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ABSTRACT

This companion guidebook augments the Federal Emergency Management Agency's publication entitled "FEMA 154, Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook." The guidebook, which provides assistance in the use of the Rapid Screening Procedure (RSP), is intended for use by public school districts with relatively large numbers of buildings (e.g., 30 or more). RSP is a process aimed at quickly and easily identifying those buildings that might pose a risk to loss of life or injury, or to severe curtailment of community services, in the event of a damaging earthquake. The guidebook offers additional explanatory and supportive information for school districts that wish to conduct a more comprehensive RSP effort than simply a "sidewalk" survey. It requires a side-by-side reading with "FEMA 154." Appendices present earthquake problems of elementary and secondary schools and modified data collection forms. (GR)

A GUIDEBOOK TO

FEMA 154 - RAPID VISUAL SCREENING OF BUILDINGS FOR POTENTIAL SEISMIC HAZARDS: A HANDBOOK

FOR USE IN THE SCREENING OF SCHOOL BUILDINGS

DECEMBER 1994

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PREFACE

Building Technology Inc. (BTI) has prepared this document in support of its efforts under Federal Emergency Management Agency (FEMA) Contract #EMW-91-C-3636, *Technology Transfer on Seismic Rehabilitation of Existing Buildings*, awarded September 1991. Under this contract BTI has been responsible for the promotion and conduct of general audience and targeted audience workshops, the development of materials (including lectures, slides, videos, and publications) in support of these workshops, the preparation and delivery of presentations under a speakers bureau, and the distribution of the entire series of FEMA publications regarding the subject of seismic mitigation of existing buildings.

This document was prepared by BTI with the assistance of Mr. Melvyn Green, P.E., president of Melvyn Green and Associates, subcontractor, and Dr. Frederick Krimgold of the Virginia Polytechnic Institute and State University, consultant.

In addition, BTI gratefully acknowledges the valuable assistance and cooperation provided by Ms. Marilyn MacCabe, Project Officer, Federal Emergency Management Agency.

INTRODUCTION

This document is a companion publication to be used in conjunction with the Federal Emergency Management Agency's document FEMA 154, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*. This guidebook is intended for use by public school districts with relatively large numbers of buildings (e.g., 30 or more). It provides guidance in the use of the Rapid Screening Procedure (RSP) specifically for school buildings.

The RSP is a process aimed at quickly and easily identifying those buildings that might pose a risk of loss of life or injury, or severe curtailment of community services in the event of a damaging earthquake. Using this method, a school district can develop a list of potentially hazardous buildings, each of which should be subjected to a more detailed engineering analysis. The district can also develop information useful in seismic retrofit planning.

The RSP generates relative scores for categories of building types. These scores are based on judgements of the likelihood of building collapse in the event of a severe earthquake, which is related to the building code-specified design earthquake. It should be noted that building damage in less severe earthquakes can also be life threatening, and therefore that the RSP should be considered as only one part of a seismic risk analysis.

FEMA 154 is intended for use by individuals and organizations which do not necessarily own the buildings being screened, and as such, do not have ready access to archival plans, building interiors, etc. Furthermore, FEMA 154 includes a wide variety of building and structural types. Finally, FEMA 154 is intended for use in conducting "sidewalk" inspections.

This guidebook has been developed to augment FEMA 154 because:

- School districts own their buildings and generally have significant information about the buildings beyond that which can be gleaned from a quick review of the exterior.
- There are fewer building and structural types typically found in schools.
- It is assumed that a more comprehensive screening of school buildings will be conducted than simply a "sidewalk" survey.

The use of this guidebook requires a side-by-side reading of FEMA 154. It is suggested that the user of this guidebook become familiar with FEMA 154 before proceeding with the specific recommendations noted herein.

CHAPTERS 1 - INTRODUCTION & 2 - EARTHQUAKE BEHAVIOR OF BUILDINGS

These chapters of FEMA 154 provide general introductory and background information.

- *2.4 Configuration Problems*

  A discussion of configuration problems specifically applicable to school buildings can be found in Appendix A (Chapter 3--Earthquake Problems of Elementary and Secondary Schools, which is excerpted from FEMA 149, *Seismic Considerations--Elementary and Secondary Schools*).

CHAPTER 3 - GENERAL SURVEY IMPLEMENTATION INSTRUCTIONS

- *3.1 Survey Implementation Sequence*

  This Guidebook anticipates that the survey is likely to be implemented by a single school district in relation to its own buildings. However, this survey could also be implemented jointly by several districts or by a regional or state agency in several school districts. In the latter cases, several additional steps may be required, such as:

  - formal approval by one or more governing bodies,
  - notification of district administrators, principals and other stakeholders,
  - use of survey results,
  - responsibilities of the individual districts, and
  - actions to be taken.

- *3.2 Budget Development and Cost Estimation*

  Note that pre-field data collection is likely to be more extensive than anticipated in FEMA 154 (see below). This should be considered carefully and adequately budgeted.

- *3.3 Pre-field Planning*

  This includes selection of the area to be surveyed, development of a mapping system for the survey area, selection of supplementary data to be included in the survey, and development of a record keeping system. This phase is simplified for a school district, since the survey is likely to include all the school buildings under its jurisdiction. The district must make the basic decision whether to combine the RSP with any other surveys/inspections, and must develop a record keeping system for the seismic survey.

- *3.4 Training of Personnel*

- *3.5 Selection and Review of Data Collection Form*

The data collection forms included in FEMA 154 have been slightly modified for application by school districts. The modified forms are included in this guidebook (see Appendix B). There are three forms applicable as a function of a region's seismic activity:

- ☐ High (H): NEHRP Map Areas 5, 6 and 7
- ☐ Moderate (M): NEHRP Map Areas 3 and 4
- ☐ Low (L): NEHRP Map Areas 1 and 2

A school district should use the appropriate form by examining its geographic location on the maps included in Appendix C.

- *3.6 Survey Tools to be Taken in the Field*

Users who are familiar with the general concepts and approach of FEMA 154 may find that this Guidebook is sufficient for field use, without requiring use of FEMA 154 in the field.

- *3.7 Selection and Use of Pre-Field Data*

Of the five general sources of relevant information identified in FEMA 154, only the last two (previous studies and soil information) are applicable to school districts.

The most relevant source of information is the archival building plans which the school district itself may maintain. An examination of archival plans may go a long way towards completing the survey form, with the field inspection used primarily to verify the information.

CHAPTER 4 - RSP METHOD AND THE DATA COLLECTION FORM

- *4.1 Overview of the RSP Method*

- *4.2 Building Location and Identification*

A survey form must be filled out for each building. A school at a particular location or address may consist of several buildings. Each building in a campus plan should be treated as a separate building. If a given school building consists of distinct parts constructed at different times (i.e., later additions) with different materials and structural systems, each part should probably be treated as a separate building, with particular attention to be paid to the joint(s) or junction(s) between them (see 4.12.6 Pounding below). This should be noted in the forms' upper right box.

- *4.3 Inspector Identification*

- *4.4 Number of Stories and Total Floor Area*

  With a few exceptions, school buildings are not likely to exceed seven stories. This has led to a modification of the "structural scores and modifiers" box on the form. High rise buildings, defined as eight stories or taller in FEMA 154 - 4.4 , should be noted, and probably subjected to a detailed engineering evaluation outside the RSP survey. URM buildings four stories or taller, which are possible in urban school districts, should be noted (see *4.12 Modifiers*, below).

- *4.5 Year Built*

  School districts are likely to have ready access to this information in their records.

- *4.6 Occupancy and Occupancy Load*

  The portion of the FEMA 154 survey form dealing with this parameter has been deleted, since a school district will survey only a limited number of building categories ----schools and their support facilities. The discussion in FEMA 154, 4.6 is mostly irrelevant. However, it should be kept in mind that auditoriums, gyms, cafeterias and similar spaces have a higher occupancy load than classrooms and laboratories, and may be classified as places of public assembly. Also, a school campus may include one or more warehouse-type buildings. The occupancy loads of different buildings may be used by school districts to establish priorities for seismic mitigation actions.

- *4.7 Non-Structural Falling Hazard*

  These hazards are independent of the building's lateral load system, which is the main subject of the RSP, yet they can be life threatening even in moderate earthquakes. Additionally, some of them are difficult to identify in a "sidewalk" inspection. However, the identification of these hazards is quite simple for a school district with full access to its buildings (roofs, attics, concealed spaces etc.), and is likely to be useful in seismic retrofit planning. This portion of the survey has been expanded on the survey form for school districts (see NONSTRUCTURAL AND OTHER HAZARDS below).

- *4.8 Sketches, Photos and Comments*

- *4.9 What to Look for and How to Find It*

  How to classify a given building is discussed at great length. Part of the problem addressed in this discussion is the difficulty of making certain classifications based merely on an exterior inspection. Since school districts will have access to archival plan information, building interiors, and concealed spaces, such as basements and attics, the building classification becomes much simpler.

  FEMA 154 classifies buildings into twelve types, defined by their structural system. These are listed in FEMA 154, Table 4-1, which is reprinted herein to assist the reader. The following points apply specifically to the classification of school buildings:

  - *4.9.5 Characteristics of Exposed Construction Materials*

    Brick buildings may be of several different types:

    Reinforced or unreinforced masonry bearing wall buildings----These can be brick, hollow clay tile, concrete masonry units or stone. Brick may be a veneer over hollow clay tile or concrete masonry units.

    Steel or concrete frame buildings----These will have brick infill between the steel or concrete columns and beams.

    The determination whether a brick wall structure is a bearing wall or frame building must be based on a review of the plans or a detailed interior investigation.

  - *4.9.6 Wood Frame (W)*

    Wood frame schools may be covered over with another material such as brick veneer or metal siding. Observations from interior utility spaces may provide the necessary construction information.

  Types S4 (steel frame with concrete shear walls), C2 (concrete frame with concrete shear walls) and PC2 (pre-cast concrete frame) are rarely used in schools and have been deleted from the forms. School districts which determine that they have such buildings should use the forms in FEMA 154.

- *4.10 Structural Score*

  The structural score (Basic Score on the survey form) is directly associated with each of the twelve building type classifications.

TABLE 4-1: BUILDING IDENTIFIERS

Building Identifier	General Description
W	Wood buildings of all types
S1	Steel moment resisting frames
S2	Braced steel frames
S3	Light metal buildings
S4	Steel frames with cast-in-place concrete shear walls
C1	Concrete moment resisting frames
C2	Concrete shear wall buildings
C3/S5	Concrete or steel frame buildings with unreinforced masonry infill walls
PC1	Tilt-up buildings
PC2	Precast concrete frame buildings
RM	Reinforced masonry
URM	Unreinforced masonry

- *4.11 Data Confidence*

  The availability of archival plans as well as the full accessibility of the buildings are likely to reduce the uncertainty of classifying the building.

- *4.12 Modifiers*

  Compute the final score by adding or subtracting the applicable modification factors to or from the basic score.

  - *4.12.1 Poor Maintenance*

    This modifier is labeled "Poor Condition" on the survey form. In addition to the items noted, a school district may have access to maintenance records, which may establish the use of this modifier with more reliability.

  - *4.12.2 Vertical Irregularity*

    This condition, irregular shape in elevation or walls not perpendicular to the ground, is probably rare in schools, which are principally low, large area buildings.

  - *4.12.3 Soft Story*

    This condition is a major discontinuity of stiffness between floors, primarily when the ground floor is more flexible than those above. In addition to the information in FEMA 154, this condition in school buildings is discussed at some detail in Appendix A.

  - *4.12.4 Torsion*

    This condition is the result of *major eccentricities in the lateral force resisting system* of the building, which leads to twisting of the building during an earthquake. In addition to the information in FEMA 154, this condition in school buildings is discussed at some detail in Appendix A.

  - *4.12.5 Plan Irregularity*

    This condition is generally described as existing in buildings with long wings that are "L", "T", "E", "U", "H", or "X" shaped in plan, and is very common in schools. Another condition often found in schools (and not discussed in FEMA 154) is a strength discontinuity in plan (a large multi-purpose area or gym adjacent to classrooms). These conditions in school buildings are discussed in some detail in Appendix A.

- *4.12.6 Pounding*

This condition *occurs when there is little or no clearance between adjacent buildings, and the buildings impact or "pound" against each other as they deflect in an earthquake.* In the case of schools this condition has been commonly observed between an original building and a later addition (See 4.2 Building Location and Identification above).

- *4.12.7 Large Heavy Cladding*

- *4.12.8 Short Columns*

This condition occurs when stiff nonstructural spandrels or wall sections are adjacent to columns. It is a condition which is common in schools, and is discussed more fully in Appendix A.

- *4.12.9 Post-Benchmark Year for Enforcement of Seismic Resistant Design*

This modifier awards a bonus to a building which has been seismically designed. *A benchmark year is the year in which modern seismic design provisions were enforced by the local jurisdiction,* and it relates, as a function of building type, to the year of adoption of a particular building code, or other code applicable to school district buildings. Table 4-4 in FEMA 154 contains benchmark years for each of the twelve building types in three code documents:

NEHRP (National Earthquake Hazards Reduction Program)
UBC (Uniform Building Code)
ANSI (American National Standards Institute, A58.1

This information is incomplete and, in some cases, dated. The building code applicable to any school district is likely to be based on one of the three model codes:

SBC (Standard Building Code, SBCCI)
NBC (BOCA National Building Code)
UBC

The SBC and NBC adopted the NEHRP seismic provisions in 1992 but contained seismic provisions based on ANSI prior to that. However more important than the year of introduction of a seismic provisions in a model code is the year of adoption of that model code in the school district's jurisdiction. Extreme care should be used when applying this benchmark year modifier, keeping in mind that the intention is to award a bonus to a building which has been seismically designed.

- *4.13 Soil Profile*

  Soil profile modifiers account for the effect of different soil conditions on the amplitude and duration of shaking during an earthquake. Two modifiers are applicable to schools:

  - ☐ SL2--Deep cohesionless or stiff clay soil conditions, including sites where the soil depth exceeds 200 ft. and the soil types overlaying rock are stable deposits of sands, gravels or stiff clays.

  - ☐ SL3--Soft to medium stiff clays and sands, characterized by 30 ft. or more of soft to medium stiff clay with or without intervening layers of sand or other cohesionless soils.

- *4.14 Comment Section on Data Collection*

- *4.15 Examples*

NONSTRUCTURAL AND OTHER HAZARDS

This portion of the RSP form has been added for schools. It is not included in the FEMA 154 forms. These hazards, if present, can be life-threatening or produce injuries while not leading to collapse of the building. In many cases they may be the cost-effective first steps in incremental seismic retrofit. The following hazards should be noted:

- *NS1 - Parapets*

  Masonry parapets extending above the roof, and if unreinforced or not braced, are often among the first elements to fall under earthquake loads.

- *NS2 - Gables*

  Unreinforced and unbraced masonry gables behave much like parapets in an earthquake. They pose a special hazard in that they are frequently located above building entrances.

- *NS3 - Chimneys*

  Along with unbraced parapets, chimneys are often among the first building elements to collapse in an earthquake.

- *NS4 - Appurtenances*

  Sculpture, trim and other decorations attached to the exterior walls or roof edges can break off and fall in an earthquake.

- *NS5 - Covered Walks*

  Covered walks are a common feature on school campuses in many parts of the country. They may pose an earthquake hazard, especially if constructed of precast concrete.

- *NS6 - Unbraced Cripple Walls*

  Cripple studs are short studs, usually between 12" and 48" in height,. They are located between the foundation and the first floor. Cripple stud walls topple during an earthquake, caused by the mass of the floor shoving on them laterally. While this is usually not a life threatening, the repair is extremely awkward and costly.

- *NS7 -Weak Masonry Foundations*

  Weak masonry has lower shear resistance, which could result in foundation failure due to shear forces.

- *NS8 - Masonry Partitions*

  Masonry partitions are usually found in corridors, and sometimes between classrooms. They provide fire resistance, durability and low maintenance. However they may topple outward into corridors, or into occupied space. Masonry partitions which are located between structural columns have been known to nearly explode in an earthquake due to in-plane lateral forces exerted on them by the columns.

CHAPTER 5 - INTERPRETATION OF STRUCTURAL SCORES

FEMA 154 suggests that a building with a final score of 2.0 or more is not at seismic risk. It suggests that if the score is above 2.0, but the building was constructed before a code benchmark year, additional review should be carried out to assure that the building is not a hazard. The following additional points should be considered for school buildings:

- If a building is intended to serve a post-disaster function (e.g., a shelter or a distribution center), a higher final score should be expected. This is because the seismic demand (forces) should be higher for such uses.

- A building with a score of less than 2.0 may be quite safe, though this should be determined on the basis of an engineering review.

- A building with a score between 2.0 and 4.0 should be reviewed by an engineer, just in case something was overlooked in the screening process.

APPENDIX A

- CHAPTER 3 - EARTHQUAKE PROBLEMS OF ELEMENTARY AND SECONDARY SCHOOLS (FEMA 149, *SEISMIC CONSIDERATIONS - ELEMENTARY AND SECONDARY SCHOOLS*)

3

EARTHQUAKE DESIGN PROBLEMS OF ELEMENTARY AND SECONDARY SCHOOLS

School Building Inventory

There are over 80,000 elementary and approximately 30,000 secondary schools in the United States. The post World War II "baby boom" caused major school construction during the 1950s and 1960s followed, in the 1970s and early 1980s, by major declines in school construction and large numbers of school closings. Since about 1985 there has been an increase in school construction due to the obsolescence of older facilities, internal migration from the Northeast to the West and Sun-belt states, new foreign immigrations, and a slight increase in school age populations.

In 1983, schools accounted for approximately 6,000 million square feet of space or almost 12 percent of the total nonresidential space in the nation. At the same time, schools are estimated to represent only 4.5 percent of the actual number of nonresidential buildings, meaning that they account for a very significant amount of square footage per building. In addition, only assembly buildings, which provide 14 square feet of space per person, have a higher occupancy density than schools, which provide 20 square feet per person. (For comparison, note that the occupant density of office buildings is 100 square feet per person and of lodging, health care, and retail facilities is 50 square feet.)

The age of a facility is of considerable importance with respect to seismic performance and, as indicated earlier, fully half of the nation's existing schools will be between 40 and 80 years old by the end of the century. Even in California, seismic design based on analysis only dates back about 50 years. Even buildings constructed as late as the early 1970s may have major seismic deficiencies. This is because of discoveries made through study of the performance of buildings in earthquakes in the 1960s and early 1970s (notably Alaska, 1964; Caracas, Venezuela, 1967; San Fernando, California, and Managua, Nicaragua, 1971). These earthquakes were the first to test modern methods of construction and, as a result, seismic codes and construction practices have improved since the 1970s.

Although this publication is not intended to be an engineering design manual, several problems of building design should be recognized by the school owner, administrator, planner, architect, or engineer as factors that may substantially increase the earthquake risk to their building. Some of these problems are addressed in seismic building codes, but their solutions reside more in the designer's understanding of seismic-resistant design than in specific code provisions. Others, such as damage to building contents, are outside the scope of any seismic code.

The basic design problems affecting the seismic performance of schools are:

- Building form irregularities in both the horizontal and vertical planes,
- Discontinuities in strength between the major structural elements of the building,
- Inadequate diaphragms,
- Effects of nonstructural elements on the structural system,
- Deficiencies in the connections that tie the elements of the building together, and
- Damage to the nonstructural components and contents of the building.

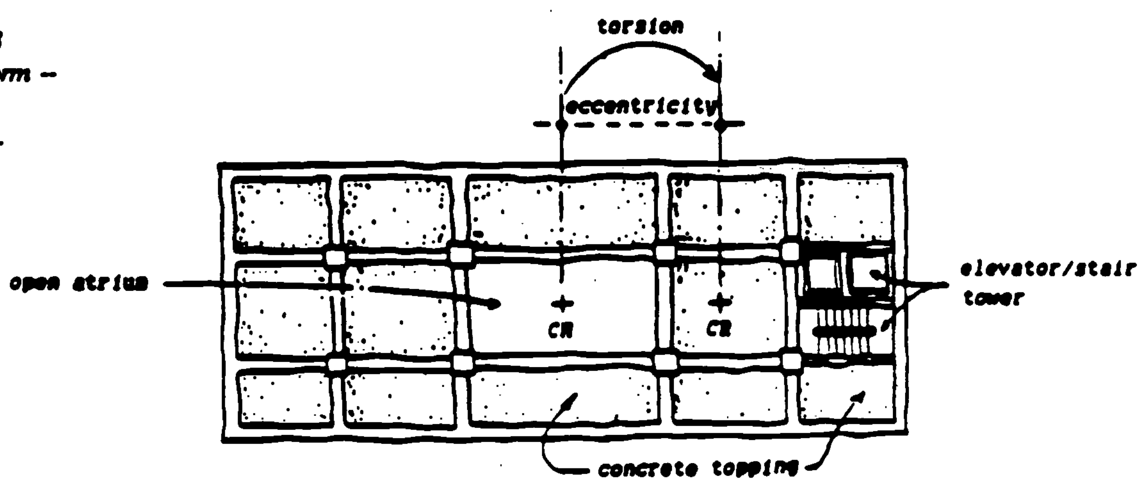
Egress complications and the disruption of post-earthquake operations are also major concerns.

Building Form Irregularities

Those who have studied the performance of buildings in earthquakes generally agree that the building's form greatly influences its performance under ground motion. This is because the shape and proportion of the building have a major effect on the distribution of earthquake forces--that is, on the relative size and nature of the forces as they work their way through the building.

A simple and symmetrical building form allows for the most even and balanced distribution of forces, but symmetry of form will not ensure low torsional effects. For instance, even in simple symmetrical rectangular buildings the location of stiff stair and elevator cores, solid and glazed walls, or other design elements that add mass to only one part of the building can result in different locations of the center of mass and the center of rigidity, and the torsion or twisting that results during an earthquakes (Figure 3) has frequently caused substantial damage.

FIGURE 3
Building form -- torsional eccentricity.



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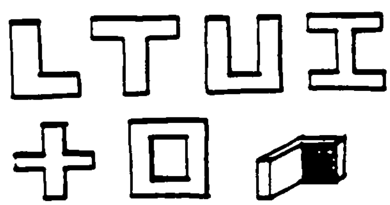
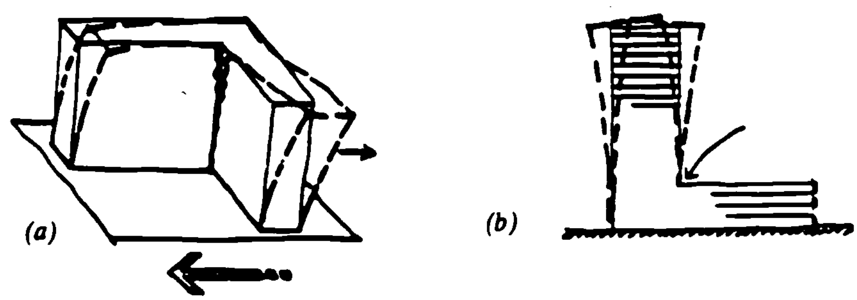
A common building form that presents seismic design problems is that of the "re-entrant corner." The re-entrant corner is the common characteristic of overall building configurations that, in plan, assume the shape of an L, T, U, H, +, or a combination of these shapes (Figure 4). These building shapes permit large plan areas to be accommodated in relatively compact form while still providing a high percentage of perimeter rooms with access to air and light. Because of these characteristics, they are commonly used in school design. These configurations are so common and familiar that the fact that they represent one of the most difficult problem areas in seismic design may seem surprising, but examples of earthquake damage to re-entrant corner type buildings are common. First noted before the turn of the century, this earthquake problem was generally acknowledged by the experts of the day in the 1920s.

FIGURE 4
Re-entrant corner plan forms.



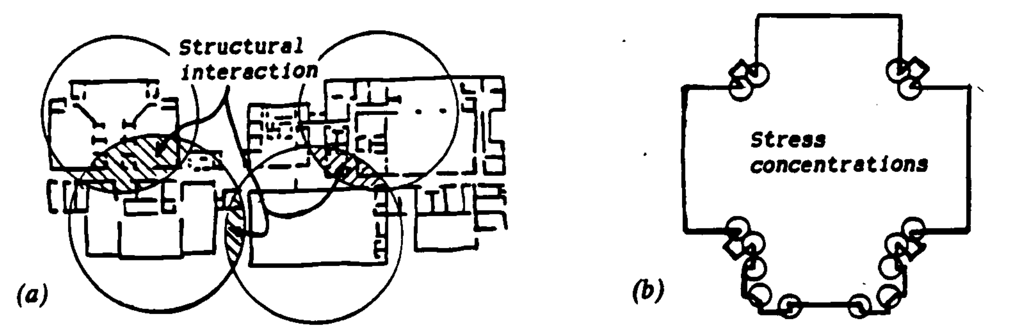
These shapes tend to produce variations of rigidity and, hence, differential motions between different portions of the building that result in a local stress concentration at the "notch" or re-entrant corner (Figure 5a). In addition, the wings of a re-entrant corner building often are of different heights so that the vertical discontinuity of a setback in elevation is combined with the horizontal discontinuity of the re-entrant corner in plan, resulting in an even more serious problem. The setback form--a tower on a base or a building with "steps" in elevation--also has intrinsic seismic problems that are analogous to those of the re-entrant corner form. The different parts of the building vibrate at different rates, and where the setbacks occur, a "notch" is created that results in stress concentration (Figure 5b).

FIGURE 5
(a) movement of L-shaped building under ground motion and (b) point of stress concentration in setback building.



Typical problems with the building forms commonly used for elementary and secondary schools are as follows:

- The use of large open multipurpose spaces for functional flexibility along with smaller traditional classroom areas and relatively rigid interior walls of masonry or concrete can cause major torsional effects in the building (Figure 6a).
- The use of interconnected clusters of areas can create many re-entrant corners and consequent stress concentrations and torsional effects (Figure 6b).
- The placement of asymmetrical rigidly connected stairways within a relatively light building can cause major torsional effects (Figure 6c).
- The use of internal courtyards can cause torsional effects at the interior corners of the building (Figure 6d).
- The use of narrow wings can cause torsional effects and stress concentrations at the re-entrant corners (Figure 6e).



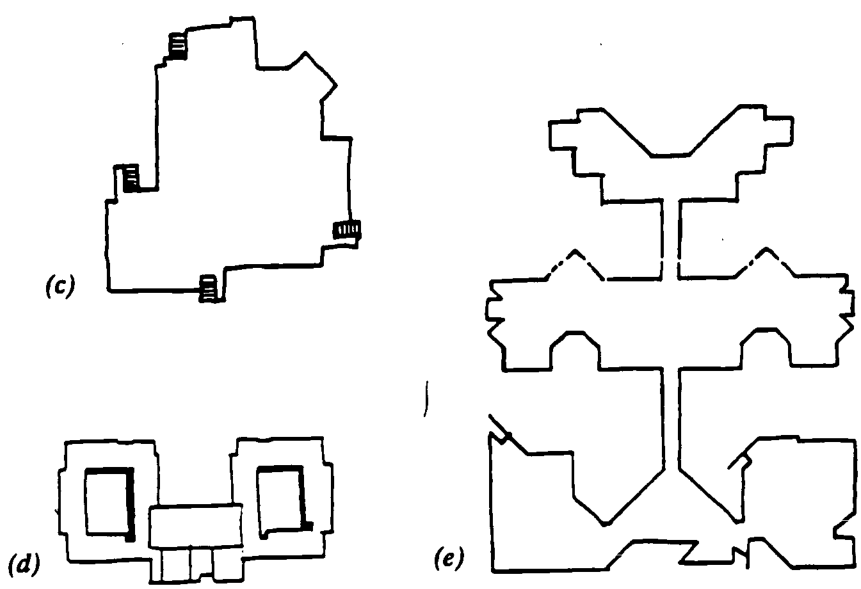
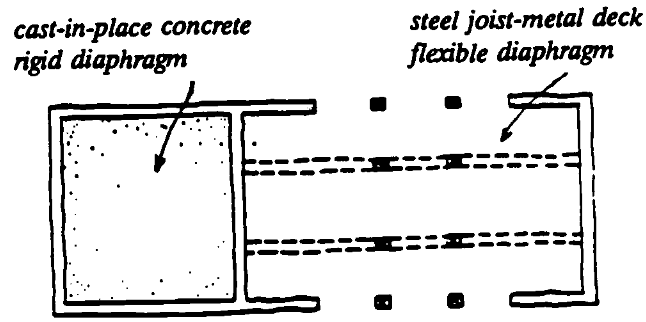


FIGURE 6
Typical problems with common school building forms:
(a) large multi-purpose rooms,
(b) cluster areas,
(c) asymmetrical stairways, (d) interior courtyards, and
(e) narrow wings.

Structural Discontinuities

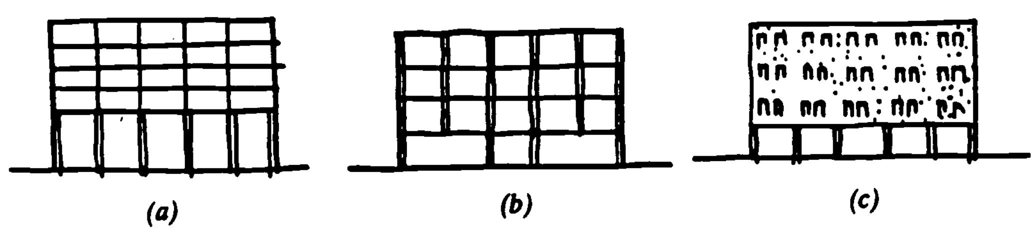
It is not generally recognized that large discontinuities (or abrupt changes) in the strength (Figure 7) or stiffness of a building can cause adverse seismic response effects. This is particularly the case where there are abrupt changes in the vertical arrangement of the structure that result in discontinuities (changes) of strength or stiffness from floor to floor.

FIGURE 7
Discontinuity in strength.



The most prominent of the problems caused by such a discontinuity is that of the "soft" first story (Figure 8), a term applied to a ground level story that is more flexible than those above. Although a "soft" story at any floor creates a problem, a stiffness discontinuity between the first and second floors tends to result in the most serious condition because forces generally are greatest near the base of a building.

FIGURE 8
"Soft" first story: (a) tall, flexible columns, (b) interrupted vertical columns, and (c) heavy superstructure over slender frame.



Three typical conditions create a "soft" story:

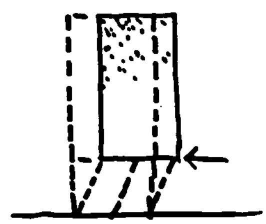
- The first occurs when there is a significant discontinuity of strength and stiffness between the vertical structure of one floor and the remainder of the structure. This discontinuity may occur because one floor, generally the first, is significantly taller than the remainder, resulting in decreased stiffness (Figure 8a).

- Discontinuity also may occur when some vertical framing elements are not brought down to the foundation but are stopped at the second floor to increase the openness at ground level. This condition creates a discontinuous load path resulting in an abrupt change of strength and stiffness at the point of change (Figure 8b).

- Finally, the "soft" story may be created by an open floor that supports heavy structural or nonstructural walls above. This situation is most serious when the wall above is a shear wall acting as a major lateral force resisting element. This condition is discussed in more detail in the next chapter since it represents a very important aspect of the "soft" story problem (Figure 8c).

The basic problem with all these variations of the "soft" story is that most of the earthquake forces in the building, and any consequent structural deformity, tends to be concentrated in the weaker floor or at the point of discontinuity instead of being more uniformly distributed among all stories. The result is that, instead of the building deflection under horizontal forces being distributed equally among all the floors, it is accommodated almost entirely in the lower floors. This causes tremendous stress concentrations at the lower floor connections; failure may occur at these points and result in the collapse or partial collapse of the upper floors (Figure 9). Where earthquake forces are not an issue, the "soft" story presents no problem, but in earthquakes around the world, buildings with this condition have suffered severely.

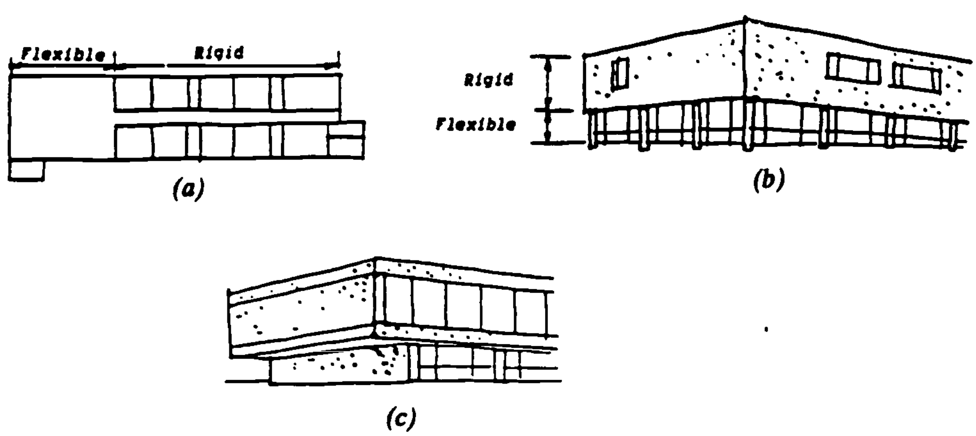
FIGURE 9
Action of "soft" first story in ground motion.



The complexity of educational facilities tends to result in vertical structural discontinuities. Among the more common situations are the following:

- The interconnection of tall, long span, flexible school areas (auditoriums, gymnasiums, cafeterias) with low, short span, rigid areas featuring shear walls (classrooms, hallways) (Figure 10a).
- The placement of stiff floors above a more flexible first floor (Figure 10b).
- Discontinuities in column or wall placement from one floor to another (Figure 10c).

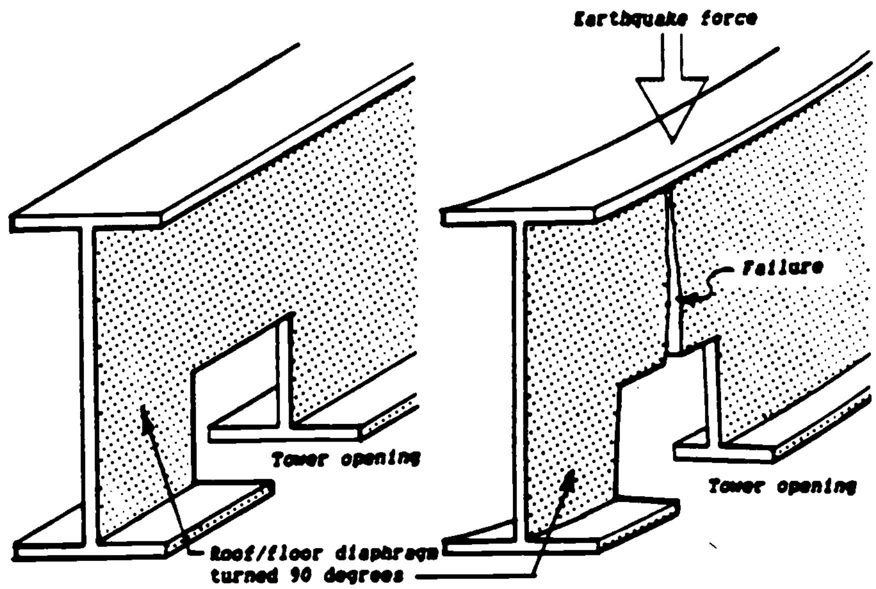
FIGURE 10
Strength discontinuity: (a) plan, (b) elevation, and (c) wall-column placement.



Roof and Floor Diaphragms

The earthquake loads at any level of a building will be distributed to the vertical structural elements through the roof and floor diaphragms. The roof/floor deck or slab (the horizontal diaphragm) responds to loads like a deep beam. The deck or slab is the web of the beam carrying the shear and the perimeter spandrel or wall is the flange of the beam resisting bending (Figure 11).

FIGURE 11
Openings in diaphragms.



Three factors are important in diaphragm design:

- The diaphragm must be adequate to transfer the forces and must be tied together to act as one unit.
- The collectors (members or reinforcing) must transfer the loads from the diaphragm into the shear wall.
- Openings or re-entrant corners in the diaphragm must be properly placed and adequately reinforced.

Inappropriate location or excessive size of openings (elevator or stair cores, atria, skylights) in the diaphragm create problems similar to those related to cutting a hole in the web of a beam. This reduces the natural ability of the web to transfer the forces and may cause failure in the diaphragm.

Displacement and Drift

Drift is the lateral displacement of one floor relative to the floor below. Buildings subjected to earthquakes need drift control to restrict damage to interior partitions, elevator and stair enclosures, glass, and envelope cladding systems and, more importantly, to minimize differential movement demands on the seismic resisting structural elements.

Drift control, or the recognition of the amount of potential drift, greatly influences the amount of damage control that is designed into the building. Since damage control generally is not a building code concern for typical buildings and since the state of the art is almost entirely empirical, the drift limits found in codes generally have been established without regard to considerations such as present worth of future repairs versus additional structural costs to limit drift.

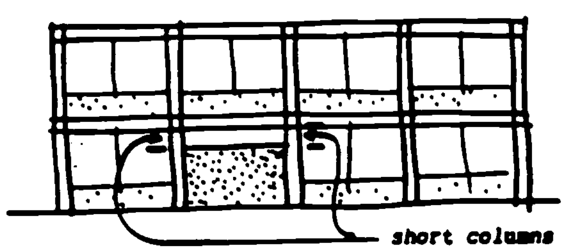
Stress or strength limitations imposed by normal design level forces occasionally may provide adequate drift control. However, the design of relatively flexible moment resisting frames and of tall, narrow shear wall buildings for seismic risk areas should be governed, at least in part, by drift considerations. In areas where the potential for high seismic loads is great, drift considerations are of major concern for buildings of medium height and higher and should be given at least some attention in the design of multistory school buildings.

Total building drift is the absolute displacement of any point in the building relative to the base. Adjoining buildings or adjoining wings of the same building must be considered since individual structures do not have identical modes of earthquake response and, therefore, have the tendency to pound against one another. Building separations or joints must be provided between adjoining structures to permit the different parts to respond independently to the earthquake ground motion.

Effects of Nonstructural Elements

Even in a building where discontinuities throughout the structure have been restricted, the location and design of certain nonstructural elements can actually change the effectiveness of the structural elements. For instance, the location of a rigid element (stair and elevator cores, masonry infill walls) between more flexible columns will change the "flexible" elements into rigid members. Since rigid members attract seismic forces, the columns could be subjected to forces many times greater than those for which they were designed and failure may result. (In engineering terms, horizontal forces are distributed in proportion to the rigidity of the resisting elements.) Thus, if a column designed for a full height deflection becomes a "shorter" column because of the location of a rigid infill wall, it will actually carry a larger portion of the lateral forces than assumed since horizontal forces are distributed in proportion to the rigidity of the resisting member (Figure 12).

FIGURE 12
Nonstructural infill creates short columns that attract earthquake forces.



The use of infill walls dramatically shortened the columns at the Recido School in Managua, Nicaragua (Figure 13). During the 1973 earthquake, the columns above the infill walls suffered extensive damage and barely escaped complete failure and roof collapse. Numerous other examples of damage attributed to such "shortened" columns were reported in Japanese schools following earthquakes in 1968 and 1978 (Figure 14).

FIGURE 13
Recido School after 1973 earthquake.

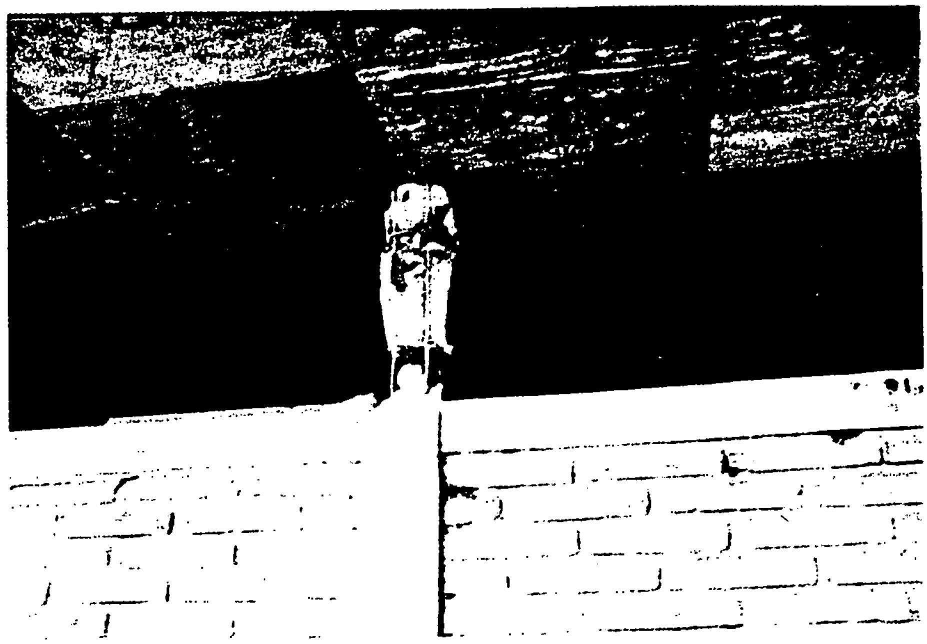
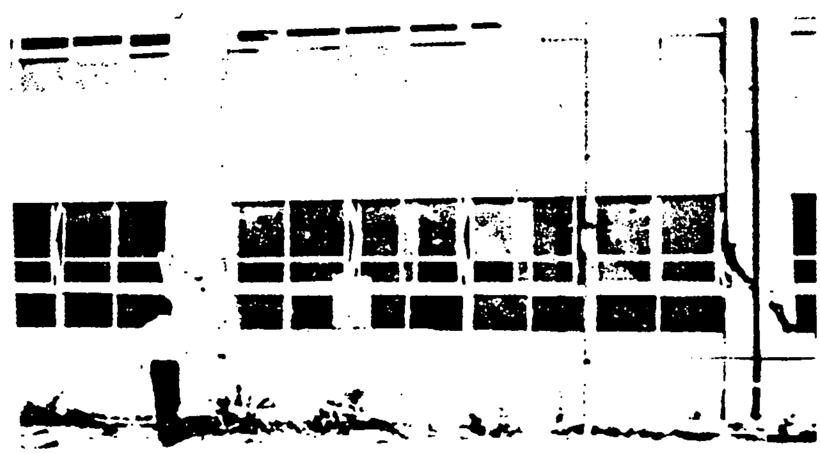


FIGURE 14
Japanese school building after 1978 earthquake.



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Particular problems in terms of the effect nonstructural components can have on the structural system in schools are as follows:

- The location of rigidly connected stairs within more flexible long span spaces (multipurpose rooms) can modify the assumed deflection of the columns surrounding the cores, creating torsion and attracting a disproportionate load to the staircase structure (Figure 15).
- The use of infill walls between columns (forming windows in classrooms) can effectively stiffen the beams and shorten the columns, attracting higher loads than assumed in the design calculations (Figures 16).
- The addition of rigid infill nonstructural walls between columns separating classrooms can increase the stiffness of the columns far above what was assumed in the structural design.

FIGURE 15
Effect of stairway placement.

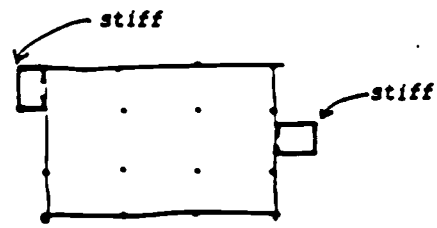
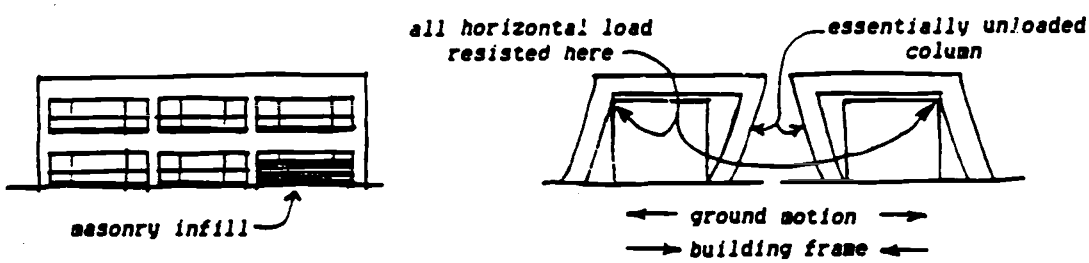


FIGURE 16
Effect of infill walls.



Connections

Structural member connections are among the most critical elements of earthquake-resistant design. Probably the most important single attribute of an earthquake-resistant building is that it is tied together to act as a unit, but no set of seismic provisions issued before the *NEHRP Recommended Provisions* (and its predecessor, the Applied Technology Council's ATC 3-06) stated this requirement. It is generally accepted by structural engineers that to develop adequate connections between structural elements is more difficult than to provide strength in the members themselves. This has been demonstrated clearly in past earthquakes where considerable damage originated at connections rather than in the structural members.

Furthermore, properly designed structural elements are usually ductile--i.e., their failure is preceded by large permanent deformations that dissipate a considerable amount of energy. On the other hand, connections often are relatively brittle. Therefore, a good structural design requires connections to be stronger than the members they connect so as to force failure to take place in the ductile members rather than in the relatively brittle connections.

A structural element cannot transmit forces in excess of the capacity of the connections used to join the elements together. Thus, structural members and the elements that connect them should be of approximately equal strength to be fully effective. If there is a weak link, the earthquake will find it.

The issue of connections is particularly important for structures that rely on a small number of supporting members, such as a roof supported by four columns. If one column or its connection fails, the roof falls. If the same roof is supported by eight columns, the loss of one column may not be serious. Engineers refer to the attribute of having more than the minimum number of structural members as "redundancy." It provides an important additional safety factor.

The large open spaces common in schools often completely lack redundancy which means that every component must remain operative to ensure the integrity of the structural system under lateral loads. Thus, appropriate connections should be used and consideration should be given to the use of higher performance connections (ductile, in particular).

A public school in Melipilla, Chile, suffered severe structural and architectural damage during a 1985 earthquake (Figure 17) because the masonry facade was not properly anchored to the structural system. Collapse occurred and classrooms were showered with glass and ceiling light fixtures. Many schools of similar design also were significantly damaged in the earthquake.

Redundant characteristics can be obtained by providing several different types of seismic-resisting systems in a building; however, the designer must be careful to consider the relative stiffness and strength of the various systems in order to avoid problems. Redundancy also can be provided by increasing the number of elements (columns, shear walls), adding new elements (cross frames, bracing), or modifying some elements (increasing reinforcement and anchoring the framing to change interior nonstructural walls and panels into shear walls).

In a moment resisting frame system, redundancy can be achieved by making all joints of the vertical load-carrying frame moment resisting. Of course, proper ductility must be provided in the members of the structural system. These multiple points of resistance can prevent a catastrophic collapse due to failure of a member or joint. However, if this system is designed with the moment resisting connections limited to exterior columns (a common practice) clad only in lightweight architectural curtain walls, the building may experience large deformations during an earthquake and, consequently, a great deal of interior damage.

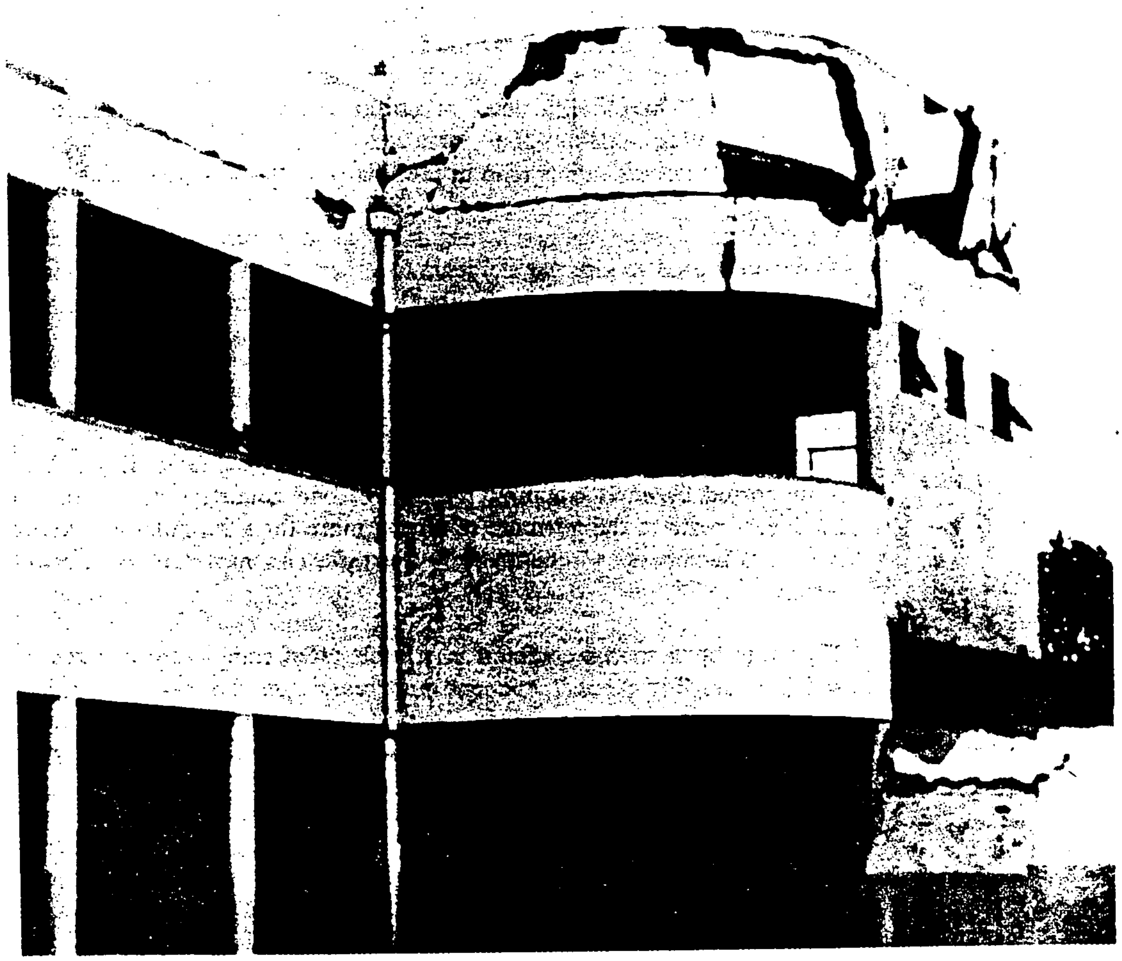
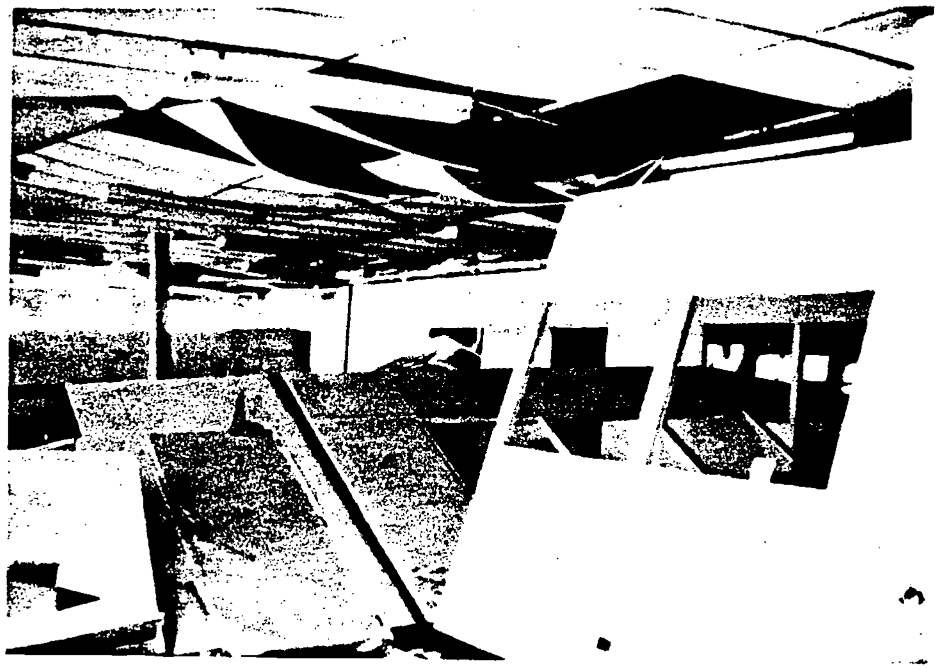


FIGURE 17
Melipilla School after 1985 earthquake in Chile.

Particular issues related to structural system redundancy in school design are as follows:

- Failure to use the large amounts of interior wall (classrooms, corridors) as redundant systems to the primary structural system and neglect of the influence of the relative stiffness of both systems (Figure 18).
- Use of limited numbers of columns (longer spans) in large open spaces (auditorium, cafeteria), causing these elements to become extremely critical.
- Discontinuity of the uniformity of the structural system through the location of large long span areas.
- Placement of openings (stacked, uniform classroom doors and windows) in the interior and exterior shear walls causing large forces to be concentrated in certain weak elements.

FIGURE 18
Collapse of interior structural partitions.



Damage to Nonstructural Components and Building Contents

Severe earthquake damage can occur even if the building structure remains essentially intact. During recent earthquakes, many buildings with no serious structural damage have suffered nonstructural damage totaling as much as 50 percent of the building replacement value. For example, the Bay Area Regional Earthquake Preparedness Project reports that the 1983 6.5 magnitude Coalinga, California, earthquake resulted in nonstructural damage totalling $2 million and that the 1987 5.9 magnitude Whittier Narrows, California, earthquake caused almost $16 million of damage, most of which was nonstructural. To understand the magnitude of the problem one need only consider that the structural system (foundation, floors, structural walls, columns, beams, etc.) constitutes only 15 to 25 percent of educational facility construction cost; therefore, the nonstructural architectural, mechanical, and electrical elements make up between 75 and 85 percent of the building's replacement value.

The nonstructural components with both life safety and major property damage consequences include exterior nonbearing walls, exterior veneers, infill walls, interior partition systems, windows, ceiling systems, elevators, mechanical equipment, and electrical and lighting equipment. All these components are subject to damage, either directly due to shaking or because of movement of the structure (which may be an intentional part of the seismic design). School occupants will be particularly vulnerable to nonstructural damage. Although school children may duck under desks and be safe from falling objects like light fixtures or glass, ceiling tile and wall finishes that fall on hallways and stairs can make movement difficult, particularly if combined with power failure and loss of lights.

Building utility systems and equipment traditionally have been designed or selected with little, if any, regard for their performance when subjected to earthquake forces. Mechanical and electrical equipment supports have been designed for gravity loads only, and attachments of moving equipment to the structure are deliberately designed to be flexible to allow for vibration isolation.

The Namioka Gymnasium, for example, received major ceiling and lighting damage during the 1983 earthquake in Nihon-Kai-Chobo, Japan. The gymnasium, which had been built only 3 years earlier, used hangers to support the ceiling system from steel purlins. These connections were not able to resist the major movements of the ceiling system during the earthquake and collapsed, which generated extensive debris (Figure 19).

FIGURE 19
Namioka Gymnasium after 1963 earthquake in Nihon-Kai-Chobo, Japan.

In assessing the impact of possible damage, secondary effects from equipment damage must be considered. Fires and explosions resulting from damaged mechanical and electrical equipment, broken laboratory equipment, and spilled chemicals represent secondary effects of earthquakes that also are a considerable hazard to life and property. During the 1983 Coalinga earthquake in California, for example, sulfuric acid and other chemicals stored in glass containers in open cabinets in a second floor high school chemistry lab overturned and broke; the acid burned through to the first floor, and the cost of just cleaning the spill was over $50,000.

Large capacity hot water boilers, other pressure vessels, and broken distillation pipes can release fluids at hazardous temperatures. Large hot water boilers that operate at over 212 degrees pose a very serious hazard since the sudden decrease in pressure caused by a rupture of the vessel can result in instantaneous conversion of superheated hot water to steam, and the remainder of the vessel can disintegrate explosively showering the area with hot material and igniting combustible material.

Free-standing kitchen equipment and electrical equipment such as transformers, switchboards, emergency generators, and lighting fixtures can fall, causing injuries as well as fires (Figures 20-21).

FIGURE 20
Electrical equipment collapse.

FIGURE 21
Ceiling/lighting system collapse.

Heating equipment located on roofs or hung in open spaces such as gymnasiums and auditoriums or service areas such as shops and kitchens typically is not designed for lateral forces. These pieces of equipment can easily fall and cause considerable damage or injury. Mechanical system grills and diffusers also can fall from ceilings (Figure 22).

Even such nonstructural components as glazing systems can create additional hazards. One junior high school in Coalinga, California, housed a library with an 8 by 10 foot, double height window of non-tempered glass on two walls. During the 1983 earthquake, these large windows imploded and completely littered the room with dagger-shaped pieces of glass. The floor tile and wooden furniture were gouged with flying glass, and the school superintendent believes that, had school been in session, death and serious injuries would have resulted (Figure 23).

FIGURE 22
Fallen ventilation system.

FIGURE 23
Junior high school in Coalinga after 1983 earthquake.

Although damage patterns for glazing systems have not been well researched, glass breakage is related to support conditions, the temper of the glass and its thickness and size, and the type and direction of loading. Large windows usually break at somewhat lower loads than smaller windows since large windows behave like a membrane or diaphragm. With sufficient space for movement within the frame, a frame that does not rack, low glass loading, and reasonably careful design and placement, good performance can be expected. Glass joint treatment also is a factor in the overall performance of a curtain wall or window unit system; if the edges are restrained, failure is likely. In this context, it also should be remembered that the sealants and gasket materials providing flexibility can lose their resiliency with age and exposure and therefore may require periodic replacement.

Post-Earthquake Egress Problems

Egress complications can be summed up by a statement made in a report on the 1964 Alaska earthquake:

> ...the final measure of a well constructed building is the safety and comfort it affords its occupants. If, during an earthquake, the occupants must exit through a shower of falling light fixtures and ceilings; maneuver through shifting and toppling furniture; stumble down dark corridors and stairs; and then be met at the street by falling glass, veneers, or facade elements...then the building certainly cannot be described as a safe building.

The problems of egress are most critical in multistory buildings and therefore, tend to apply to larger schools. Stairs are the critical means of egress out of a multistory school during and after an earthquake, but several things can happen to stairwells during an earthquake:

- Stairs tend to act as diagonal bracing between floors, and damaging loads and racking induced in them by interstory drift may result in collapse or failure.
- Stairs usually are anchored to the floors and their stiffness tends to attract forces that may cause severe damage or collapse (Figure 24).
- Masonry or concrete fire walls surrounding the stairs can fracture leaving the egress pathway littered with debris that may be impassable.

Experience indicates that doors and frames often jam in earthquakes and cannot be opened (especially by children). Heavy fire doors leading to egress routes are especially vulnerable because fire safety regulations require a heavy and tight assembly that becomes immovable when the door frame is distorted by earthquake motion.

Safe, direct, unobstructed exit routes should be planned so students and teachers can safely exit a school. Lockers, ceiling systems, lighting systems, ventilation systems, and windows that enclose these routes must be designed as critical components and be located so that their failure will not impede egress (Figure 25).

FIGURE 24
Stairway failure.

FIGURE 25
Blocked egress route.

Fire codes require school egress routes to have emergency lighting and signage; however, the anchorage of these elements in both the horizontal and vertical direction must be considered in their design. Canopies and porches at the entrances to the school are especially vulnerable if not designed for lateral loads. Their collapse may cause injuries among exiting occupants and they can become a major impediment to emergency procedures.

Disruption of Post-earthquake Operations

School buildings are often viewed by the community as local refuge, collection, or safe areas after a major disaster. This function may be formally recognized in a disaster response plan or the school may just be seen this way by neighborhood residents. And, of course, parents will want to ascertain that their children are safe as soon as possible after an earthquake. Thus, many people can be expected to converge on neighborhood schools searching for information, medical attention, or safe refuge during major power failure and inclement weather.

Disruption of regular or emergency operations can occur after an earthquake due to avoidable property damage. Some of the less critical elements (in terms of life safety and therefore codes) can cause inordinate amounts of delay in using the school as a safe refuge. Examples of these are mechanical, power, and communications system (public address or telecommunications) failure and lighting and ceiling collapse. Such damage can be minimized by designing to appropriate seismic provisions, which will save the public large sums in replacement costs.

Conclusion

The kinds of problems outlined above all stem from lack of attention to the seismic problem during design. While, as noted, design to a seismic code cannot guarantee freedom from seismic problems, adherence to such a code will ensure a basic level of safety that is difficult to obtain in any other way. Beyond the mandated requirements of a code, which set a minimum rather than a preferred standard of seismic design, the very act of designing to a seismic code requires a rational approach to design that focuses attention on those seismic issues discussed above which are not dealt with directly in code provisions.

The next chapter discusses the ways in which the *NEHRP Recommended Provisions* in particular and understanding of seismic design issues in general can work to protect elementary and secondary schools against these problems.

APPENDIX B

- MODIFIED DATA COLLECTION FORMS

________________________ (NEHRP Map Areas 1,2, Low)

Screening for Seismically Hazardous School Buildings

Address ________________________

________________________ Zip ________

Other Identifiers ________________________

No. Stories ________ Year Built ________

Inspector ________________ Date ________

Total Floor Area (sq. ft.) ________________________

Building Name ________________________

Use ________________________

Scale: ________

INSTANT PHOTO

POSSIBLE NON-STRUCTURAL & OTHER HAZARDS			
Parapets		Appurtenances	
Gables		Roof Tile	
Cornices		Covered Walks	
Chimneys		Interior Walls	
Towers		Unbraced Cripple Walls	
Signs		Weak Masonry Fdns.	
Other			

DATA CONFIDENCE

STRUCTURAL SCORES AND MODIFIERS

BUILDING TYPE	W	S1 (MRF)	S2 (BR)	S3 (LM)	C1 (MRF)	C3/S5 (URM NF)	PC1 (TU)	RM	URM*
Basic Score	8.5	3.5	2.5	6.5	4.0	3.0	3.5	4.0	2.5
Poor Condition	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Vert. Irregularity	-0.5	-0.5	-0.5	-0.5	-1.0	-1.0	-1.0	-0.5	-1.0
Soft Story	-1.0	-2.0	-2.0	-1.0	-2.0	-1.0	-1.0	-2.0	-1.0
Torsion	-1.0	-2.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Plan Irregularity	-1.0	-0.5	-0.5	-0.5	-0.5	-0.5	-1.0	-1.0	-1.0
Pounding	N/A	-0.5	-0.5	N/A	-0.5	N/A	N/A	N/A	N/A
Large Heavy Cladding	N/A	-2.0	N/A	N/A	-1.0	N/A	N/A	N/A	N/A
Short Columns	N/A	N/A	N/A	N/A	-1.0	-1.0	N/A	N/A	N/A
Post Benchmark Year	+2.0	+2.0	+2.0	+2.0	+2.0	N/A	+2.0	+2.0	N/A
SL2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
SL3	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
FINAL SCORE									

*For URM building ≥ 4 stories Basic Score = 2.0

COMMENTS

Detailed Evaluation Required

YES NO

Data Collection Form

(NEHRP Map Areas 3.4, Moderate)

Screening for Seismically Hazardous School Buildings

Scale: ________

Address ____________________

____________________ Zip ________

Other Identifiers ____________________

No. Stories ________ Year Built ________

Inspector ____________________ Date ________

Total Floor Area (sq. ft.) ____________________

Building Name ____________________

Use ____________________

INSTANT PHOTO

POSSIBLE NON-STRUCTURAL & OTHER HAZARDS

Parapets		Appurtenances	
Gables		Roof Tile	
Cornices		Covered Walks	
Chimneys		Interior Walls	
Towers		Unbraced Cripple Walls	
Signs		Weak Masonry Fdns.	
Other			

DATA CONFIDENCE

STRUCTURAL SCORES AND MODIFIERS

BUILDING TYPE	W	S1 (MRF)	S2 (BR)	S3 (LM)	C1 (MRF)	C3/S5 (URM NF)	PC1 (TU)	RM	URM*
Basic Score	6.0	4.0	3.0	6.0	3.0	2.0	3.5	3.5	2.0
Poor Condition	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Vert. Irregularity	-0.5	-0.5	-0.5	-0.5	-1.0	-1.0	-1.0	-0.5	-1.0
Soft Story	-1.0	-2.0	-2.0	-1.0	-2.0	-1.0	-1.0	-2.0	-1.0
Torsion	-1.0	-2.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Plan Irregularity	-1.0	-0.5	-0.5	-0.5	-0.5	-0.5	-1.0	-1.0	-1.0
Pounding	N/A	-0.5	-0.5	N/A	-0.5	N/A	N/A	N/A	N/A
Large Heavy Cladding	N/A	-2.0	N/A	N/A	-1.0	N/A	N/A	N/A	N/A
Short Columns	N/A	N/A	N/A	N/A	-1.0	-1.0	N/A	N/A	N/A
Post Benchmark Year	+2.0	+2.0	+2.0	+2.0	+2.0	N/A	+2.0	+2.0	N/A
SL2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
SL3	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6

FINAL SCORE

*For URM building ≥ 4 stories Basic Score = 1.5

COMMENTS

Detailed Evaluation Required

YES NO

Data Collection Form

(NEHRP Map Areas 5,6,7, High)

Screening for Seismically Hazardous School Buildings

Address ______ Zip ______

Other Identifiers ______

No. Stories ______ Year Built ______

Inspector ______ Date ______

Total Floor Area (sq. ft.) ______

Building Name ______

Use ______

INSTANT PHOTO

Scale: ______

POSSIBLE NON-STRUCTURAL & OTHER HAZARDS

Parapets		Appurtenances	
Gables		Roof Tile	
Cornices		Covered Walks	
Chimneys		Interior Walls	
Towers		Unbraced Cripple Walls	
Signs		Weak Masonry Fdns.	
Other			

DATA CONFIDENCE

STRUCTURAL SCORES AND MODIFIERS

BUILDING TYPE	W	S1 (MRF)	S2 (BR)	S3 (LM)	C1 (MRF)	C3/S5 (URM NF)	PC1 (TU)	RM	URM*
Basic Score	4.5	4.5	3.0	5.5	2.0	1.5	2.0	3.0	1.0
Poor Condition	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Vert. Irregularity	-0.5	-0.5	-0.5	-0.5	-1.0	-0.5	-1.0	-0.5	-0.5
Soft Story	-1.0	-2.5	-2.0	-1.0	-2.0	-1.0	-1.0	-2.0	-1.0
Torsion	-1.0	-2.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Plan Irregularity	-1.0	-0.5	-0.5	-0.5	-0.5	-0.5	-1.0	-1.0	-1.0
Pounding	N/A	-0.5	-0.5	N/A	-0.5	N/A	N/A	N/A	N/A
Large Heavy Cladding	N/A	-2.0	N/A	N/A	-1.0	N/A	N/A	N/A	N/A
Short Columns	N/A	N/A	N/A	N/A	-1.0	-1.0	N/A	N/A	N/A
Post Benchmark Year	+2.0	+2.0	+2.0	+2.0	+2.0	N/A	+2.0	+2.0	N/A
SL2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
SL3	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6

FINAL SCORE

*For URM building ≥ 4 stories Basic Score = .5

COMMENTS

Detailed Evaluation Required

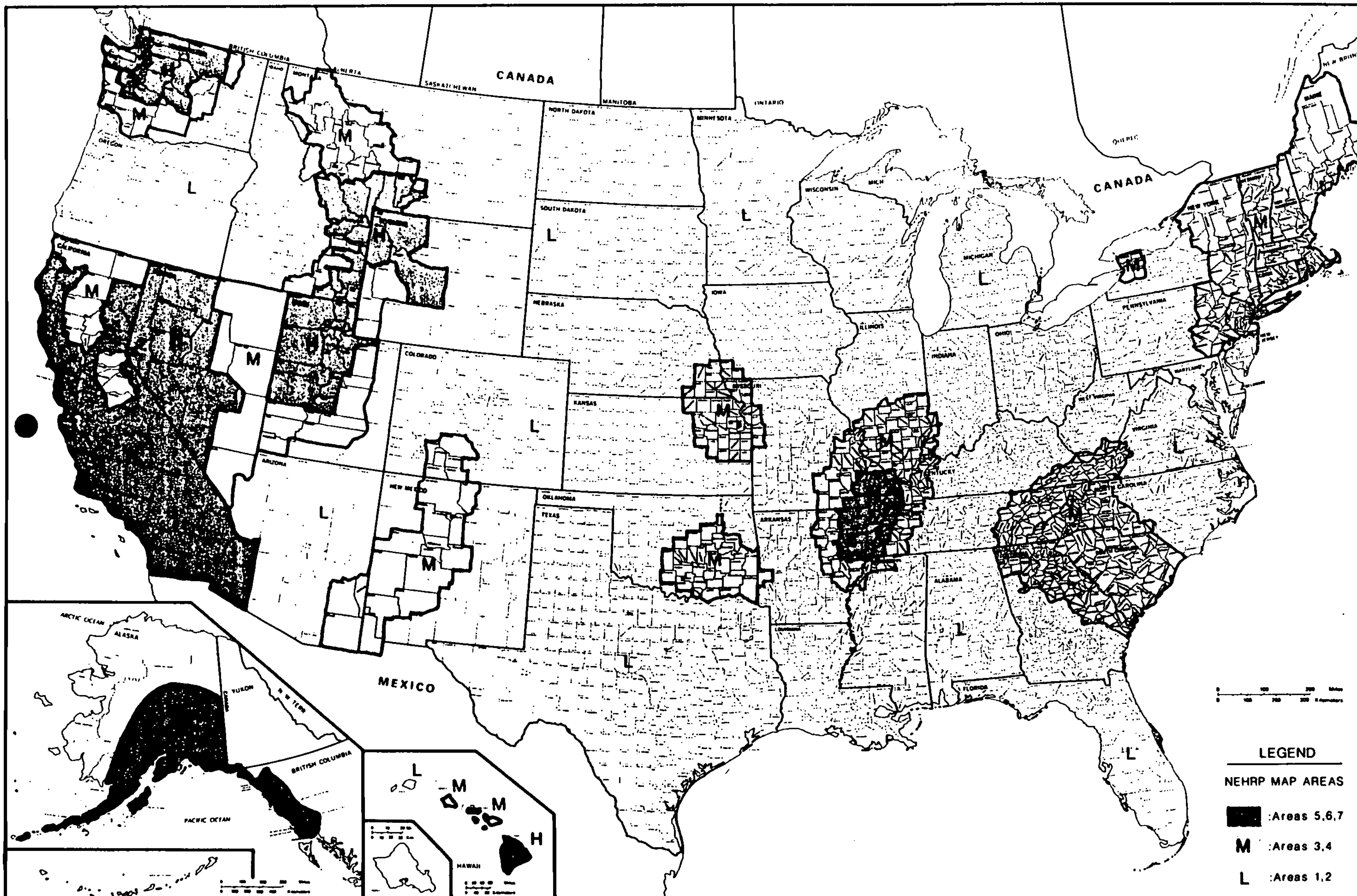
YES NO

Data Collection Form

APPENDIX C

- SEISMIC MAPS

United States



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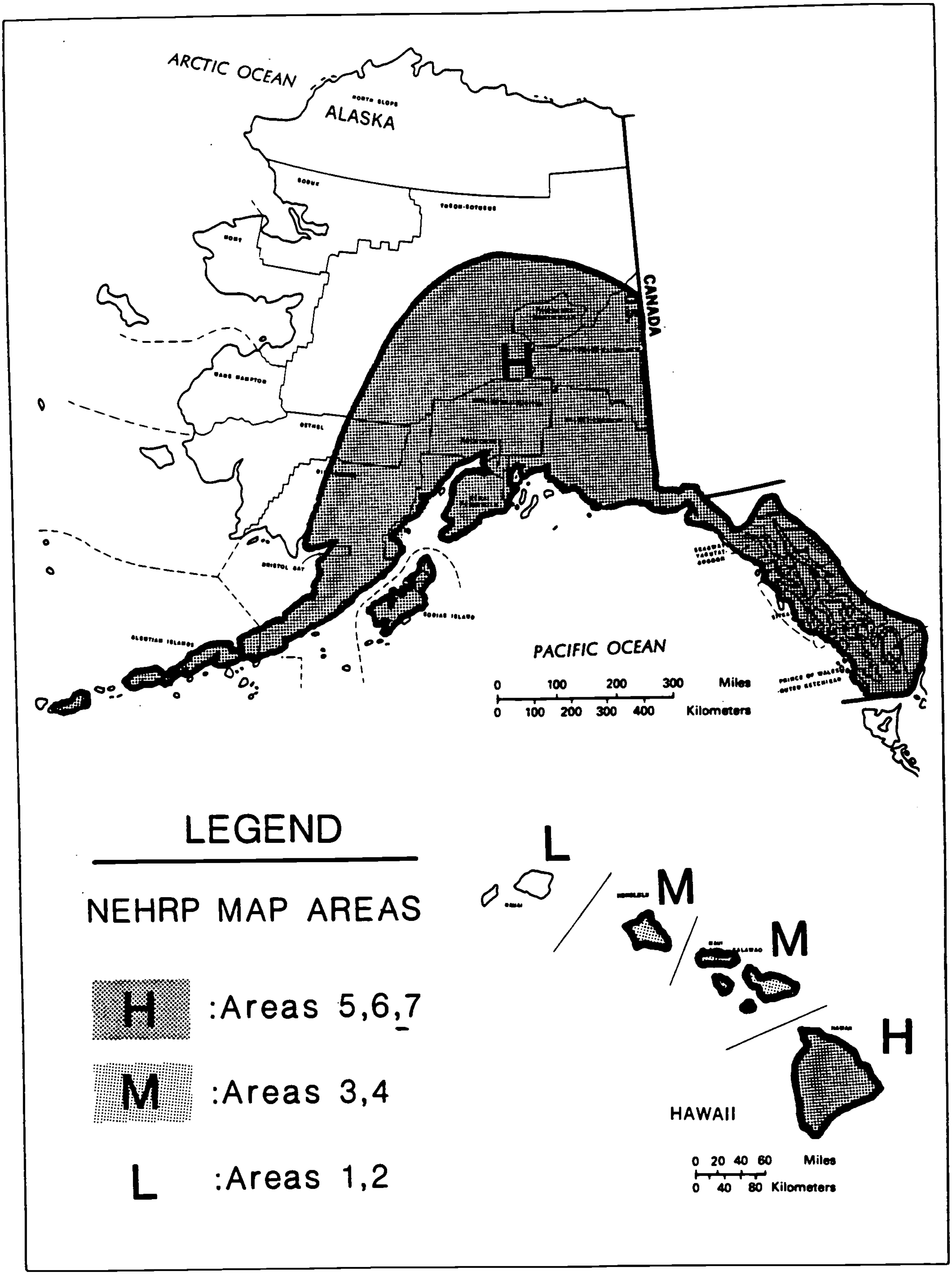

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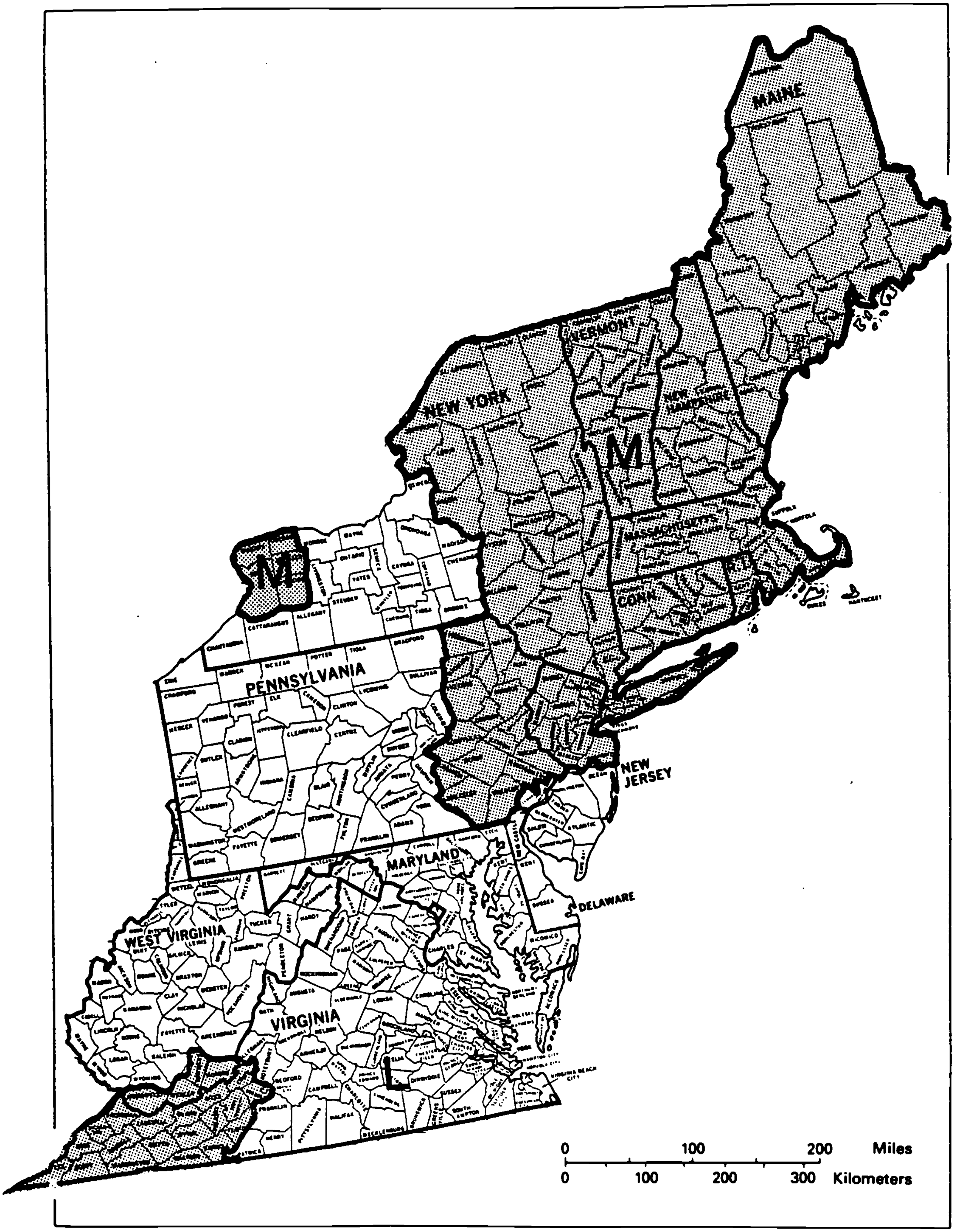
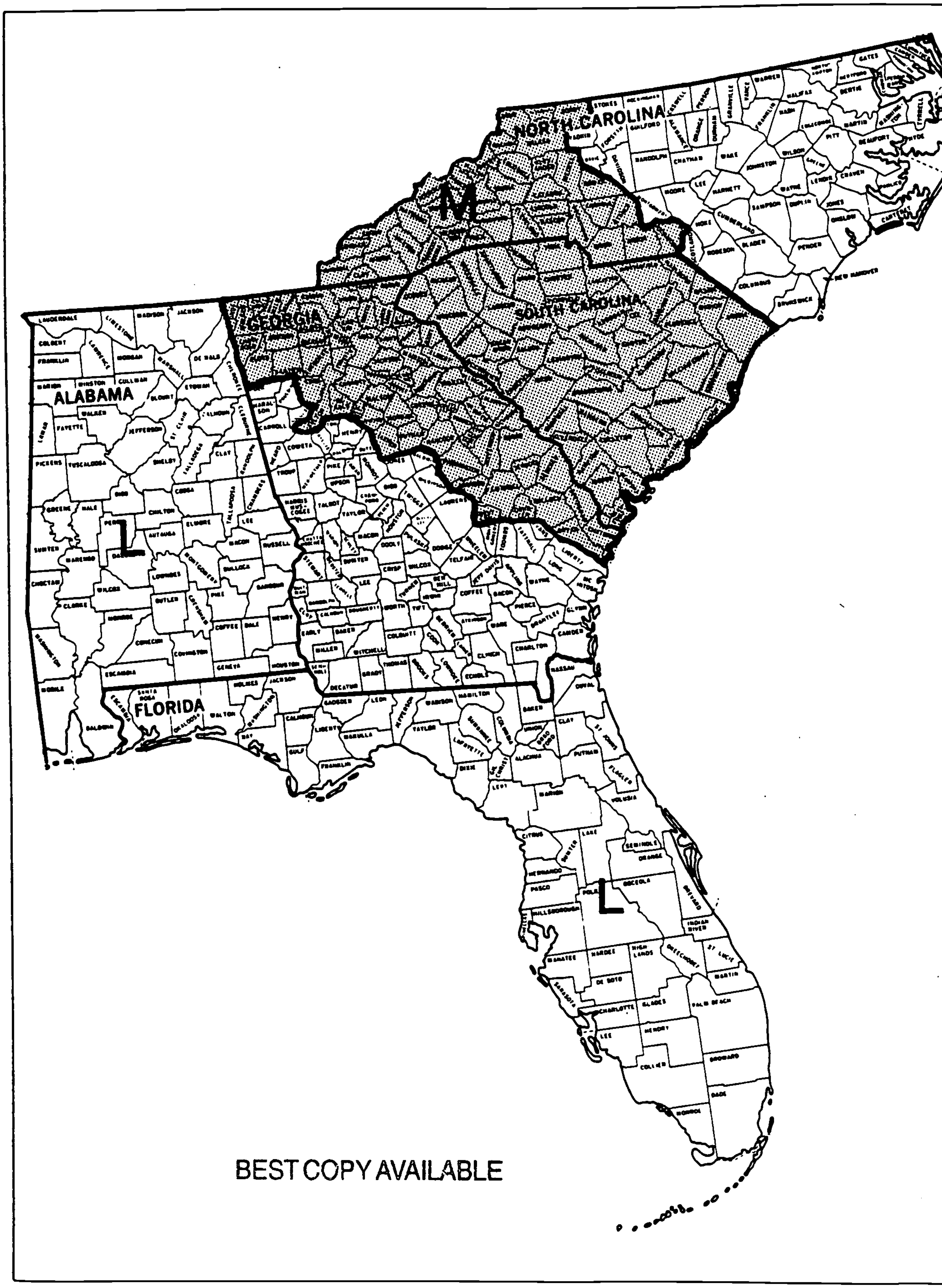
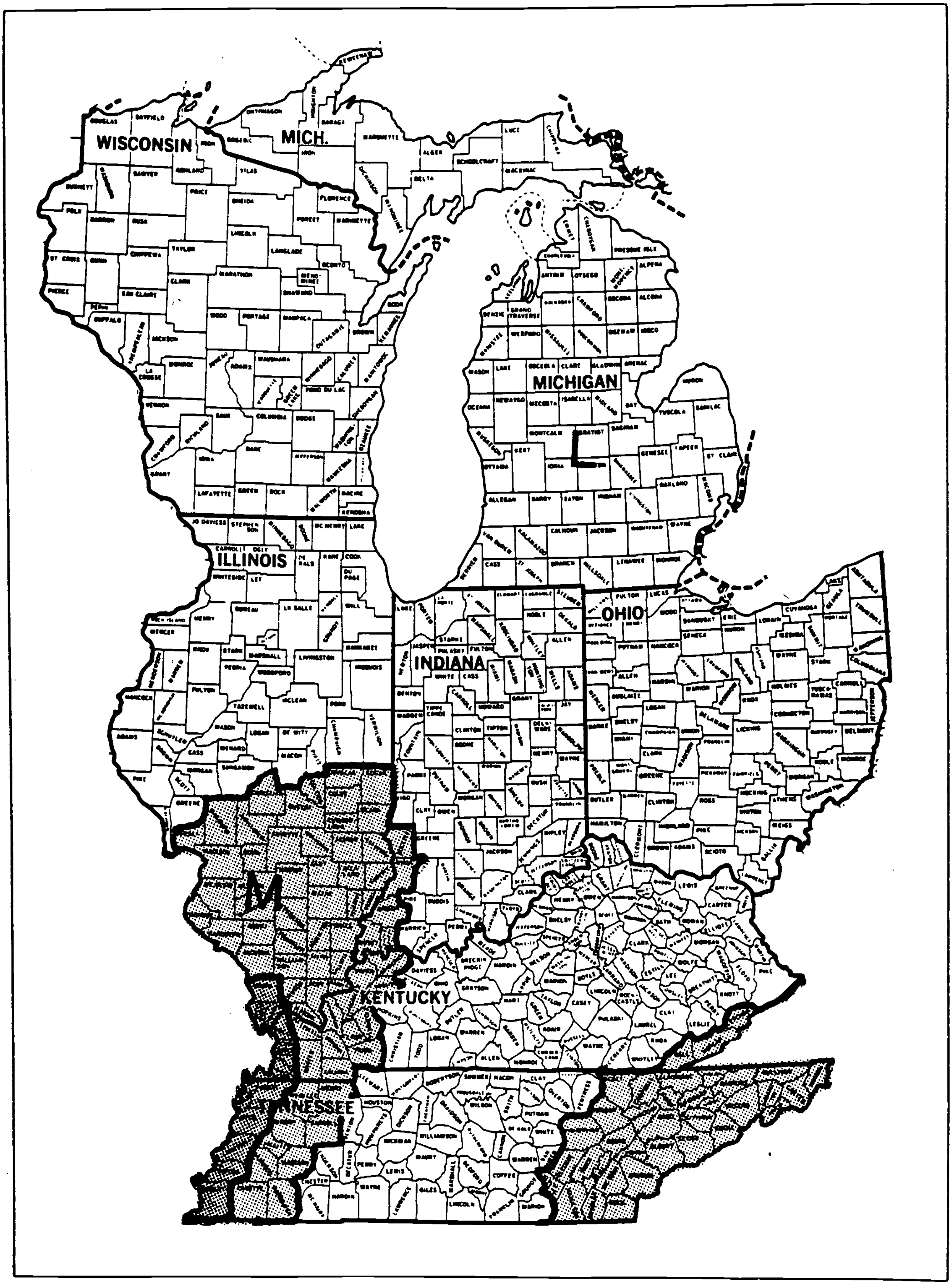
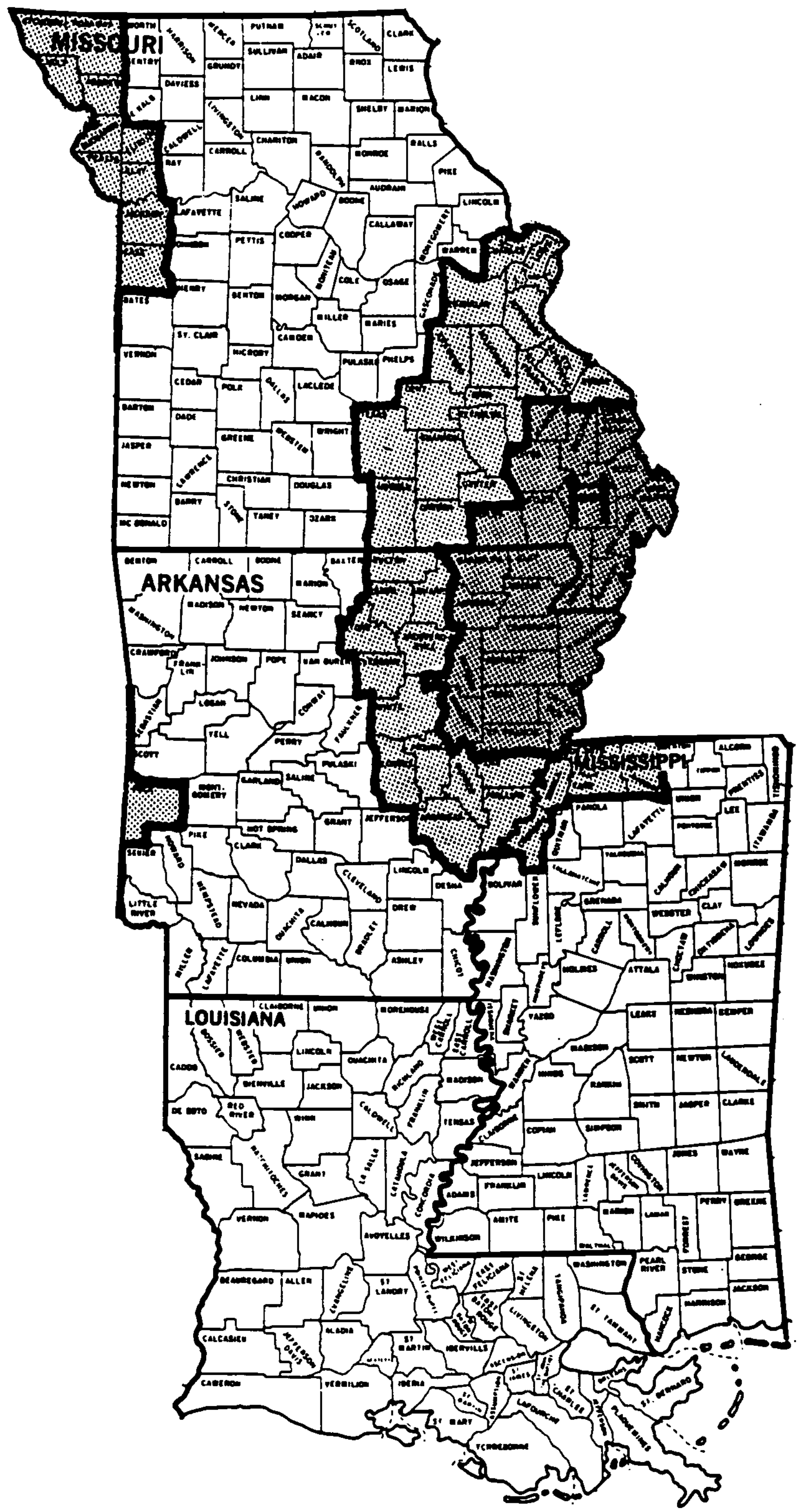
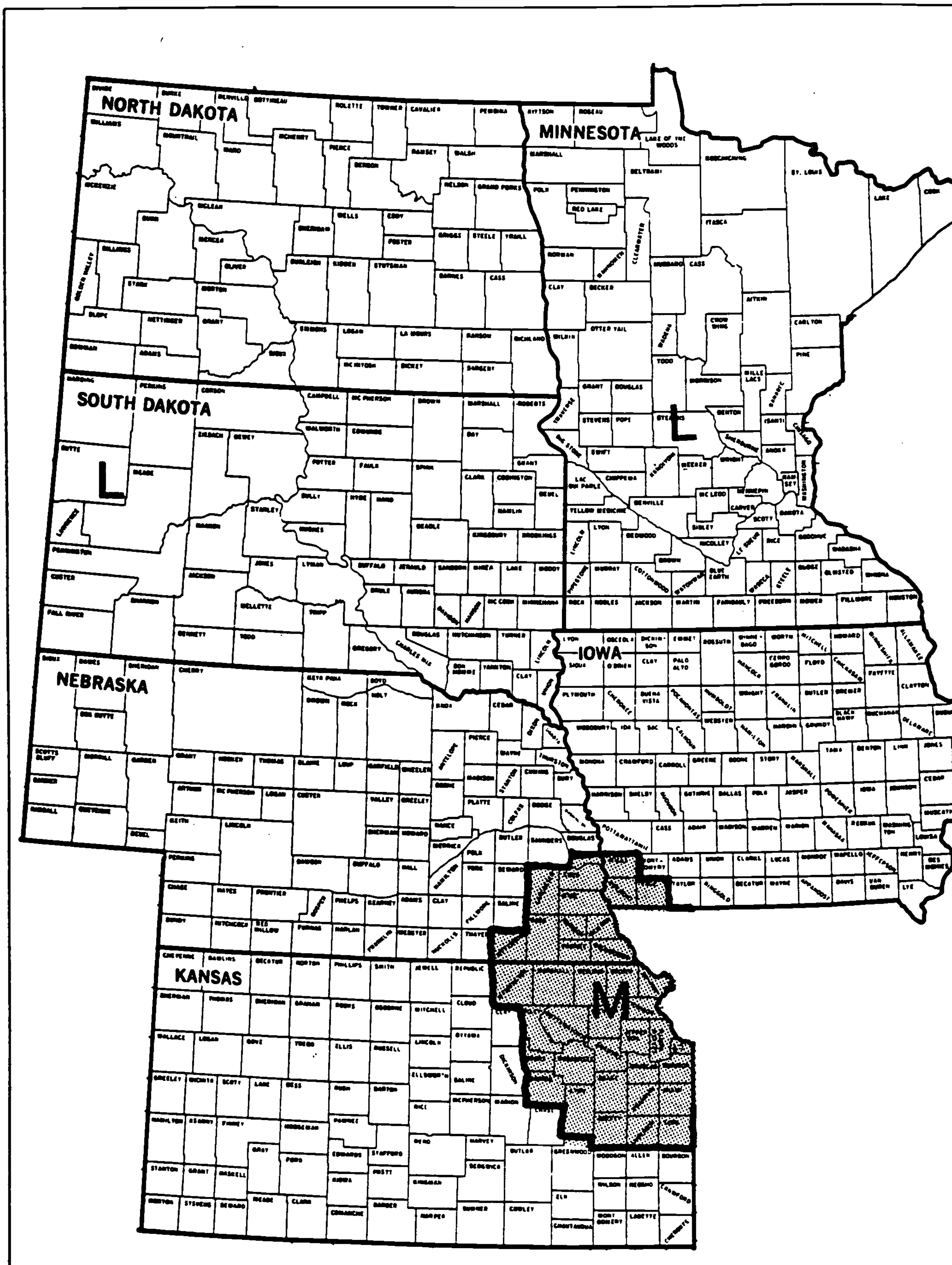

MAINE
VERMONT
NEW YORK
NEW HAMPSHIRE
M
M
CONN
PENNSYLVANIA
NEW JERSEY
MARYLAND
DELAWARE
WEST VIRGINIA
VIRGINIA
L
0 100 200 Miles
0 100 200 300 Kilometers

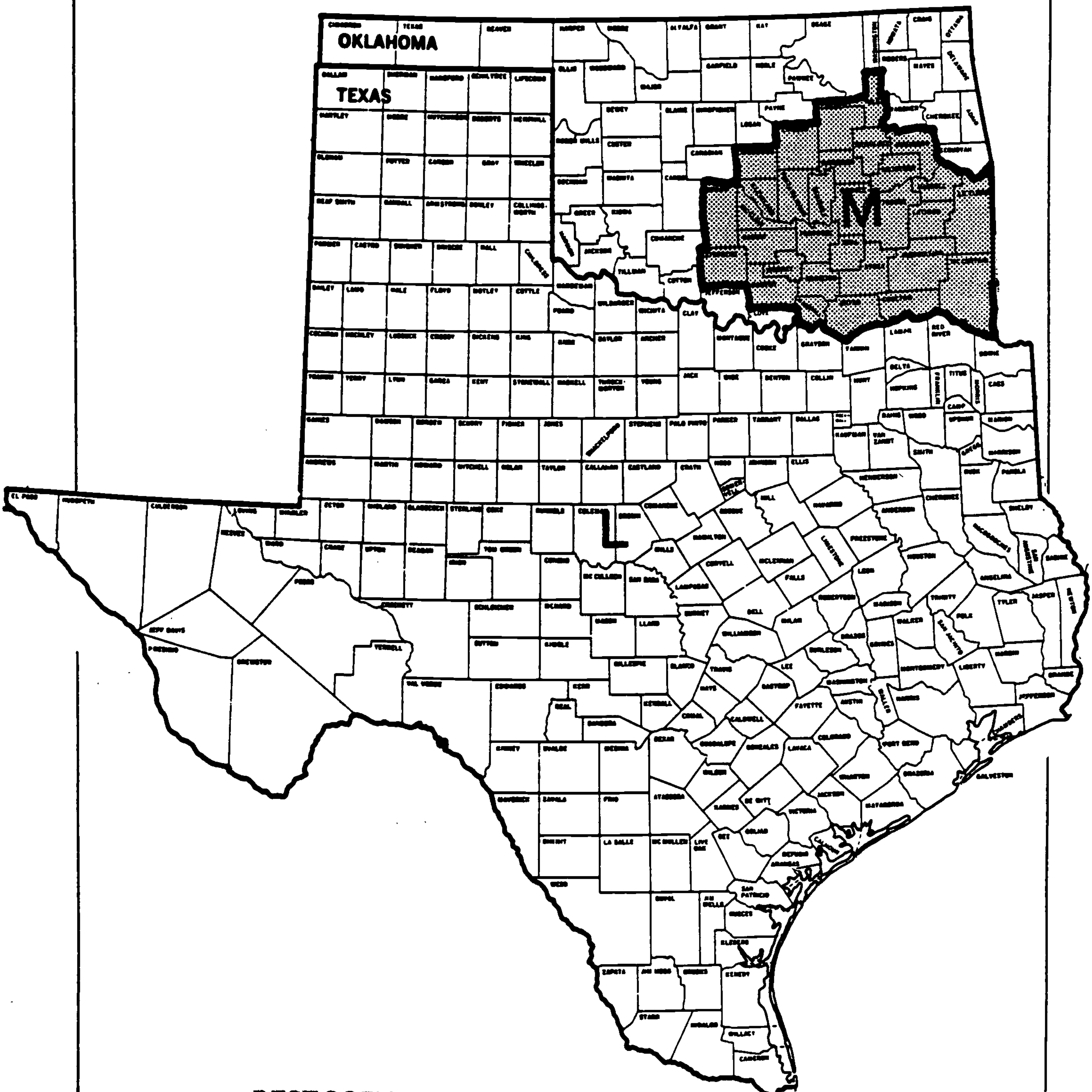

NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
ALABAMA
FLORIDA
M
L
L
L

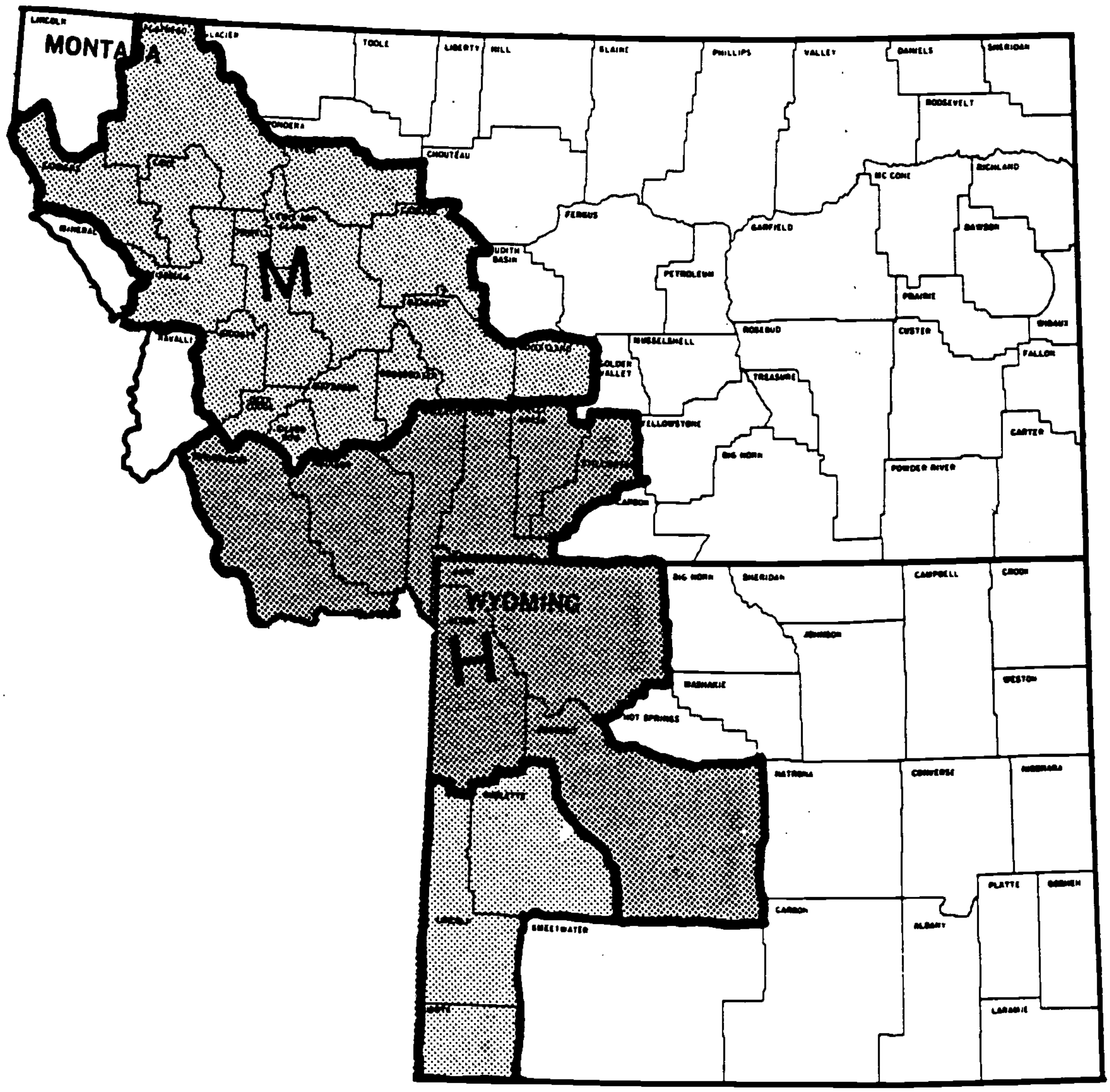

WISCONSIN
MICH.
MICHIGAN
ILLINOIS
INDIANA
OHIO
KENTUCKY

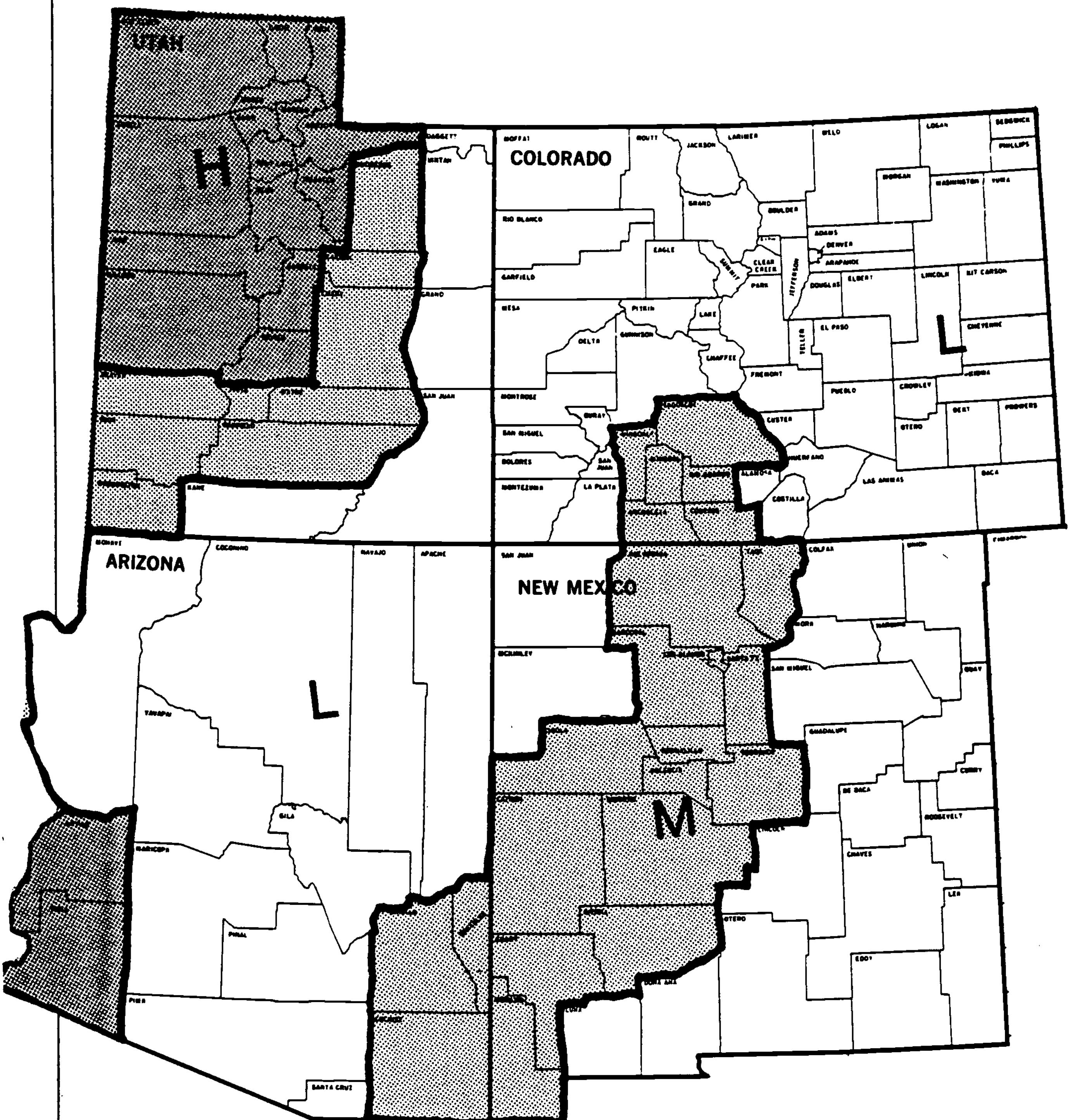

MISSOURI
ARKANSAS
LOUISIANA


NORTH DAKOTA
MINNESOTA
SOUTH DAKOTA
L
L
NEBRASKA
IOWA
KANSAS
M

ATC-21


OKLAHOMA
TEXAS
M
L


M
WYOMING
H



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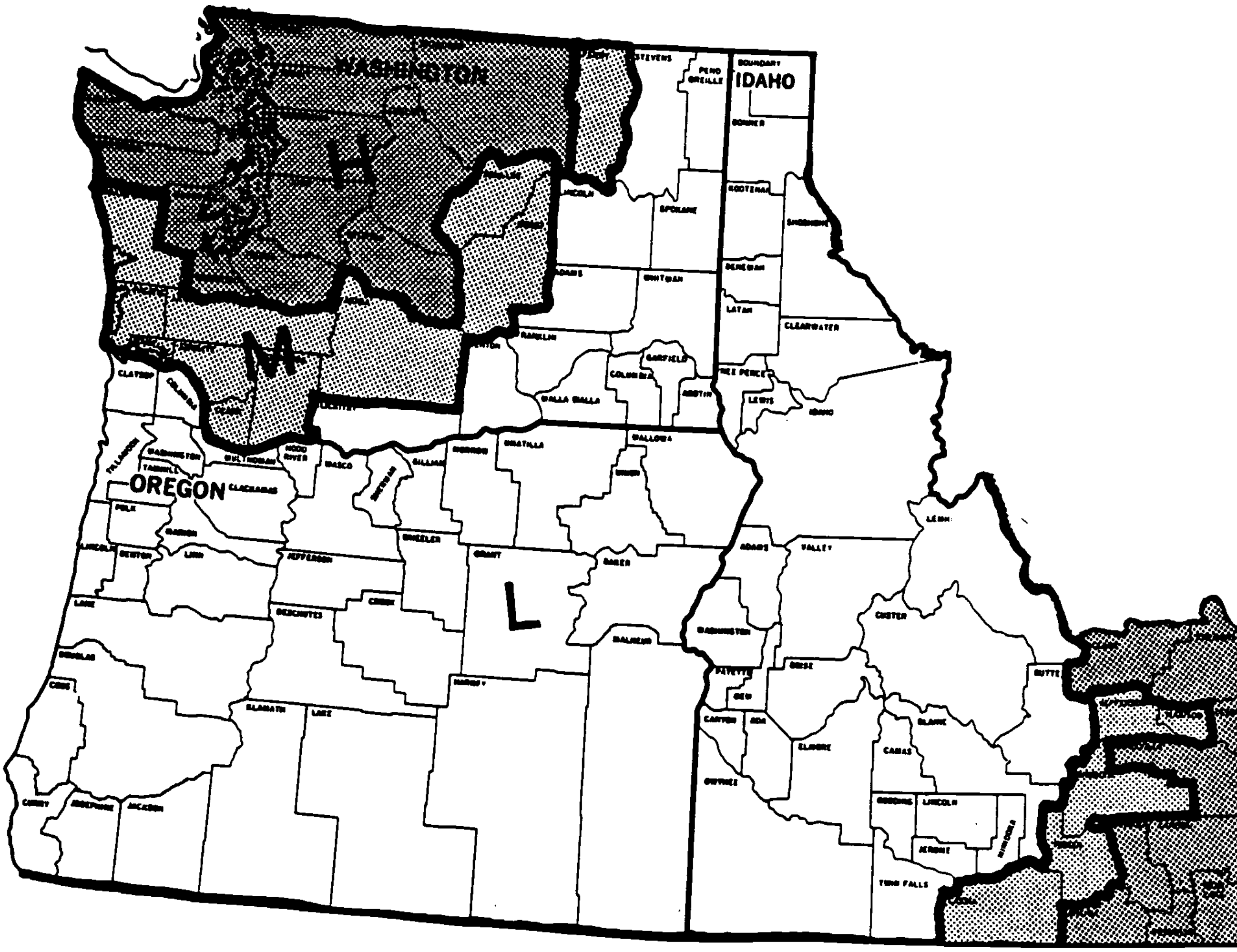

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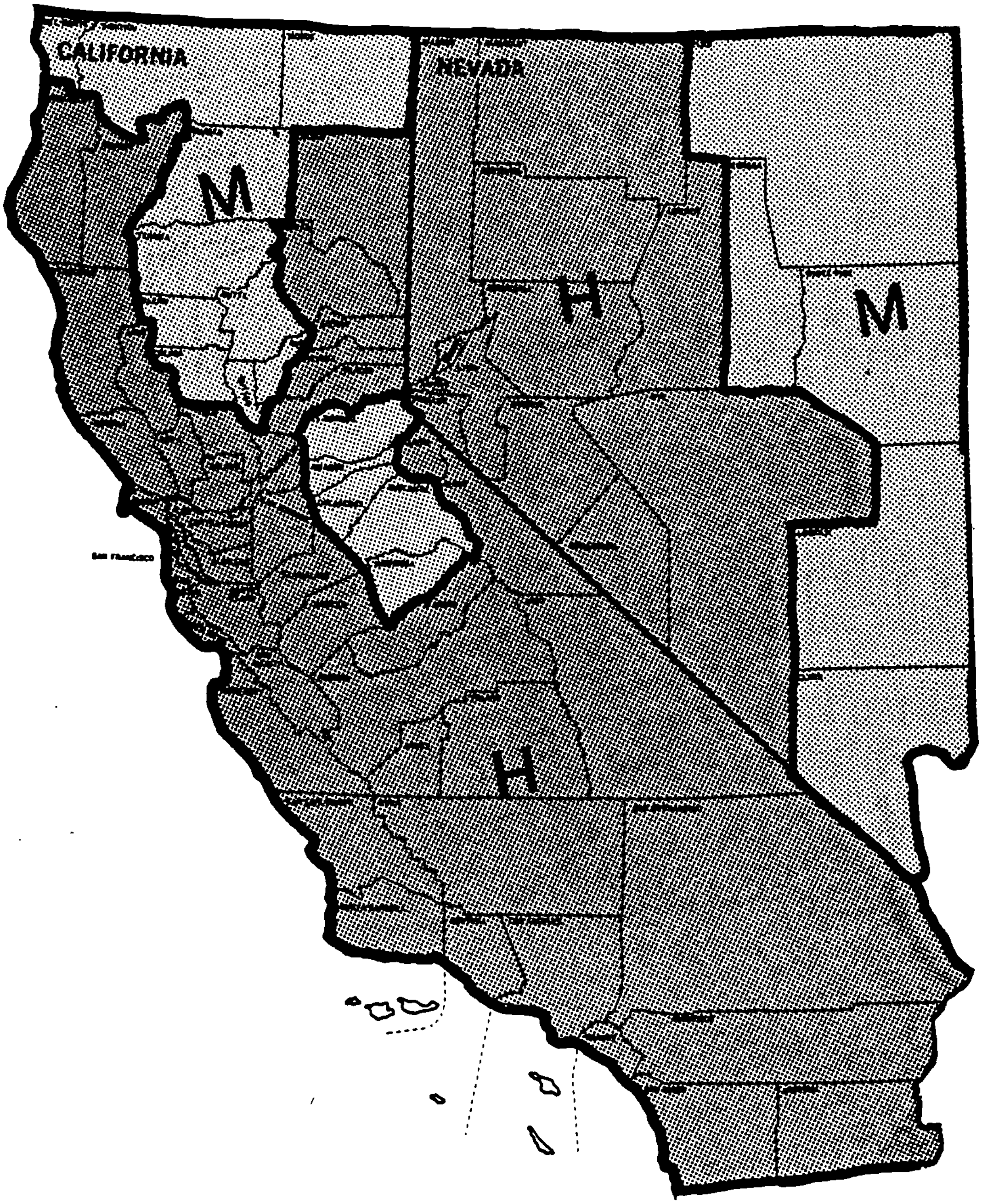

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