Research Report
KTC-90-6

# PLAN FOR CONTINUING EARTHQUAKE MITIGATION AND RECOMMENDED EMERGENCY RESPONSE PROCEDURES FOR WESTERN KENTUCKY


by

L. John Fleckenstein
Engineering Geologist

David L. Allen
Chief Research Engineer

and

Vincent P. Drnevich
Co Principle Investigator

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky



in cooperation with
Transportation Cabinet
Commonwealth of Kentucky

and

Federal Highway Administration
U.S.Department of Transportation



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16. Abstract

Concern has grown in recent years over the seismic activity of the New Madrid seismic zone in Western Kentucky. In 1987, the Kentucky Transportation Cabinet commissioned the Kentucky Transportation Center to analyze and assess the possible effects of an earthquake on highway facilities. Since 1987, over 1,000 miles of priority routes have been recommended for the transportation of goods and services after a major earthquake. This report summarizes the mitigation research that has been conducted. This report also discusses a plan for continuing earthquake mitigation in Kentucky through seminars, discusses bridge retrofitting, and makes recommendations for a post earthquake response.

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## EXECUTIVE SUMMARY

An awareness of earthquakes and their possible effects upon the nation's infrastructure are critically important to the public, and in particular, to public officials. The nation's highway system is one of the most important components of the infrastructure. After the occurrence of an earthquake, the highway system is the primary mode of transporting emergency supplies and services into an affected area. Thus, it is important to catalog the important components of the highway system and attempt to anticipate the possible damage to these components from an earthquake.

Western Kentucky is in a high risk earthquake zone. In 1811-1812, three of the most severe earthquakes in American history shook the country. The location of these earthquakes was not on the infamous San Andreas fault nor anywhere along the well-known fault laden Pacific coast but was near a small town on the Mississippi River where the states of Kentucky and Missouri share a border. It is this river town, New Madrid, Missouri, that is the namesake of a region now regarded by seismologists and disaster response planners as the most hazardous earthquake zone east of the Rocky Mountains -- the New Madrid seismic zone.

Concern has grown in recent years over the seismic activity of the New Madrid seismic zone in Western Kentucky. In 1987, the Kentucky Transportation Cabinet commissioned the Kentucky Transportation Center to analyze and assess the possible effects of an earthquake on highway facilities. Since 1987, over 1,000 miles of priority routes have been recommended for the transportation of goods and services after a major earthquake. This report summarizes the mitigation research that has been conducted. This report also discusses a plan for continuing earthquake mitigation in Kentucky through seminars, discusses bridge retrofitting, and makes recommendations for a post earthquake response.

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## INTRODUCTION

An awareness of earthquakes and their possible effects upon the nation's infrastructure are critically important to the public, and in particular, to public officials. The nation's highway system is one of the most important components of the infrastructure. After the occurrence of an earthquake, the highway system is the primary mode of transporting emergency supplies and services into an affected area. Thus, it is important to catalog the important components of the highway system and attempt to anticipate the possible damage to these components from an earthquake. Figure 1 indicates areas within the United States that are at risk of being damaged by a major earthquake (1).

Western Kentucky is in a high risk earthquake zone. In 1811-1812, three of the most severe earthquakes in American history shook the country. The location of these earthquakes was not on the infamous San Andreas fault nor anywhere along the well-known fault laden Pacific coast but was near a small town on the Mississippi River where the states of Kentucky and Missouri share a border (Figure 2)(2). It is this river town, New Madrid, Missouri, that is the namesake of a region now regarded by seismologists and disaster response planners as the most hazardous earthquake zone east of the Rocky Mountains--the New Madrid seismic zone.

In addition to these three great earthquakes, there are several other well documented factors demonstrating the susceptibility of the New Madrid region to the recurrence of major earthquakes. Through a decade of extensive research, an ancient crustal rift has been found to underlie the relatively shallow sediments comprising the region's surface. This type of geologic structure is prone to seismic activity. The New Madrid rift also known as the Reelfoot Rift Complex has been identified as being of sufficient size to generate major earthquakes (Figure 3(2) and 4(3)). Further evidence of the area's seismicity is the 488 earthquakes greater than a magnitude of 3 that have been recorded between 1811 to mid 1974 (Figure 5)(2). Over 2,000 earthquakes have been detected in the zone since 1974 (Figure 6)(2). Though most have been of a magnitude below the threshold of human perception, their existence clearly indicates the high level of seismic activity occurring in the zone.

Seismologists have calculated the probabilities of recurrence of sizeable earthquakes in the New Madrid rift zone. The probability of a magnitude 6.3 earthquake (Richter scale) within 50 years is from 86 to 97 percent. The probability of that same earthquake occurring within the next 15 years is from 40 to 63 percent (4). For comparison, the 1971 San Fernando earthquake (magnitude 6.6) killed 58 people and caused $480 million worth of damage. The 1988 Armenian earthquake of similar magnitude killed approximately 25,000 to 30,000 people.

The probability of a magnitude 7.6 earthquake occurring within 50 years is from 19 to 29 percent. The probability for this size earthquake occurring within 15 years drops to a range of 5.4 to 8.7 percent. On February 4, 1975, the Haicheng earthquake in China had a magnitude of 7.3 and destroyed or damaged about 90 percent of the structures in a city of 90,000 people. Figure 7 shows the cumulative number of different magnitude earthquakes a year that occur in the New Madrid Seismic Zone (2).

When comparing historical earthquakes of similar magnitude, one must take into consideration that death totals and damage estimates will vary greatly due to the geology, population density, types of building, and quality of construction.

For a given earthquake, effects at a given location are described by the Modified Mercalli Intensity (MMI) scale (5) which ranges from I (no damage and felt only by instruments) to XII (total destruction). Details of the MMI scale are given in Table 1. Values of MMI associated with the 1811-1812 earthquakes are shown in Figure 8. The potential for damage and destruction from earthquakes in Western Kentucky is significant.

## BACKGROUND

In 1982, the Governor's Task Force on Earthquake Hazards and Safety was created to evaluate Kentucky's earthquake risk and to make recommendations for responding to those risks. This task force recommended increased public awareness and education programs, improved emergency response planning and training, improved building codes and seismic restraint designs, evaluation of other mitigation measures, and participation in national and regional earthquake forums and funding programs.

In 1984, Governor Collins created the Governor's Earthquake Hazards and Safety Technical Advisory Panel (GEHSTAP) to analyze scientific and engineering data regarding seismic risks in Kentucky and to make specific recommendations on mitigation, public awareness, response planning, and policy development for public health and safety. The States are dependent on their highway systems for the movement of goods and services. Due to the possible adverse effects a major earthquake could have on this system, the Earthquake Stability and Transportation Subcommittee (ESTS) of GEHSTAP was formed.

ESTS has encouraged the Kentucky Transportation Cabinet to secure funding for developing and implementing an earthquake hazard mitigation plan in an attempt to safeguard the highway system against catastrophic earthquake failure. As a result, in 1987 Cabinet officials commissioned the Kentucky Transportation Center investigators at the University of Kentucky to analyze and assess the possible effects of an earthquake on highway facilities. The study area includes the 26 western-most counties in Kentucky that are adjacent to the New Madrid seismic zone (Figure 9).

### Objectives

The objectives of this study were as follows:

1. To make a literature search and identify publications relating to the topic and review those articles containing up-to-date and relevant information. To utilize that information and data as applicable to the following objectives.

2. To research and recommend criteria and policy for determining priority routes and identifying the functions of those routes.

3. To analyze selected man-made and natural structures that are judged marginally stable for a design seismic event for each priority route, and to make recommendations on remedial action for a particular structure. These recommendations may include retrofitting selected

bridges; stabilizing some earth embankments, dams and natural slopes, power transmission lines, and pipelines; and preventing subsidence from underground mines. These structures would be analyzed only if their failure would adversely affect a priority route.

4. To recommend emergency response procedures and policies for transportation engineering personnel, and to develop a training program for district highway personnel on implementing these procedures in the event of an earthquake emergency. These procedures would supplement emergency procedures developed by other agencies, and would relate only to keeping priority routes open in the event of a seismic emergency.

5. To review current seismic design codes for transportation facilities and to recommend changes to the Department of Highways.

6. To research and develop a procedure for updating seismic risks maps for all priority routes.

### Completed Objectives

As fulfillment of objectives 2 and 3, Research Report UKTRP-88-2 "Earthquake Hazard Mitigation of Transportation Facilities" was submitted to Kentucky Transportation Cabinet officials in January 1988. The report recommends over 1,000 miles of highways to be utilized as emergency or "priority" routes (Figure 10)(6). These would be the primary routes used for transporting emergency supplies and personnel after the occurrence of an earthquake. Also, it is anticipated that these would be the first routes repaired after the occurrence of an earthquake. The priority routes were visually surveyed and all natural and man-made features along these routes that are considered seismically significant were cataloged. This includes dams, pipelines, power lines, high fills, cut slopes, buildings, mines, bridges, trees, faults, etc.

The initial task in identifying these priority routes was to decide where they should begin; that is, in the event of a major earthquake, the point at which the transport of goods and services would originate. Ideally, the city chosen should possess the following attributes:

1. Sufficient size to contain all necessary personnel, supplies, and facilities to respond quickly to a major emergency;

2. Proximity to the high hazard area to speed the relief effort but not so close as to suffer the same high risk potential;

3. Easy access from other major cities in the State; and

4. Sufficient routes to provide relatively direct access to all 26 high-risk counties.

The city best fitting these criteria is Bowling Green. Located at the eastern edge of the earthquake zone in Warren County, Bowling Green meets both the size criterion (population 40,450) and the accessibility criterion (Louisville and Nashville via Interstate 65 and Lexington via the Bluegrass Parkway). Bowling Green provides access to the 26-county area via US 68/KY 80. This road was chosen as the main east-west artery because it crosses Lake Barkley and Kentucky Lake upstream from the dams impounding those bodies of water. Additional priority routes were added on the upstream side of Lake Barkley and Kentucky Lake through northern Tennessee (Figure 11)(7).

In 1989, individual research reports for each of the 26 counties in the study area were submitted to Kentucky Transportation Cabinet officials (Research Reports KTC-89-4 through KTC-89-29). An additional report was issued for priority routes in Northern Tennessee (KTC-89-41). The reports list and discuss all natural and man-made features that were logged along the priority routes that are considered seismically significant. All seismically significant features were logged in a data base and strip maps showing these features were prepared for each route and county. For completion of Objective 3, a seismic analysis for each bridge on the priority routes will be submitted to the Kentucky Transportation Cabinet officials in 1990. The bridge report will contain an inventory of all 276 bridges cataloged on the priority routes. The seismic analysis of each bridge was completed in January 1990. It is estimated that 111 bridges will need retrofitting at a total cost of $6.5 million (8). This does not include the bridges over Kentucky Lake and Lake Barkley located on US 68/KY 80.

A bibliography is included at the end of this report to document completion of Objective 1.

## RECOMMENDATIONS ON CONTINUING EARTHQUAKE MITIGATION IN KENTUCKY

### Staff Position Of Earthquake Coordinator

To continue earthquake mitigation in Kentucky, a staff position in the Transportation Cabinet should be established. The person assigned to this position should be responsible for maintaining the priority route data base, strip maps, bridge data base, and to supervise the hardening of the priority routes against potential earthquake damage. Hardening would include bridge retrofitting, stabilization of rock and soil cuts, and those seismically significant features that could be retrofitted. This position would also require working closely with officials in the 26 high risk counties and the three highway district offices. This individual should also conduct earthquake training seminars to educate state officials and maintenance personnel, develop a working post earthquake response plan, and further earthquake mitigation in Kentucky.

### Updating Priority Route Data Base and Seismic Risk Maps

The Earthquake Coordinator should be responsible for updating the seismic risk maps. The coordinator should also be aware of any closure or detour of a priority route. The priority route data base from which the seismic risk maps are generated is constantly changing. Changes in the data base include various types of road construction (widening, detour, failures, etc), retrofitting, bridge construction, etc. The routes should be inspected by department personnel yearly so that the seismic risk maps may be updated. A standard updating form should be developed for such purpose. Forms would be forwarded to the Earthquake Coordinator.

### Earthquake Training Seminar

The Earthquake Coordinator should be responsible for conducting earthquake training

seminars to educate state officials and department personnel about earthquakes in Kentucky. The seminar should be presented yearly. A supplementary video tape should be developed for new personnel. The seminar should include the general history of earthquakes, the history of earthquakes in Kentucky, behavior of earthquakes, current seismic research, mitigation, priority routes, bridge retrofitting, and post earthquake response.
A general outline for a training seminar is included in a Appendix A.

### Post Earthquake Response Team

One of the main duties of the Earthquake Coordinator should be to develop and supervise (when the need arises) a post earthquake response team. The Earthquake Coordinator should work closely with the Bowling Green Chief District Engineer and the Chief District Engineers from Districts 1 and 2 to develop an action plan in case of the occurrence of a major earthquake in Western Kentucky. Included in this plan would be equipment needs for a proper response, a team of estimators to check for damage after the occurrence of an earthquake, and maintenance personnel trained for quick, safe, temporary repairs on bridges and priority routes. Included in Appendix A is a discussion of post earthquake response. A flow chart illustrating various post earthquake responses is included in Appendix B.

### Scope of Earthquake Mitigation

The Earthquake Coordinator should be also aware of other potential hazards that may not only affect transportation but local industry, environment, and possibly the eastern United States. These features include possible loss of a major gas transmission line, a large dam, and possible failure of one of the many large crude oil and gasoline pipelines located throughout the State. Loss of a major gas transmission line would severely affect industry and millions of homes. Loss of a dam and/or dams such as the ones impounding Kentucky Lake and Lake Barkley would devastate towns along the Cumberland, Tennessee, Ohio, and Mississippi rivers. There could also be loss of drinking water, electricity, and transportation. A failure or break in one of the large pipelines could have devastating effects upon ground water and drinking water. Several pipelines cross Kentucky and the Ohio River. A 40-inch pipeline crosses the western part of the State through Fulton, Hickman, Carlisle, and Ballard Counties.

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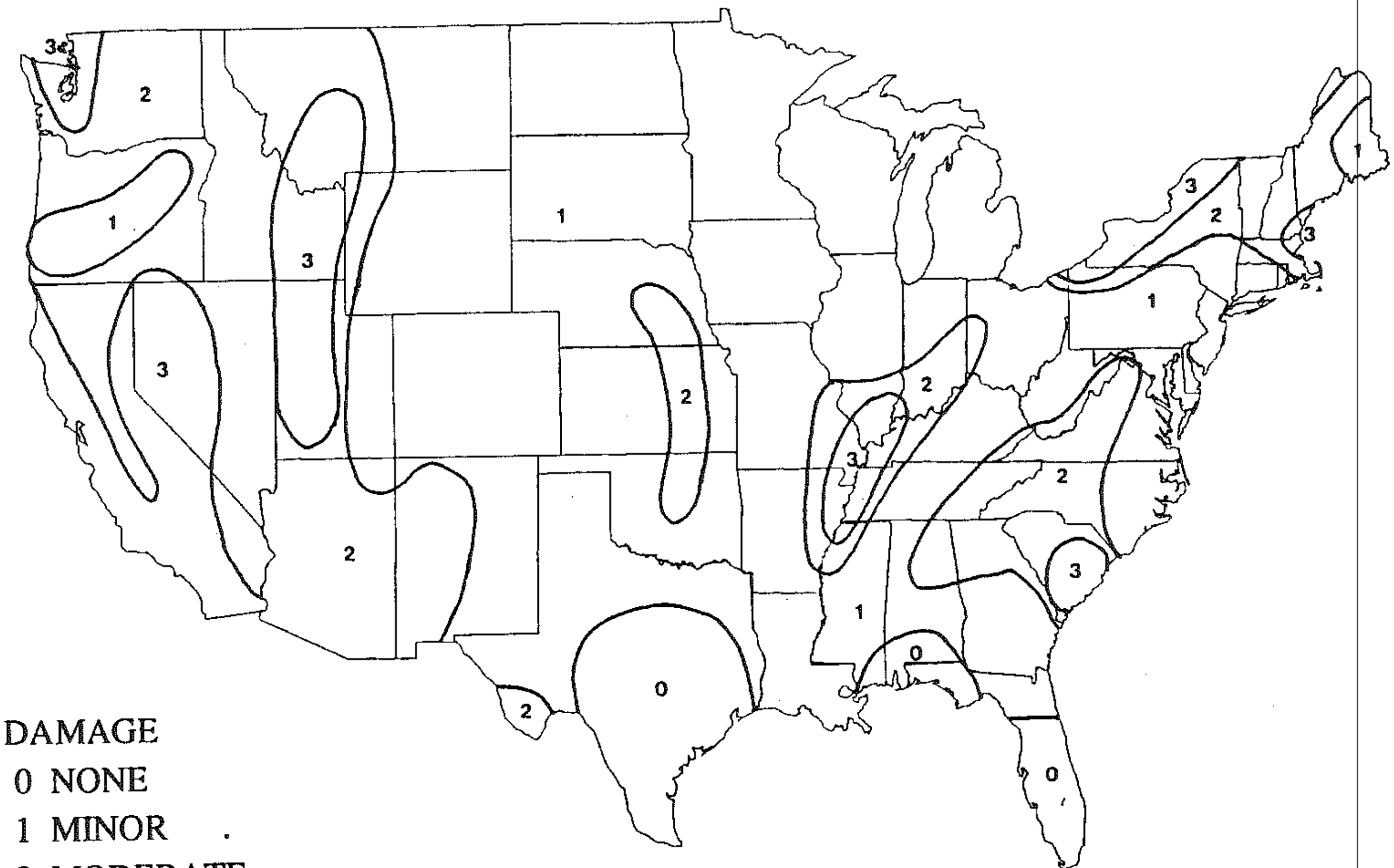


DAMAGE
0 NONE
1 MINOR
2 MODERATE
3 MAJOR

Figure 1. UBC/1973 Seismic Zone Map for the U.S.

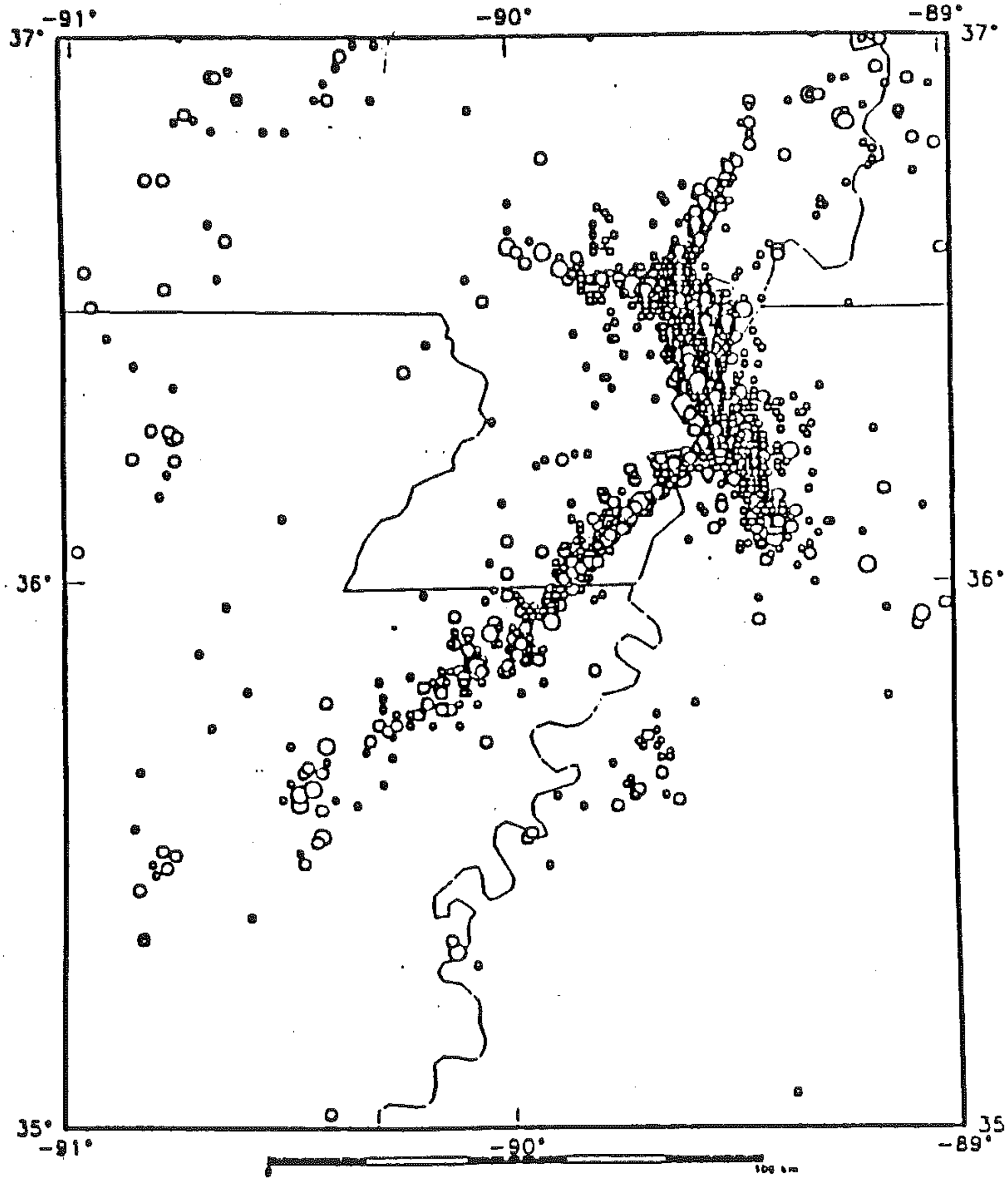



Figure 2. New Madrid Seismic Zone 1974-1987

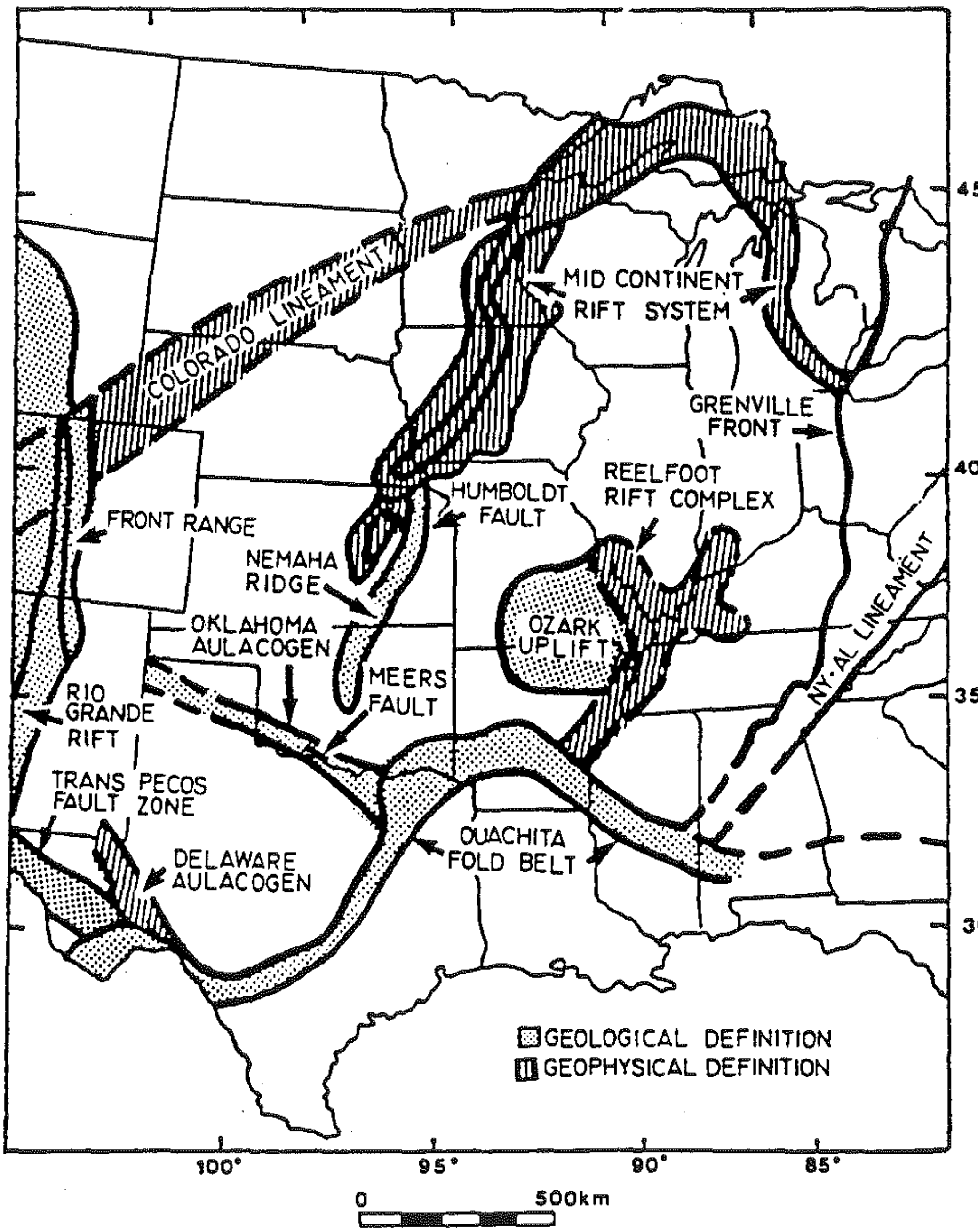



Figure 3. Central U.S. Primary Tectonic Features

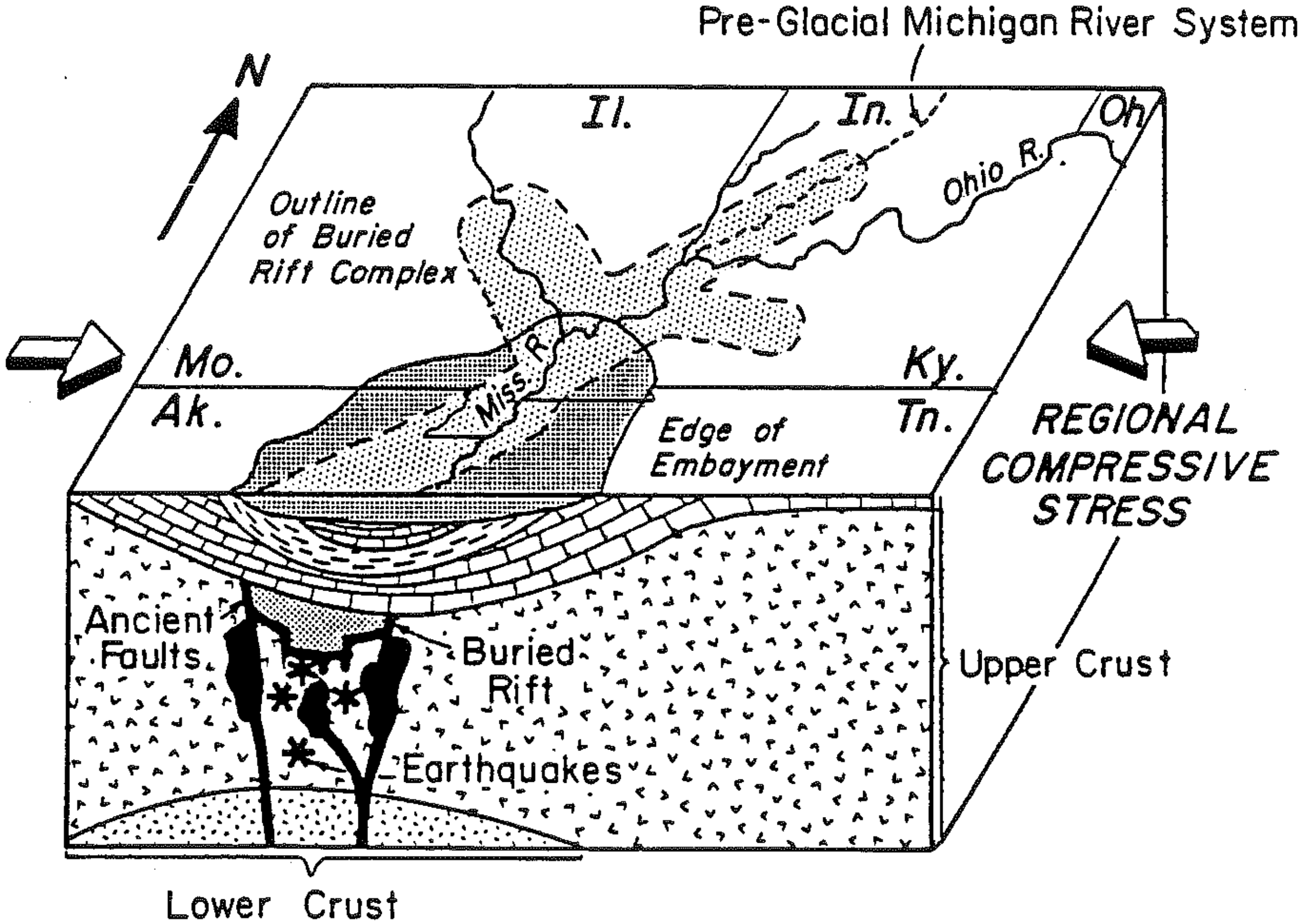



Figure 4. Block Diagram of Buried Reelfoot Rift Complex
(after Braile et al., 1982)

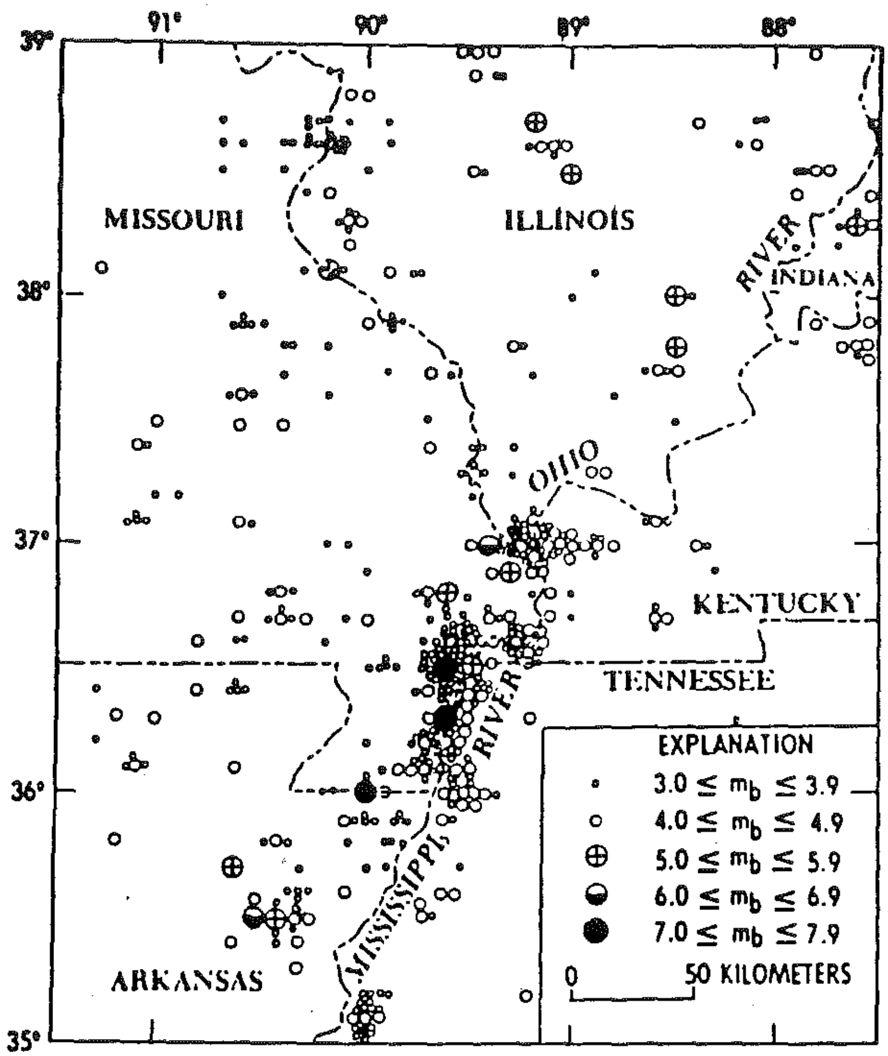



Figure 5. Epicenter of 488 Earthquakes of Magnitude 3 and Greater Occurring in the Central Mississippi Valley from 1811 to Mid-1974 Stauder, 1982).

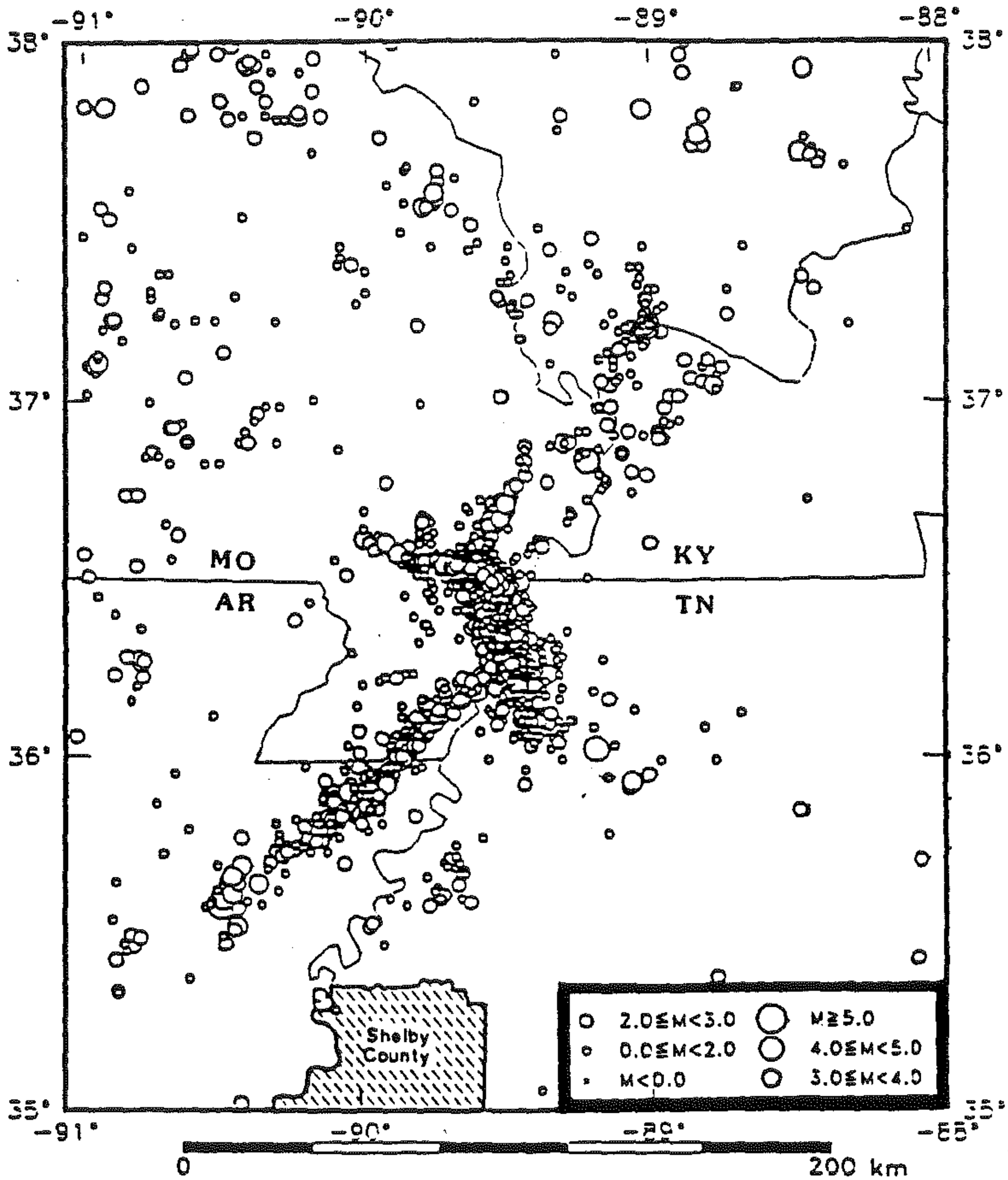



Figure 6. Epicenters of New Madrid Earthquakes (1974-1988).

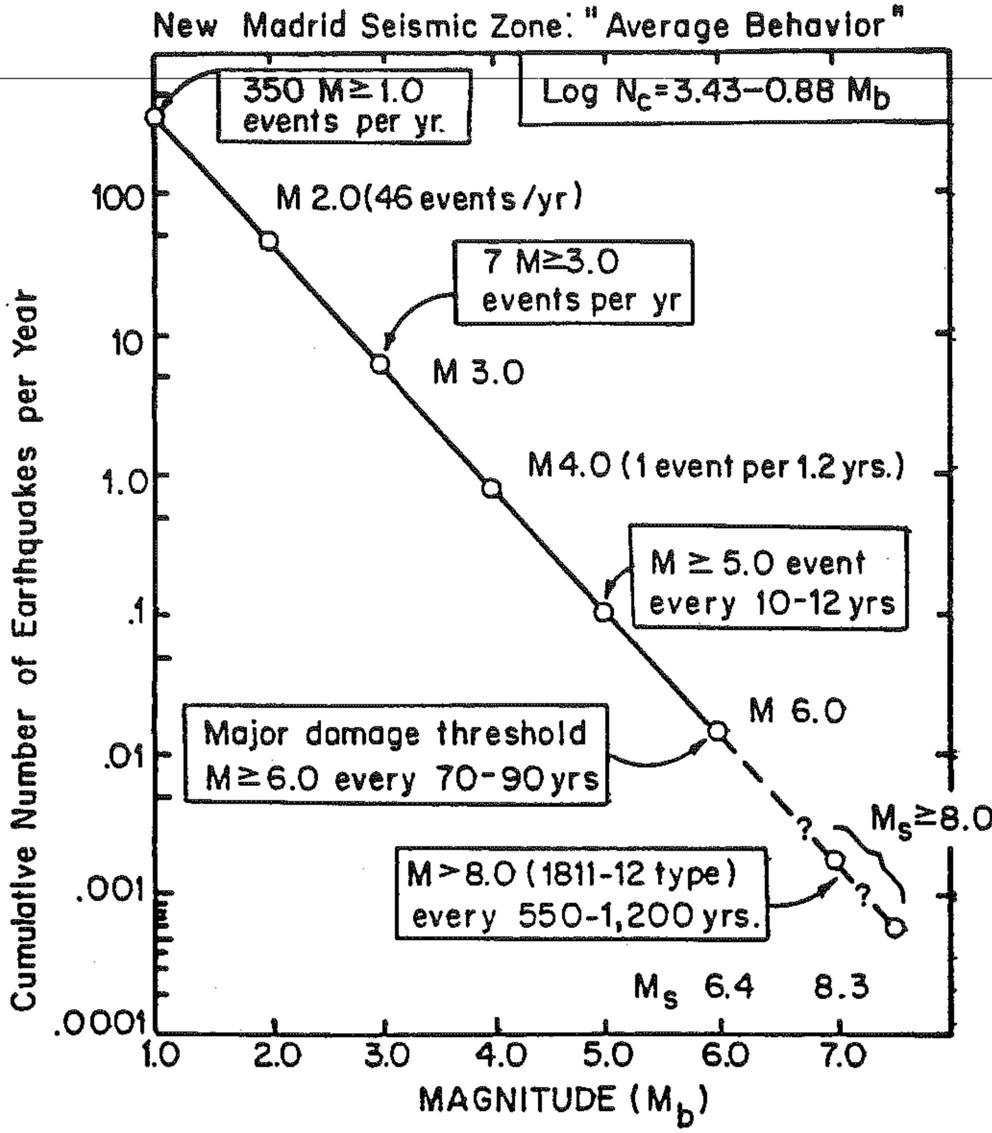



Figure 7. Frequency-Magnitude Curve for New Madrid Earthquakes (after Johnston, A.C., 1982)

**Table 1: MODIFIED MERCALLI INTENSITY SCALE**

Modified Mercalli Intensity Scale, 1956 Version

The following comments by Dr. Richter precede the published statement of the intensity scale:

...Each effect is named at the level of intensity at which it first appears frequently and characteristically. Each effect may be found less strongly, or in fewer instances, at the next lower grade of intensity; more strongly or more often at the next higher grade. A few effects are named at two successive levels to indicate a more gradual increase.

Masonry A, B, C, D. To avoid ambiguity of language, the quality of masonry, brick or otherwise, is specified by the following lettering.

Masonry A. Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar, reinforced by not designed in detail to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weakness like failing to tie corners, but neither reinforced nor designed against horizontal forces.

Masonry D. Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

The following list represents the twelve grades of the scale.

I. Not felt. Marginal and long-period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorable placed.

III. Felt indoors, Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.

V. Felt outdoors; direction estimated. Sleepers awakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken, Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken.

VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices. Same cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundation if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. Frame structures, if not bolted, shifted off foundations. Frames cracked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand crater.

X. Most masonry and frame structures destroyed with their foundations. Some will-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large land slides. Water thrown on banks of canals, river, lakes, etc. Sand and mud shifted horizontally on beaches and flat lands. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown in the air.

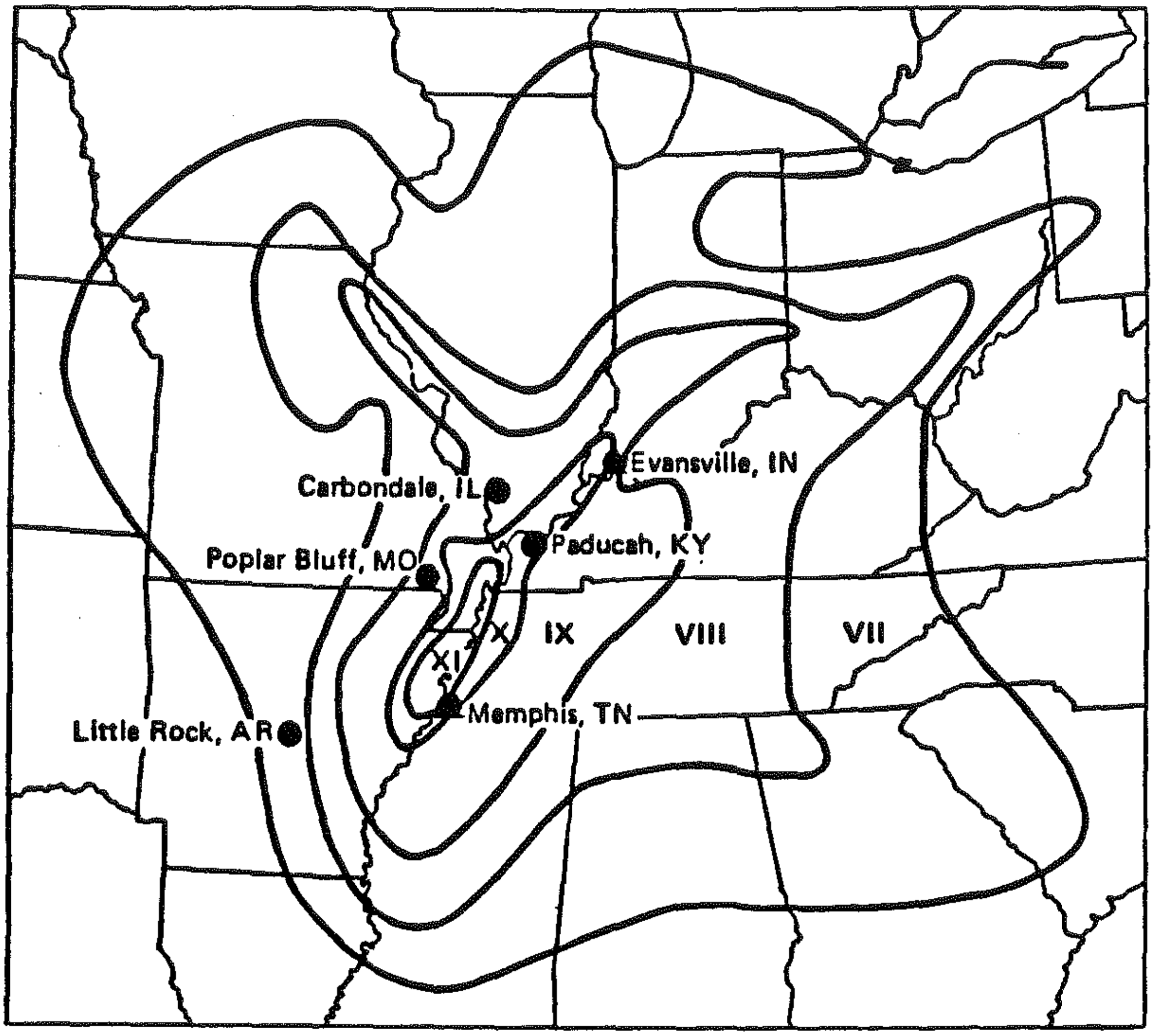



Figure 8. Location of New Madrid Seismic Zone and the Mercalli Modified Intensity Scale Suggesting the Possible Effects of an Earthquake as Severe as the 1811-1812 Quakes (Source--U.S. Geological Survey).

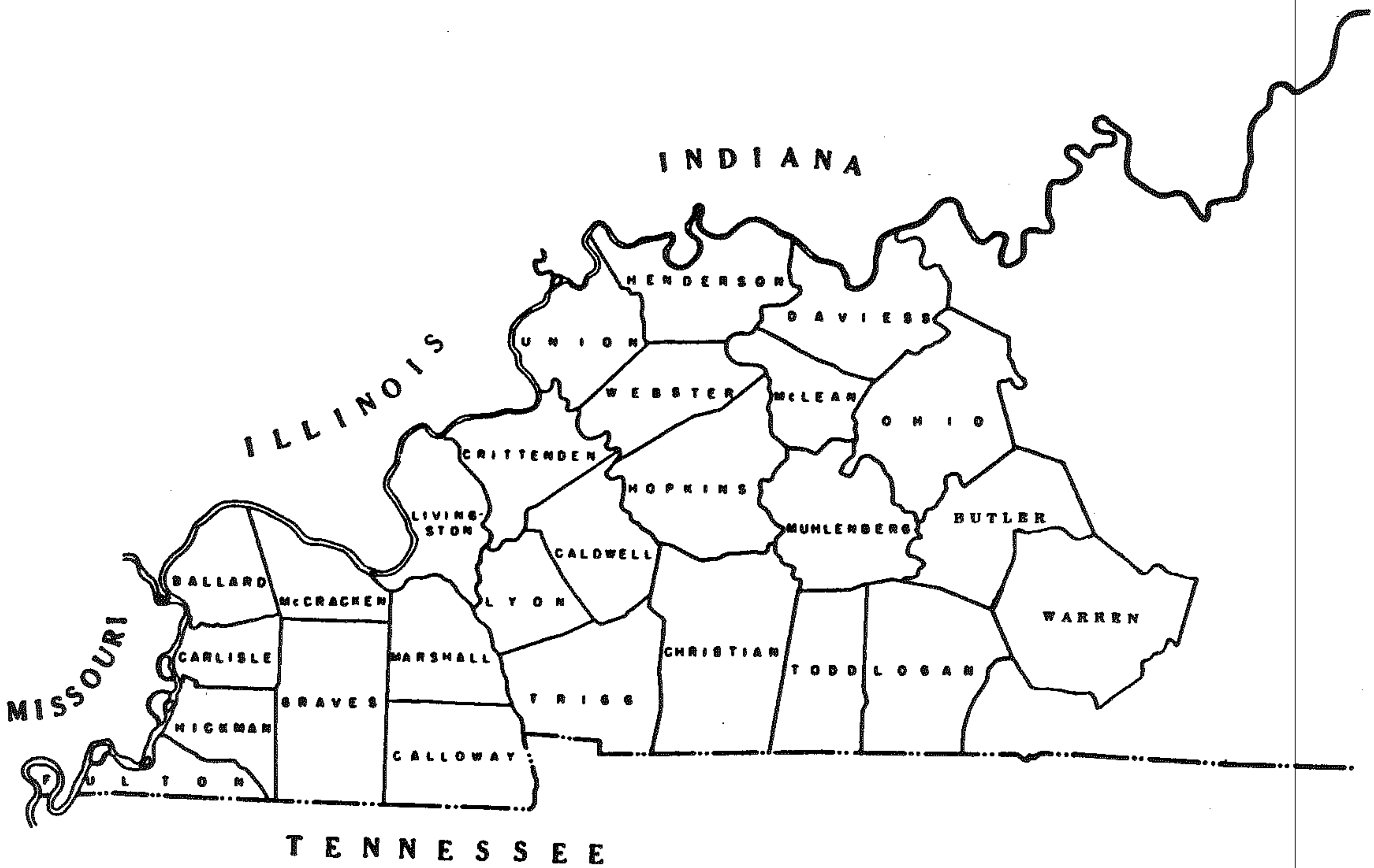



Figure 9. The Twenty-six Counties Included in This Study.

APPENDIX A
EARTHQUAKE TRAINING SEMINAR

## EARTHQUAKE TRAINING SEMINAR

The following is an outline for the suggested seminar.

I. BACKGROUND

A. History of Earthquakes

B. Behavior of Earthquakes

C. History of Earthquakes in Kentucky

D. Current Seismic Research

E. Earthquake Mitigation

1. CUSEPP

2. GEHSTAP

3. ESTS

4. Priority Routes

5. Data Base

6. Strip Maps

7. County Information

II. Bridge Retrofitting

III. Response Team

### A. History of Earthquakes

A great earthquake ranks as one of nature's most catastrophic and devastating events. Earthquakes and their related hazards have destroyed large cities and taken thousands of lives in a few seconds. In 1886, an earthquake in Charleston South Carolina claimed 60 lives and approximately $23 million in property damage. The 1906 San Francisco earthquake claimed 700 lives and $524 million in property damage. The 1964 earthquake in Alaska claimed 131 lives and $500 million in property damage. The San Fernando earthquake in 1971 claimed 65 lives and $553 million in property damage. The 1989 San Francisco earthquake claimed 62 lives. This is only a small portion of the recorded earthquakes which have occurred within the United States that have claimed thousands of lives and caused billions of dollars in property damage.

## B. Behavior of Earthquakes

Earthquakes occur as a result of the release of stress within in rock which was under strain. Breakage of rocks and resulting movement along a fault produces seismic waves. Primary and secondary waves travel within the rock layers and other more complex waves travel along the surface of the earth (1). Surface waves roll along the ground surface and create the greatest amount of damage to structures such as roads, buildings. bridges, etc.

The focus of an earthquake is the point within the rock where initial motion takes place and the epicenter is the point at the ground surface directly above the focus.

The strength of an earthquake is measured by its magnitude. Magnitude is determined as the amplitude of the largest wave which is recorded by a seismograph. The amplitude is measured on a logarithmic scale. An earthquake of magnitude of 7.0 would be 10 times greater than an earthquake of magnitude of 6.0.

Another means of measurement is by the Modified Mercalli Intensity scale (MMI). The MMI scale is a visual measurement of the earthquake intensity and damage. The scale ranges from I (no damage and felt only by instruments) to XII (total destruction). Details of the MMI scale are presented in Table 1.

The amount of damage which occurs as the result of an earthquake depends upon several variables. Magnitude of the earthquake, population density, seismic design codes, and the geology of the area (surface material) all have an effect upon total damage.

As shown in Figure 12, amplification of shaking at the earth's surface is greatly effected by the surface material (1). Basically the softer the surface material is the greater the shaking. For example, during the October 1989, earthquake in San Francisco more damage occurred around the Bay Area where buildings are constructed on old fill and Bay mud. This is one of the greatest concerns in Western Kentucky since numerous buildings are constructed upon loosely consolidated river deposits such as alluvium. Another problem that evolves during an earthquake is liquefaction. Liquefaction is a loss of soil support due to an increase in pore-water pressure due to intense shaking (such as an earthquake). This occurs commonly in soils that are highly saturated. During liquefaction, the soil changes form from a solid to a liquid. The resulting change is a loss of soil support. A number of structures in Western Kentucky rely upon the soil for support. Structures constructed upon loosely consolidated soils such has muds, silts, and sands will stand a greater chance of being damaged during an earthquake.

## C. History of Earthquakes in Kentucky

In 1811-1812, three of the most severe earthquakes in American history shook the country. The location of these quakes was near a small town on the Mississippi River where the state of Kentucky and Missouri share a border. It is this river town, New Madrid, Missouri, that is the namesake of a region now regarded by seismologists and disaster response planners as the most hazardous earthquake zone east of the Rocky Mountains--the New Madrid seismic zone (Figure 2).

Between 1811-1812, hundreds of tremors were felt until March 15, 1812. During this period, three series of shocks struck the New Madrid region. These had magnitudes of 7.5, 7.3 and 7.8 (Richter Scale). Ground motion waves of eight feet in height and sand spewing like geysers from the ground were reported. The most remarkable and permanent occurrence of the 1811-1812 earthquakes was the creation of Reelfoot Lake in Western Tennessee. For a time, the course of the Mississippi reversed. On February 12, 1812, the river apparently rose above and below New Madrid and which caused a temporary change in course.

Until July, 1980, Kentucky officials had done very little to prepare for the effects of a major earthquake. A 5.2 earthquake struck in northern Kentucky, approximately 50 km east-northeast of Lexington near the small Kentucky town of Sharpsburg on July 27, 1980. Major damage occurred in Maysville approximately 50 km from the epicenter. It is theorized that ground motion in Maysville was amplified 2 to 3 times due to the underlying alluvium.

The Sharpsburg earthquake was the result of right-lateral, strike slip movement along a fault. The Sharpsburg quake has little seismic correlation with the New Madrid Fault Zone. The Sharpsburg quake demonstrated the vulnerability of all of Kentucky to potentially damaging quakes and high potential for damage to occur in area's constructed over alluvial deposits. The area in most eminent danger and therefore of greatest concern is that surrounding the New Madrid seismic zone.

### D. Current Seismic Research

In addition to these three great earthquakes, there are several other well documented factors demonstrating the susceptibility of the New Madrid region to the recurrence of major earthquakes. Through a decade of extensive research, an ancient crustal rift has been found to underlie the relatively shallow sediments comprising the region's surface. This type of geologic structure is prone to seismic activity. The New Madrid rift, also known as the Reelfoot Rift Complex, has been identified as being of sufficient size to generate major earthquakes (Figure 3 and 4). Further evidence of the area's seismicity is the 488 earthquakes greater than a magnitude of 3 that have been recorded between 1811 to mid 1974 (Figure 5). Over 2,000 earthquakes have been detected in the zone since 1974 (Figure 6). Though most have been of a magnitude below the threshold of human perception, their existence clearly indicates the high level of seismic activity occurring in the zone.

Seismologists have calculated the probabilities of recurrence of sizeable earthquakes in the New Madrid rift zone. The probability of a magnitude 6.3 earthquake (Richter scale) within 50 years is from 86 to 97 percent. The probability of that same earthquake occurring within the next 15 years is from 40 to 63 percent. For comparison, the 1971 San Fernando earthquake (magnitude 6.6) killed 58 people and caused $480 million worth of damage. The 1988 Armenian earthquake of similar magnitude killed approximately 25,000 to 30,000 people.

The probability of a magnitude 7.6 earthquake occurring within 50 years is from 19 to 29 percent. The probability for this size earthquake occurring within 15 years drops to a range of 5.4 to 8.7 percent. On February 4, 1975, the Haicheng earthquake in China had a magnitude of 7.3 and destroyed or damaged about 90 percent of the structures in a city of 90,000 people. Figure 7 shows the cumulative number of different magnitude earthquakes a year that occur in the New Madrid Seismic Zone.

## E. EARTHQUAKE MITIGATION

### 1. CUSEPP

In 1981, the Federal Emergency Management Agency (FEMA) initiated the Central United States Earthquake Preparedness Project (CUSEPP) to help state governments increase their capability to respond to damaging earthquakes, to promote mitigation activities, and to encourage cooperation between state in the area of emergency planning.

### 2. GEHSTAP

In 1984, Governor Collins created the Governor's Earthquake Hazards and Safety Technical Advisory Panel (GEHSTAP) to analyze scientific and engineering data regarding seismic risks in Kentucky and to make specific recommendations on mitigation, public awareness, response planning, and policy development for public health and safety.

### 3. ESTS

The States are dependent upon their highway systems for the movement of goods and services. Due to the possible adverse effects that a major earthquake could have on this system, the Earthquake Stability and Transportation Subcommittee (ESTS) of GEHSTAP was formed. ESTS encouraged the Kentucky Transportation Cabinet officials to secure funding for generating and implementing an earthquake hazard mitigation plan in an attempt to safeguard the highway system against catastrophic earthquake failure. As a result, Cabinet officials commissioned Kentucky Transportation Center investigators at the University of Kentucky to analyze and assess the possible effects of an earthquake on highway facilities.

### 4. Priority Routes

Over 1,000 miles of highways have been selected to be utilized as emergency or priority routes (Figure 10). These would be the primary routes used for transporting emergency supplies and personnel after the occurrence of an earthquake. It is anticipated that these would be the first routes repaired after the occurrence of an earthquake. The priority routes were visually surveyed and all natural and man-made features along these routes that are considered seismic significant were cataloged. This includes dams, pipelines, power lines, high fills, cut slopes, buildings, mines, bridges, trees, faults, etc.

The initial task in identifying these priority routes was to decide where they should begin; that is, in the event of a major earthquake, the point at which the transport of goods and services should originate. The city chosen should possess the following attributes:

1. Sufficient size to contain all necessary personnel, supplies, and facilities to respond quickly to a major emergency;

2. Proximity to the high hazard area to speed the relief effort but not so close as to suffer the same high risk potential;

3. Easy access from other major cities within the State; and

4. Sufficient routes to provide relatively direct access to all 26 high-risk counties.

The city best fitting these criteria is Bowling Green. Located at the eastern edge of the earthquake zone in Warren County, Bowling Green meets both the size criterion (population 40,450) and the accessibility criterion (Louisville and Nashville via I 65 and Lexington via the Bluegrass Parkway). Bowling Green provides access to the 26-county area via US 68/KY 80; this road was chosen as the main east-west artery because it crosses Lake Barkley and Kentucky Lake upstream from the dams impounding those bodies of water. Additional priority routes were added on the upstream side of Lake Barkley and Kentucky Lake through northern Tennessee (Figure 11).

## 5. Strip Maps

Strip maps were compiled upon completion of the visual survey of the priority routes. Compilations were made in a strip manner (10 miles per page) with mileposts increasing up the page. Each feature identified during visual surveys is shown in symbol form beside the appropriate mile point number. Feature locations are rounded to the nearest tenth of a mile (Figure 13). These maps were produced in two formats, one separating them by route and the other separating them by county. This will enable relief personnel examining the maps to be aware of all potential hazards that may be encountered along the entire length of a priority route as well as making it possible to distribute maps to county officials showing just those seismically significant features under their jurisdiction.

## 6. Data Base

The priority route data base was entered on an IBM Lap Top computer. The data were entered into a DBASE program called QUAKE5. The QUAKE5 program establishes separate files for each priority route. The entire data base in QUAKE5 was then loaded into a program called COMBINED which enables the user to sort the files by county and route. A program called DETAIL 8 which produces the county reports uses the data in the COMBINED data file and converts them into a standard data file to be used in WordPerfect. The entire data file contains 292,320 bytes of information.

## 7. County Information

Individual reports were prepared for each of the 26 counties. Each report contains a short history about earthquakes in Kentucky and discusses the probabilities of an earthquake. The reports also introduces the Modified Mercalli Intensity scale which illustrates the damage that could occur today if we had an earthquake similar to the 1811-1812 earthquakes (Figure 14). The reports introduce the priority route for each county, lists all seismically significant features along the priority routes in each county, and discusses each feature in some detail (Figure 15). All the seismically significant features were also logged on strip maps. An alluvial map showing location of weak soil is also included in each report (Example Figure 16).

# II. BRIDGE RETROFITTING

Within the 1,000 miles of priority routes, 276 bridges have been cataloged. With few exceptions, existing highway bridges in the study area have not been designed to resist motions and forces that may be generated by earthquakes. According to the seismic analysis, 111 bridges have been determined to be possibly unsafe during a major earthquake. Figure 17 shows the number of unsafe bridges on the priority route system for each county.

Kentucky officials are considering retrofitting highway bridges against the possible damage that could be sustained by an earthquake generated by the New Madrid Fault Zone. Information gathered by California investigators has been used in these analyses.
An earthquake measuring 6.6 on the Richter scale did extensive damage in Sylmar and the surrounding area in the northwest San Fernando Valley of Los Angeles County on February 9, 1971. Approximately $15 million of damage was done to the highway system. Half of that damage was on bridges. In 1971 California Highway Department officials established a bridge retrofitting plan. California officials identified 12,500 state bridges, of which 1,259 were judged to need retrofitting. Retrofit work was completed on 702 structures at an average cost of $41,262 per bridge as of June 21, 1983.

### Retrofitting Philosophy

The goal of retrofitting is to increase the seismic resistance of a bridge to minimize the probability of total collapse and should eliminate or reduce the hazard to human life as much as possible. Bridges on critical routes should be capable of carrying emergency vehicles after damage. It is not practical or economically feasible to retrofit a bridge so that it will have the same seismic resistance as a new structure designed to current seismic specifications.

### What Type of Bridge Should Be Considered for Retrofitting ?

Single span square structures should not normally require retrofitting (Figure 18).

Skewed bridges have a tendency to rotate. Longitudinal seismic forces produce transverse components of force which tend to rotate the span each time it moves back and forth. Longer structures are more likely the to rotate from their bearings. Long narrow structures having narrow support seats stand a greater chance of catastrophic failure (Figure 19). If a bridge is wide in relation to its length, it may be locked between its abutments so that the rotation is negligible if the force is longitudinal. Transverse Shaking may damage the bearings, Shear keys, of curtain walls (Figure 20).

Long, continuous, non-skewed bridges having diaphragm type abutments without intermediate hinges or joints should not require retrofitting. Bridges having bearings at the abutments may require transverse restrainers (Figure 21).

Long, simply supported, non-skewed, multi-span bridges having narrow seats less than 6-inches probably should be retrofitted (Figure 22).

Long, continuous, skewed or curved bridges without intermediate hinges or joints are more prone to seismic damage than similar square bridges (Figure 23). Structural segments which are not adequately restrained act independently and may tend to separate when shaken.

Sharply curved bridges which have seismically inadequate bearings at an abutment and which have very flexible or seismically deficient columns may require additional restraint at the abutments.

Long continuously reinforced concrete slab bridges normally do not need to be retrofitted. This is based upon the assumption that if the suspended span becomes unseated the deadload of the resulting cantilever will not be sufficient to make it fail. Any bridge having large steel support bearings should be considered for retrofitting.

### Methods of Retrofitting

It is not practical to attempt to alleviate all potential earthquake damage to the majority of these structures because of their age. There are several methods of retrofitting that are available. Lead cored isolating bearings can be purchased but at a high cost (Figure 24). The best suited and most cost effective retrofitting would be using cable and bar restrainers (Figure 25), diaphragms, and catch blocks (Figure 26).

California officials initiated a retrofitting program in 1971. In July 1989, California personnel forwarded University of Kentucky investigators the latest retrofitting procedures. California retrofitting relies heavily on cable and bar restrainers. There was concern by the authors, since the San Francisco earthquake in October 1990 that retrofitting methods that had previously been used may not have been effective. However, California officials, have verbally indicated that approximately 848 retrofitted bridges were in the area most effected by the earthquake. Of those 848 bridges, only one received considerable damage, and that has since been graded to minor damage. It appears that cable and bar restrainers are effective and practical means of retrofitting bridges against earthquake motions.

## III. ESTABLISH A RESPONSE TEAM

A plan should be developed for post earthquake response. In addition to training state and local personnel about earthquakes and mitigation. An information gathering center and a command post should be established at Bowling Green for the entire priority route system for post earthquake response. The District 3 Chief District Engineer should be in charge of gathering information on the condition of the priority routes from the 26 counties after a major earthquake. District 3 office personnel should have an up to date map of the entire priority route system listing critical features. Priority routes that are drivable should be marked on the up dated map in green and red showing failures (closures) as information is gathered from the 26 counties concerning conditions. Bowling Green District office personnel work closely with the Red Cross, DES, and the National Guard to help with the movement of goods and services into the earthquake stricken zone.

A post-earthquake response group should be selected to estimate damage sustained by the priority routes. The group would consist of state personnel and local firms consisting of engineers, inspectors, and maintenance personnel that would evaluate the damage done to the surrounding priority routes. This information should be channeled to the District 3 Office. The groups would report the condition of the priority routes and if necessary, an estimate of repair time involved would be made. The group would also designate detour routes if needed and report those routes to officials in Bowling Green and the surrounding area's. This group would then report to the construction squad the location of damage to priority routes. Every county that has a priority route should have an evaluation group and a construction squad for emergency response.

The construction squad would consist of engineers and construction and maintenance personnel who make repairs or clear the priority routes. They would relay information on repair time and construction progress back to the District 3 Office.

**Post Earthquake Response (Equipment)**

Post earthquake response time would depend upon communication and equipment availability. It is highly probable that telephones will be out of service for a considerable amount of time after an earthquake. An emergency radio service should be established between the districts and counties, with all counties capable of contacting Bowling Green. All priority routes should be marked each mile with delineated posts and some a marker on the road surface showing the priority route, county and the milepost. All bridges on the priority routes should also be marked in some manner. It is probable that estimators and construction personnel may have to be brought into an area and might be unfamiliar with the priority routes. Each evaluation group should be outfitted with equipment for inspecting the routes.

**Estimators (equipment list)**

1. Helicopter
2. FWD Vehicles
3. ATV
4. Radio
5. Priority route map
6. Instamatic Camera
7. Portable raft
8. Binoculars
9. Inspection gear (ropes, harness, ladder)
10. Rating sheet
11. Flashlights, and emergency lighting
12. Chain saw for clearing downed trees

**Construction Group (equipment list)**

1. Heavy equipment (Trucks, backhoes, dozers, cranes)
2. Floating bridges
3. Construction supplies (I-beams, stockpiles of aggregate, culvert pipes, etc.)
4. Chain saws for clearing obstructions
5. Emergency lighting

It is possible that estimators and construction personnel may not be able to respond due to transportation problems, and/or personal problems after an earthquake. It may be possible the two groups will have to work together. Additional personnel and equipment should be obtained from the private sector.

After establishing the post earthquake response plan, training seminars should be conducted two times yearly. An earthquake drill should be conducted yearly.

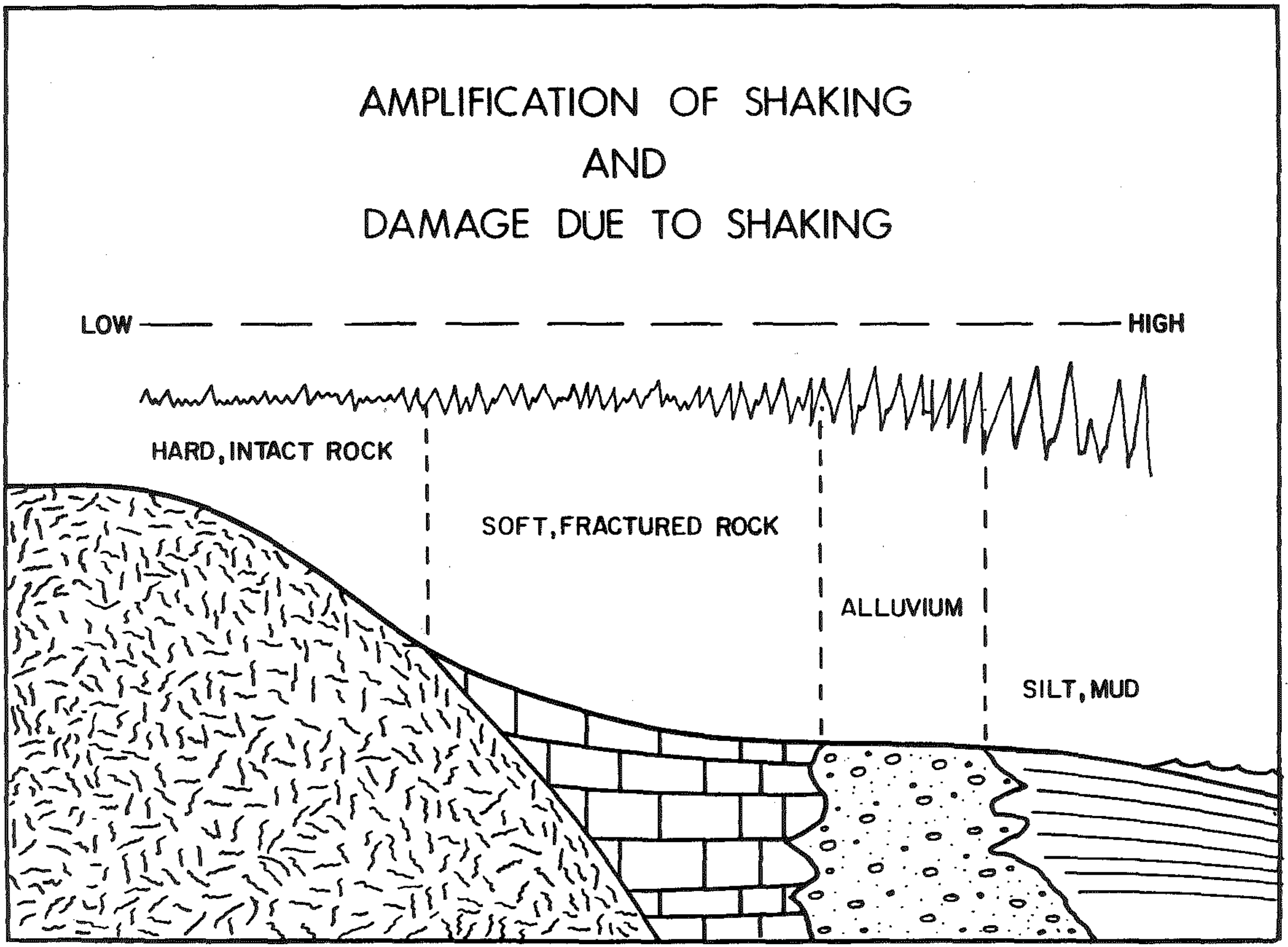



Figure 12. Amplification of Shaking in Softer Rock and Soil during an Earthquake.

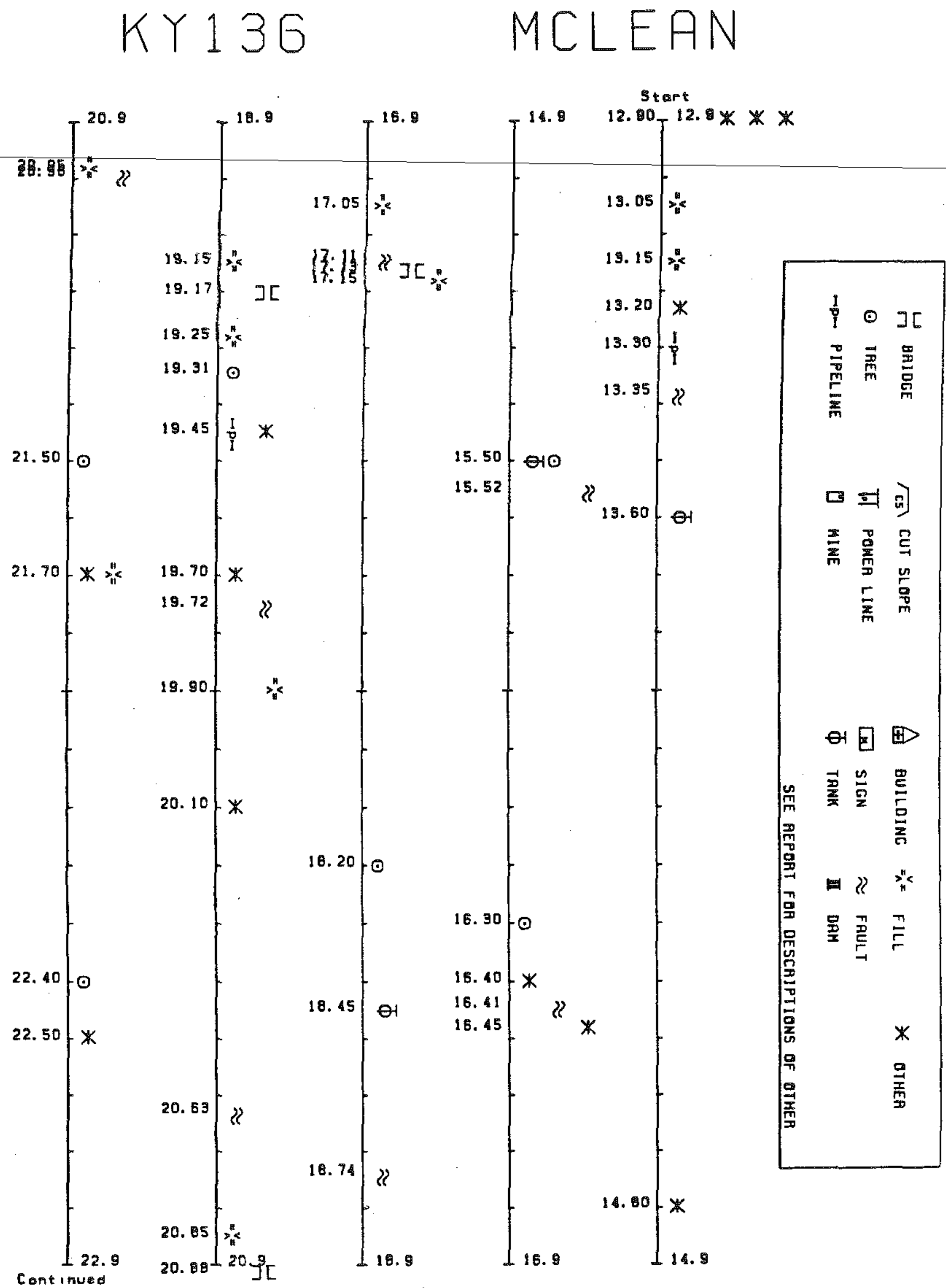



Figure 13. Strip Map.

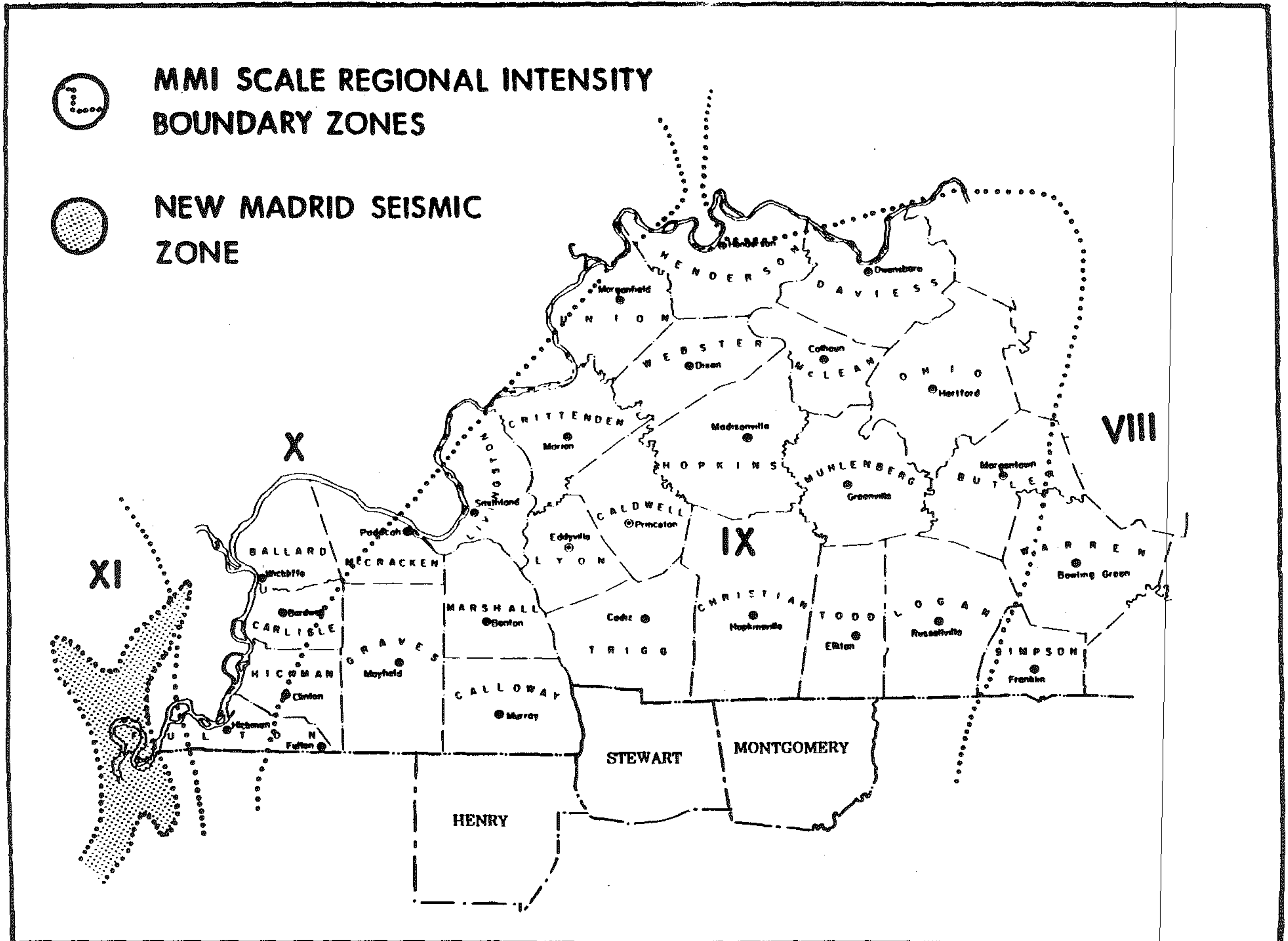



Figure 14. The Twenty-six Counties in Kentucky, and the Three Counties in Tennessee are Included in this Study.

Report by County and Milepost
for McLean County - Kentucky
KY 136

| Milepoint | Feature | Data |
|---|---|---|
| 19.31 | Trees | Number of Trees 200 Height 30 feet<br>Diameter 18 in. Ending Milepoint 19.70<br>Distance From Road 15 feet<br>Road Surface Type - Flexible |
| 19.45 | Pipeline | Pipeline Type - Gas<br>Road Surface Type - Flexible |
| 19.45 | Other | Gas Shutoff Valve 300 feet South of Road<br>Road Surface Type - Flexible |
| 19.70 | Other | Pond: 25 feet from Road, (150 x 200) feet<br>Road Surface Type - Flexible |
| 19.72 | Fault | Fault |
| 19.90 | Fill | Material Type - Soil Height 15 feet<br>Side slope 2:1 Length 70 feet<br>Crest 25 feet Type Fill - Other<br>Road Surface Type - Flexible |
| 20.10 | Other | Caved Mine Adits<br>Road Surface Type - Flexible |
| 20.63 | Fault | Fault |
| 20.85 | Fill | Material Type - Soil Height 15 feet<br>Side slope 2:1 Length 200 feet<br>Crest 25 feet Type Fill - Other<br>Road Surface Type - Flexible |
| 20.88 | Bridge | Number of Spans 7 Over Stream Concrete T-Beam<br>End 1 Fixed Pier 1 Fixed Pier 2 Fixed<br>Pier 3 Fixed Pier 4 Fixed Pier 5 Fixed<br>Pier 6 Fixed End 2 Fixed<br>Deck Type - Concrete Length 253 feet<br>Width 19 feet Pier Type - Solid<br>SPC Rating - B Surface Type - Flexible<br>Expansion Type - Other<br>End 1 Substructure - Stub<br>End 2 Substructure - Stub<br>Foundation Type - Unknown |

Figure 15. Data Base from County Report.

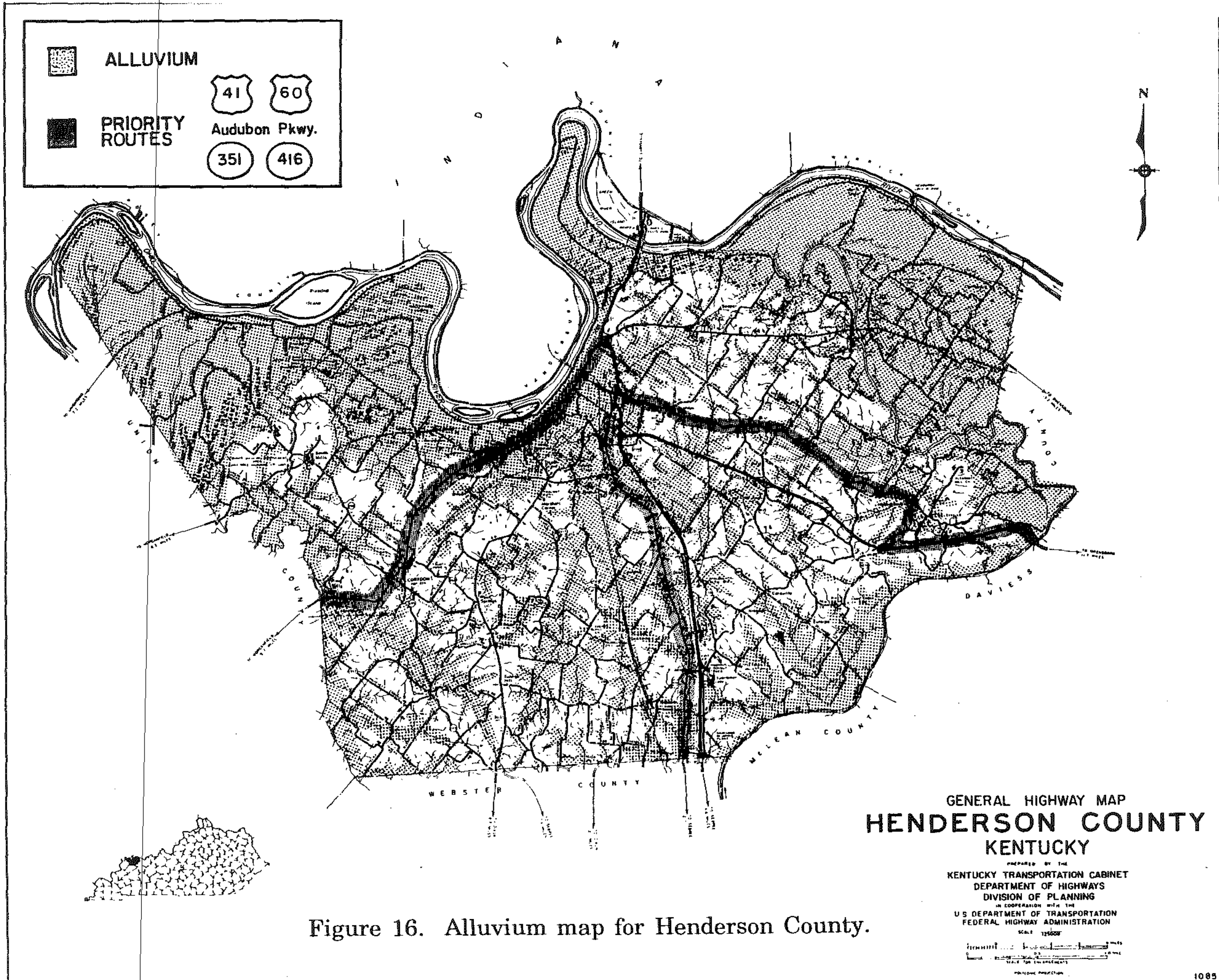



Figure 16. Alluvium map for Henderson County.

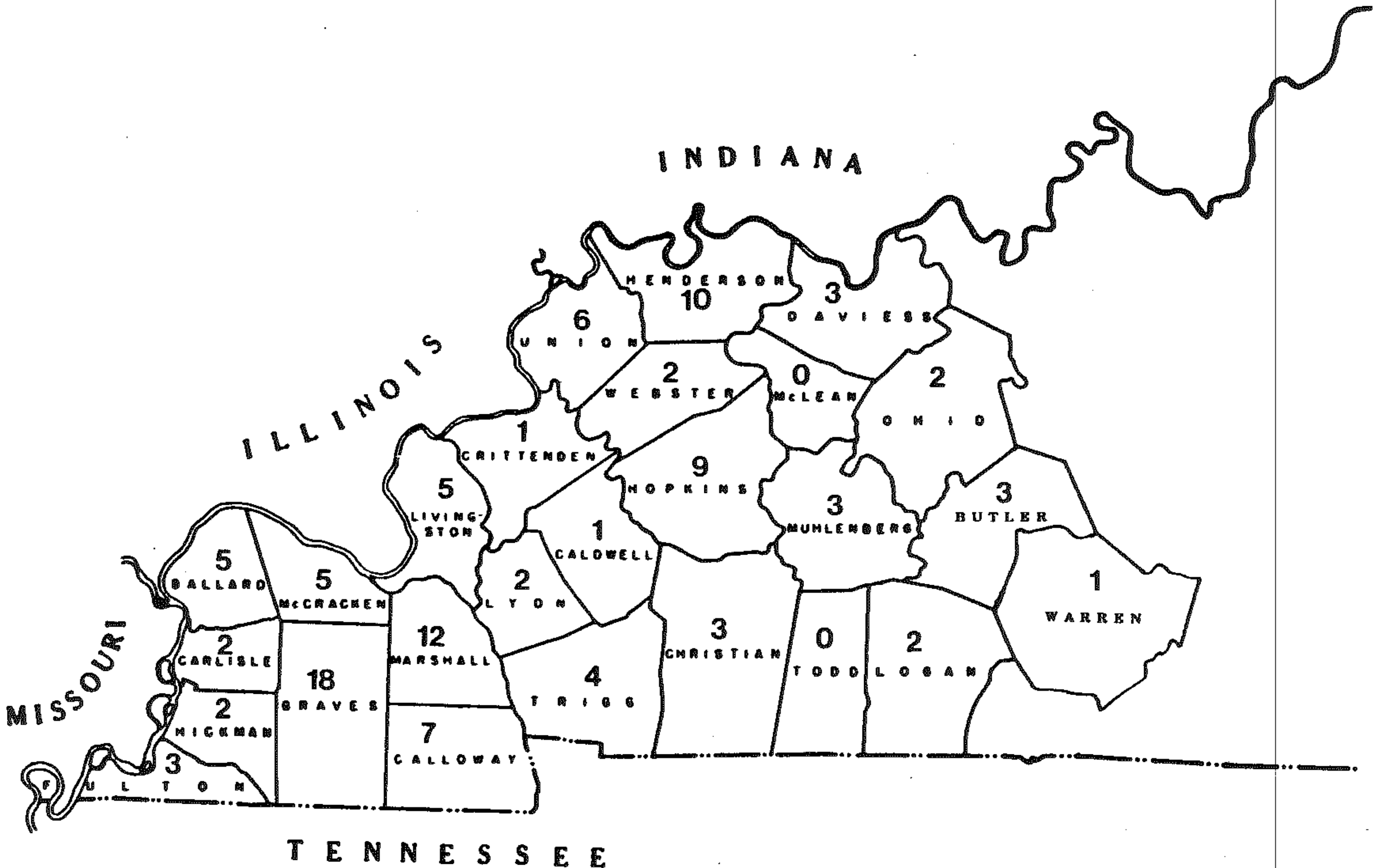



Figure 17. Number of Unsafe Bridges for Each County in Priority Route System.

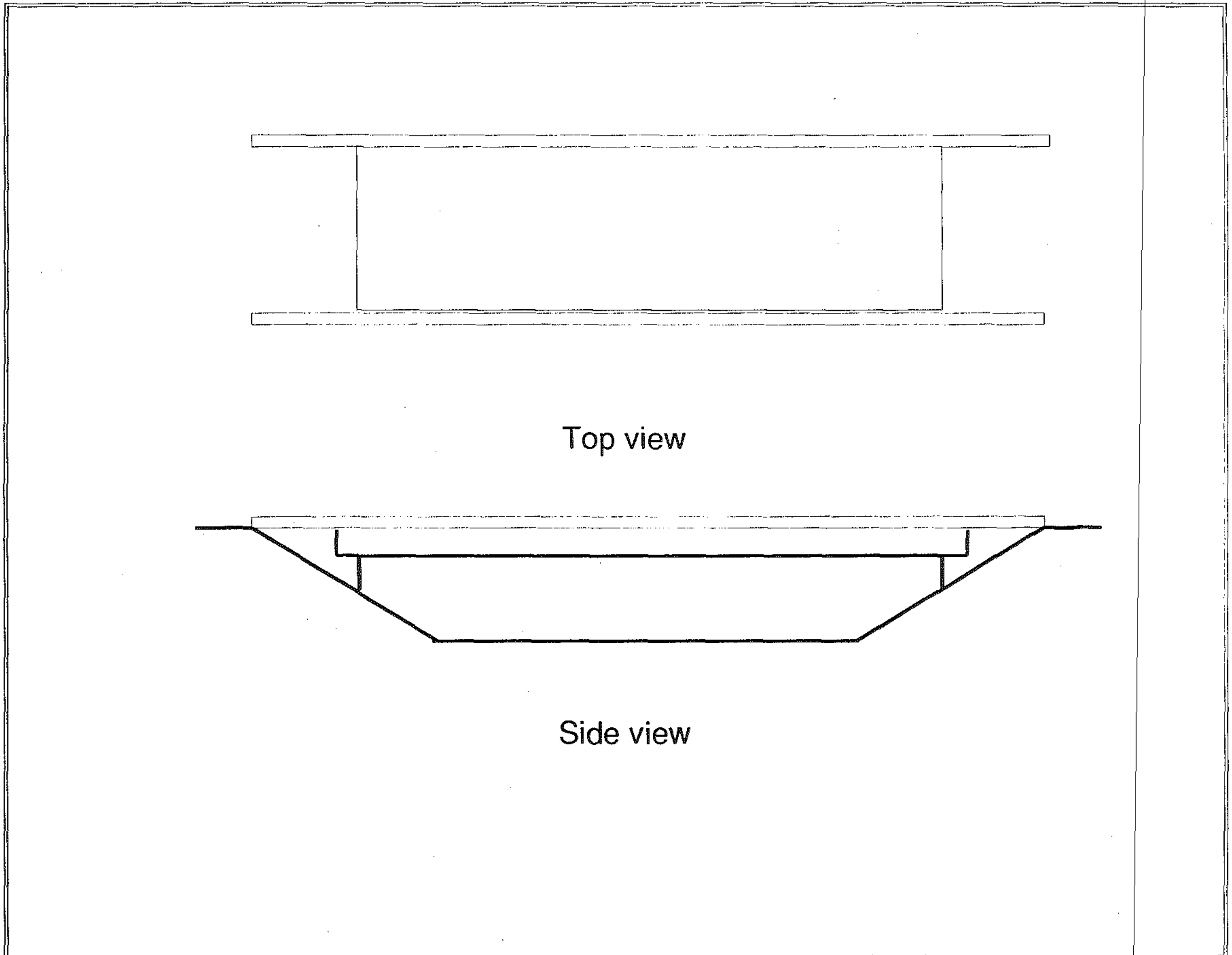



Figure 18. Single Span Square Structure Will Need Little if Any Retrofitting.

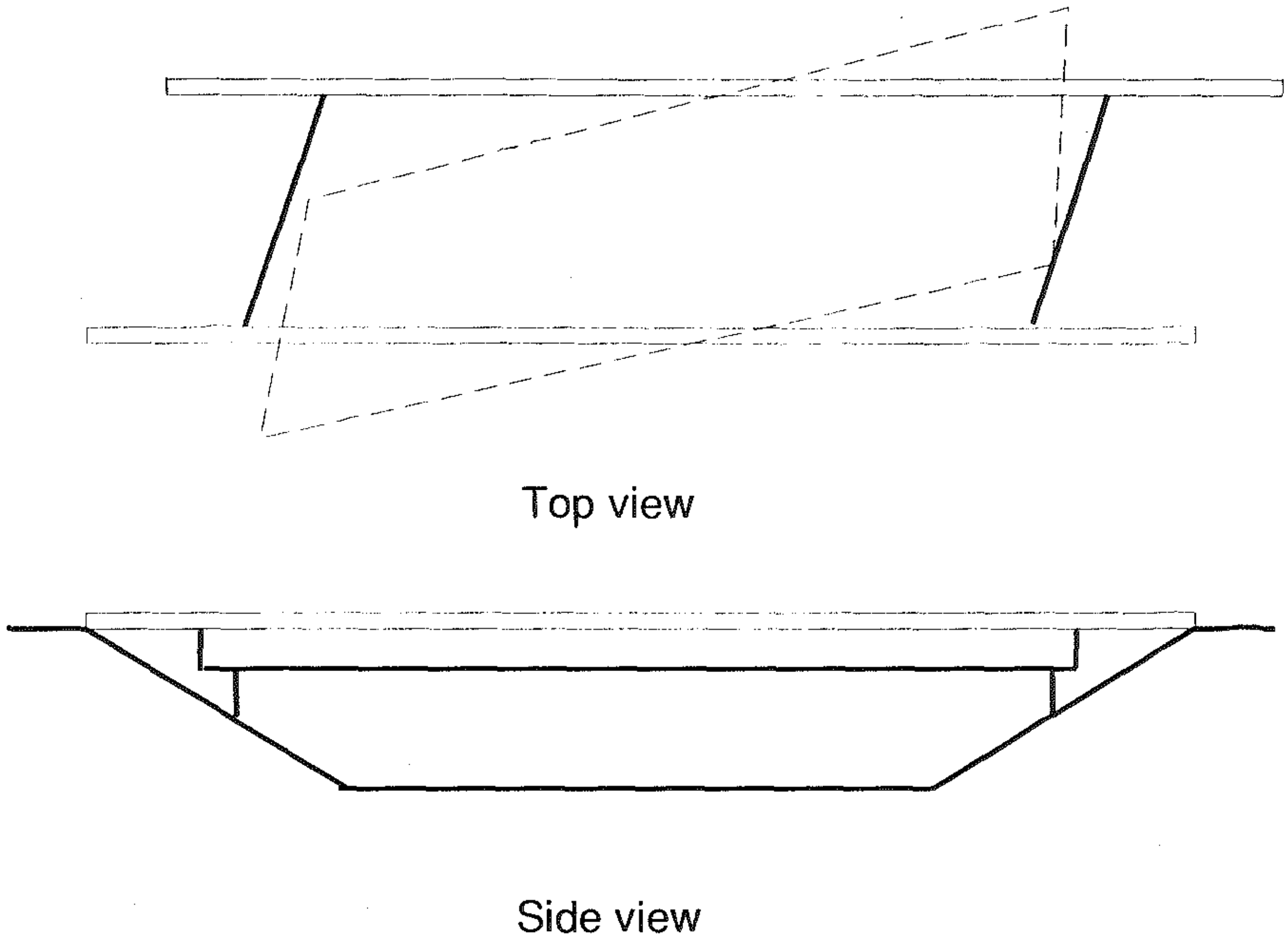



Figure 19. Skewed, Long Narrow Structure with Narrow Support Seats Are Prone to Rotate.

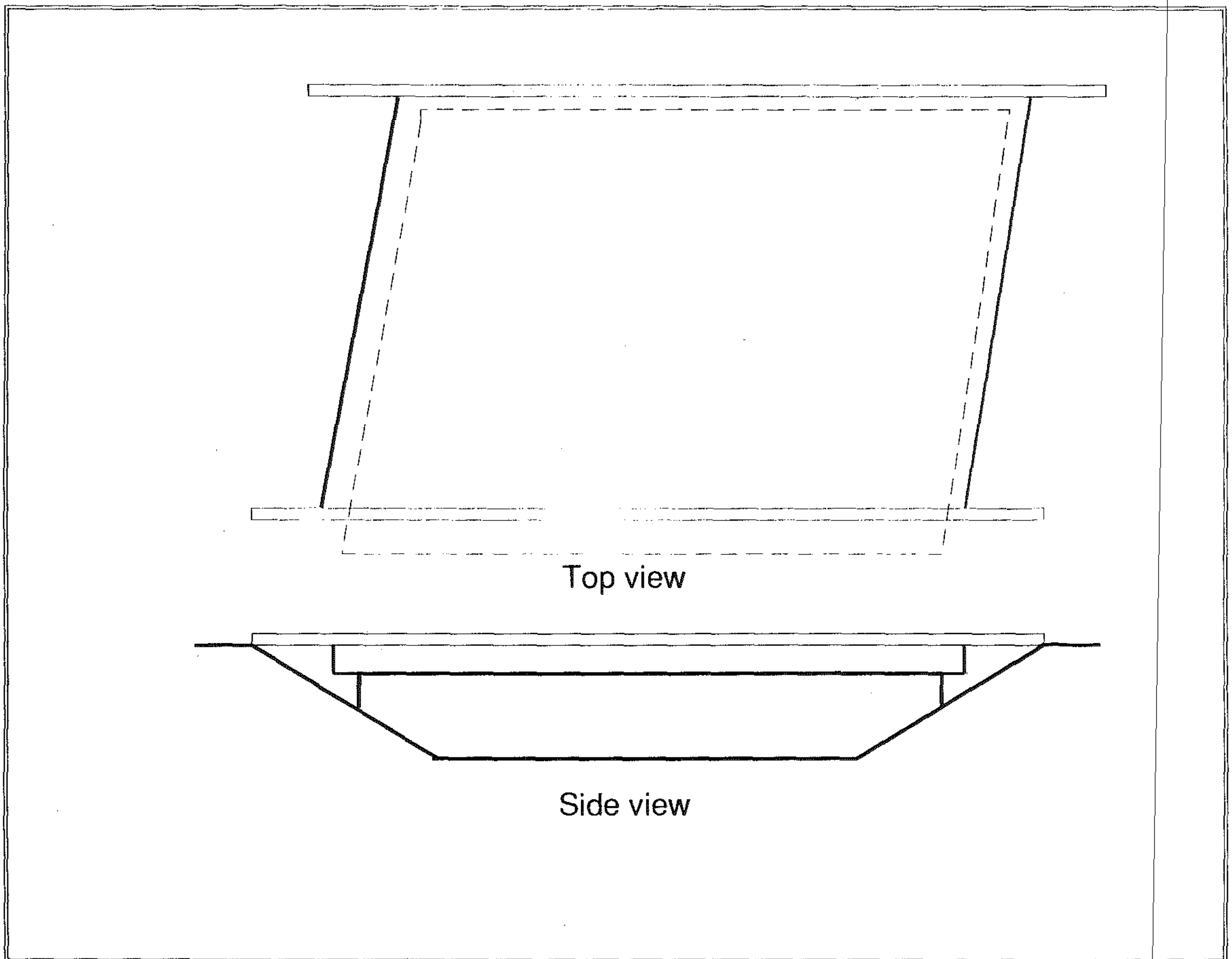



Figure 20. Transverse Shaking may Damage the Bearings, Shear Keys, or Curtain Walls in Skewed Bridges that Are Wide in Relation to Their Links.

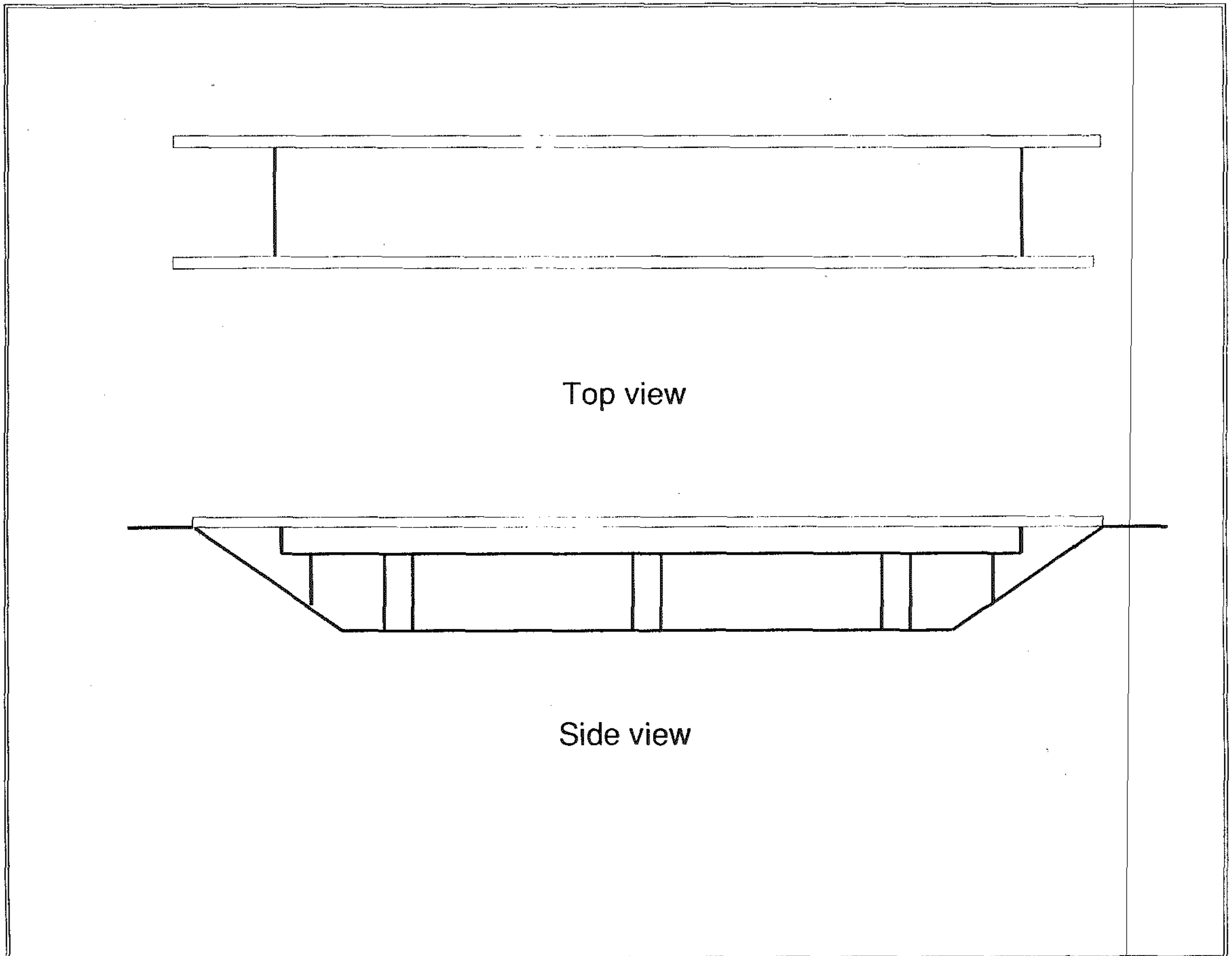



Figure 21. Long, Continuous, Non-Skewed Bridges will Need Little if any Retrofitting (depends on type of bearing).

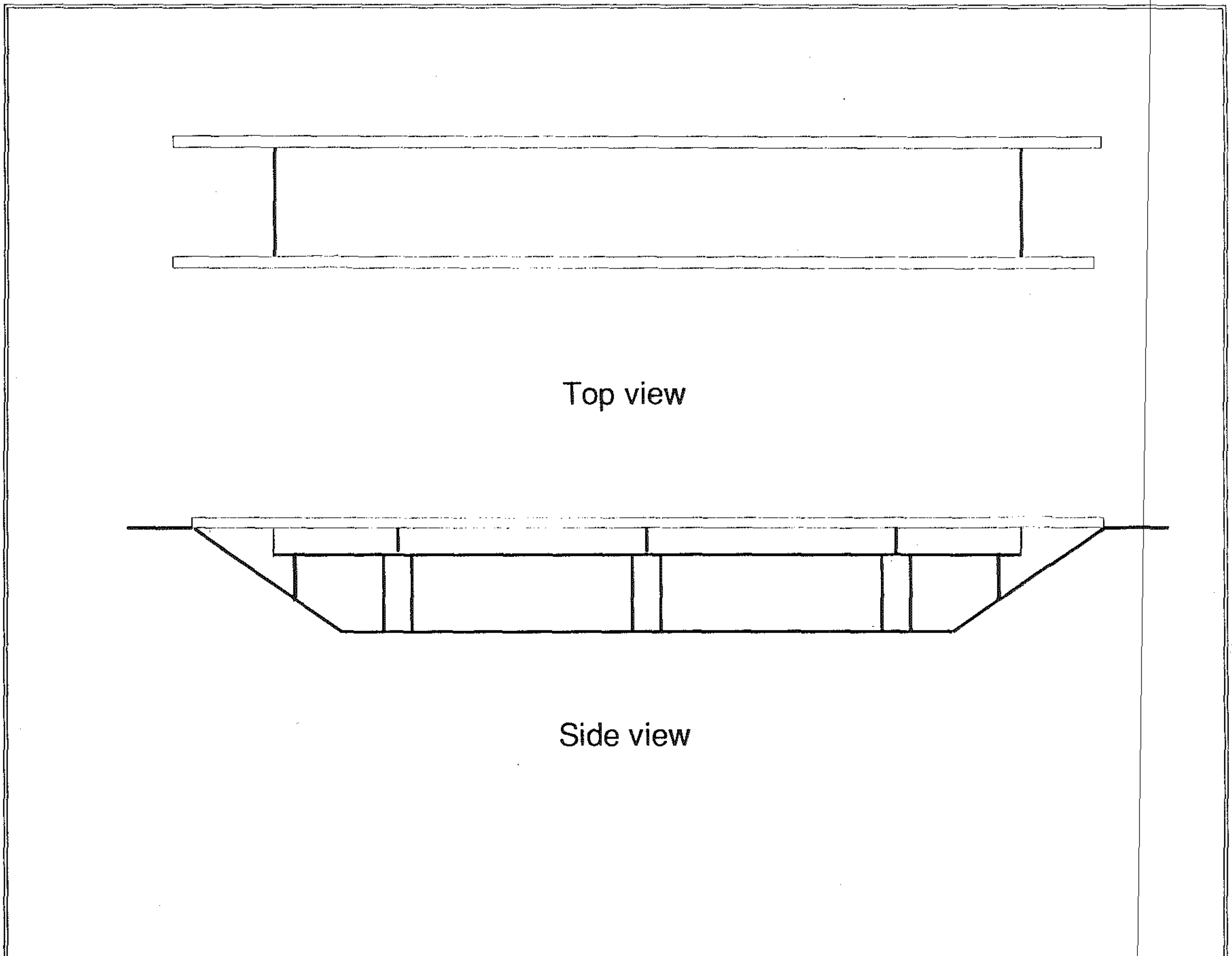



Figure 22. Long, Simply Supported, Non-Skewed, Multi-Span Bridges Usually will need to be Retrofitted.

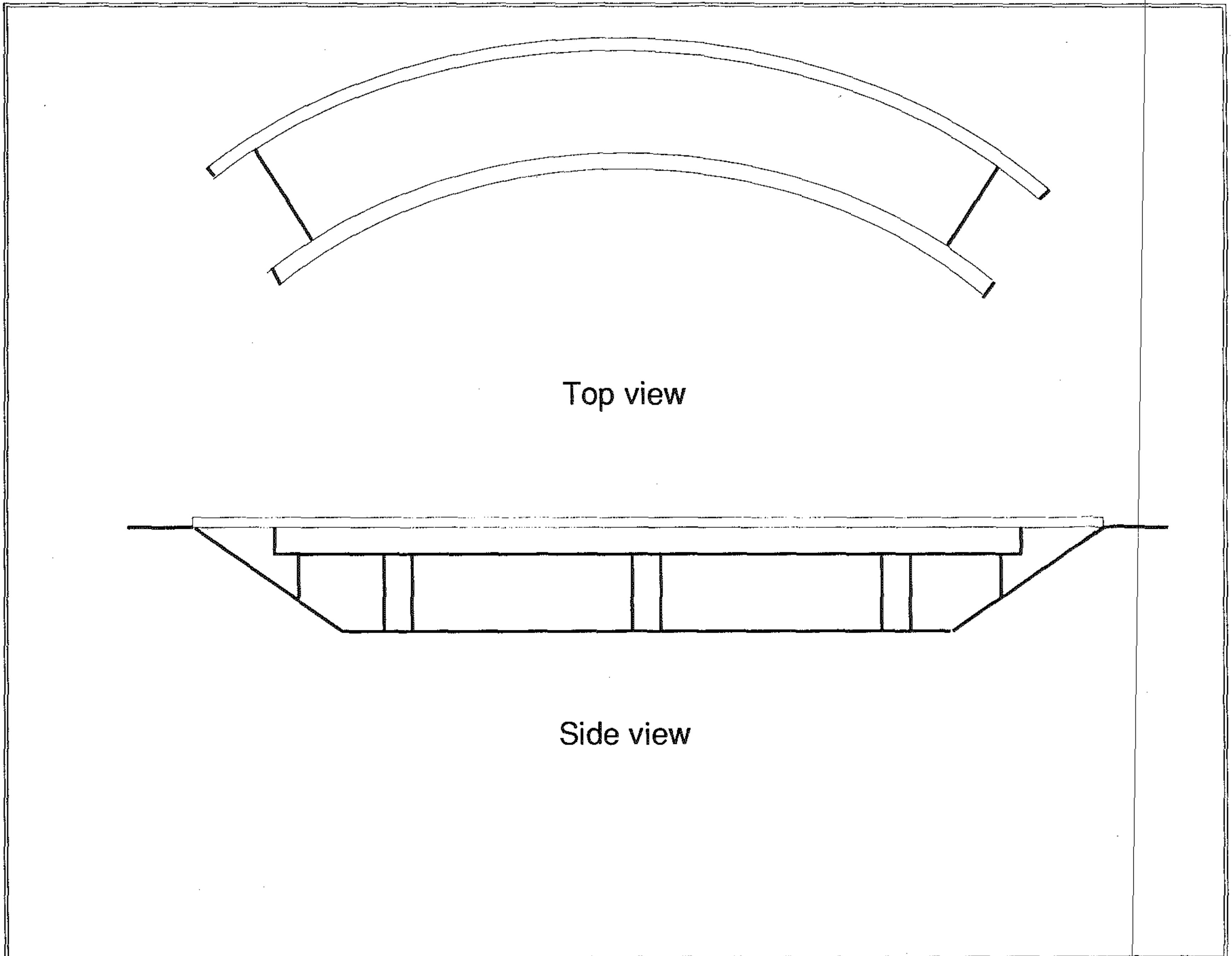



Figure 23. Long, Continuous, Curved Bridges will Need Retrofitting.

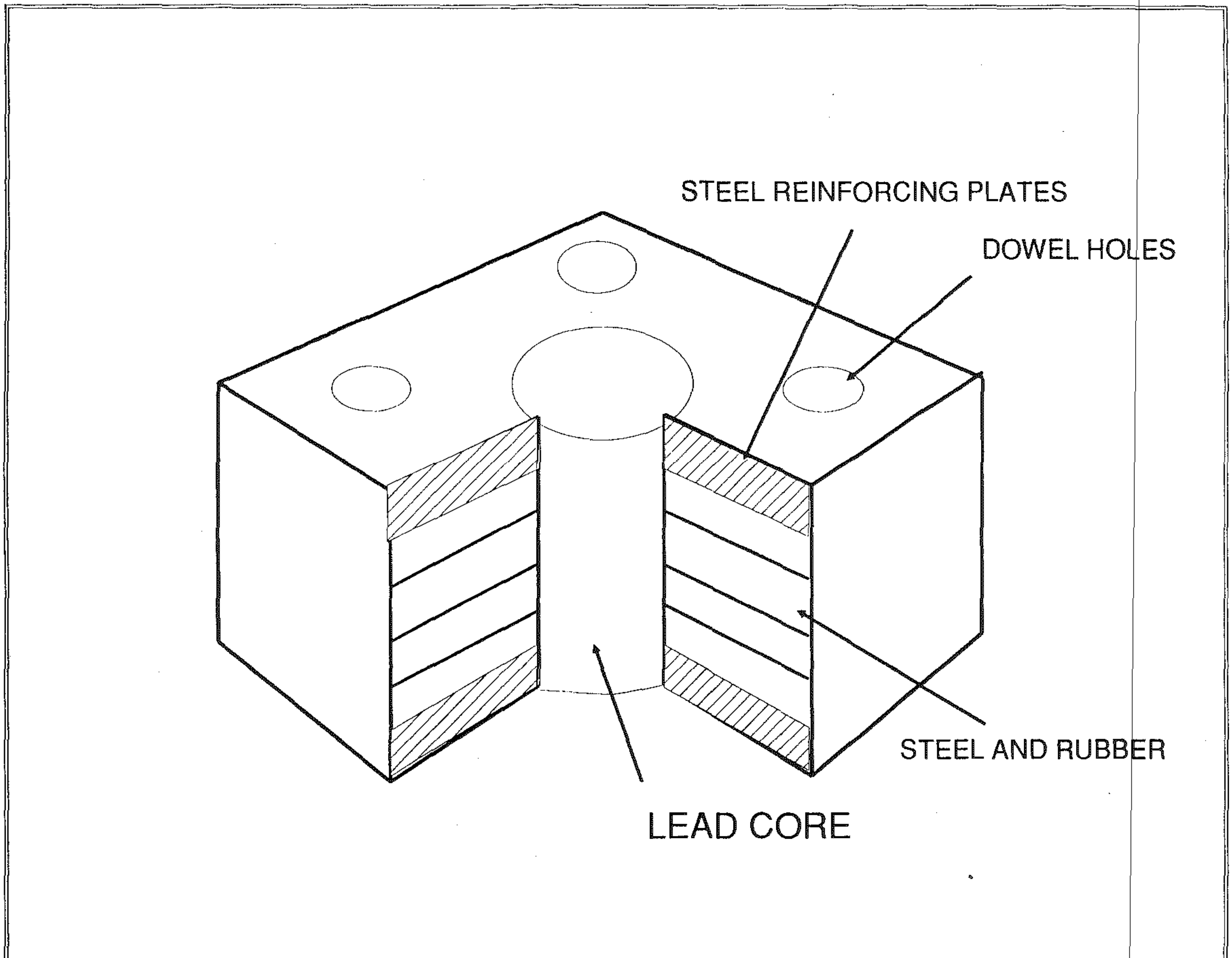



Figure 24. Isolation Bearing.

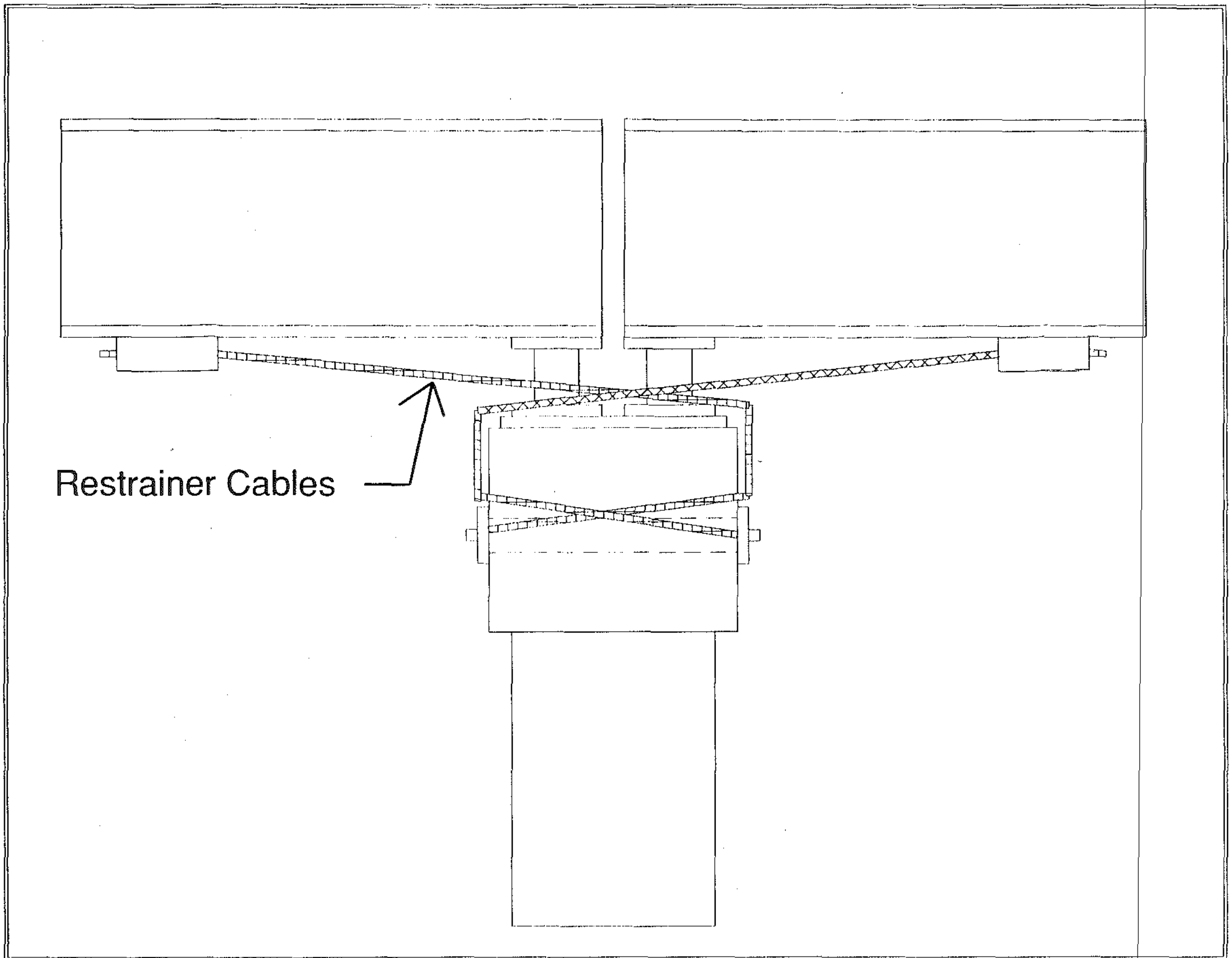



Figure 25. Restrainer Cable System.

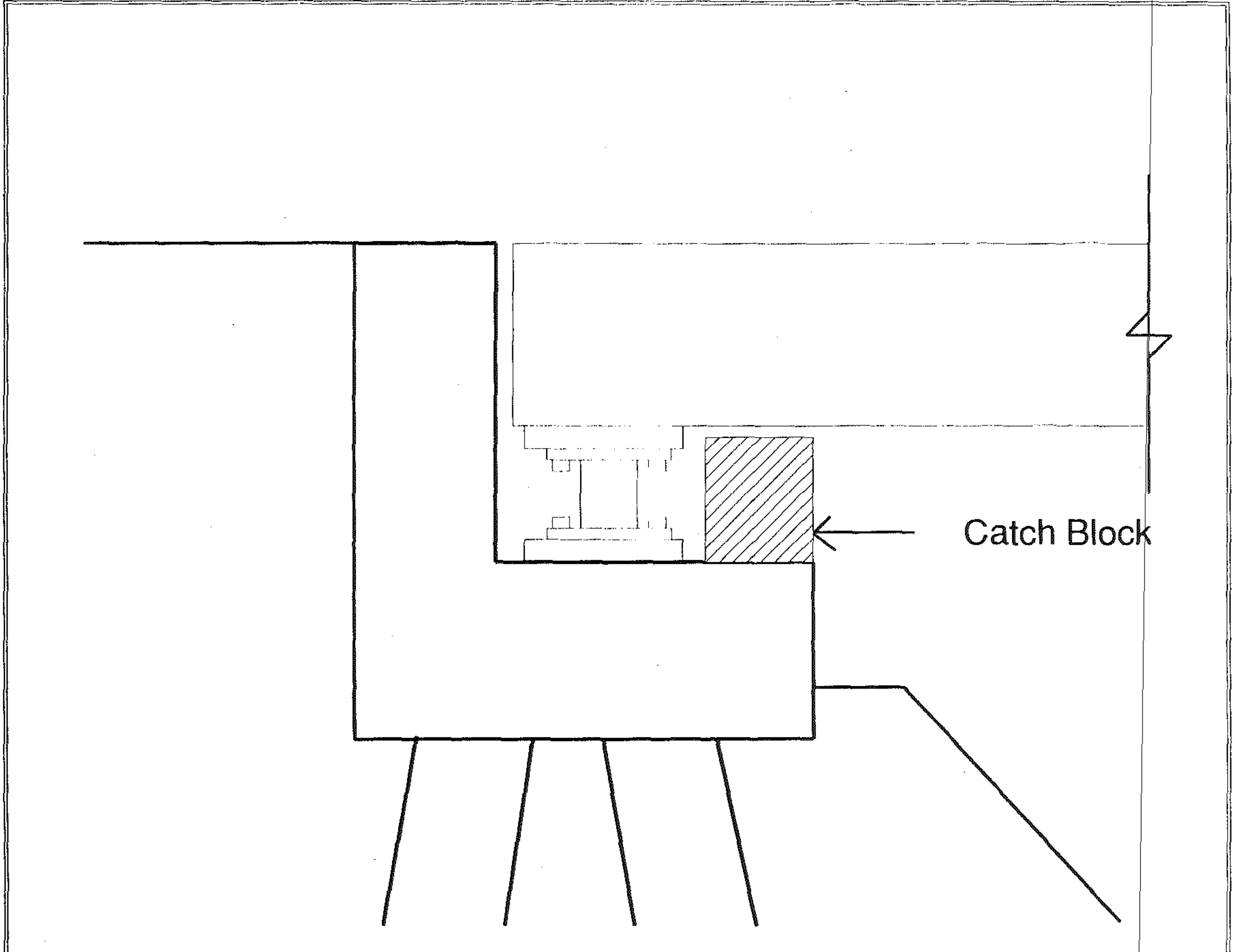
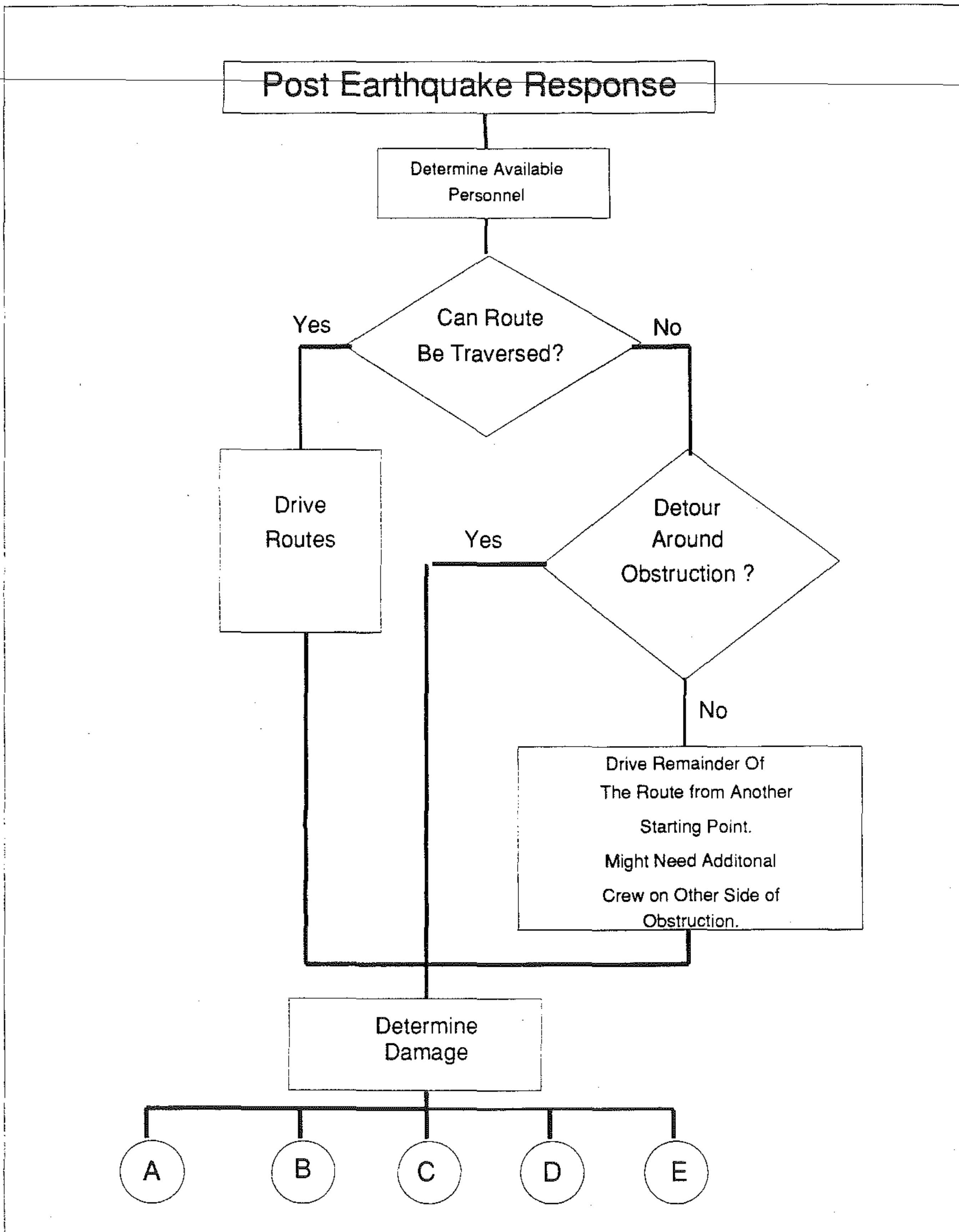
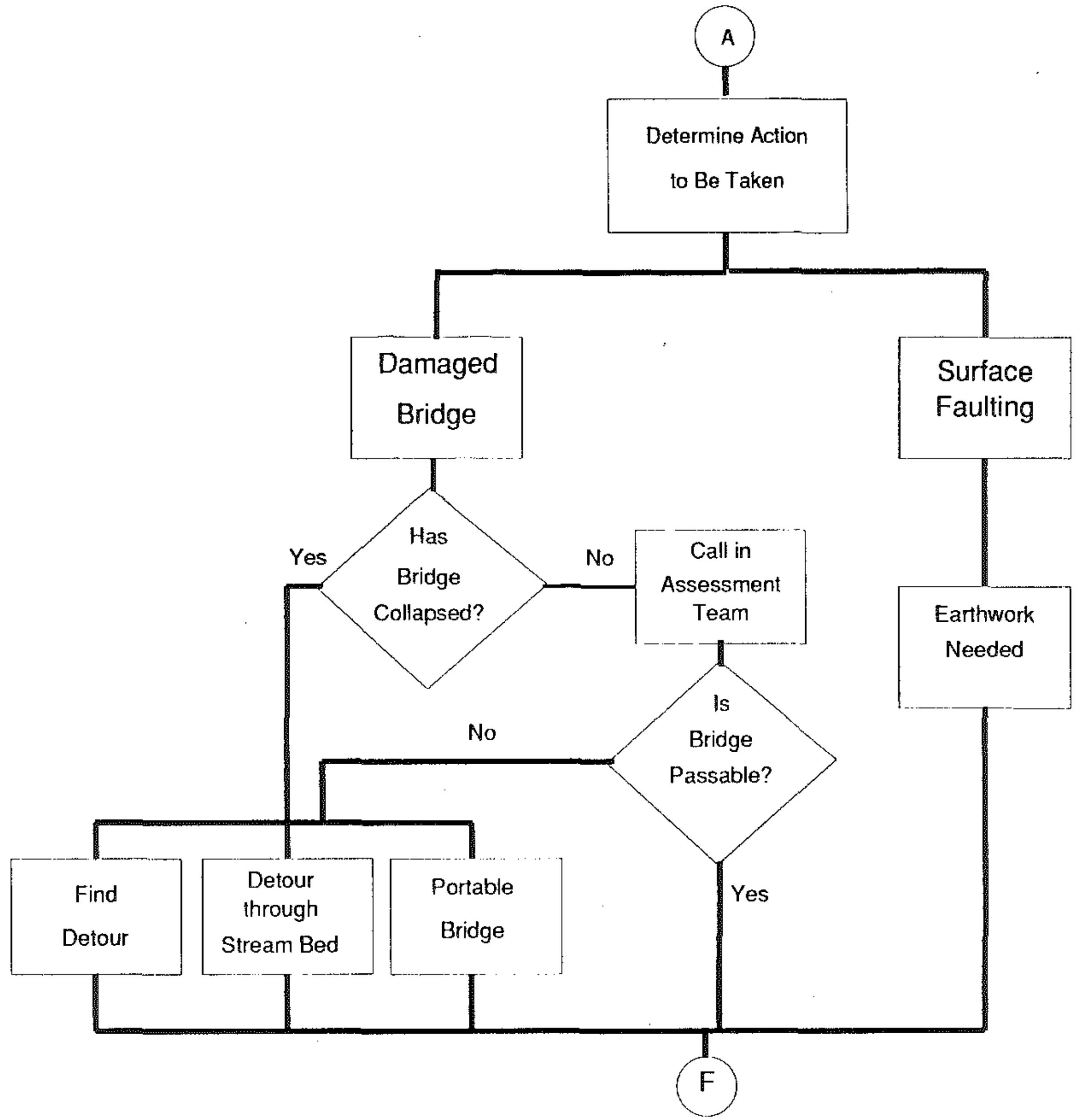
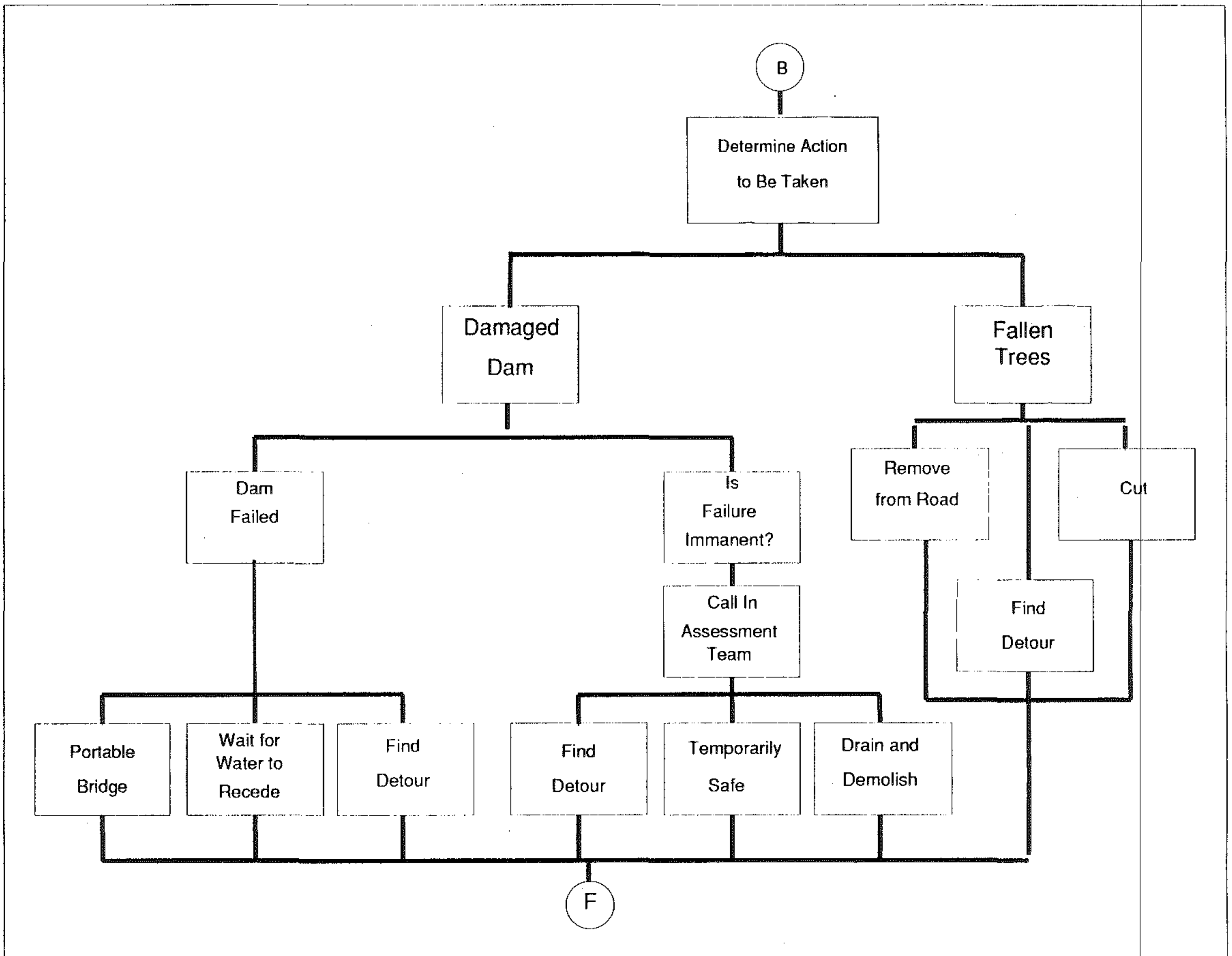


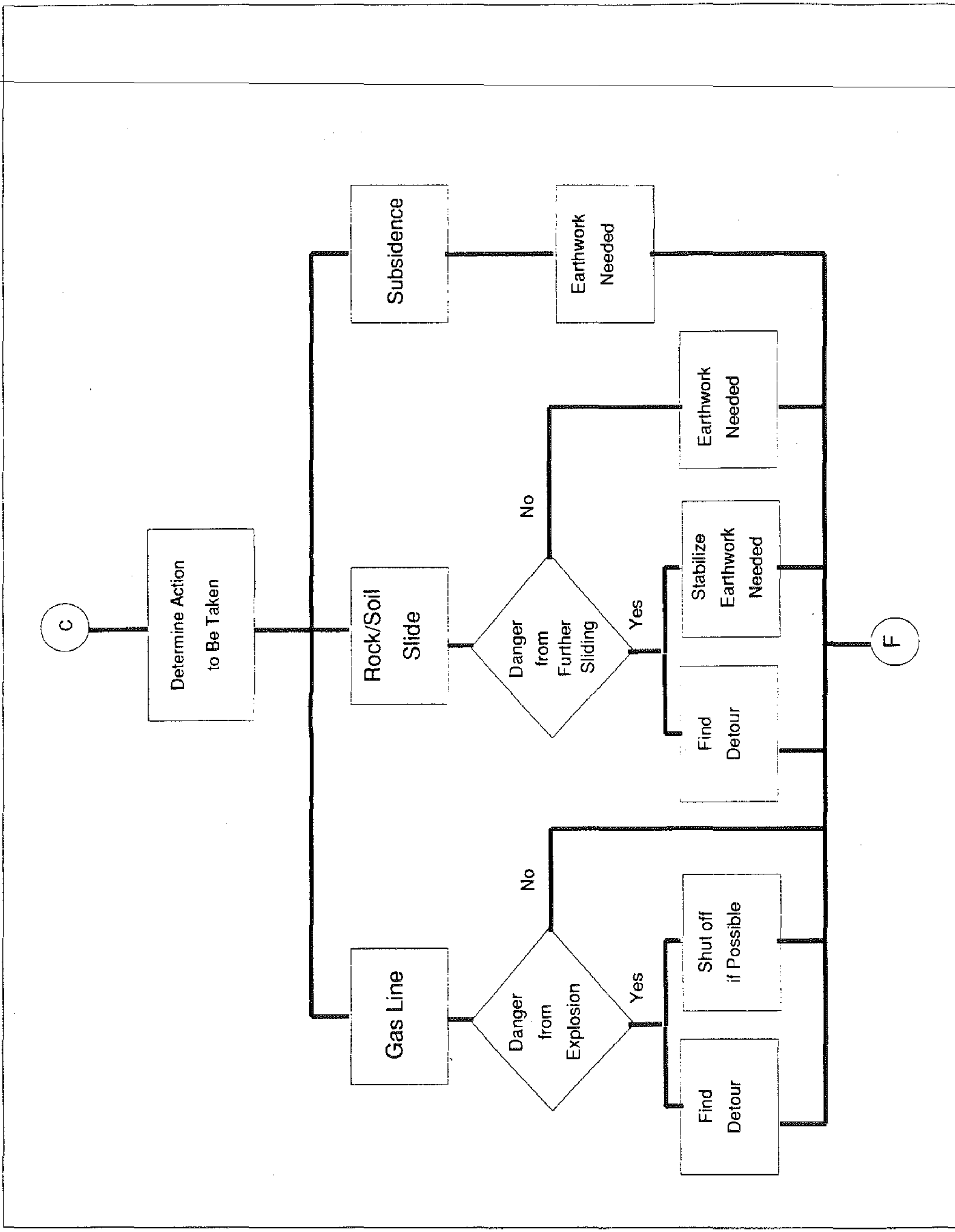

Figure 26. Supplemental Support/Catch Block.

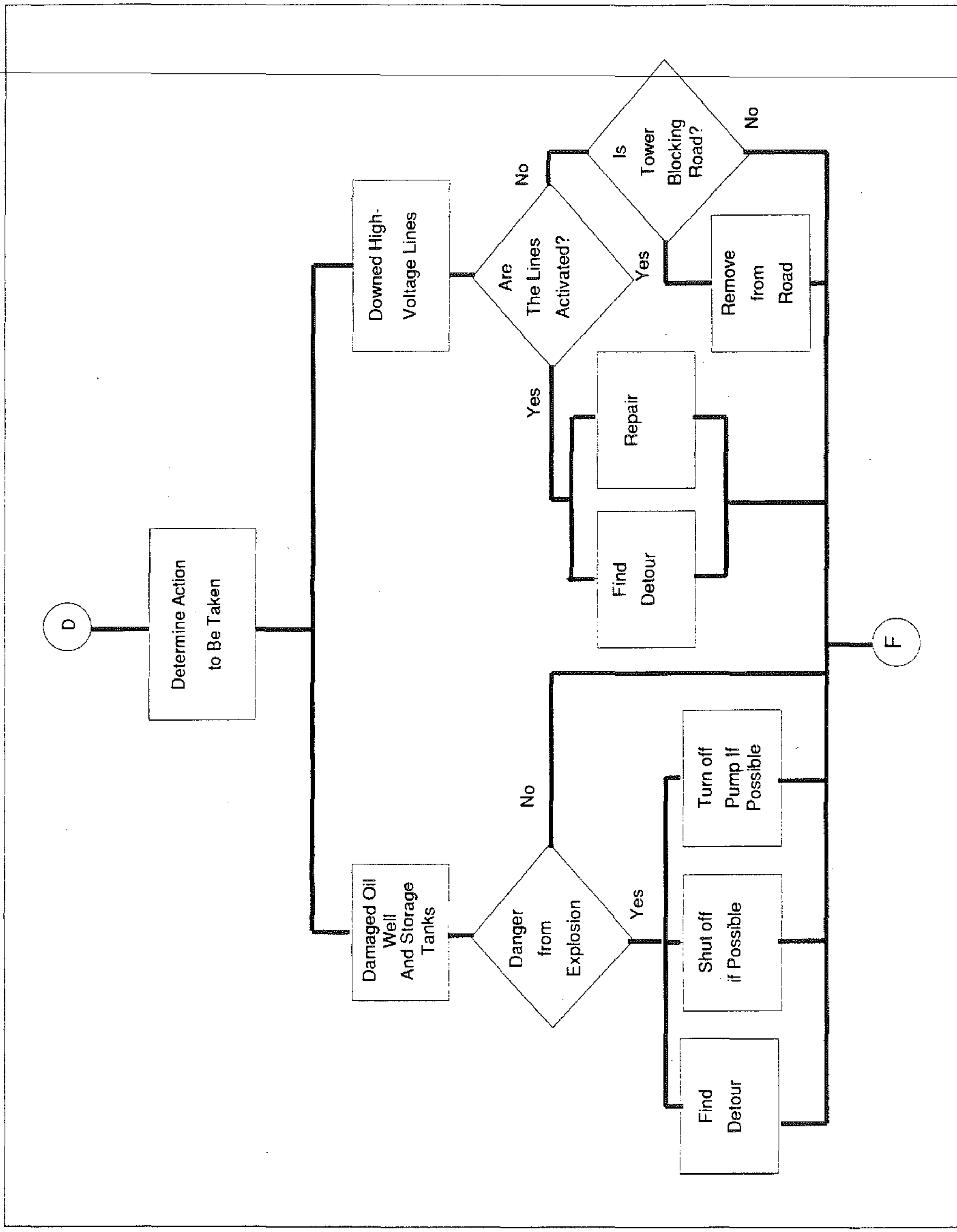
# APPENDIX B
# FLOW CHARTS FOR
# POST EARTHQUAKE RESPONSE

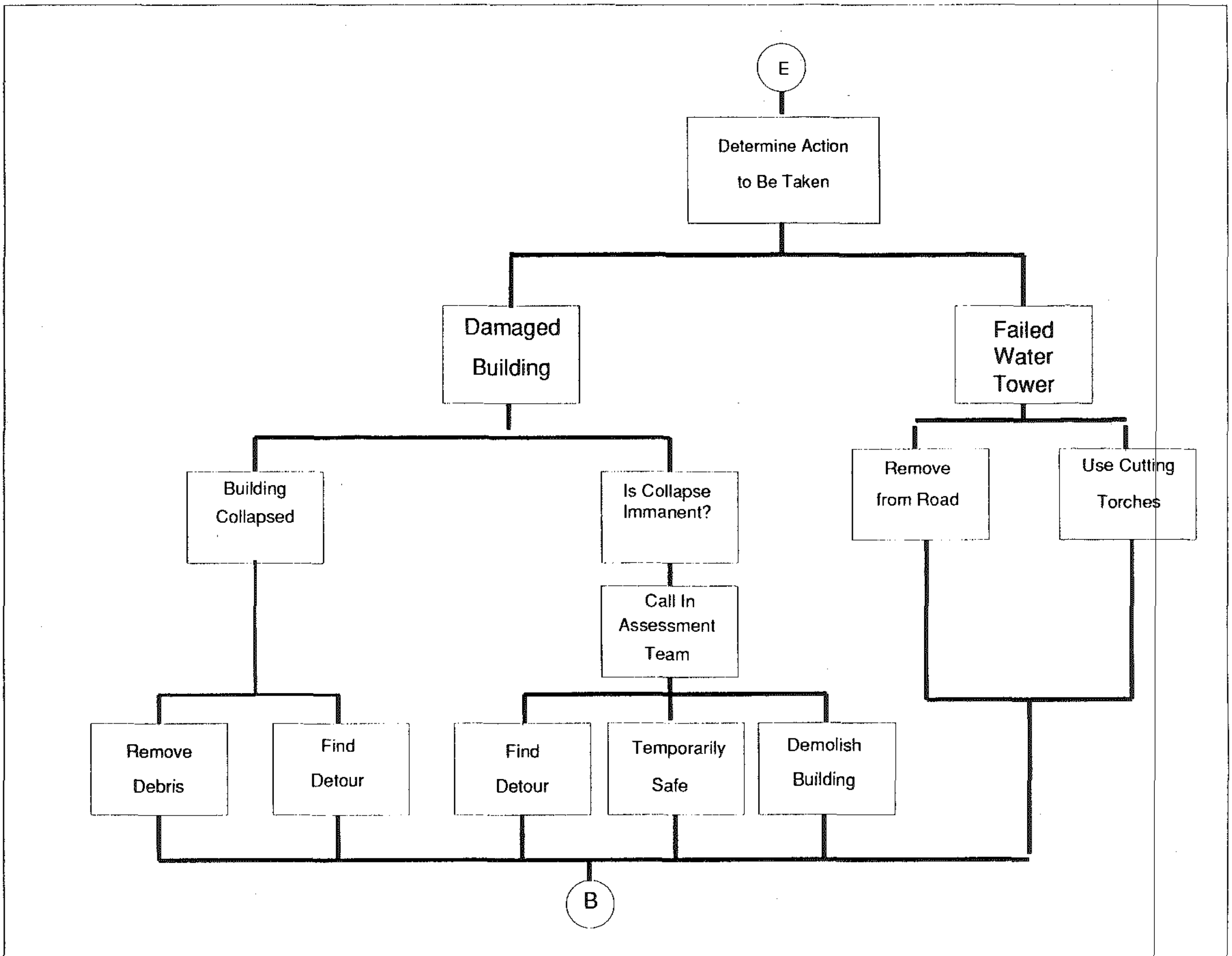

Post Earthquake Response
Determine Available Personnel
Can Route Be Traversed?
Yes
No
Drive Routes
Detour Around Obstruction ?
Yes
No
Drive Remainder Of The Route from Another Starting Point.
Might Need Additonal Crew on Other Side of Obstruction.
Determine Damage
A
B
C
D
E

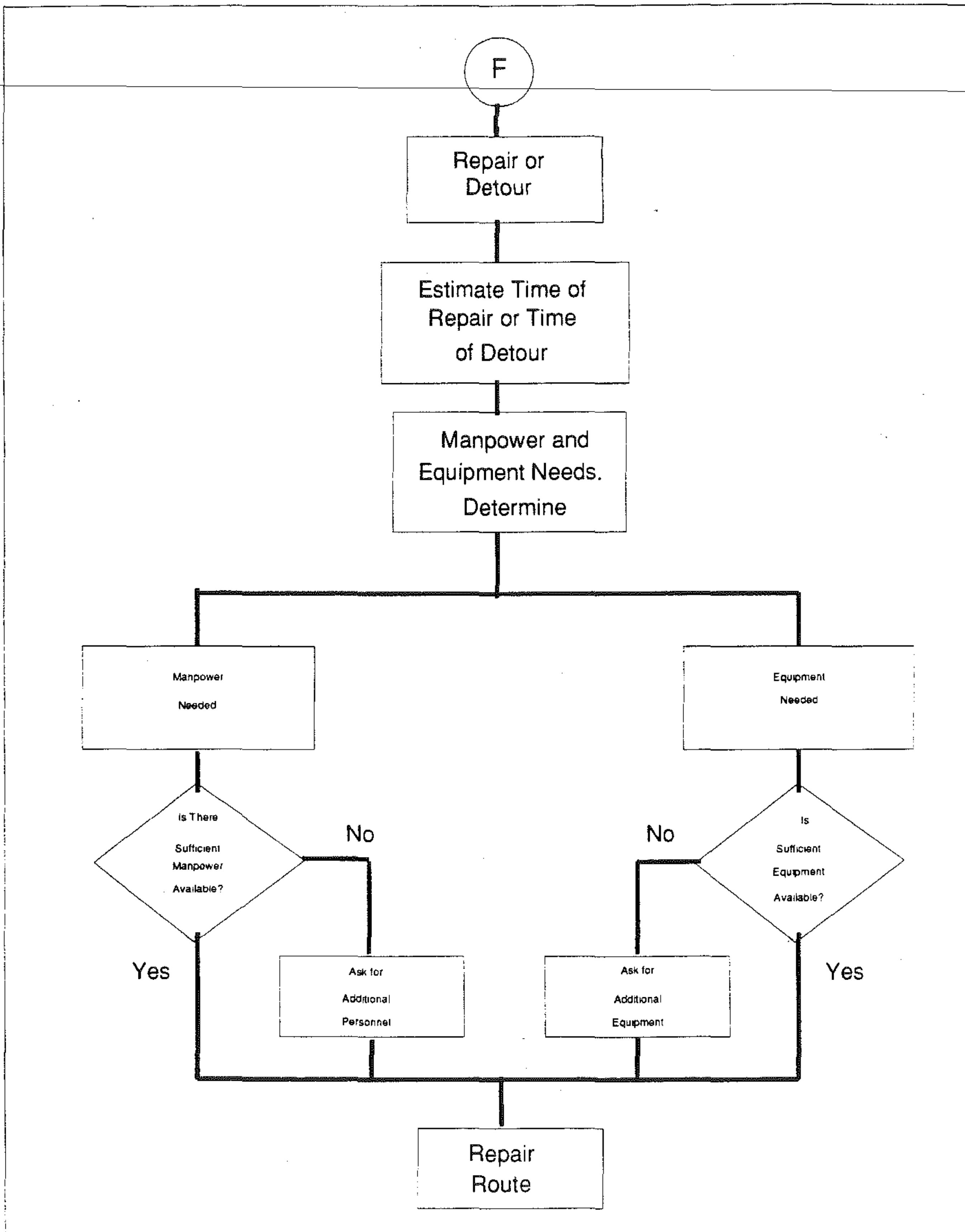

A
Determine Action to Be Taken
Damaged Bridge
Surface Faulting
Has Bridge Collapsed?
Yes
No
Call in Assessment Team
Earthwork Needed
Is Bridge Passable?
No
Yes
Find Detour
Detour through Stream Bed
Portable Bridge
F


B
Determine Action to Be Taken
Damaged Dam
Fallen Trees
Dam Failed
Is Failure Immanent?
Call In Assessment Team
Remove from Road
Cut
Find Detour
Portable Bridge
Wait for Water to Recede
Find Detour
Find Detour
Temporarily Safe
Drain and Demolish
F


C
Determine Action to Be Taken
Gas Line
Rock/Soil Slide
Subsidence
Danger from Explosion
Yes
No
Find Detour
Shut off if Possible
Danger from Further Sliding
Yes
No
Find Detour
Stabilize Earthwork Needed
Earthwork Needed
Earthwork Needed
F


D
Determine Action to Be Taken
Downed High-Voltage Lines
Are The Lines Activated?
No
Yes
Is Tower Blocking Road?
No
Yes
Remove from Road
Repair
Find Detour
Damaged Oil Well And Storage Tanks
Danger from Explosion
No
Yes
Turn off Pump If Possible
Shut off if Possible
Find Detour
F


E
Determine Action to Be Taken
Damaged Building
Failed Water Tower
Building Collapsed
Is Collapse Immanent?
Call In Assessment Team
Remove from Road
Use Cutting Torches
Remove Debris
Find Detour
Find Detour
Temporarily Safe
Demolish Building
B



F
Repair or Detour
Estimate Time of Repair or Time of Detour
Manpower and Equipment Needs. Determine
Manpower Needed
Equipment Needed
Is There Sufficient Manpower Available?
No
No
Is Sufficient Equipment Available?
Yes
Ask for Additional Personnel
Ask for Additional Equipment
Yes
Repair Route