on shaking in earthquakes. In general, appreciable differences in shaking may exist at sites only a thousand feet apart.

The old conclusion still holds: That, for finding the safest location for a building in a region where there are active faults, it is more important to look for sites on bedrock than for locations with a maximum distance from the faults. This advice also allows for the fact that a fault considered to be dead may well become alive again and that frequently the location of faults is unknown.

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[1] Bull. Seis. Soc. Am., Vol 47, No. 3.

APPENDIX D

MAPPING FOR EARTHQUAKE RISK

(from Richter, "Seismic Regionalization."[1])

ABSTRACT

In the USSR earthquake risk is now officially mapped by division into areas numbered with the degrees of the Modified Mercalli intensity scale, to show maximum reasonably expectable intensity during future earthquakes on ground of the prevailing character. This paper presents and discusses maps on the same plan for the Los Angeles Basin and its vicinity, for California, and for the United States.

The effect of variation of ground from point to point can be shown only on a large scale. This is microregionalization; the map for the Los Angeles Basin is an example. Small-scale regionalization maps require generalization. Prevailing ground is selected, not strictly by percentage of area, but by considering the foundation likely to be used for construction, in mountainous areas mostly small alluvial patches less stable than the surrounding rock.

Regionalization and especially microregionalization can be used in construction and planning, as indicating maximum effects to be considered in designing permanent structures. In adjusting insurance rates, and in designing temporary structures, statistical frequency of occurrence is also involved.

Over small areas, regionalization depends largely on local variation of ground and geology; over large areas, distance from active faults must be considered. Attention should be given to the effect of structural trends and of wave path on the form of isoseismal curves.

Mapping for the Los Angeles Basin area is reasonably definite. That for California is fairly reliable, but less so in desert and mountain areas. That for the United States is in part highly speculative and subject to substantial change.

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[1] <u>Bull</u>. <u>Seis</u>. <u>Soc</u>. <u>Am</u>., Vol, 49, No. 2.

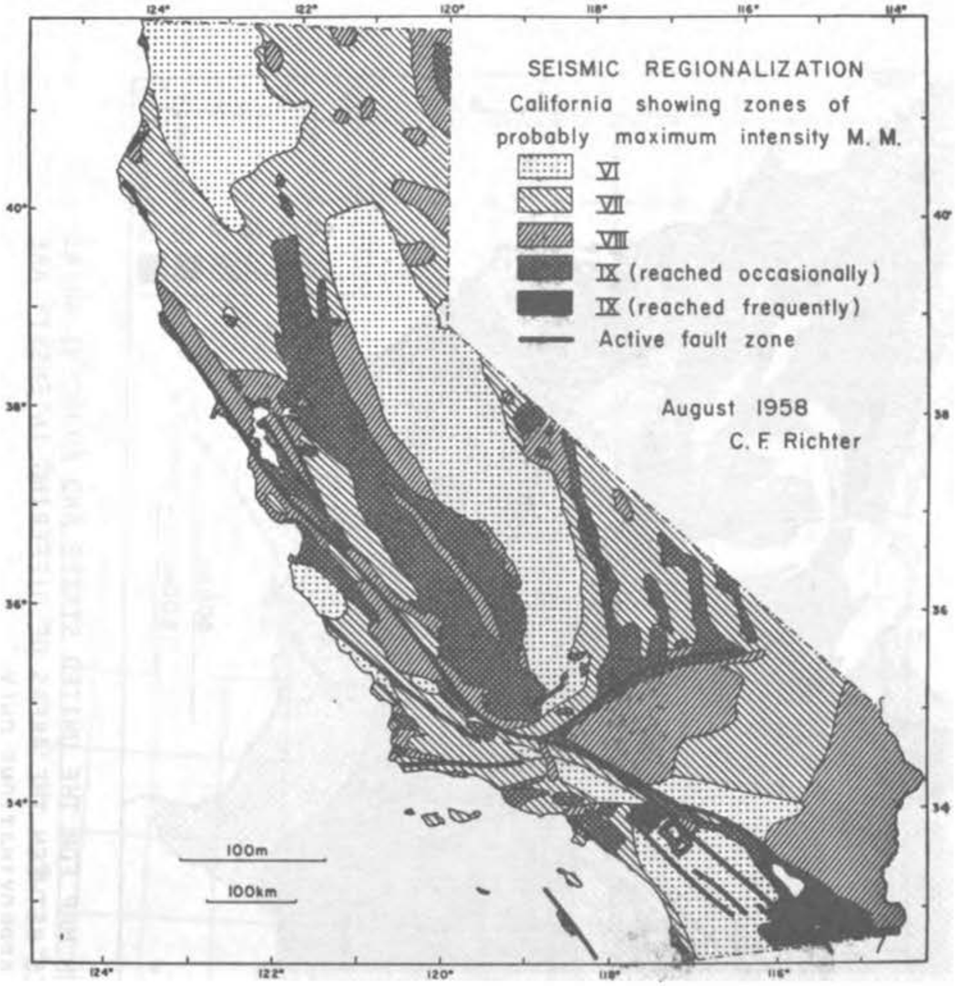

Fig. 1 REGIONALIZATION MAP FOR CALIFORNIA

GENERAL PROCEDURE

...On the accompanying maps for California [Fig. 1] and the United States [Fig. 2], rating of IX may be taken similarly as indicating IX or perhaps over. On the California map [Fig. 3], some of the chief active fault zones have been indicated by heavy bands as areas of special risk, not merely of high intensity, but of exceptional manifestations...

The Imperial Valley has been given special marking to indicate probability that IX may be reached, at any point in the area, more frequently than at points outside it.

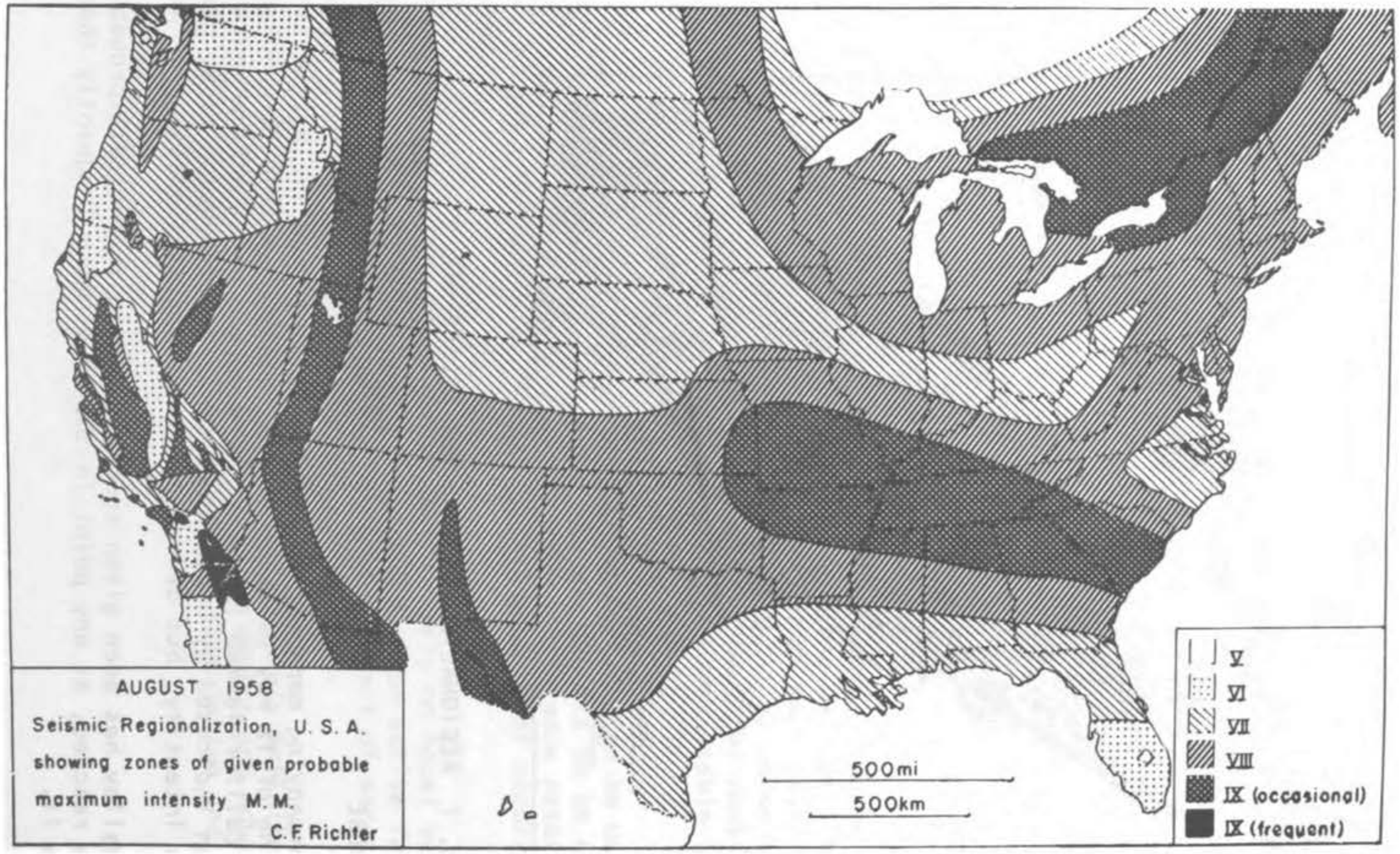

Fig. 2 TENTATIVE REGIONALIZATION MAP FOR THE UNITED STATES AND ADJACENT AREAS. OUTSIDE CALIFORNIA, LINES BETWEEN THE AREAS OF DIFFERING INTENSITY ARE APPROXIMATIONS ONLY.

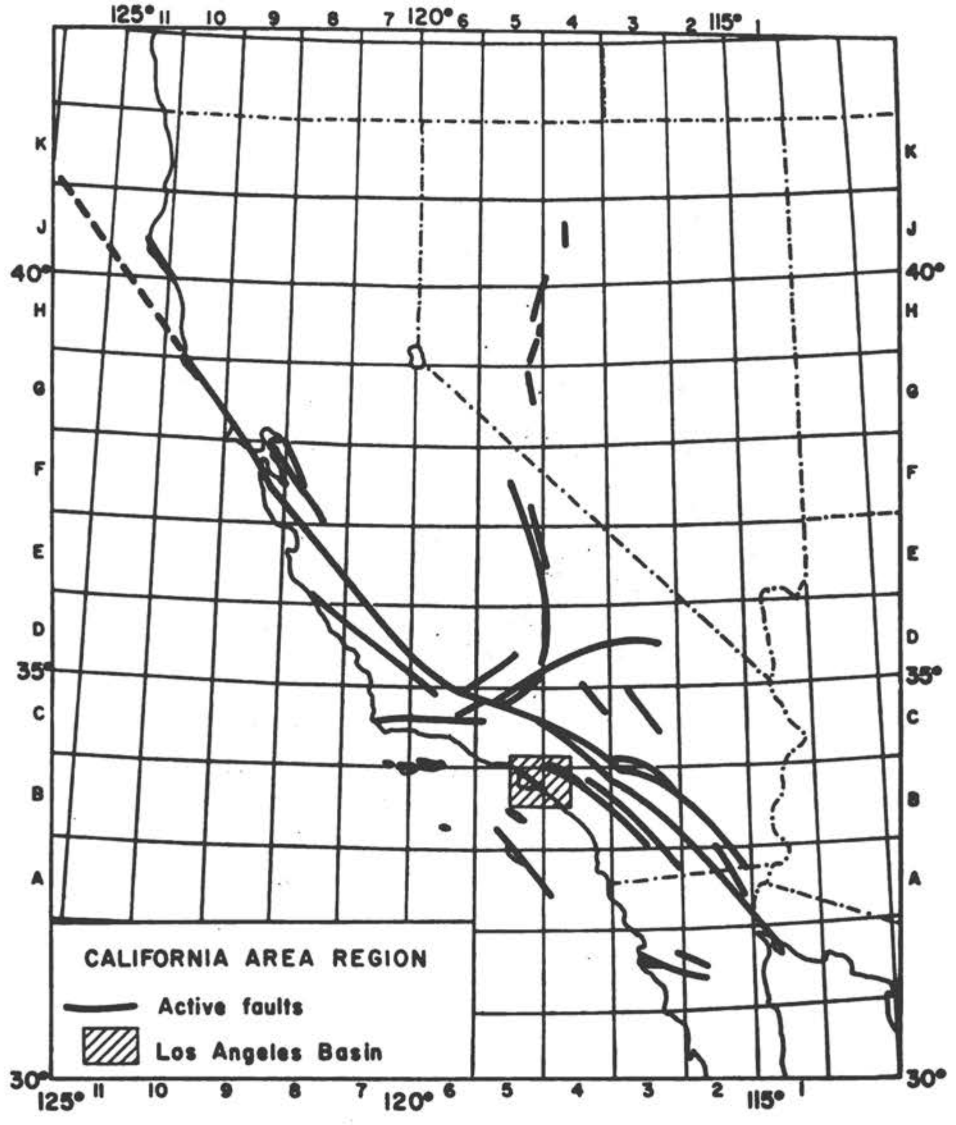

Fig. 3 CALIFORNIA, SHOWING FAULTS AND LOCATION OF AREA MAPPED IN... [Fig. 1].

On the map for the Los Angeles Basin [Fig. 4], IX may be taken as a maximum not likely to be exceeded.

Earthquake magnitudes are given throughout this paper so far as possible on the original basis developed for California (Richter, 1935), or on the M scale used for distant earthquakes (Richter, 1958a, b). Where historical data only are available, the magnitude cited is merely an estimate.

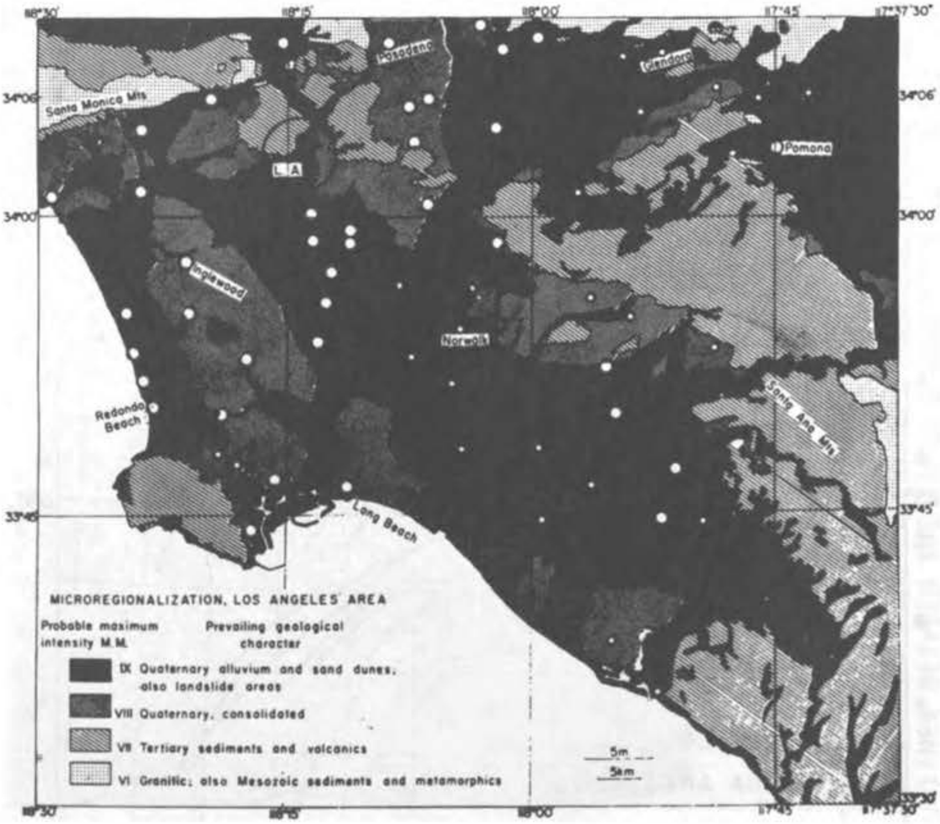

Fig. 4 MICROREGIONALIZATION MAP, LOS ANGELES BASIN AND ITS VICINITY, SOUTHERN CALIFORNIA

Where the same area is covered by microregionalization and by small-scale regionalization, or in transferring the latter to a still smaller scale, problems of generalization arise. These will be evident on comparing... [Fig. 1, 2, and 3] representing the Los Angeles Basin, California, and the United States. It is necessary to omit small patches and irregularities which are apparent on a large-scale map but cannot be shown clearly on a small scale.

APPENDIX E
SEISMIC PROBABILITY MAPS

HISTORY OF THE SEISMIC PROBABILITY MAP THAT IS NOW INCLUDED AS PART OF THE UNIFORM BUILDING CODE

1. Excerpt from Seismological Activities of the U. S. Coast and Geodetic Survey in 1948 by E. B. Roberts and F. P. Ulrich.[1]

   A seismic probability map of the United States was prepared with advice of leading seismologists of the country, including J. P. Buwalda, Perry Byerly, B. Gutenberg, Andrew Lawson, L. Don Leet, D. J. Linehan (S. J.), J. B. Macelwane (S. J.), C. F. Richter, V. C. Stechschulte (S. J.), H. O. Wood, and the authors.

2. Excerpts from Seismological Activities of the U. S. Coast and Geodetic Survey in 1949 by E. B. Roberts and F. P. Ulrich.[2]

   A revised seismic probability map was published.... The revised map changes Charleston, S. C. from Zone 3 to Zone 2, and sets up a Zone 3 in the Puget Sound region of Washington, which was formerly included in Zone 2.

3. As indicated by the excerpt from BSSA Vol. 42 given below, the Coast and Geodetic Survey withdrew sponsorship of the map and offered in its stead a map showing distribution of earthquakes. Since 1952, the annual publication United States Earthquakes has included a map showing the location of destructive and near-destructive earthquakes. A copy of the latest issue (1964) with accompanying statement is shown as Fig. 2,....

4. "Earthquake Risk in the United States" (Official Statement by the U. S. Department of Commerce, Coast and Geodetic Survey, January 1952):

   The Seismic Probability Map of the United States, SMC-76, issued by the U. S. Coast and Geodetic Survey in 1951, has been withdrawn from circulation because it was found to be subject to misinterpretation and too general to satisfy the requirements of many users.

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[1] Bull. Seis. Soc. Am., Vol. 40 (1950), p. 213.

[2] Ibid., Vol. 41 (1951), p. 219.

In place of the Seismic Probability Map the Bureau offers a map showing the distribution of important earthquakes which can be used as a guide in evaluating earthquake risk.[1] The plotted earthquakes are divided into four intensity groups indicated by small dots, large dots, small ringed dots, and large ringed dots. These symbols represent, respectively, earthquakes of intensities VI and VII, VIII, IX, and X and over, according to the Modified Mercalli Intensity Scale of 1931.

The Coast and Geodetic Survey strongly recommends the use of its earthquake catalogues in making final risk evaluations for any locality. Serial 609, Earthquake History of the United States, Parts I and II, is available for this purpose from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., or from field stations of the Coast and Geodetic Survey, at 35 cents for Part I (United States and Alaska, exclusive of California and Western Nevada), and 15 cents for Part II (California and Western Nevada). The Bureau will assist in making such evaluations on request.

If it is desired to classify an area according to the zoning system recognized by the Uniform Building Code..., Zone 3 would apply if major earthquake damage has occurred and repetition may be expected. Zone 2 would be one which has experienced moderate damage one or more times and the probability of a major earthquake is less than for Zone 3. A few areas, especially in the eastern half of the country, would be considered in Zone 2 if considerable damage has been experienced in a limited area only at long intervals. Zone 1 would include areas that have experienced minor damage but no structural damage and the probability of a major earthquake is less than in Zone 2. Zone 0 would be one in which there appears to be no reasonable probability of earthquake damage.

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[1] This map was also published in "Seismological Activities of the U. S. Coast and Geodetic Survey in 1949," by E. B. Roberts and F. P. Ulrich, Bull. Seis. Soc. Am., Vol. 41 (1951), p. 218, Fig. 6.

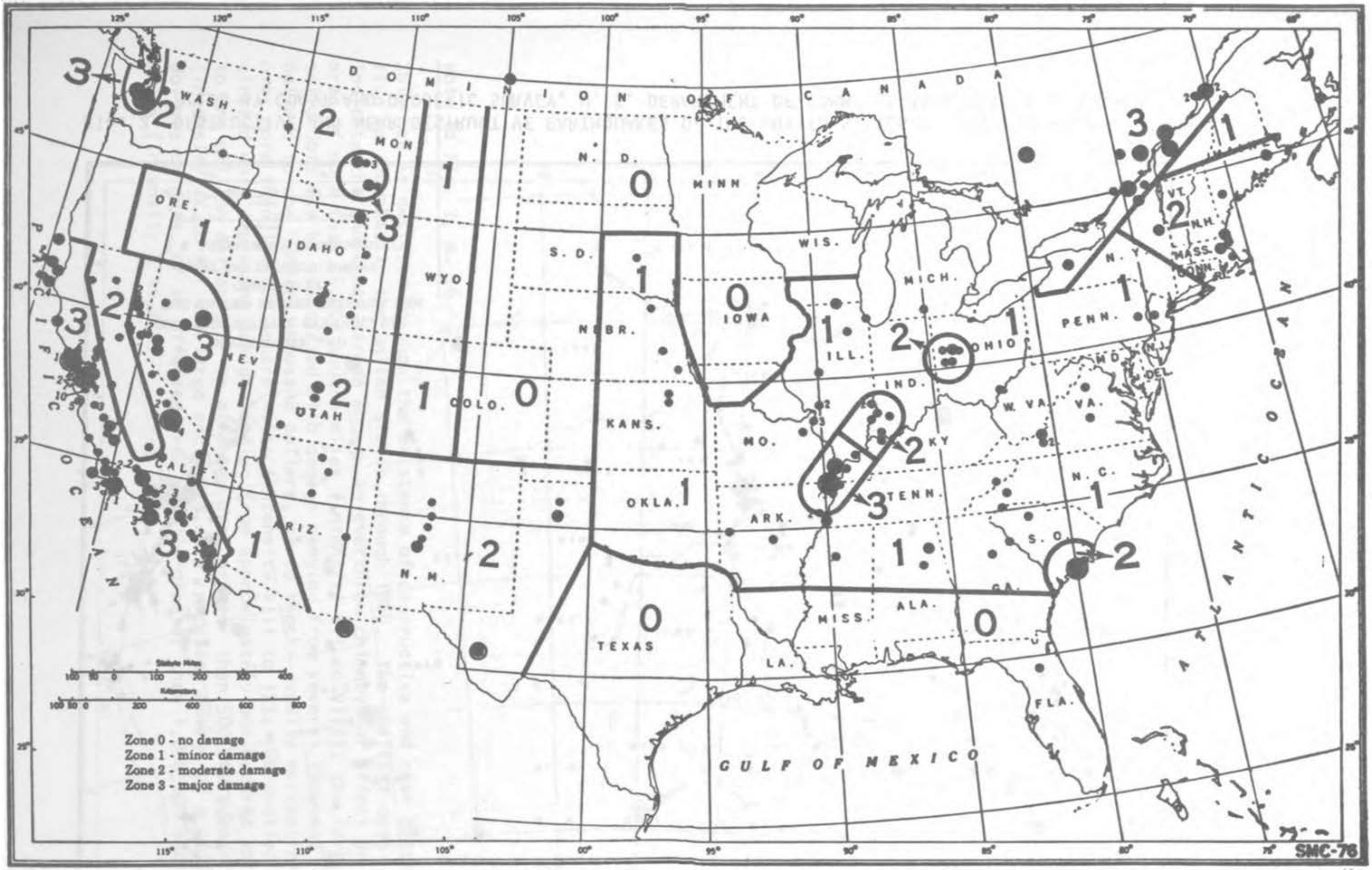

Fig. 1 MAP OF THE UNITED STATES SHOWING ZONES OF APPROXIMATELY EQUAL SEISMIC PROBABILITY (as approved by the Pacific Coast Building Officials Conference in Twenty-Eighth Annual Meeting for inclusion in the 1952 Edition of the Uniform Building Code. This map of seismic probability is a part of this Code.)

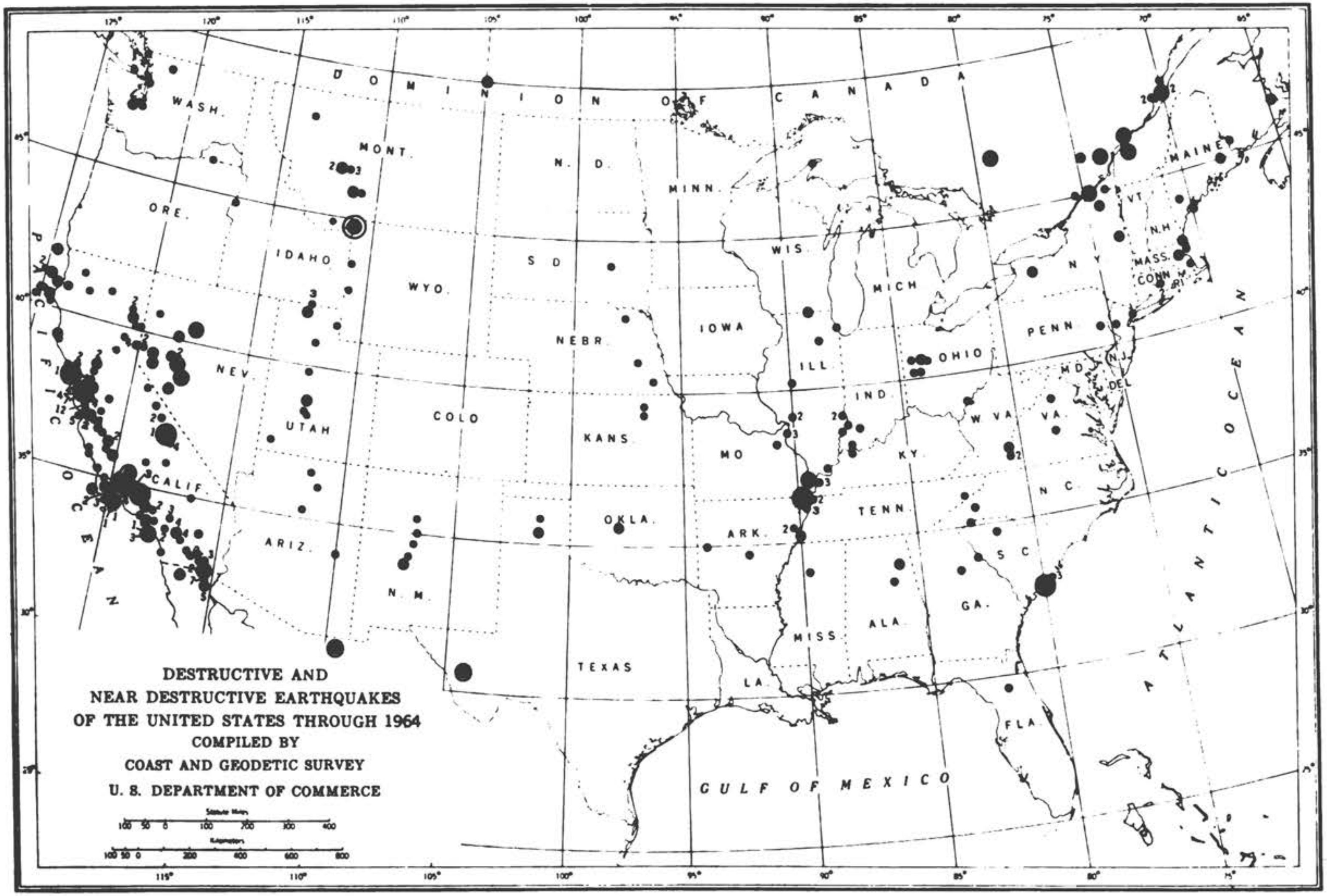

Fig. 2 DESTRUCTIVE AND NEAR DESTRUCTIVE EARTHQUAKES OF THE UNITED STATES THROUGH 1964 COMPILED BY COAST AND GEODETIC SURVEY, U. S. DEPARTMENT OF COMMERCE (See note next page.)

Note to Fig. 2, p. 36

This map is designed to show the existence of destructive and near destructive earthquakes in the United States through 1964. The smallest dots indicate the shock was strong enough to overthrow chimneys or affect an area of more than 25,000 square miles (intensity VII to VIII); the largest solid dots may be associated with damage ranging from several thousand dollars to one hundred thousand dollars, or to shocks usually perceptible over more than 150,000 square miles (intensity VIII to IX); the smaller encircled dots represent damage ranging from approximately one hundred thousand to one million dollars, or an affected area greater than 500,000 square miles (intensity IX to X); the large encircled dots represent damage of a million dollars or more, or an affected area usually greater than 1,000,000 square miles (intensity X to XII).