

NATIONAL CENTER FOR EARTHQUAKE
ENGINEERING RESEARCH

State University of New York at Buffalo

LIQUEFACTION POTENTIAL OF
SURFICIAL DEPOSITS IN THE CITY OF
BUFFALO, NEW YORK

by

M. Budhu

Department of Civil Engineering and Engineering Mechanics
University of Arizona
Tucson, AZ 85721

and

R. Giese and L. Baumgrass

Departments of Geology and Civil Engineering
State University of New York at Buffalo
Buffalo, NY 14260

Technical Report NCEER-89-0036

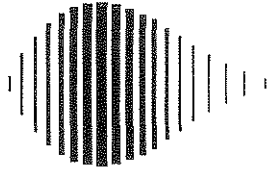
January 17, 1989

This research was conducted at the University of Arizona and the State University of New York at Buffalo and was partially supported by the National Science Foundation under Grant No. ECE 86-07591.

NOTICE

This report was prepared by Arizona State University and the State University of New York at Buffalo as a result of research sponsored by the National Center for Earthquake Engineering Research (NCEER). Neither NCEER, associates of NCEER, its sponsors, Arizona State University, State University of New York at Buffalo, nor any person acting on their behalf:

- a. makes any warranty, express or implied, with respect to the use of any information, apparatus, method, or process disclosed in this report or that such use may not infringe upon privately owned rights; or
- b. assumes any liabilities of whatsoever kind with respect to the use of, or the damage resulting from the use of, any information, apparatus, method or process disclosed in this report.



**LIQUEFACTION POTENTIAL OF SURFICIAL DEPOSITS
IN THE CITY OF BUFFALO, NEW YORK**

by

M. Budhu¹, R. Giese² and L. Baumgrass³

January 17, 1989

Technical Report NCEER-89-0036

NCEER Project Number 87-1305

NSF Master Contract Number ECE 86-07591

- 1 Associate Professor, Department of Civil Engineering and Engineering Mechanics, University of Arizona (formerly at State University of New York at Buffalo)
- 2 Professor, Department of Geological Sciences, State University of New York at Buffalo
- 3 Graduate Student, Department of Geological Sciences, State University of New York at Buffalo

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
State University of New York at Buffalo
Red Jacket Quadrangle, Buffalo, NY 14261

PREFACE

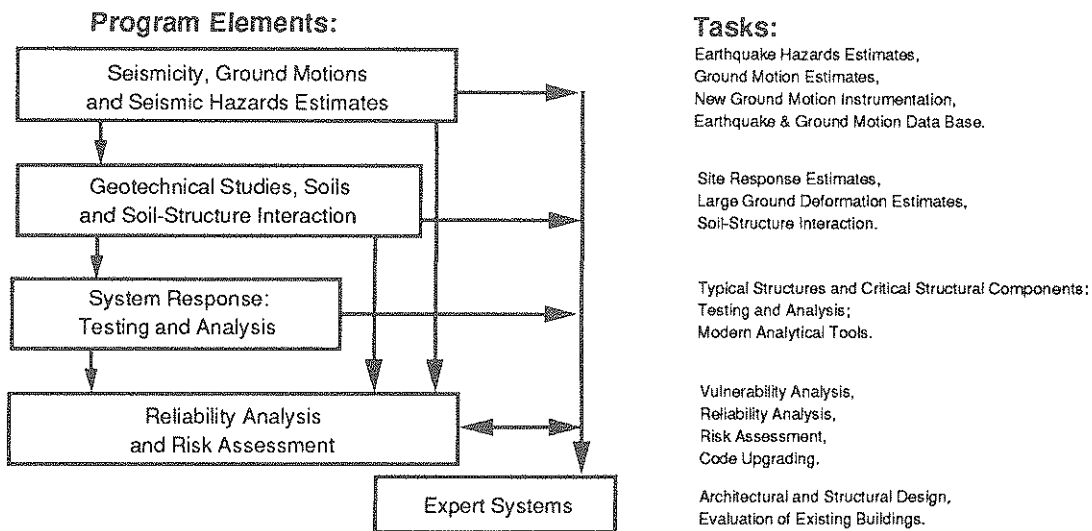
The National Center for Earthquake Engineering Research (NCEER) is devoted to the expansion and dissemination of knowledge about earthquakes, the improvement of earthquake-resistant design, and the implementation of seismic hazard mitigation procedures to minimize loss of lives and property. The emphasis is on structures and lifelines that are found in zones of moderate to high seismicity throughout the United States.

NCEER's research is being carried out in an integrated and coordinated manner following a structured program. The current research program comprises four main areas:

- Existing and New Structures
- Secondary and Protective Systems
- Lifeline Systems
- Disaster Research and Planning

This technical report pertains to Program 1, Existing and New Structures, and more specifically to geotechnical studies.

The long term goal of research in Existing and New Structures is to develop seismic hazard mitigation procedures through rational probabilistic risk assessment for damage or collapse of structures, mainly existing buildings, in regions of moderate to high seismicity. The work relies on improved definitions of seismicity and site response, experimental and analytical evaluations of systems response, and more accurate assessment of risk factors. This technology will be incorporated in expert systems tools and improved code formats for existing and new structures. Methods of retrofit will also be developed. When this work is completed, it should be possible to characterize and quantify societal impact of seismic risk in various geographical regions and large municipalities. Toward this goal, the program has been divided into five components, as shown in the figure below:



Geotechnical studies constitute one of the important areas of research in Existing and New Structures. Current research activities include the following:

1. Development of linear and nonlinear site response estimates.
2. Development of liquefaction and large ground deformation estimates.
3. Investigation of soil-structure interaction phenomena.
4. Development of computational methods.
5. Incorporation of local soil effects and soil-structure interaction into existing codes.

The ultimate goal of projects concerned with geotechnical studies is to develop methods of engineering estimation of large soil deformations, soil-structure interaction, and site response.

In this report, the authors use a standard technique, the standard penetration test (STP), to evaluate liquefaction as it applies to the city of Buffalo, New York. The use of a probabilistic variant of the method in this type of evaluation represents an approach which is becoming more widely used.

ABSTRACT

The potential for earthquake-induced liquefaction of cohesionless sediments in Buffalo, New York was calculated from geotechnical data using a probabilistic method. The essential geotechnical data used were the standard penetration number, the depth of ground water and the grain size of the soils. Although the selected area of this study (approximately 48 square miles) has a moderate amount of seismic activity, it was found that the probability of liquefaction is generally less than 10 percent for a peak ground acceleration of 0.15 g. An area about 2 square miles trapped between Lake Erie and the Buffalo River, however, was found to have a moderate potential (probability 10-50 percent) for liquefaction.

ACKNOWLEDGEMENT

We thank NCEER for funding this study through grants 86-1022 and 87-1305. Several persons have contributed to this study by supplying us with geotechnical and geological data. Some of these are:

Mr. Steve Pulley, Empire Soils Investigations, Inc.; Mr. Andrew Kuscerik, Empire Soils Investigations, Inc.; Mr. John Kolber, United States Army Corps of Engineers, Buffalo District; Mr. Ivan Pecknic, New York State Department of Transportation; Mr. Larry Grasso, City of Buffalo Department of Public Works; Ms. Patricia Coty, National Center for Earthquake Engineering Research, Office of Information Services.

Mr. Jim Webster, NCEER Librarian, who was tragically killed in an automobile accident, gave us tremendous help in tracking down the numerous bibliographic citations on liquefaction.

TABLE OF CONTENTS

Section	Title	Page
1	INTRODUCTION	1-1
2	GEOLOGIC CONDITIONS OF STUDY AREA	2-1
2.1	Area Seismicity	2-1
2.2	Bedrock Geology	2-5
2.3	Surficial Geology	2-7
2.4	Disturbed Sediments	2-12
3	LIQUEFACTION POTENTIAL EVALUATION	3-1
3.1	The Influence of Geologic Setting	3-1
3.2	Field Test to Determine Liquefaction Susceptibility	3-2
3.2.1	Correction for Hammer Ratio and Relative Soil Density	3-3
3.2.2	Normalization of Effective Overburden Pressure	3-3
3.3	Calculation of Liquefaction Potential	3-3
3.4	Liquefaction Probability	3-4
4	METHODOLOGY USED FOR LIQUEFACTION POTENTIAL MAPPING	4-1
4.1	Data Collection	4-1
4.2	Representative Drilling Logs	4-1
4.3	Determination of Liquefaction Potential	4-3
5	ASSESSMENT OF LIQUEFACTION POTENTIAL	5-1
6	CONCLUSIONS	6-1
7	REFERENCES	7-1
	APPENDIX A Listing of Historical Earthquakes Located in New York State Between 1737 and 1977.....	A-1

LIST OF ILLUSTRATIONS

Figure	Title	Page
1-1	Site Location Encompassing the City of Buffalo	1-2
2-1	Eastern United States Seismicity.....	2-2
2-2	Epicentral Locations and Intensities of Western New York Earthquakes.....	2-3
2-3	Clarendon-Linden Fault Zone.....	2-6
2-3	Bedrock Formations of the Study Area.....	2-8
2-5	Bedrock Elevations	2-9
2-6	Surficial Geologic Map of Buffalo.....	2-10
2-7	Fence Diagram of Study Area.....	2-11
2-8	Locations of Filled Areas.....	2-14
3-1	Seed's $(N1)_{60}$ CSR Relationship (Seed's Criteria Plot) - Silty Sands	3-5
3-2	Liao's $(N1)_{60}$ CSR Relationship Indicating Probability of Liquefaction	3-6
4-1	Test Boring Locations.....	4-2
5-1	Liquefaction Potential Map.....	5-6

LIST OF TABLES

Table	Title	Page
2-I	General Stratigraphic Sequence of Study Area in Buffalo.....	2-13
5-I	Liquefaction Probability Calculations	5-2

SECTION 1

INTRODUCTION

Liquefaction-induced ground deformation and failure can cause extensive damage to structures and lifeline utilities as attested, for example, by the Great Alaskan earthquake in 1964 and the San Francisco earthquake in 1971. Thus, a knowledge of the location of potentially liquefiable soils in seismicity active areas should be an integral part of an earthquake hazards reduction program. The term liquefaction is commonly used to define a condition in which a saturated cohesionless soil is transformed from a solid condition to a viscous fluid condition by dynamic loading. Some areas in the city of Buffalo, especially along the waterfront of Lake Erie and the Buffalo River, contain loose cohesionless sediments. These types of sediments generally have very high potential to liquefy if the ground water level is at or near the ground surface.

In this report, an evaluation of the potential for earthquake-induced liquefaction of sediments in the City of Buffalo, New York is presented. The study area selected, based on a preliminary study of the geology and the seismicity of western New York, is shown in Figure 1-1. Preliminary findings for a portion of the selected area were reported in NCEER Technical Report NCEER-87-0009 (Budhu et al., 1987).

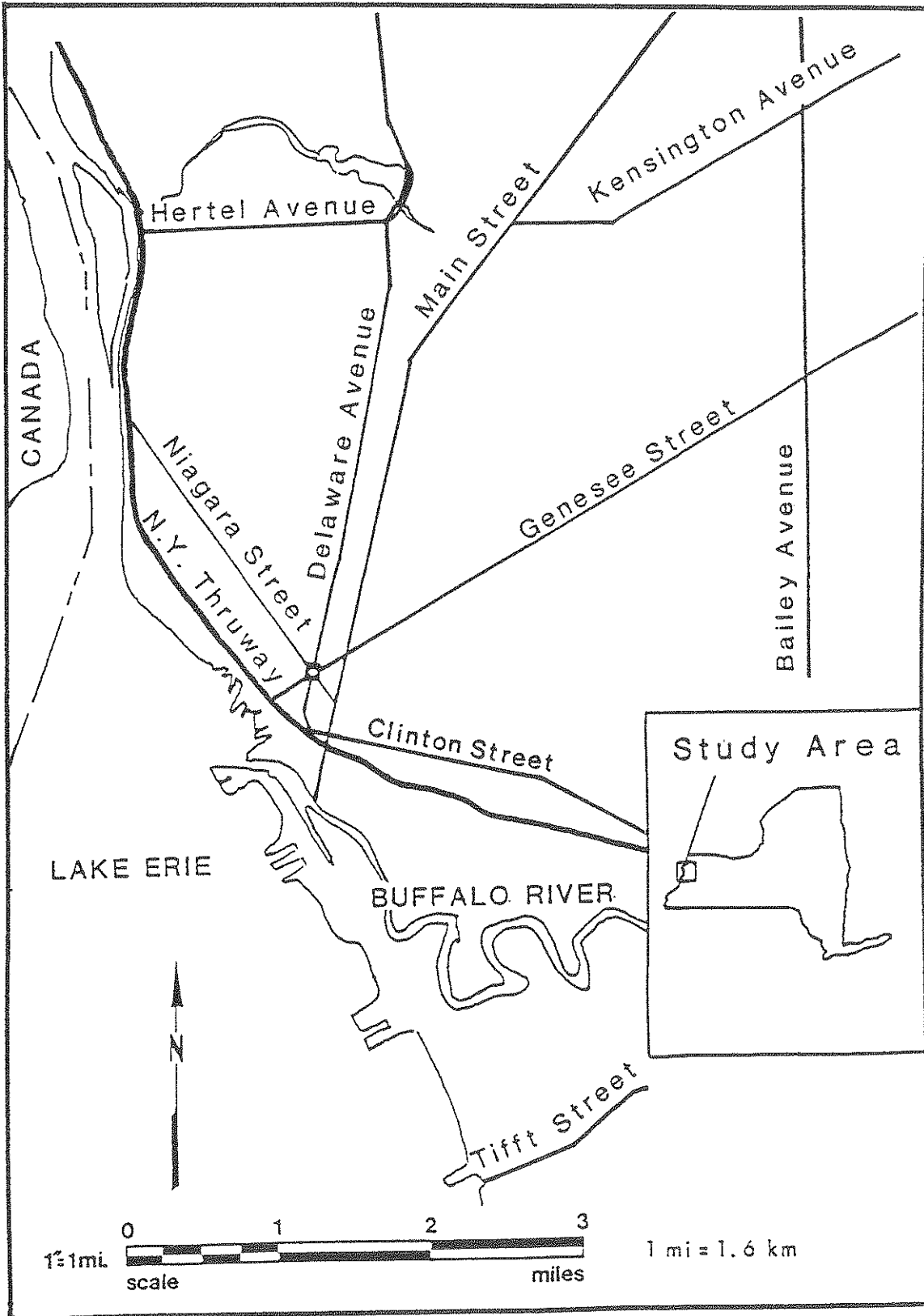


FIGURE 1-1 Site Location Encompassing the City of Buffalo

SECTION 2

GEOLOGIC CONDITIONS OF STUDY AREA

2.1 Area Seismicity

The eastern United States and Canada are in an intraplate zone of moderate seismic activity. Looking at event with Modified Mercalli intensities greater than or equal to VIII, these are located in Quebec (La Malbaie), the zone from northern New York to Kirkland Lake, Boston, New Madrid, Charleston, Attica and Massena, and a few other, apparently isolated events. Four active seismic zones in the eastern United States and Canada have been identified by Sbar and Sykes (1977): a northwest trending belt from northern New York to Kirkland Lake, Ontario; a north- northwest trending zone from Boston, Massachusetts through central New Hampshire; a cluster of activity approximately 130 km northeast of Quebec City and the Attica-Dale region of western New York (Figure 2-1). Additional zones of moderate seismic activity in New York are present in western Lake Ontario, the Adirondack mountains and the Hudson highlands. Figure 2-2 shows epicentral locations and Modified Mercalli intensity values for historical New York State earthquakes. A listing of historical earthquakes from 1737 to 1977 along with hypocenter, time, date, and intensity information is presented in Appendix A (after Stover et al., 1981).

According to Barosh (1985), earthquakes in the eastern U.S. are due to coastal downwarping, adjacent bulging, and interior subsidence caused by widening of the Atlantic basin. All major historical earthquakes have occurred within or near these zones. Two sets of fracture zones are related to the opening of the Atlantic basin; an initial set of north-trending fractures and a subsequent set of northwest-trending fractures.

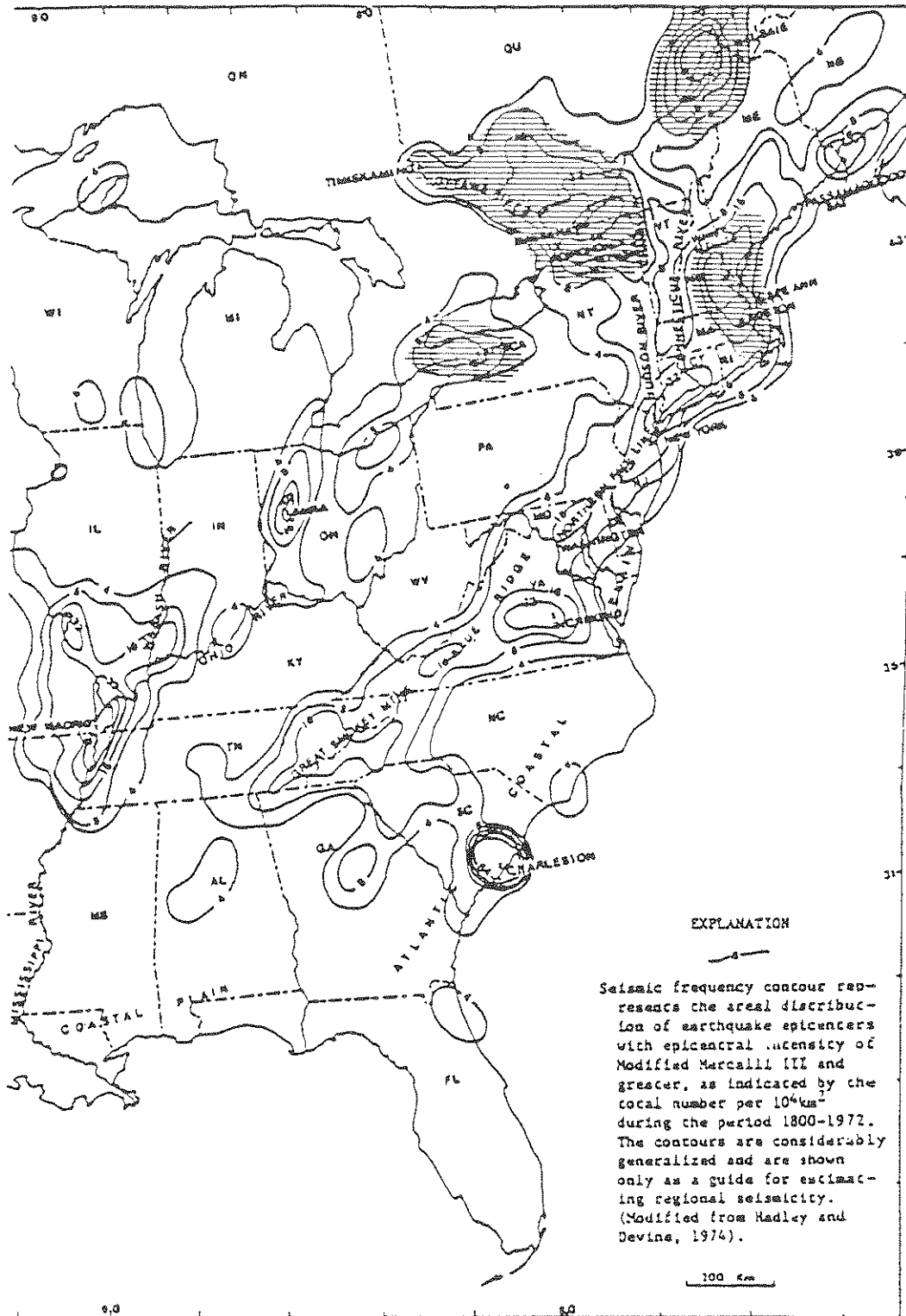


FIGURE 2-1 Eastern United States Seismicity. Shaded Areas Depict Seismicity Zones of Sbar and Sykes (1977). After Barosh (1985).

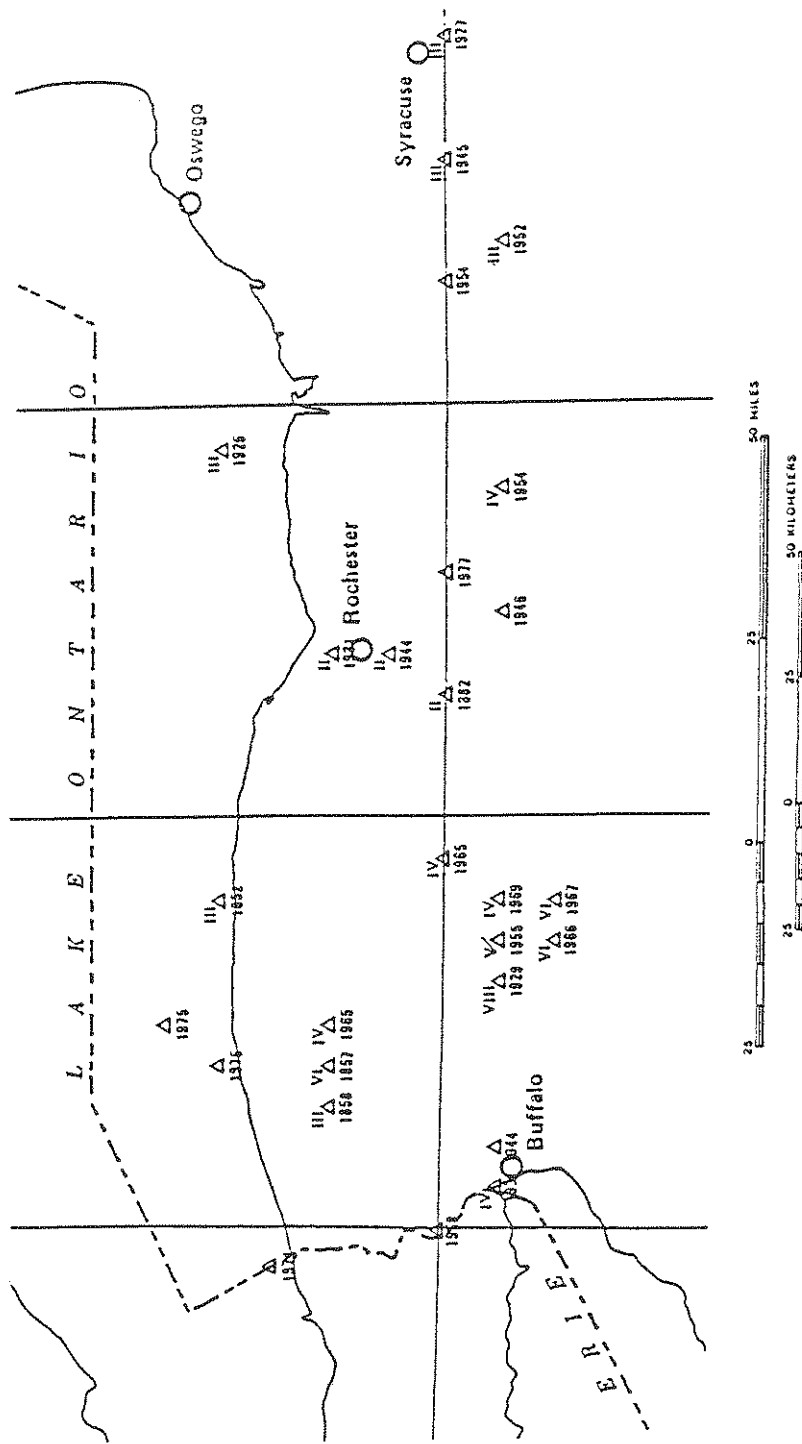


FIGURE 2-2 Epicentral Locations and Intensities of Western New York Earthquakes. Roman Numerals Denote Modified Mercalli Intensity Values. After Stover et al. (1981).

Earthquakes in New York generally occur where the two fracture zones intersect belts of vertical movement (Barosh, 1985). Analysis of the geographic distribution of earthquakes in New York since 1720 and the seismic energies released by these earthquakes as a function of time indicates a cyclical nature of earthquake occurrence (Mitronovas and Nottis, 1985). According to Mitronovas and Nottis (1985), secular variations in seismicity throughout New York do not occur randomly but instead reflect the forces which trigger the seismicity. Sbar and Sykes (1977) proposed the existence of different stress domains in the eastern and central United States. A domain of ENE oriented horizontal compressive stress extends approximately from Hudson Bay on the north to the Mississippi embayment on the south. This zone possibly ranges westward to the Rocky Mountains and eastward to Baffin Island. This stress domain is characterized by dominantly normal faulting near the Mississippi embayment and thrust faulting to the north of the embayment. The ENE stress orientation is relatively uniform from Ohio to eastern New York and southern Ontario, with the exception of the Attica-Dale area. The Attica-Dale stress domain trends WNW as evidenced by fault plane solutions, hydrofracture stress measurements, and pop-ups (Sbar and Sykes, 1977). The origin of this deviation is unknown, but may be attributable to past earthquakes.

The Attica-Dale area is the site of the largest earthquake recorded in western New York. This earthquake occurred on August 12, 1929 and had a Modified Mercalli intensity of VIII and an estimated magnitude of 5 to 6. Its principal shock had a duration of 12 seconds and tremors occurred for six minutes. The earthquake was experienced over an area of 130,000 square kilometers (Fletcher and Sykes, 1977). The overall damage incurred by this earthquake was slight. However, the effects were strongly felt at some locations

throughout the area (Buffalo Courier Express, 8/13/29). The seismicity of the Attica-Dale area is attributed to the Clarendon-Linden fault system (Figure 2-3). This system is a north-northeast trending 5 to 15 kilometer wide zone of steeply dipping reverse and normal faults in Precambrian basement and lower Paleozoic bedrock (Fakundiny et al., 1978). Vertical offset is estimated to range between 30 and 90 meters in Ordovician through Devonian rocks (Hutchison et al., 1979). The Clarendon-Linden fault zone extends from north of the Pennsylvania border to Lake Ontario. Seismic and magnetic data indicate that the fault zone continues beneath Lake Ontario as the Scotch Bonnet Rise, and for an additional 100 kilometers into the Bancroft area of southern Ontario (Hutchison et al., 1979). The Clarendon-Linden fault system is perhaps the longest and oldest active fault in the eastern United States as evidenced by activity over several intervals (Fakundiny et al., 1978). Fakundiny et al., (1978) suggest the following evidences for the Clarendon-Linden activity (1) aeromagnetic anomalies suggest strike-slip movement in Precambrian basement rocks; (2) thickened Trenton group carbonate rocks to the east of the fault system indicate growth faulting during Ordovician time; (3) the system forms an open down-to-the-west monoclinial fold above Silurian bedrock; and (4) intermittent activity may have occurred during Pleistocene time.

2.2 Bedrock Geology

Precambrian Canadian Shield rocks consisting of metagabbros, granites, marbles, and mafic rocks are exposed approximately 150 kilometers to the north of the study area (Fakundiny et al., 1978). It is probable that this suite of crystalline rocks also underlies the sedimentary section of western New York. Exposed bedrock ranges in age from Late

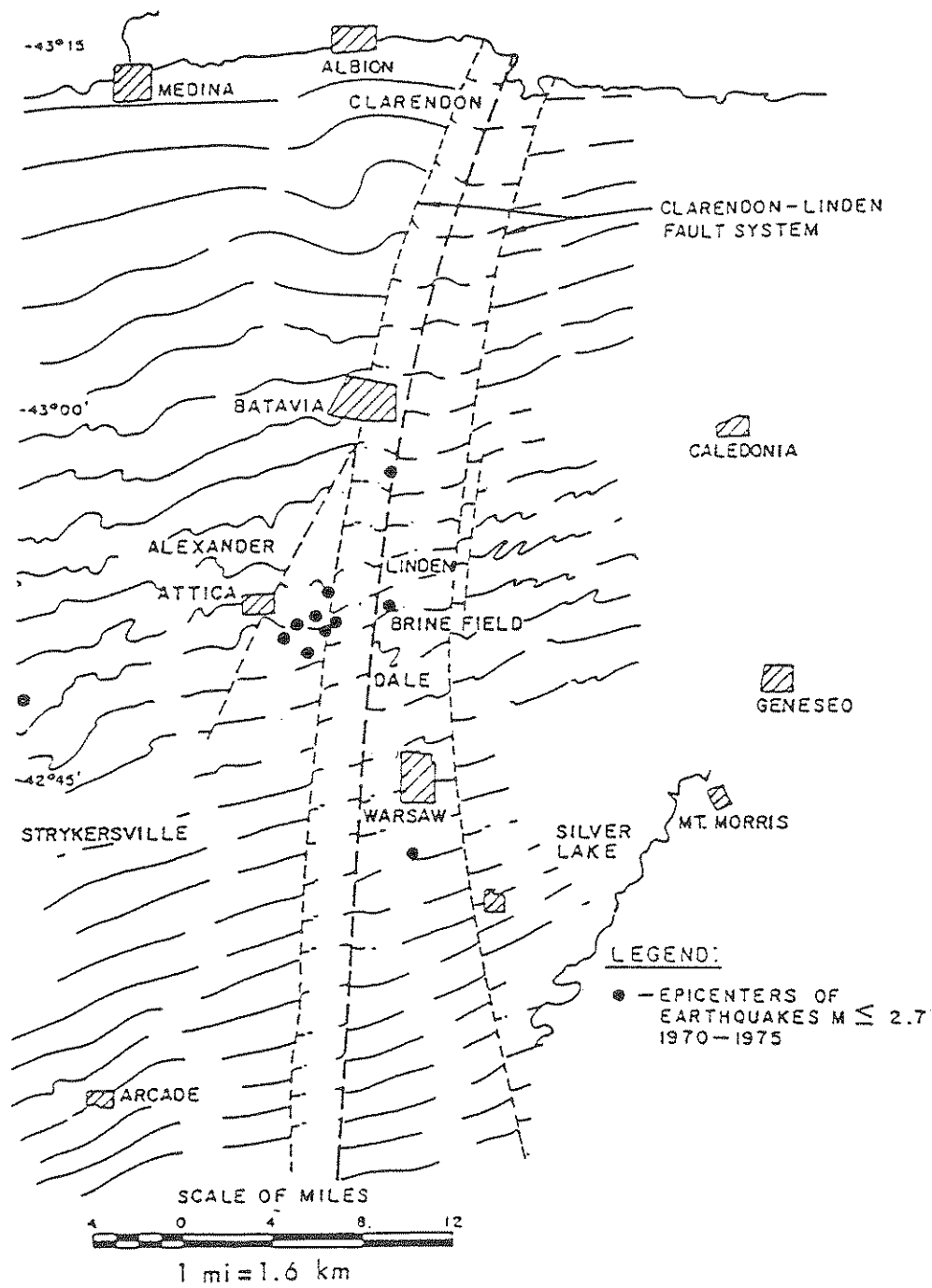


FIGURE 2-3 Clarendon-Linden Fault Zone. (After Van Tyne, 1975).

Silurian to Middle Devonian. Lower Devonian rocks are not represented in the stratigraphic record. Sedimentary rocks have a regional southerly dip of approximately 40 ft. per mile (Buehler and Tesmer, 1963). Figure 2-4 shows area bedrock and Figure 2-5 shows elevations of the bedrock surface. Several channels have been incised into this surface. Two main channel systems are located generally in the present Scajacquada Creek and Buffalo River drainage basins. The origin of these channels is uncertain. Some or all may be relicts of subaerial drainage during interglacial intervals. However, some may be products of subglacial meltwater movement.

2.3 Surficial Geology

A surficial geologic map and a fence diagram of the study area are shown in Figure 2-6 and Figure 2-7 respectively. General descriptions of the sediments were compiled from drilling logs. Sediment descriptions and in-situ density values given on drilling records have been interpreted to correlate major depositional units and formulate a general geologic description of the study area (Table 2-I). Regional deposits are designated as units 1 through 4, youngest to oldest, respectively. Unit 4 is divided into sub-units 4A and 4B to denote facies change. Localized deposits (i.e. channel deposits) are not numerically designated.

The Main Street channel is filled with sand and gravel deposits that are coarse in upper reaches and grade to fine sand at the south end of the system. Lenses and thick seams of silty sand are interfingered between the bedrock and Unit 4 at the south end of the Main Street-Buffalo River bedrock channel. Sediments in this system range in thickness from 2

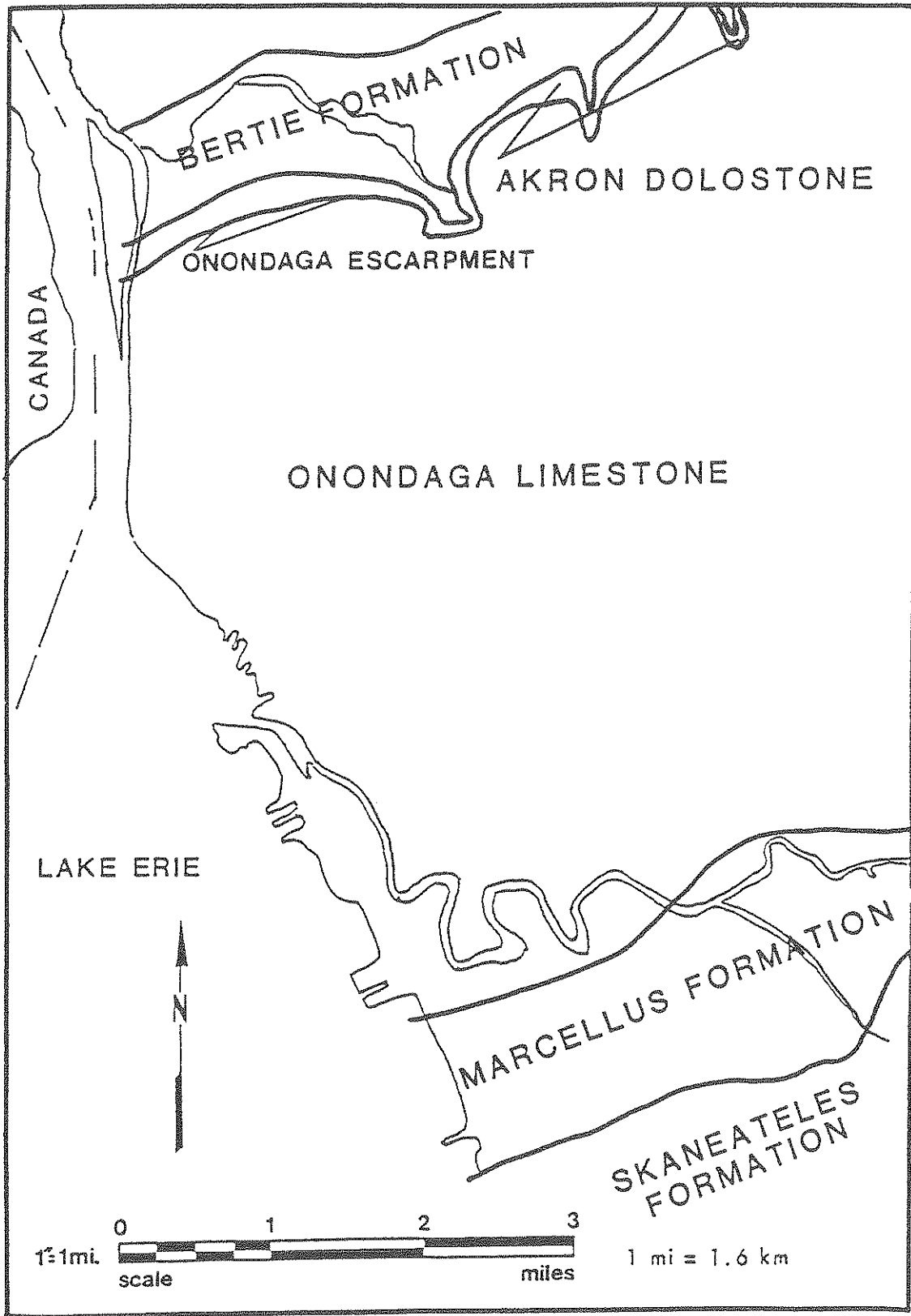


FIGURE 2-4 Bedrock Formations of Study Area. After Buehler and Tesmer (1963).

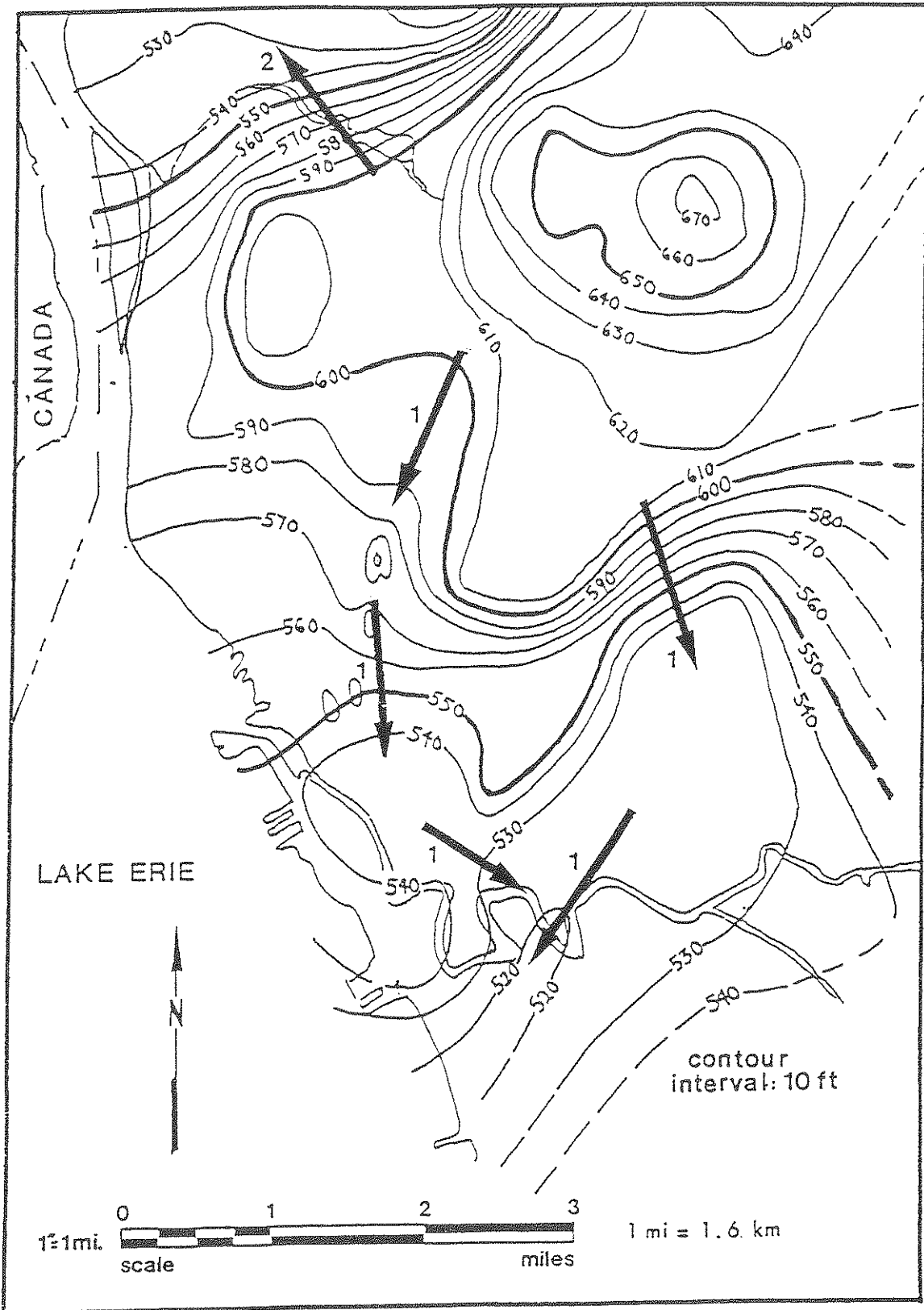


FIGURE 2-5 Bedrock Elevations. Arrows Show Flow Directions of Bedrock Channels. (1) Main Street-Buffalo River Channel; (2) Scajacquada Creek Channel.

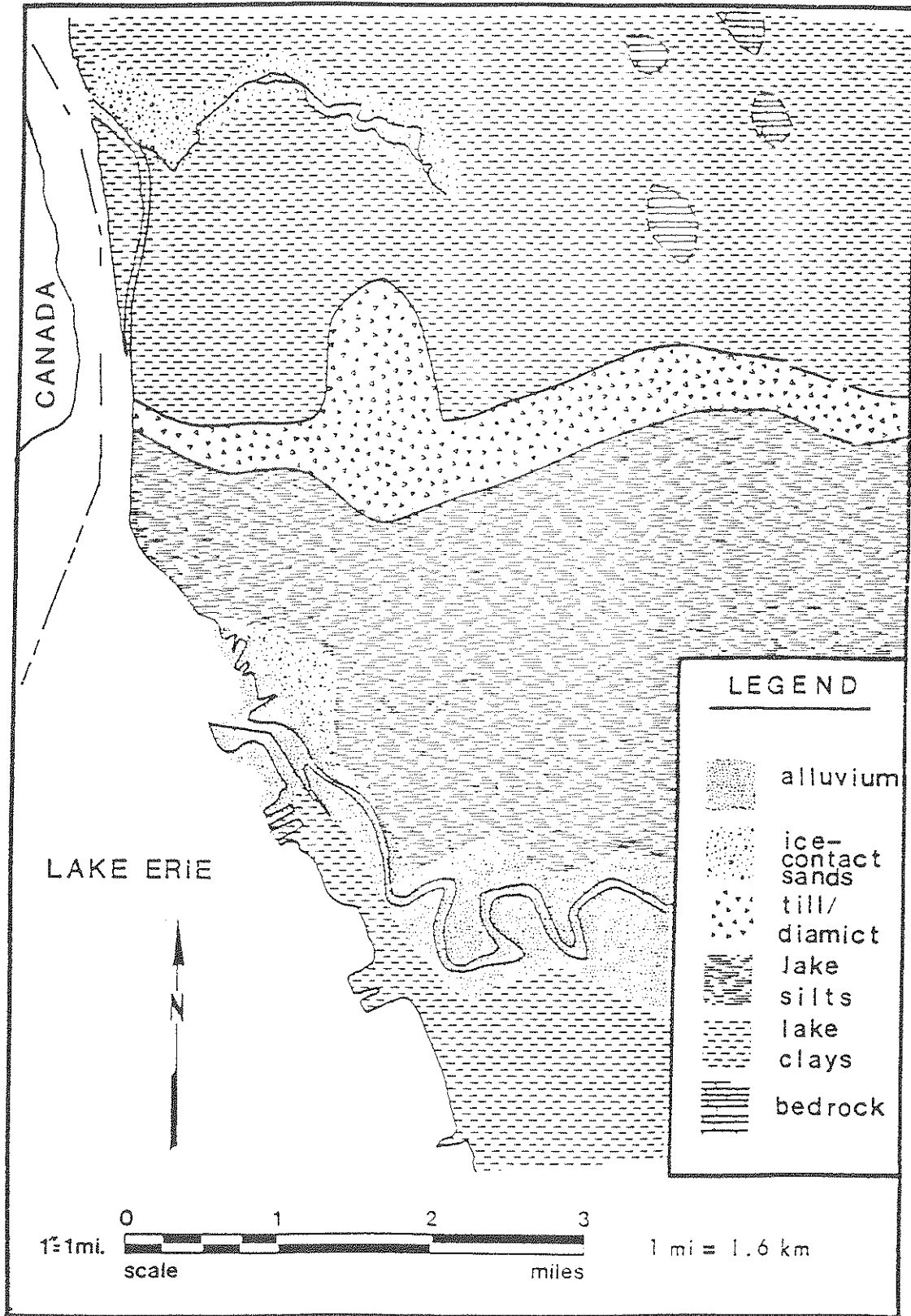


FIGURE 2-6 Surficial Geologic Map of Buffalo

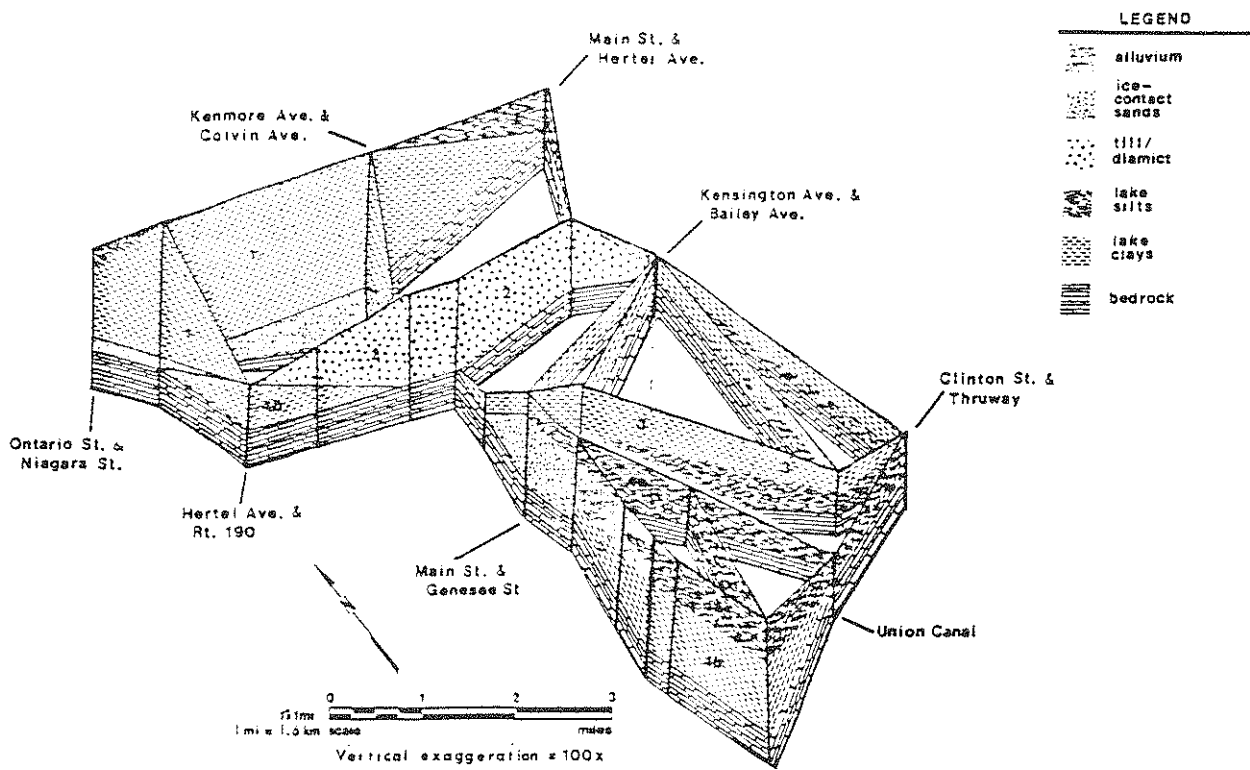


FIGURE 2-7 Fence Diagram of Study Area. See Table 2-1 for Explanation of Unit Members.

to 80 ft. The Scajacquada Creek channel is filled with gravelly sand which overlies an approximately 12 ft thick layer of diamict. Sediments in this system typically consist of firm to very compact gravelly sand and sandy gravel with a trace of silt.

2.4 Disturbed Sediments

Surficial deposits have been disturbed by dredging and landfilling at many locations throughout the waterfront area (Figure 2-8). A network of inland waterways, canals, and slips were constructed in the 1800's in the Tiff Street, Black Rock Harbor, and Buffalo Harbor areas. These inland waterways were filled in the early 1900's as alternate transportation systems were implemented. The present Lake Erie shoreline has been extended 600 to 800 ft. lakeward of its natural position by extensive filling since the 1800's. Off-shore deposits are presently being dredged or filled over by Army Corps of Engineers diked disposal area projects. The fill consists of dredgings and debris.

Table 2-I. General Stratigraphic Sequence of the Study Area in Buffalo.

Unit	Thickness	Description
1	2-75 ft. 0.6-23 m	Layered clayey silt and silty clay, grey, with fine stones; firm to very dense.
2	25-50 ft. 8-15 m	Interbedded diamict* consisting of till, stony silt/clay, and sand; silt and clay stiff to hard; sand compact to dense.
3	15-20 ft. 5-6.5 m	Silty clay brownish-grey; with sand laminae and fine stones; stiff to hard.
4a	2-20 ft. 0.6-6 m	Layered clayey silt and clay with trace clay; grey to greyish brown; medium to soft; rhythmically bedded in areas.
4b	2-40 ft. 0.6-12 m	Silty clay with fine sand laminae; red-brown to grey; soft to stiff; rhythmically bedded in areas.

Notes:

* *Diamict* is a non-genetic term meaning a "poorly sorted, unlithified gravel-sand-mud admixture" (Eyles, 1983).

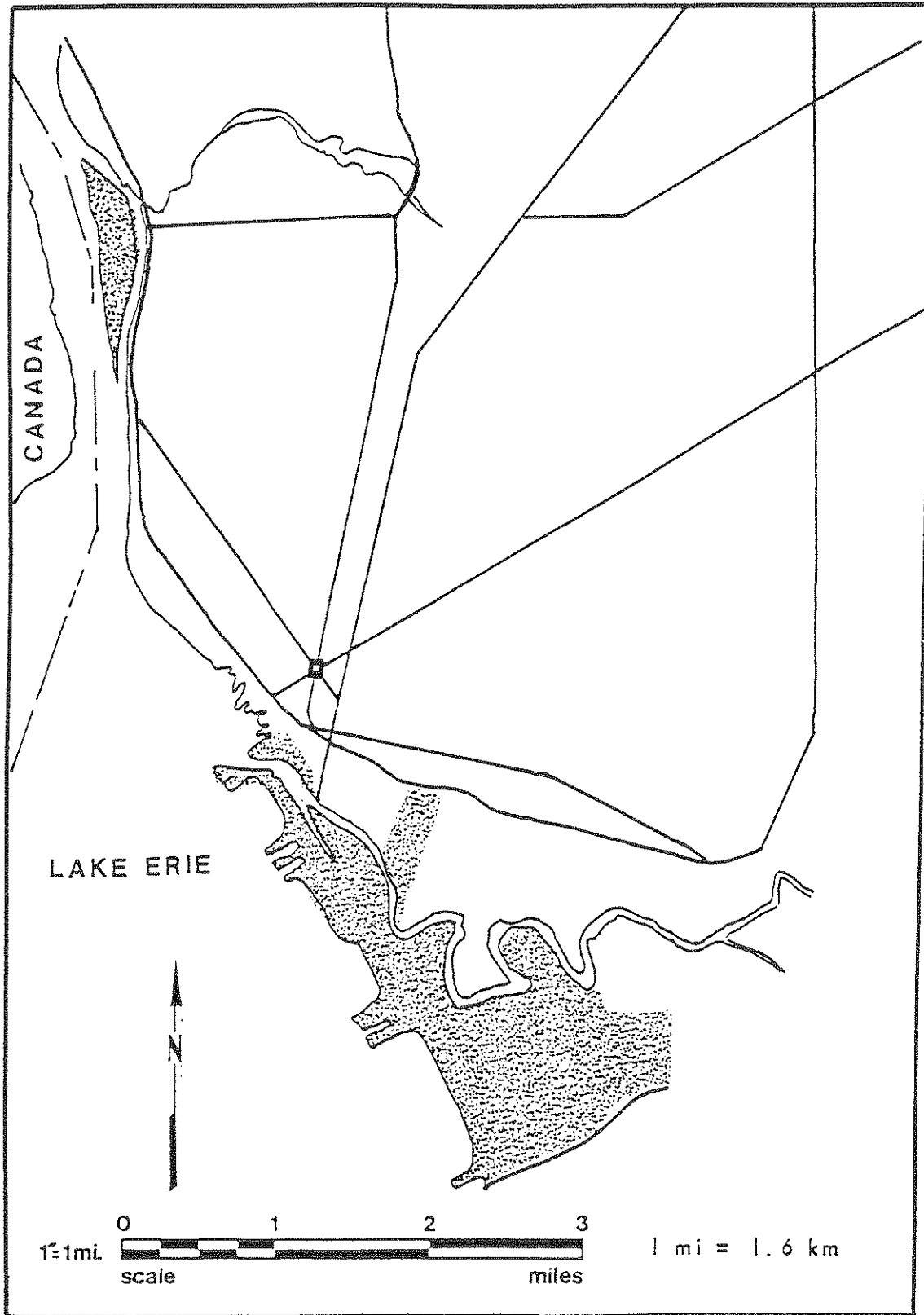


FIGURE 2-8 Locations of Filled Areas. Shaded Zones Depict General Areas of Waterfront Land Created by Landfilling.

SECTION 3

LIQUEFACTION POTENTIAL EVALUATION

3.1 The Influence of Geologic Setting

The primary geologic criteria of liquefaction susceptibility are (1) depositional age, (2) depositional environment, (3) depth of burial and (4) water table depth (Youd and Hoose, 1977). Liquefaction due to earthquakes has rarely, if ever, been observed in deposits older than Pleistocene. This is primarily due to induration of units with age via processes of intergranular cementation and by overburden preconsolidation in the case of glaciated terrains. In general, fluvial and deltaic sediments are most susceptible to liquefaction. Other types of deposits sensitive to liquefaction include alluvial fans, plains, beaches, terraces, playa, and estuarine deposits. In these deposits, liquefaction does not occur as commonly as in fluvial and deltaic sediments. The process of deposition is an important factor in the sorting and density of a sediment. Fluvial and deltaic sediments typically have a lower percentage of fines (clay and silt size particles) than other water-laid deposits (with the exception of beach deposits) because of relatively greater current velocities during their deposition. A high percentage of fines lends some cohesion to a sediment and thereby increases its shear strength. The depth to the water table, or height of the saturated soil column, is one of the critical factors in determining liquefaction susceptibility. Cohesionless soils with perched water zones are likely to be as susceptible as zones beneath the actual groundwater table. However, perched water tables are less likely to cause extensive damage due to their isolated occurrences.

3.2 Field Test to Determine Liquefaction Susceptibility

In current practice, the potential of a soil to liquefy is related to the Standard Penetration Test (SPT) (ASTM D1586-84). The SPT test involves the dropping of a hammer of a certain weight from a fixed height and counting the number of blows required to penetrate each of 3 six inches of a split sampling tube of length 18 inches into the soil. The SPT number called the N-value is the average number of blows for the last 2 of 6 inches of a full penetration of 18 inches. ASTM D1586-84 standard (referred to in this report as the standard) stipulates that the hammer should weigh 140 lbs. and the height of fall should be 30 inches. There are many shortcomings of the SPT which raise doubts on its usefulness as a reliable test not only for liquefaction studies but also for soil properties determination. Nevertheless, the SPT is a simple test, a large body of test data is available and SPT numbers (N) have been correlated to sites which have liquefied.

In order to make use of the available SPT data (many from non-standard tests, that is, the weight of the hammer, the height of the drop and the drive systems vary from ASTM (D1586-84), the N values were corrected for a hammer energy ratio of 60%, N_{60} , (Seed et al., 1984), and to an effective overburden pressure of 1 ton per square foot, $N_{1(60)}$, (Seed et al., 1983). For this study, N values were corrected as shown in the following sections.

3.2.1 Correction for Hammer Ratio and Relative Soil Density

The hammer ratio (R_s) was calculated from (Lowe and Zaccheo, 1975):

$$R_s = \frac{D_o^3 - D_i^3}{144WH} \quad (3.1)$$

where D_o and D_i are the outer and inner diameters of the sampling tube in inches (respectively); W is the hammer weight in lbs; and H is the distance of the hammer fall in inches. Relative soil densities of less than 50% were corrected using Equation 3.2.

$$N_e = \frac{N}{4050 R_s^{5/7}} \quad (3.2)$$

where N_e is the corrected value and N is the field value. This equation was derived by Budhu et al. (1987) from the graphs produced by Lowe and Zaccheo (1975).

3.2.2 Normalization of Effective Overburden Pressure

The effective overburden pressure is normalized to a value of 1 ton per square foot by (Liao and Whitman, 1985):

$$N_{1(60)} = C_n N_{60} \quad (3.3)$$

where C_n is a correction coefficient equal to $(\sigma^{-1/2})$.

3.3 Calculations of Liquefaction Potential

A procedure for evaluating liquefaction potential on the basis of observed field performance data has been established by Seed et al. (1984). This method employs a correlation between sediment penetration resistance and the average cyclic shear stress ratio (τ_{av}/σ) required for liquefaction.

To evaluate liquefaction potential by this method, a peak ground acceleration value (a_{\max}) for a design earthquake is selected and the average cyclic shear stress ratio value for each soil layer is calculated from

$$\frac{\tau_{av}}{\sigma} = 0.65 \frac{a_{\max} \sigma^t}{g \sigma} r_d \quad (3.4)$$

where g is the acceleration due to gravity, σ^t is the total vertical stress, σ is the effective vertical stress and r_d is an average stress reduction factor that decreases approximately linearly from a value of 1 at the ground surface to a value of 0.9 at a depth of 35 ft.

Figure 3-1 shows the coordinate values of $[N_{1(60)}, (\tau_{av}/\sigma)]$ for sites with similar average grain size which have liquefied. Coordinates of $[N_{1(60)}, (\tau_{av}/\sigma)]$ that lie above the field performance curve will liquefy under an earthquake of magnitude 7.5.

3.4 Liquefaction Probability

Probabilistic models for evaluation of liquefaction potential have been developed by Liao et al. (1988) using regression analyses of SPT data from 278 sites at which liquefaction occurred. One of these models, the Cyclic Stress Ratio (CSR) model assigns probability of liquefaction values to average cyclic shear stress ratio vs. corrected SPT curves. This model is similar to that of Seed et al. (1984) except that, rather than having one demarcation curve, there are now several curves each delimiting a different probability for liquefaction (Figure 3-2)

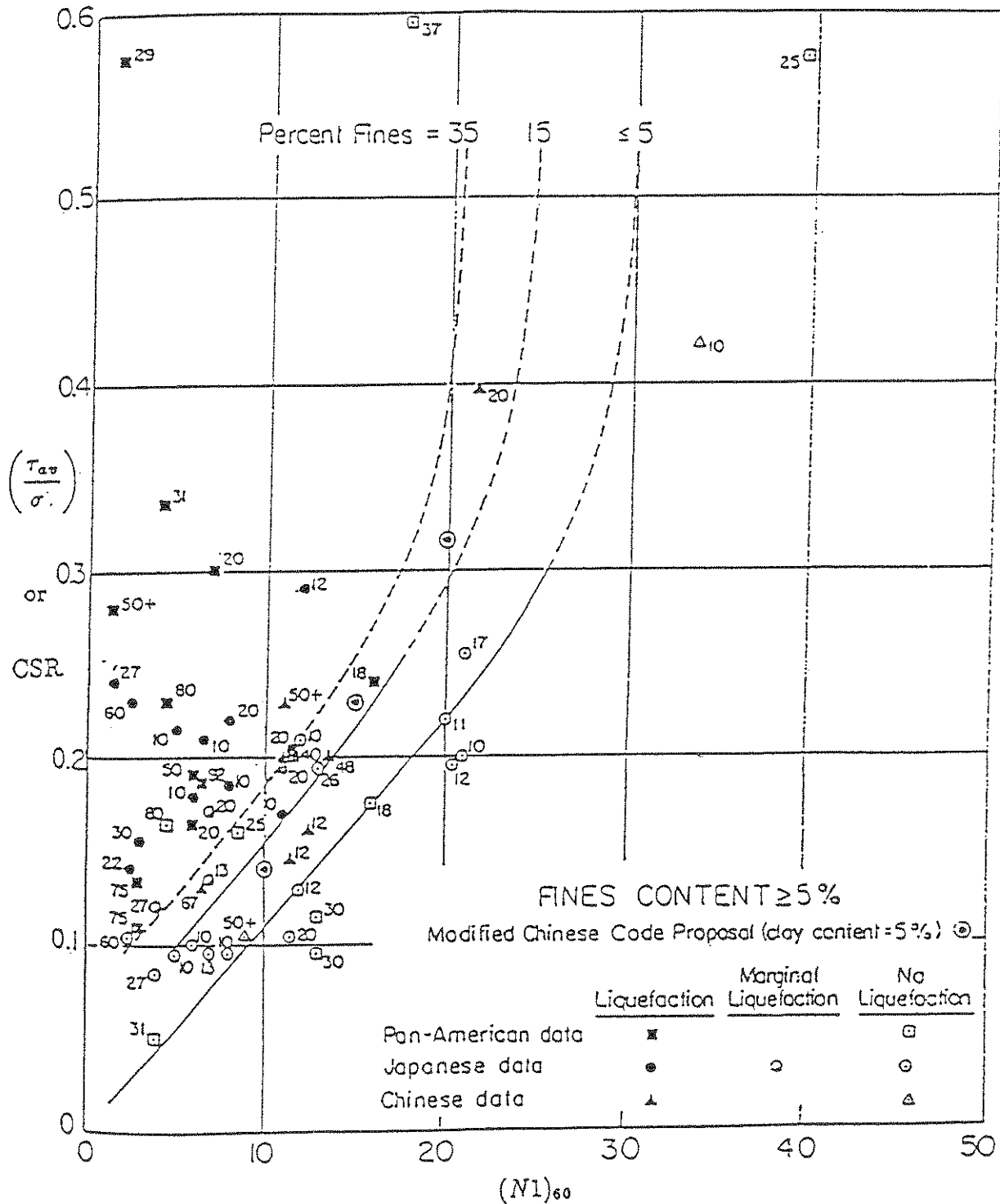


FIGURE 3-1 Seed's $(N1)_{60}$, CSR Relationship (Seed's Criteria Plot) - Silty Sands (After Seed et al., 1984).

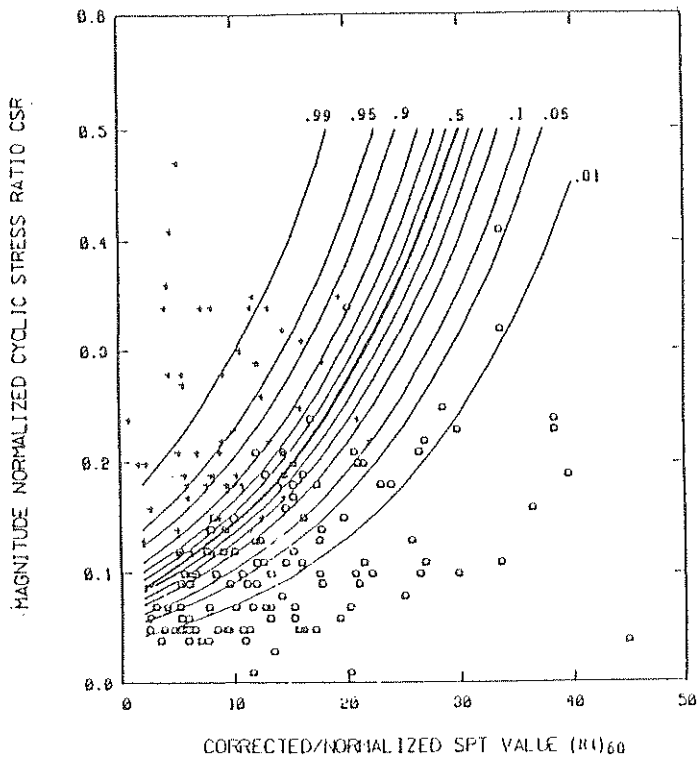


FIGURE 3-2a Liao's $(N1)_{60}$, CSR Relationship Indicating Probability of Liquefaction (Liao's Criteria Plots) - Clean Sands - Fines Content $\leq 12\%$ (After Liao et al., 1988).

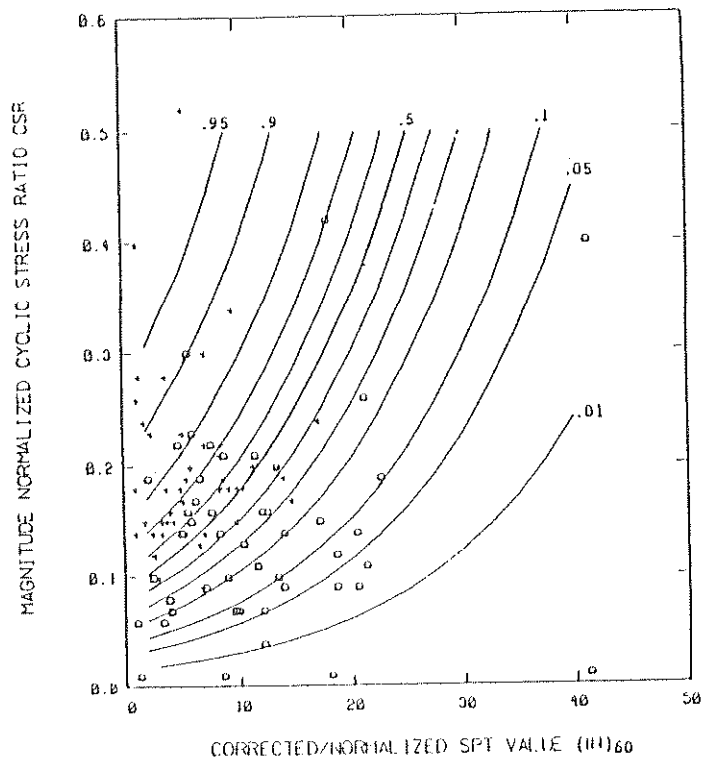


FIGURE 3-2b Liao's $(N1)_{60}$, CSR Relationship Indicating Probability of Liquefaction - Silty Sands - Fines Content $\geq 12\%$ (After Liao et al., 1988).

SECTION 4

METHODOLOGY USED FOR LIQUEFACTION POTENTIAL MAPPING

4.1 Data Collection

A literature search was implemented through the on-line computer databases, GEO-REF, GEOBASE, and GEOARCHIVE at the National Center for Earthquake Engineering Research Office of Information Services. Newspaper articles documenting the local effects of past earthquakes were extracted from the Buffalo Courier Express (1929) and the Buffalo Gazette (1812). These newspapers were found in the Buffalo Historical Society archives. Geologic and engineering reports, and approximately 2,000 drilling logs were collected from several agencies (in particular, the United States Army Corps of Engineers, Buffalo District; Geotechnical Section, New York State Department of Transportation; City of Buffalo Department of Public Works; Engineering and Survey Divisions, City of Buffalo Sewer Authority; Empire Soils/Thomsen Associates, Inc.) in the greater Buffalo area.

4.2 Representative Drilling Logs

Approximately 500 drilling logs were chosen as representative borings (see location in Figure 4-1) and incorporated into a database by the following criteria:

- (1) Location with respect to the study area
- (2) Clarity of geologic description by drillhole logging personnel

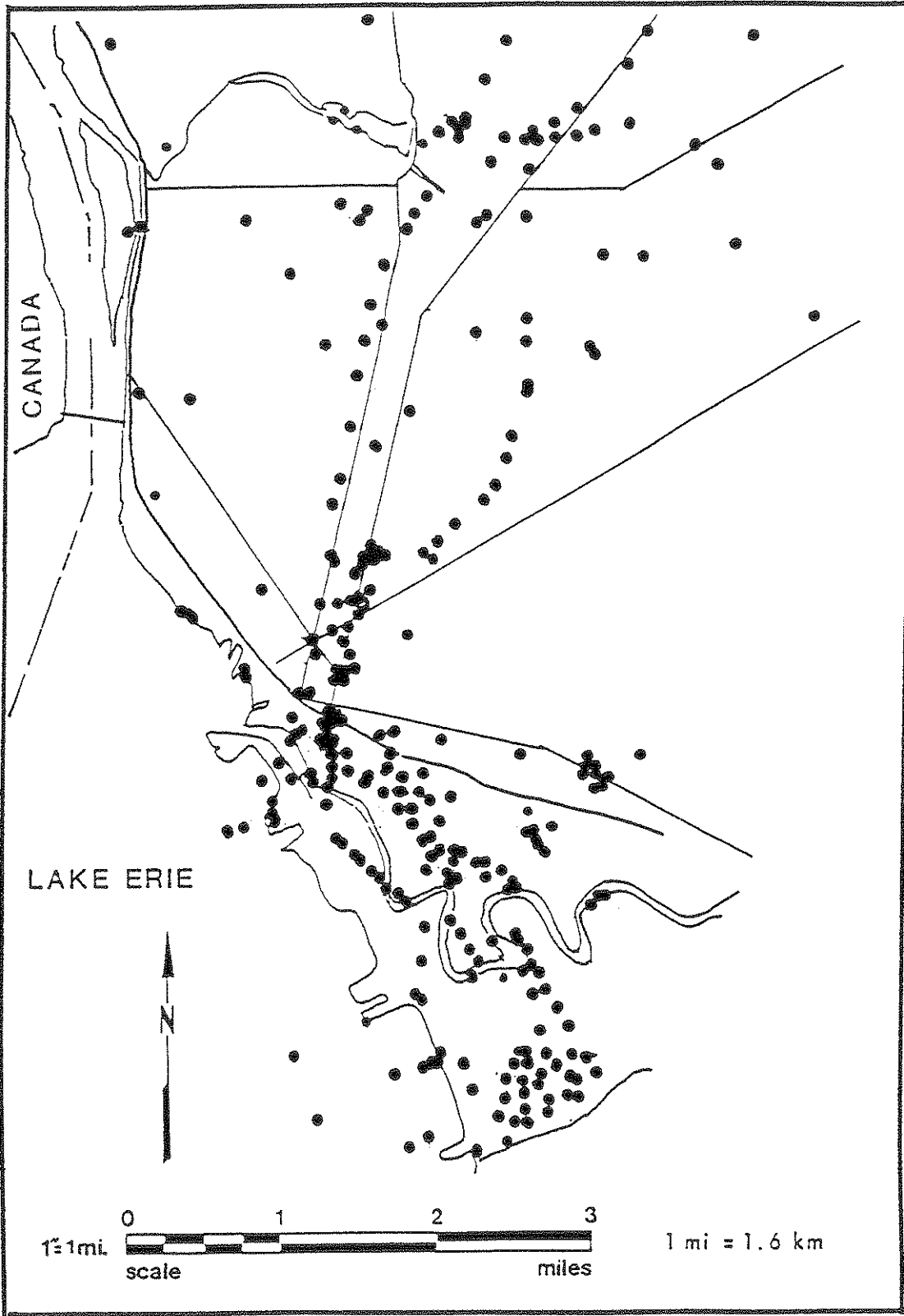


FIGURE 4-1 Test Boring Locations

(3) Similarity of stratification and of N-values with other nearby boreholes

Geographic coordinates were determined for each test boring using survey data and USGS quadrangle maps. Sediments were correlated by logged descriptions of textural composition and gradations, relative elevations, and mineralogic color ranges. Textural and sorting characteristics were determined from the Unified Soil Classification System and ASTM descriptions that were recorded on the drilling logs.

4.3 Determination of Liquefaction Potential

Potentially liquefiable sand deposits at depths of 50 feet or less and with N-values of 15 or less were extracted from the database. Soil layers with thicknesses less than one foot were not considered due to conventions of the SPT test (the N-value being the average number of blows for the last 2 of 6 inches of a full penetration of 18 inches). N-values were standardized to represent a hammer energy ratio of 60% (N_{60}) and an effective overburden pressure of 1 ton/ft² (Seed et al., 1984). Cyclic shear stress ratios were calculated according to Seed et al. (1983) using a peak seismic acceleration value of 0.15g (Algermissen et al., 1982). Coordinates of [$N_{1(60)}, \tau_{av}/\sigma$] were compared to type curves according to Seed et al. (1984) to determine liquefiability. Liquefaction probability values were determined by the critical stress ratio method of Liao et al. (1988), using an assumed average bulk unit weight of 110 lbs./ft³. A liquefaction potential probability map has been produced essentially using the methods established by Seed et al. (1983) and the probability curves of Liao et al. (1988). The liquefaction potential map is divided into zones corresponding to arbitrarily selected descriptions of high, moderate and low

probability according to the following scheme.

H	high	probability of liquefaction	> 50%
M	moderate	probability of liquefaction	10 - 50%
L	low	probability of liquefaction	< 10%

SECTION 5

ASSESSMENT OF LIQUEFACTION POTENTIAL

Table 5-I presents a typical liquefaction potential and probability calculations for identified liquefaction susceptible locations. All of the susceptible sediments are of glaciofluvial origin with the exception of a pocket of loose sand north of the Buffalo Moraine. Figure 5-1 is the liquefaction potential map for the study area. Examination of geologic conditions in the City of Buffalo according to criteria proposed by Youd and Hoose (1977) shows possible liquefaction opportunity for areas along the Buffalo waterfront and Buffalo River. Local seismic conditions and activities near the Clarendon-Linden fault zone and the occurrences of moderate intensity earthquakes in western New York and Lake Ontario appear to provide sufficient opportunity for liquefaction induced ground failure. Unconsolidated deposits of western New York partly meet the criteria for liquefaction susceptibility:

1. The geologic age of unconsolidated sediments is Pleistocene or younger.
2. The deposits appear to be loose sediments that were deposited by fluvial and glaciofluvial processes.
3. The water table is generally very shallow near the waterfront and Buffalo River areas where liquefaction prone deposits are present.

Our computations of liquefaction potential from the geotechnical data did not reveal any areas of high liquefaction potential. Approximately 3 square miles of the identified susceptible sites have moderate liquefaction probability. Except for a shallow pocket of

Table 5-1. Liquefaction Probability Calculations. See the text for details of the calculations.

LAT. (N)	LONG. (W)	BORE ID	SURF. ELEV. (FT)	GW ELEV. (FT)	UNIT LAYER BASE (FT)	LAYER THKNS (FT)	SPT-N VALUE (FIELD)	USCS CLAS.	% FINES	RD	TOTAL STRESS (*)	EFF. STRESS (FSF)	HAMMER WEIGHT (LBS)	FALL (IN)	SPOON OD (IN)	HAMMER RATIO RS	CORR. FOR SPT	STD. SPT N	C _n NI(60)	CSR (**)	PROB. LIQ. (a)	CLASS. (b)		
51.33	51.87	K1-27	581.3	575.3	566.3	24.0	9.0	4	SW	10	0.93	2640	2628.5	140	30	2.0	8.93E-06	1.00	3.99	0.87	3.48	0.091	40	M
51.67	51.78	K1-23	581.9	576.9	567.9	17.0	3.0	1	SM	50	0.93	1870	1859.5	140	30	2.0	8.93E-06	1.00	1.00	1.04	1.04	0.093	50	M
51.85	51.23	K1-28	578.7	574.2	562.7	19.0	3.0	25	SM	10	0.94	2090	2077.0	140	30	2.0	8.93E-06	1.00	24.96	0.98	24.49	0.093	1	L
51.88	50.70	NFB-22	582.3	559.3	559.3	28.0	5.0	19	SP	10	0.92	3080	3077.5	140	30	2.0	8.93E-06	1.00	18.97	0.81	15.29	0.089	7	L
52.10	51.35	K1-32	584.4	572.0	560.4	30.0	6.0	17	SW	10	0.91	3300	3285.4	140	30	2.0	8.93E-06	1.00	16.97	0.78	13.24	0.089	7.5	L
52.03	52.33	K1-16	581.3	574.3	566.3	18.0	3.0	3	SM	50	0.95	1980	1970.5	140	30	2.0	8.93E-06	1.00	2.99	1.01	3.02	0.093	38	M
52.39	51.51	NFB-2	583.7	570.0	559.7	28.0	4.0	10	SW	10	0.92	3080	3067.7	140	30	2.0	8.93E-06	1.00	9.98	0.81	8.06	0.090	10	M
52.40	51.32	NFB1-A	586.1	579.7	563.1	30.5	7.5	27	SW	10	0.91	3355	3334.7	140	30	2.0	8.93E-06	1.00	26.95	0.77	20.87	0.089	1	L
52.45	52.17	K1-14	580.7	567.7	567.7	19.0	6.0	7	SW	10	0.94	2090	2087.0	140	30	2.0	8.93E-06	1.00	6.99	0.98	6.84	0.092	30	M
52.45	51.58	NFB-3	581.2	574.0	557.7	28.0	4.5	18	SW	10	0.92	3080	3061.5	140	30	2.0	8.93E-06	1.00	17.97	0.81	14.52	0.090	1	L
52.47	51.50	NFB-12	583.6	563.6	560.6	28.0	5.0	10	SW	10	0.92	3080	3072.5	140	30	2.0	8.93E-06	1.00	9.98	0.81	8.05	0.090	10	M
52.48	52.25	K1-13	581.0	564.5	562.0	25.0	6.0	36	SW	10	0.93	2750	2744.5	140	30	2.0	8.93E-06	1.00	35.94	0.85	30.68	0.090	1	L
52.55	53.06	B08511388	579.5	576.5	566.5	25.5	12.5	4	SM	30	0.92	2805	2780.8	140	30	2.0	8.93E-06	1.00	3.99	0.85	3.38	0.091	38	M
52.55	51.45	NFB-13	579.7	572.7	562.0	13.0	6.0	3	SM	50	0.96	1430	1427.0	140	30	2.0	8.93E-06	1.00	2.99	1.18	3.55	0.094	39	M
52.62	52.32	K1-12	581.1	569.0	552.0	35.1	6.0	14	SM	50	0.89	3861	3841.0	140	30	2.0	8.93E-06	1.00	13.98	0.72	10.09	0.088	5	L
52.65	52.81	B08511382A	582.5	569.5	564.5	27.0	9.0	15	SW	0	0.92	2970	2960.5	140	30	2.0	8.93E-06	1.00	14.97	0.82	12.31	0.090	4	L
52.75	52.28	OOT-ONT-91	586.4	571.4	558.4	32.0	4.0	22	SW	10	0.90	3520	3505.0	250	18	2.0	8.93E-06	0.95	20.89	0.76	15.78	0.089	1	L
52.75	51.72	NFB-16	582.2	553.7	553.7	38.0	9.5	22	SW	10	0.89	4180	4175.3	140	30	2.0	8.93E-06	1.00	21.96	0.69	15.20	0.086	1	L
52.77	51.87	NFB-8	586.6	576.0	557.6	33.0	4.0	5	SP	10	0.90	3630	3609.6	140	30	2.0	8.93E-06	1.00	4.99	0.74	3.72	0.088	30	M
52.78	52.45	OOT-ONT-96	594.6	573.1	576.6	46.8	28.8	3	SM	50	0.86	5148	5137.1	250	18	2.0	8.93E-06	0.95	2.85	0.62	1.78	0.084	40	M
52.80	52.32	OOT-ONT-89	599.7	599.7	577.6	42.1	20.0	20	SM	50	0.87	4631	4598.9	250	18	2.0	8.93E-06	0.95	18.99	0.66	12.53	0.086	12	M
52.82	51.82	NFB-17	586.1	553.1	553.1	43.0	10.0	14	SW	10	0.87	4750	4725.0	140	30	2.0	8.93E-06	1.00	13.98	0.65	9.09	0.085	8	M
59.52	52.35	BEC-A3-C-11	621.0	601.0	597.0	45.0	21.0	15	SM	50	0.87	4950	4935.5	140	30	2.0	8.93E-06	1.00	14.97	0.64	9.53	0.085	14	M

(a) Liao et al. (1987)

(b) Budhu et al. (1987)

(*) Assumed unit weight = 110 pounds per cubic foot

(**) Design a(max) value = 0.15 g

LAT: 2 degrees

LONG: 8 degrees

SURF. Ground surface elevation

ELEV. in feet (USGS datum)

GW Groundwater table

ELEV elevation in feet

UNIT Elevation at top of

ELEV depositional unit

LAYER Depth to base of

BASE depositional unit

LAYER Thickness of suspected

TKNS liquefiable layer

SPT-N Field in-situ density value

VALU from SPT

USCS Sediment description from

CLAS, Unified Soil Class. System

FINES Percentage of sediment < #200 sieve

EFF. active stress

STRESS

SPOON Outside diam. of spoon

OD

COOR. n factor for

FOR penetration test

SPT apparatus

STD Corrected SPT N value

SPT N

PROB. Probability of liquefaction

LIQ.

CLASS

H is > 50%

M is 10 to 50%

L is < 10%

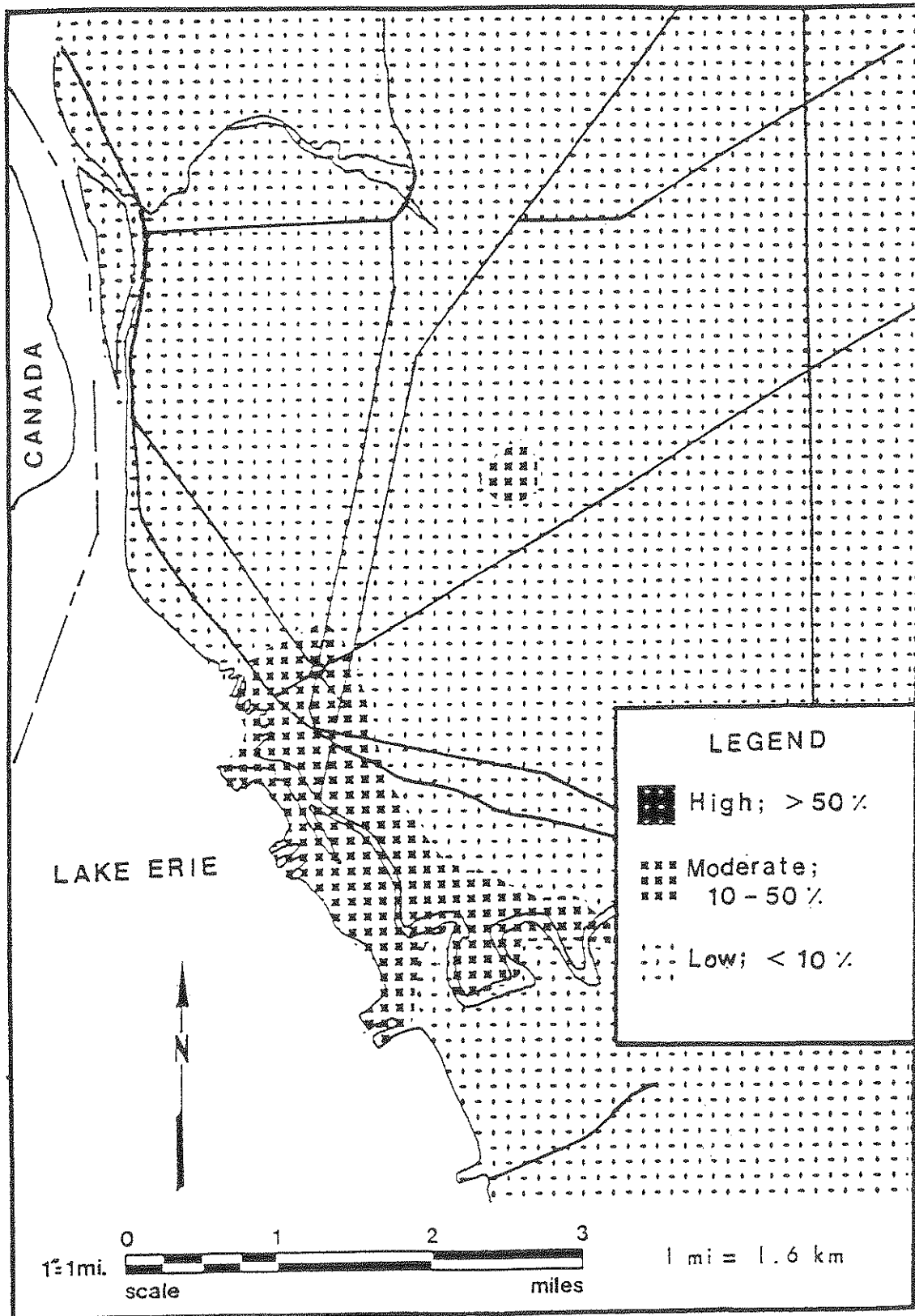


FIGURE 5-1 Liquefaction Potential Map. Shaded Zones Represent Categories of Liquefaction Potential Corresponding to Liquefaction Probability.

loose sand near the Buffalo Moraine which is susceptible to liquefaction, the sandy deposits are generally dense and are not susceptible to liquefaction. Probable liquefaction potential exists in areas of dumped fill along the Lake Erie shoreline and Buffalo River. This fill is in a loose condition and comprised of river and harbor dredgings, etc. SPT measurements in heterogeneous fills are of questionable value for use in liquefaction calculations and as such we suggest that caution be exercised in the interpretation of the moderate liquefaction potential obtained for the fill site between Lake Erie and the Buffalo River (compare Figure 3-2 with Figure 5-1). Much of the City has negligible liquefaction potential owing to the glaciolacustrine origin of surficial deposits and the preconsolidation of granular sediments by glaciation. Gravelly sands existing near the bedrock surface are not susceptible to liquefaction because of their high density, size (coarse) and high confining pressures due to the depth of burial. The ability of soft clays to amplify strong ground motions causing localized liquefaction of the seams and lenses of sand interbedded between the clay sediments was not considered.

SECTION 6

CONCLUSIONS

Although an examination of local seismicity shows sufficient seismic opportunity for earthquake-induced liquefaction in Buffalo, the potential for liquefaction of the cohesionless sediments is low. An area about 2 square miles of moderate liquefaction potential (probability between 10% and 50%) exists between Lake Erie and the Buffalo River. This part of Buffalo consists of loose waterfront fills, and we have doubts about the applicability of current liquefaction-potential methodology to these deposits.

SECTION 7
REFERENCES

1. Algermissen, S. Y., D. M. Perkins, P. C. Thenhaus, S. L. Hansen, and B. L. Bender (1982) "Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States." United States Geological Survey Open File Report 82-1033, 99p.
2. American Society for Testing and Materials (1987) Annual Book of ASTM Standards, Vol. 4.08, Soil and Rock; Building Stones.
3. Barosh, P. J. (1985) "Earthquake Controls and Zonation in New York," in Hays, W. W. and P. L. Gori (eds.), 1985, United States Department of the Interior Geological Survey Proceedings of Conference XXIX: A Workshop on Continuing Actions to Reduce Potential Losses from Future Earthquakes in New York and Nearby States. United States Geological Survey Open File Report 85-386.
4. Budhu, M., Vijayakumar, R. F. Giese, and L. Baumgras (1987) "Liquefaction Potential for New York State: A Preliminary Report on Sites in Manhattan and Buffalo" National Center for Earthquake Engineering Research Technical Report NCEER-87-0009. Buehler, E. J. and I. H. Tesmer (1963) Geology of Erie County, New York. Buffalo Society of Natural Sciences Bulletin, Vol. 21, No. 3.
5. Buehler, E. J. and I. H. Tesmer (1963) Geology of Erie County. Buffalo Soc. Nat. Sci. Bull., Vol. 21, 118 pp.
6. Buffalo Courier-Express Volume XCIV No. 225, 8/13/29 and 8/14/29 editions.
7. Buffalo Drilling Company, Inc. (1985) Drilling Logs, City of Buffalo Sewer Authority, South Buffalo Storm Drainage Project.
8. Buffalo Gazette, Volume 1. May 26, 1812; April 1, 1812; March 11, 1812; February 26, 1812 editions. Calkin, P. E. (1988) Personal communications.

9. Fakundiny, R. H. et al. (1978) "Structural Instability Features in the Vicinity of the Clarendon-Linden Fault System, Western New York and Lake Ontario," *Advances in Analysis of Geotechnical Instabilities*, University of Waterloo Press (1978), SM Study No. 13, Paper 4, pp 121-178.
10. Fakundiny, R. H., J. W. Pifer, and P. W. Pomeroy (1978) "Clarendon-Linden Fault System of Western New York: Longest (?) and Oldest (?) Active Faults in the Eastern United States," *Geological Society of America, Abstracts, Programs* 10:2, 1978, 42 p.
11. Fletcher, J. B. and L. R. Sykes (1977) Earthquakes related to hydraulic mining and natural seismic activity in Western New York. *J. Geophys. Res.*, Vol. 82, 3767-3780.
12. Hutchinson, D. R., P. E. Pomeroy, R. J. Wold, and H. C. Halls (1979) A geophysical investigation concerning the continuation of the Clarendon-Linden fault across Lake Ontario. *Geology* Vol. 7, 206-210.
13. Liao, S. S. C., D. Veneziano, and R. V. Whitman (1988) "Regression Models for Evaluating Liquefaction Probability." *Journal of the Geotechnical Engineers Division, ASCE*, Vol. 114, No. 4.
14. Liao, S. S. C., and R. V. Whitman (1985) "Overburden Correction Factors for SPT in Sand," *Journal of Geotechnical Engineering, ASCE*, 112(No. 3) 373-377.
15. Lowe, J. and P. Zacco (1975) "Subsurface Explorations and Sampling," Chapter 1, *Foundation Engineering Handbook*, 1-66, Hans F. Winterkorn and Hsai-Yang (eds.), New York: Van Nostrand Reinhold Company.
16. Mitronovas, W. and G. N. Nottis (1985) "Seismicity of New York: Current Status of Scientific Knowledge and Research in Historical Seismicity," in Hays, W. W. and P. L. Gori (eds.) (1985) *United States Department of the Interior Geological Survey Proceeding of Conference XXIX: A Workshop on Continuing Actions to Reduce Potential Losses from Future Earthquakes in New York and Nearby States*. United States Geological Survey Open File Report 85-386.

17. Nuttli, O. W. (1973) Seismic wave attenuation and magnitude relations for Eastern North America: *J. Geophys. Res.* 78, 876-885.
18. Richter, C. F. (1958) *Elementary Seismology*: W. H. Freeman, Inc. San Francisco, 768 pp.
19. Sbar, M. L. and L. B. Sykes (1977) "Seismic and Lithospheric Stress in New York and Adjacent Areas," *Journal of Geophysical Research*, Vol. 82, pp. 5771-5786.
20. Seed, H. B., K. Tokimatsu, L. F. Harder, and R. M. Chung (1984) "The Influences of SPT Procedures in Soil Liquefaction Resistance Evaluations." Report No. UBC/EERC-84/15, Earthquake Engineering Research Center, University of California, Berkeley, California.
21. Seed, H. B., I. M. Idriss, and I. Arango (1983) "Evaluation of Liquefaction Potential Using Field Performance Data," *Journal of Geotechnical Engineering*, ASCE 109 (3): 458-482.
22. Stover, C. W., L. M. Barnhard, B. G. Reagor, and S. T. Algermissen (1981) "Seismicity Map of the State of New York", U.S.G.S. MF-1281.
23. Van Tyne, A. M. (1975) "Clarendon-Linden Structure, Western New York", New York State Museum and Science Service, Geological Survey Open File Report 10.
24. Youd, T. L. and S. N. Hoose (1977) "Liquefaction Susceptibility and Geologic Setting" *Proceedings of the Sixth World Conference on Earthquake Engineering*, Vol. 3, Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

APPENDIX A
A LISTING OF HISTORICAL EARTHQUAKES LOCATED IN
NEW YORK STATE (FROM STOVER ET AL, 1981) WHICH
OCCURRED BETWEEN 1737 AND 1977

Year	Month	Day	Time	Lat.	Long.	Depth	Mag.	Note	Scale
1977	12	15	8:55	43.03	77.44	5	2.6	1	
1977	9	28	17:21	44.39	73.89	3	3.1	2	III
1976	10	20	23:42	44.69	73.89	1	2.8	2	
1976	8	20	22:08	41.11	73.75	6	2.5	2	
1976	5	11	13:18	40.48	73.8	1	2.8	2	
1976	4	28	21:32	44.58	74.63	1	2.8	2	
1975	11	3	20:54	43.91	74.65	5	3.9	2	IV
1975	10	28	21:45	41.57	73.93				II
1975	10	24	7:43	41.59	73.93	3	2.2	2	II
1975	10	24	7:08	41.62	73.98	5	2	2	II
1975	10	8	9:00	43.48	78.5	5	2.6	2	III
1975	7	19	20:59	41.43	73.79	5	2.3	2	III
1975	7	11	1:44	44.32	73.87	2	2.8	2	VI
1975	6	9	18:39	44.87	73.65	11	4.2	2	
1975	5	14	00:08	43.4	78.6		2.9	1	
1975	2	20	08:06	40.3	73.2		2.9	2	
1975	1	28	00:15	45	73.8		2.6	1	IV
1975	1	15	19:16	44.9	74.56	0	2.6	2	
1975	1	4	20:40	44.89	74.55	0	2.7	2	
1975	1	4	20:40	44.89	74.55	0	2.8	2	
1974	11	27	10:28	43.33	79.11	0	3.3	1	
1974	9	18	6:23	43.4	73.8	5	2.5	1	
1974	6	7	19:45	41.6	73.95	3	3.3	1	VI
1974	6	2	14:42	44.7	74.6		2.5	1	
1974	3	18	16:05	44.5	74.9		2.7	1	
1973	6	16	8:41	43.76	74.47	1	3.3	2	
1973	6	15	10:32	43.92	74.4	3	3.2	2	
1973	6	15	8:20	43.89	74.43	1	3.4	2	
1973	6	11	10:08	44	74		2.8	1	
1973	2	9	4:46	42.8	78.3		2.7	1	
1973	2	2	23:09	44.4	74.7		2.8	2	
1972	11	2	5:15	44.8	74.6		3	1	
1972	3	15	12:10	43.7	74.7		2.6	1	
1972	2	15	23:53	43.3	73.6		2.6	1	
1971	7	10	8:15	43.91	74.44	2	3.7	1	
1971	6	21	2:48	43.9	74.48	2	3.6	1	
1971	5	23	9:29	43.93	74.47	1	3.4	1	
1971	5	23	6:24	43.9	74.48	9	3.9	1	
1969	8	13	2:42	42.9	78.2		2.5	2	
1967	11	22	21:10	41.2	73.8				
1967	6	13	19:08	42.83	78.23	1	4.4	2	
1966	6	30	.. ..	44.4	73.7				
1966	5	21	7:30	41.2	74				
1966	1	1	13:23	42.84	78.25	0	4.6	2	
1966	1	1	11:29	42.8	78.3		3	1	
1966	1	1	10:30	42.8	78.2				
1965	9	29	20:57	41.4	74.4				
1965	8	28	1:55	43	78.1		3.1	1	
1965	7	16	11:06	43.2	78.5		3.5	1	
1964	11	30	10:47	41.3	73.9				
1964	11	30	00:34	42.8	74.9		2.6	1	
1964	11	17	17:08	41.2	73.7				

Year	Month	Day	Time	Lat.	Long.	Depth	Mag.	Note	Scale
1964	9	29	00:16	41.2	73.7				
1964	6	16	13:00	45	74.2		2.7	1	
1964	6	4	23:40	44.7	75.3		2.8	1	
1964	3	29	9:16	44.9	74.9				
1963	7	1	19:59	42.6	73.8		3.3	1	
1963	5	19	19:14	43.5	75.2		3.5	1	
1963	5	19		43.2	73.3				
1963	2	16	8:00	44.9	73.7		2.6	1	
1963	1	30	14:15	44	75.9		3	1	
1962	11	27	4:14	41.5	73.8		1.7	1	
1962	10	2	23:45	44.8	74.3				
1962	5	6		39.9	75.5				
1961	9	29	6:30	44.9	74.9				
1961	4	20	13:00	45	74.8		2	1	
1958	8	22	14:25	43	79		3.6	1	
1958	5	6	19:00	42.7	73.8				
1958	2	12	13:29	44.8	75.3		2.6	1	
1958	1	11	16:36	44.9	74.9				
1957	11	30	6:27	45	74.8				
1957	2	20	15:45	44.9	74.9				
1956	7	27	1:34	44.7	73.8		3.4	1	
1955	8	16	7:35	42.9	78.3				
1955	1	21	12:20	42.9	73.8				
1955	1	21	8:40	42.9	73.8				
1954	12	15	17:35	44.8	74.7				
1954	12	13	3:53	44.6	74.6	12	3.6	1	
1954	9	29	3:50	44	75.9				
1954	5	20	22:01	45	74.2	20	2.7	1	
1954	4	21	15:45	44.7	73.5				
1954	2	1	00:37	43	76.7		3.3	1	
1954	1	31	12:30	42.9	77.2				
1953	4	26	1:17	44.7	73.5		2.6	1	
1952	12	21	12:00	44.9	74.9				
1952	11	20	... ..	42.9	76.6				
1952	10	8	21:40	41.7	74				
1952	8	25	00:07	43	74.5				
1951	12	8	4:37	41.7	73.9				
1951	11	6	17:37	44.92	73.55	31	3.7	1	
1951	9	3	21:26	41.3	74.3		4.4	1	
1949	2	7	6:17	44.9	74.9				
1948	11	22	23:32	44.4	74.3		2.9	1	
1948	8	7	... ..	44	74				
1948	7	7	7:15	44.7	75				
1948	4	4	2:44	44.2	73.8		2.5	1	
1947	10	29	15:45	45	74.9				
1946	12	25	4:48	45	74.9		3	1	
1946	11	28	22:00	43.9	73.8				
1946	11	11	10:20	45	74.9		3	1	
1946	11	10	11:41	42.9	77.5		3.1	1	
1946	9	4	19:29	45	74.9		2.3	1	
1946	6	27	21:06	44.6	74.5		3	1	
1946	6	20	23:09	44.4	74.2				

Year	Month	Day	Time	Lat.	Long.	Depth	Mag.	Note	Scale
1946	3	20	3:02	44.3	75.9				
1946	3	20	2:29	44.3	75.9				
1946	3	20	2:01	44.3	75.9				
1946	3	16	4:20	45	74.9				
1946	2	13	15:10	45	74.9				II
1945	12	2	15:22	45	74.9		3	1	
1945	6	24	1:56	45	74.9		2.7	1	
1945	4	15	15:30	43	76.4				III
1945	4	15	14:20	43	76.4				III
1945	4	15	13:15	43	76.4				III
1945	1	2	23:00	45	74.9				III
1945	1	1	10:00	45	74.9				III
1945	1	1	5:45	45	74.9				III
1944	12	31	5:30	45	74.9				III
1944	12	27	10:07	45	74.9				III
1944	12	5	12:00	45	74.9				III
1944	11	25	13:00	45	74.9				III
1944	11	23	7:00	45	74.9				III
1944	11	20	1:15	45	74.9				III
1944	11	17	10:15	45	74.9				III
1944	11	11	3:30	45	74.9				IV
1944	11	9	3:15	45	74.9				IV
1944	11	8	23:00	45	74.9				III
1944	10	31	8:42	45	74.9		4	1	IV
1944	10	26	00:57	45	74.9				III
1944	10	20	23:39	45	74.9				III
1944	10	17	13:00	45	74.9				III
1944	10	13	10:00	45	74.9				III
1944	10	13	2:33	45	74.9		2.7	1	
1944	10	10	00:00	45	74.9				III
1944	10	9	7:00	45	74.9				III
1944	10	9	1:45	45	74.9		2.3	1	
1944	10	9	1:00	45	74.9				III
1944	10	8	13:50	45	74.9				III
1944	10	6	13:00	45	74.9				III
1944	10	5	21:00	45	74.9				III
1944	10	5	11:30	45	74.9				III
1944	10	4	13:35	45	74.9				III
1944	10	4	00:30	45	74.9				III
1944	10	3	.. ..	45	74.9				III
1944	9	30	19:50	45	74.9				III
1944	9	24	19:00	45	74.9				III
1944	9	19	1:00	45	74.9				III
1944	9	18	4:55	45	74.9				III
1944	9	16	23:40	45	74.9				III
1944	9	16	4:05	45	74.9				III
1944	9	13	22:00	45	74.9		2.7	1	IV
1944	9	13	17:40	45	74.9				III
1944	9	13	2:45	45	74.9				III
1944	9	9	23:24	45	74.9		4.1	1	IV
1944	9	8	19:50	45	74.9				III
1944	9	8	19:35	45	74.9		2.8	1	

Year	Month	Day	Time	Lat.	Long.	Depth	Mag.	Note	Scale
1944	9	8	10:11	45	74.9		2.5	1	
1944	9	8	9:50	45	74.9				III
1944	9	7	13:55	45	74.9		2.5	1	
1944	9	7	2:47	45	74.9				III
1944	9	7	1:30	45	74.9				III
1944	9	7	.. .	45	74.9				III
1944	9	6	13:30	45	74.9				III
1944	9	5	11:10	45	74.9		2.8	1	
1944	9	5	10:56	45	74.9		3.3	1	
1944	9	5	8:51	45	74.65	1	4.6	1	
1944	9	5	8:30	45	74.9		3.4	1	
1944	9	5	4:38	44.96	74.72	12	5.8	2	VIII
1944	5	29	23:03	44.7	73.8				II
1944	2	26	21:58	42.9	78.8				
1944	1	16	10:00	43.1	77.6				II
1943	10	15	23:00	44.4	74.2		2.5	1	
1943	6	11	22:51	41.1	71.8				II
1943	5	9	11:03	44.8	73.8		3.2	1	
1942	10	2	22:29	42.5	73.8		3	1	
1942	10	1	20:58	44	73.5		2.5	1	
1942	5	24	11:33	44.7	73.8		3.9	1	
1942	5	24	7:15	44.7	73.8		2.9	1	
1942	1	31	4:11	44.7	73.9		2.7	1	
1941	12	12	23:28	44.9	73.7		2.7	1	II
1941	10	21	6:10	44.8	74.8		3.3	1	
1941	10	21	5:23	44.8	74.8		2.2	1	
1941	10	20	21:29	44	75.9				II
1941	10	9	22:07	44	75.9				II
1941	7	29	00:24	41.1	73.8				III
1941	4	29	14:05	40.5	72.5		2.5	1	
1941	4	4	8:10	44.7	73.9		3.3	1	
1941	4	3	19:52	44.7	73.9		2.5	1	
1941	2	1	18:28	44.6	75.2				II
1940	9	27	.. .	41.6	75.7				II
1940	9	26	23:30	44.7	73.4		2.9	1	III
1940	6	4	18:14	40	72				II
1940	6	4	18:13	40	72				II
1940	5	20	1:26	44.6	75.2				II
1940	5	10	19:23	40	72				II
1940	4	27	22:44	40	72				II
1940	4	27	22:37	40	72				II
1940	4	27	22:31	40	72				II
1940	4	13	8:23	44.8	74.9		2.6	1	
1940	4	12	1:58	42.8	74.6				II
1939	10	25	14:46	42.2	73.8				II
1939	10	21	8:59	43.3	73.3				II
1939	9	21	20:30	41.4	74.1				II
1939	6	1	3:36	44.6	75.2				III
1939	2	24	00:20	42.9	78.3				III
1939	2	21	....	44.8	74.3				II
1938	11	18	22:19	44.8	75.3				V
1938	10	21	7:18	41.2	73.7				II

Year	Month	Day	Time	Lat.	Long.	Depth	Mag.	Note	Scale
1938	8	23	7:11	41.2	73.7				III
1938	8	23	5:18	41.2	73.7				III
1938	7	29	7:44	41	73.7				III
1938	5	5	00:35	44.8	74.3				IV
1937	10	12	6:...	41.2	73.8				II
1937	10	12	3:...	41.2	73.8				II
1937	7	19	3:51	40.7	73.7				IV
1937	3	10	5:30	44.6	75.2				IV
1937	2	21	12:...	42.1	76.8				II
1936	6	21	4:40	44.7	74.2				IV
1936	6	21	4:...	44.7	74.2				IV
1936	6	21	4:...	44.7	74.2				II
1936	6	21	3:...	44.7	74.2				II
1936	6	21	3:40	44.7	74.2				III
1935	11	1	6:30	42.6	74.6				II
1935	1	28	9:01	44.8	74.3		3.2	1	III
1935	1	28	6:00	44.8	74.3				IV
1934	6	5	20:11	44.8	74.3				III
1934	4	15	18:05	44.8	74.3				III
1934	4	15	2:28	44.7	73.8		4.5	1	VI
1933	10	29	....	43	74.7				IV
1933	6	26	14:10	41	73.8				III
1933	5	20	19:57	44.8	74.7				III
1932	12	29	4:28	44	73.9				V
1932	12	7	16:45	44.4	74.1				III
1932	12	7	4:05	44.3	74.1				IV
1932	12	7	3:15	44.3	74.1				IV
1931	11	3	15:30	44.6	75.2				II
1931	6	7	2:30	43.2	77.6				II
1931	6	7	00:00	43.2	77.6				II
1931	5	4	18:43	44.8	74.3				III
1931	4	22	....	42.9	78.9				IV
1931	4	20	19:54	43.47	73.78	5	4.7	2	VII
1930	11	2	2:35	44.8	74.3				III
1930	1	17	....	42.8	78.3				II
1930	1	4	....	43.1	75.3				II
1929	12	3	12:50	42.8	78.3				IV
1929	12	2	22:14	42.8	78.3				IV
1929	8	12	11:24	42.91	78.4	9	5.2	2	VIII
1929	8	12	8:45	42.9	78.4				III
1929	8	12	6:...	42.2	77.2				III
1929	6	5	7:00	44.8	74.3				III
1928	3	19	3:20	44.5	74.3				III
1928	3	18	15:20	44.5	74.3		4.1	1	VI
1927	10	24	11:00	44.7	73.7				IV
1927	3	31	21:30	43	76.1				III
1927	3	31	21:00	43	76.1				III
1927	3	29	20:30	43	76.1				III
1927	3	14	14:15	44.6	75.4				IV
1927	3	12	22:14	44.6	75.2				IV
1926	5	22	....	41.7	73.9				II
1926	5	12	3:30	40.9	73.9				V

Year Month Day Time Lat. Long. Depth Mag. Note Scale

Year	Month	Day	Time	Lat.	Long.	Depth	Mag.	Note	Scale
1926	1	27	....	44.3	74.1				IV
1925	5	23	....	43.4	77.1				III
1925	4	7	20:18	43	76.1				III
1922	12	8	21:24	44.5	75.2				V
1921	1	27	....	43.3	73.7				IV
1921	1	19	10:00	43.3	73.7				IV
1917	10	2	2:14	43.3	73.7				III
1917	5	17	10:08	44.7	75.5				II
1917	1	26	....	44.4	74.1				II
1916	11	2	2:32	43.3	73.7				V
1916	10	30	....	43.3	73.7				III
1916	6	8	21:15	41	73.8				IV
1916	2	3	4:20	43	74				I
1916	2	2	16:26	42.9	74				I
1916	1	5	13:56	43.7	73.7				I
1915	2	21	23:41	44.7	73.4				IV
1913	8	10	15:15	44	74				IV
1911	1	29	7:..	44.7	75.5				II
1910	5	1	20:..	40.7	73.5				II
1910	3	3	11:15	44.3	74.2				III
1907	1	24	11:30	42.8	74				IV
1907	1	24	7:30	42.8	74				IV
1903	12	25	12:30	44.7	75.5				V
1897	5	28	3:16	44.5	73.5				VI
1896	5	20	....	43.2	75.2				II
1894	12	17	....	42.5	73.8				IV
1893	3	9	5:30	40.6	74				V
1889	8	10	....	43.4	73.7				IV
1886	9	9	....	42.5	73.4				II
1886	9	3	....	42.5	73.4				II
1886	1	25	00:04	41.6	73.8				IV
1885	1	31	10:05	41.3	73.8				III
1885	1	4	11:06	41.3	73.9				III
1884	8	11	....	40.6	74				V
1884	8	10	19:07	40.6	74				VII
1882	9	13	....	43	77.7				II
1882	4	2	....	42.9	74.2				II
1881	9	25	....	42.1	76.8				II
1881	4	21	16:30	40.9	73.1				III
1881	3	19	2:30	42.8	73.9				III
1880	9	6	7:00	45	74.8				III
1879	4	14	16:15	45	74.8				II
1878	12	29	2:32	42.7	74.3				III
1878	12	25	2:..	40.8	73.8				II
1878	10	4	7:30	41.5	74				V
1878	2	5	16:20	40.8	73.9				V
1877	11	14	14:40	45	74.8				III
1877	11	4	6:56	44.5	74				VII
1877	5	14	....	42.8	73.9				II
1877	5	11	....	42.8	73.7				II
1876	1	8	21:30	43.2	78.7				II
1874	12	13	4:..	41.4	73.9				II

Year	Month	Day	Time	Lat.	Long.	Depth	Mag.	Note	Scale
1874	12	11	3:25	40.9	73.8				V
1874	1	5	21:00	44.7	75.5				II
1873	4	25	19:00	44.8	74.2				V
1873	3	18	....	44.6	75.1				II
1872	7	11	10:25	40.9	73.8				V
1867	12	18	8:00	44.7	75.2				VI
1858	1	1	22:00	43.2	78.7				III
1857	10	23	20:15	43.2	78.6				VI
1855	12	17	19:00	43.3	73.7				IV
1855	2	7	4:30	42	74				VI
1855	1	17	....	40.8	73.6				II
1853	3	12	7:30	43.7	75.5				VI
1852	12	15	21:00	43.4	78.2				III
1847	9	29	....	40.5	70.4				V
1847	7	9	....	43.3	73.7				III
1847	1	12	4:30	42.6	73.7				II
1841	1	25	....	40.7	74				III
1840	1	16	20:00	43	75				VI
1804	5	18	....	40.7	74				III
1737	12	19	3:45	40.8	74				VII

**NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
LIST OF PUBLISHED TECHNICAL REPORTS**

The National Center for Earthquake Engineering Research (NCEER) publishes technical reports on a variety of subjects related to earthquake engineering written by authors funded through NCEER. These reports are available from both NCEER's Publications Department and the National Technical Information Service (NTIS). Requests for reports should be directed to the Publications Department, National Center for Earthquake Engineering Research, State University of New York at Buffalo, Red Jacket Quadrangle, Buffalo, New York 14261. Reports can also be requested through NTIS, 5285 Port Royal Road, Springfield, Virginia 22161. NTIS accession numbers are shown in parenthesis, if available.

- NCEER-87-0001 "First-Year Program in Research, Education and Technology Transfer," 3/5/87, (PB88-134275/AS).
- NCEER-87-0002 "Experimental Evaluation of Instantaneous Optimal Algorithms for Structural Control," by R.C. Lin, T.T. Soong and A.M. Reinhorn, 4/20/87, (PB88-134341/AS).
- NCEER-87-0003 "Experimentation Using the Earthquake Simulation Facilities at University at Buffalo," by A.M. Reinhorn and R.L. Ketter, to be published.
- NCEER-87-0004 "The System Characteristics and Performance of a Shaking Table," by J.S. Hwang, K.C. Chang and G.C. Lee, 6/1/87, (PB88-134259/AS). This report is available only through NTIS (see address given above).
- NCEER-87-0005 "A Finite Element Formulation for Nonlinear Viscoplastic Material Using a Q Model," by O. Gyebe and G. Dasgupta, 11/2/87, (PB88-213764/AS).
- NCEER-87-0006 "Symbolic Manipulation Program (SMP) - Algebraic Codes for Two and Three Dimensional Finite Element Formulations," by X. Lee and G. Dasgupta, 11/9/87, (PB88-219522/AS).
- NCEER-87-0007 "Instantaneous Optimal Control Laws for Tall Buildings Under Seismic Excitations," by J.N. Yang, A. Akbarpour and P. Ghaemmaghami, 6/10/87, (PB88-134333/AS).
- NCEER-87-0008 "IDARC: Inelastic Damage Analysis of Reinforced Concrete Frame - Shear-Wall Structures," by Y.J. Park, A.M. Reinhorn and S.K. Kunnath, 7/20/87, (PB88-134325/AS).
- NCEER-87-0009 "Liquefaction Potential for New York State: A Preliminary Report on Sites in Manhattan and Buffalo," by M. Budhu, V. Vijayakumar, R.F. Giese and L. Baumgras, 8/31/87, (PB88-163704/AS). This report is available only through NTIS (see address given above).
- NCEER-87-0010 "Vertical and Torsional Vibration of Foundations in Inhomogeneous Media," by A.S. Veletsos and K.W. Dotson, 6/1/87, (PB88-134291/AS).
- NCEER-87-0011 "Seismic Probabilistic Risk Assessment and Seismic Margins Studies for Nuclear Power Plants," by Howard H.M. Hwang, 6/15/87, (PB88-134267/AS). This report is available only through NTIS (see address given above).
- NCEER-87-0012 "Parametric Studies of Frequency Response of Secondary Systems Under Ground-Acceleration Excitations," by Y. Yong and Y.K. Lin, 6/10/87, (PB88-134309/AS).
- NCEER-87-0013 "Frequency Response of Secondary Systems Under Seismic Excitation," by J.A. HoLung, J. Cai and Y.K. Lin, 7/31/87, (PB88-134317/AS).
- NCEER-87-0014 "Modelling Earthquake Ground Motions in Seismically Active Regions Using Parametric Time Series Methods," by G.W. Ellis and A.S. Cakmak, 8/25/87, (PB88-134283/AS).
- NCEER-87-0015 "Detection and Assessment of Seismic Structural Damage," by E. DiPasquale and A.S. Cakmak, 8/25/87, (PB88-163712/AS).
- NCEER-87-0016 "Pipeline Experiment at Parkfield, California," by J. Isenberg and E. Richardson, 9/15/87, (PB88-163720/AS).

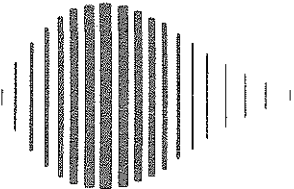
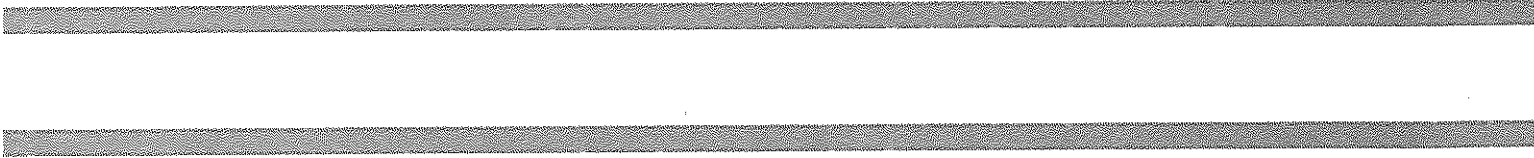
- NCEER-87-0017 "Digital Simulation of Seismic Ground Motion," by M. Shinozuka, G. Deodatis and T. Harada, 8/31/87, (PB88-155197/AS). This report is available only through NTIS (see address given above).
- NCEER-87-0018 "Practical Considerations for Structural Control: System Uncertainty, System Time Delay and Truncation of Small Control Forces," J.N. Yang and A. Akbarpour, 8/10/87, (PB88-163738/AS).
- NCEER-87-0019 "Modal Analysis of Nonclassically Damped Structural Systems Using Canonical Transformation," by J.N. Yang, S. Sarkani and F.X. Long, 9/27/87, (PB88-187851/AS).
- NCEER-87-0020 "A Nonstationary Solution in Random Vibration Theory," by J.R. Red-Horse and P.D. Spanos, 11/3/87, (PB88-163746/AS).
- NCEER-87-0021 "Horizontal Impedances for Radially Inhomogeneous Viscoelastic Soil Layers," by A.S. Veletsos and K.W. Dotson, 10/15/87, (PB88-150859/AS).
- NCEER-87-0022 "Seismic Damage Assessment of Reinforced Concrete Members," by Y.S. Chung, C. Meyer and M. Shinozuka, 10/9/87, (PB88-150867/AS). This report is available only through NTIS (see address given above).
- NCEER-87-0023 "Active Structural Control in Civil Engineering," by T.T. Soong, 11/11/87, (PB88-187778/AS).
- NCEER-87-0024 "Vertical and Torsional Impedances for Radially Inhomogeneous Viscoelastic Soil Layers," by K.W. Dotson and A.S. Veletsos, 12/87, (PB88-187786/AS).
- NCEER-87-0025 "Proceedings from the Symposium on Seismic Hazards, Ground Motions, Soil-Liquefaction and Engineering Practice in Eastern North America," October 20-22, 1987, edited by K.H. Jacob, 12/87, (PB88-188115/AS).
- NCEER-87-0026 "Report on the Whittier-Narrows, California, Earthquake of October 1, 1987," by J. Pantelic and A. Reinhorn, 11/87, (PB88-187752/AS). This report is available only through NTIS (see address given above).
- NCEER-87-0027 "Design of a Modular Program for Transient Nonlinear Analysis of Large 3-D Building Structures," by S. Srivastav and J.F. Abel, 12/30/87, (PB88-187950/AS).
- NCEER-87-0028 "Second-Year Program in Research, Education and Technology Transfer," 3/8/88, (PB88-219480/AS).
- NCEER-88-0001 "Workshop on Seismic Computer Analysis and Design of Buildings With Interactive Graphics," by W. McGuire, J.F. Abel and C.H. Conley, 1/18/88, (PB88-187760/AS).
- NCEER-88-0002 "Optimal Control of Nonlinear Flexible Structures," by J.N. Yang, F.X. Long and D. Wong, 1/22/88, (PB88-213772/AS).
- NCEER-88-0003 "Substructuring Techniques in the Time Domain for Primary-Secondary Structural Systems," by G.D. Manolis and G. Juhn, 2/10/88, (PB88-213780/AS).
- NCEER-88-0004 "Iterative Seismic Analysis of Primary-Secondary Systems," by A. Singhal, L.D. Lutes and P.D. Spanos, 2/23/88, (PB88-213798/AS).
- NCEER-88-0005 "Stochastic Finite Element Expansion for Random Media," by P.D. Spanos and R. Ghanem, 3/14/88, (PB88-213806/AS).
- NCEER-88-0006 "Combining Structural Optimization and Structural Control," by F.Y. Cheng and C.P. Pantelides, 1/10/88, (PB88-213814/AS).
- NCEER-88-0007 "Seismic Performance Assessment of Code-Designed Structures," by H.H.-M. Hwang, J.-W. Jaw and H.-J. Shau, 3/20/88, (PB88-219423/AS).

- NCEER-88-0008 "Reliability Analysis of Code-Designed Structures Under Natural Hazards," by H.H-M. Hwang, H. Ushiba and M. Shinozuka, 2/29/88, (PB88-229471/AS).
- NCEER-88-0009 "Seismic Fragility Analysis of Shear Wall Structures," by J-W Jaw and H.H-M. Hwang, 4/30/88, (PB89-102867/AS).
- NCEER-88-0010 "Base Isolation of a Multi-Story Building Under a Harmonic Ground Motion - A Comparison of Performances of Various Systems," by F-G Fan, G. Ahmadi and I.G. Tadjbakhsh, 5/18/88, (PB89-122238/AS).
- NCEER-88-0011 "Seismic Floor Response Spectra for a Combined System by Green's Functions," by F.M. Lavelle, L.A. Bergman and P.D. Spanos, 5/1/88, (PB89-102875/AS).
- NCEER-88-0012 "A New Solution Technique for Randomly Excited Hysteretic Structures," by G.Q. Cai and Y.K. Lin, 5/16/88, (PB89-102883/AS).
- NCEER-88-0013 "A Study of Radiation Damping and Soil-Structure Interaction Effects in the Centrifuge," by K. Weissman, supervised by J.H. Prevost, 5/24/88, (PB89-144703/AS).
- NCEER-88-0014 "Parameter Identification and Implementation of a Kinematic Plasticity Model for Frictional Soils," by J.H. Prevost and D.V. Griffiths, to be published.
- NCEER-88-0015 "Two- and Three- Dimensional Dynamic Finite Element Analyses of the Long Valley Dam," by D.V. Griffiths and J.H. Prevost, 6/17/88, (PB89-144711/AS).
- NCEER-88-0016 "Damage Assessment of Reinforced Concrete Structures in Eastern United States," by A.M. Reinhorn, M.J. Seidel, S.K. Kunnath and Y.J. Park, 6/15/88, (PB89-122220/AS).
- NCEER-88-0017 "Dynamic Compliance of Vertically Loaded Strip Foundations in Multilayered Viscoelastic Soils," by S. Ahmad and A.S.M. Israil, 6/17/88, (PB89-102891/AS).
- NCEER-88-0018 "An Experimental Study of Seismic Structural Response With Added Viscoelastic Dampers," by R.C. Lin, Z. Liang, T.T. Soong and R.H. Zhang, 6/30/88, (PB89-122212/AS).
- NCEER-88-0019 "Experimental Investigation of Primary - Secondary System Interaction," by G.D. Manolis, G. Juhn and A.M. Reinhorn, 5/27/88, (PB89-122204/AS).
- NCEER-88-0020 "A Response Spectrum Approach For Analysis of Nonclassically Damped Structures," by J.N. Yang, S. Sarkani and F.X. Long, 4/22/88, (PB89-102909/AS).
- NCEER-88-0021 "Seismic Interaction of Structures and Soils: Stochastic Approach," by A.S. Veletsos and A.M. Prasad, 7/21/88, (PB89-122196/AS).
- NCEER-88-0022 "Identification of the Serviceability Limit State and Detection of Seismic Structural Damage," by E. DiPasquale and A.S. Cakmak, 6/15/88, (PB89-122188/AS).
- NCEER-88-0023 "Multi-Hazard Risk Analysis: Case of a Simple Offshore Structure," by B.K. Bhartia and E.H. Vanmarcke, 7/21/88, (PB89-145213/AS).
- NCEER-88-0024 "Automated Seismic Design of Reinforced Concrete Buildings," by Y.S. Chung, C. Meyer and M. Shinozuka, 7/5/88, (PB89-122170/AS).
- NCEER-88-0025 "Experimental Study of Active Control of MDOF Structures Under Seismic Excitations," by L.L. Chung, R.C. Lin, T.T. Soong and A.M. Reinhorn, 7/10/88, (PB89-122600/AS).
- NCEER-88-0026 "Earthquake Simulation Tests of a Low-Rise Metal Structure," by J.S. Hwang, K.C. Chang, G.C. Lee and R.L. Ketter, 8/1/88, (PB89-102917/AS).
- NCEER-88-0027 "Systems Study of Urban Response and Reconstruction Due to Catastrophic Earthquakes," by F. Kozin and H.K. Zhou, 9/22/88.

- NCEER-88-0028 "Seismic Fragility Analysis of Plane Frame Structures," by H.H-M. Hwang and Y.K. Low, 7/31/88, (PB89-131445/AS).
- NCEER-88-0029 "Response Analysis of Stochastic Structures," by A. Kardara, C. Bucher and M. Shinozuka, 9/22/88, (PB89-174429/AS).
- NCEER-88-0030 "Nonnormal Accelerations Due to Yielding in a Primary Structure," by D.C.K. Chen and L.D. Lutes, 9/19/88, (PB89-131437/AS).
- NCEER-88-0031 "Design Approaches for Soil-Structure Interaction," by A.S. Veletsos, A.M. Prasad and Y. Tang, 12/30/88, (PB89-174437/AS).
- NCEER-88-0032 "A Re-evaluation of Design Spectra for Seismic Damage Control," by C.J. Turkstra and A.G. Tallin, 11/7/88, (PB89-145221/AS).
- NCEER-88-0033 "The Behavior and Design of Noncontact Lap Splices Subjected to Repeated Inelastic Tensile Loading," by V.E. Sagan, P. Gergely and R.N. White, 12/8/88, (PB89-163737/AS).
- NCEER-88-0034 "Seismic Response of Pile Foundations," by S.M. Mamoon, P.K. Banerjee and S. Ahmad, 11/1/88, (PB89-145239/AS).
- NCEER-88-0035 "Modeling of R/C Building Structures With Flexible Floor Diaphragms (IDARC2)," by A.M. Reinhorn, S.K. Kunnath and N. Panahshahi, 9/7/88, (PB89-207153/AS).
- NCEER-88-0036 "Solution of the Dam-Reservoir Interaction Problem Using a Combination of FEM, BEM with Particular Integrals, Modal Analysis, and Substructuring," by C-S. Tsai, G.C. Lee and R.L. Ketter, 12/31/88, (PB89-207146/AS).
- NCEER-88-0037 "Optimal Placement of Actuators for Structural Control," by F.Y. Cheng and C.P. Pantelides, 8/15/88, (PB89-162846/AS).
- NCEER-88-0038 "Teflon Bearings in Aseismic Base Isolation: Experimental Studies and Mathematical Modeling," by A. Mokha, M.C. Constantinou and A.M. Reinhorn, 12/5/88, (PB89-218457/AS).
- NCEER-88-0039 "Seismic Behavior of Flat Slab High-Rise Buildings in the New York City Area," by P. Weidlinger and M. Ettouney, 10/15/88, (PB90-145681/AS).
- NCEER-88-0040 "Evaluation of the Earthquake Resistance of Existing Buildings in New York City," by P. Weidlinger and M. Ettouney, 10/15/88, to be published.
- NCEER-88-0041 "Small-Scale Modeling Techniques for Reinforced Concrete Structures Subjected to Seismic Loads," by W. Kim, A. El-Attar and R.N. White, 11/22/88, (PB89-189625/AS).
- NCEER-88-0042 "Modeling Strong Ground Motion from Multiple Event Earthquakes," by G.W. Ellis and A.S. Cakmak, 10/15/88, (PB89-174445/AS).
- NCEER-88-0043 "Nonstationary Models of Seismic Ground Acceleration," by M. Grigoriu, S.E. Ruiz and E. Rosenblueth, 7/15/88, (PB89-189617/AS).
- NCEER-88-0044 "SARCF User's Guide: Seismic Analysis of Reinforced Concrete Frames," by Y.S. Chung, C. Meyer and M. Shinozuka, 11/9/88, (PB89-174452/AS).
- NCEER-88-0045 "First Expert Panel Meeting on Disaster Research and Planning," edited by J. Pantelic and J. Stoye, 9/15/88, (PB89-174460/AS).
- NCEER-88-0046 "Preliminary Studies of the Effect of Degrading Infill Walls on the Nonlinear Seismic Response of Steel Frames," by C.Z. Chrysostomou, P. Gergely and J.F. Abel, 12/19/88, (PB89-208383/AS).

- NCEER-88-0047 "Reinforced Concrete Frame Component Testing Facility - Design, Construction, Instrumentation and Operation," by S.P. Pessiki, C. Conley, T. Bond, P. Gergely and R.N. White, 12/16/88, (PB89-174478/AS).
- NCEER-89-0001 "Effects of Protective Cushion and Soil Compliancy on the Response of Equipment Within a Seismically Excited Building," by J.A. HoLung, 2/16/89, (PB89-207179/AS).
- NCEER-89-0002 "Statistical Evaluation of Response Modification Factors for Reinforced Concrete Structures," by H.H-M. Hwang and J-W. Jaw, 2/17/89, (PB89-207187/AS).
- NCEER-89-0003 "Hysteretic Columns Under Random Excitation," by G-Q. Cai and Y.K. Lin, 1/9/89, (PB89-196513/AS).
- NCEER-89-0004 "Experimental Study of 'Elephant Foot Bulge' Instability of Thin-Walled Metal Tanks," by Z-H. Jia and R.L. Ketter, 2/22/89, (PB89-207195/AS).
- NCEER-89-0005 "Experiment on Performance of Buried Pipelines Across San Andreas Fault," by J. Isenberg, E. Richardson and T.D. O'Rourke, 3/10/89, (PB89-218440/AS).
- NCEER-89-0006 "A Knowledge-Based Approach to Structural Design of Earthquake-Resistant Buildings," by M. Subramani, P. Gergely, C.H. Conley, J.F. Abel and A.H. Zaghaw, 1/15/89, (PB89-218465/AS).
- NCEER-89-0007 "Liquefaction Hazards and Their Effects on Buried Pipelines," by T.D. O'Rourke and P.A. Lane, 2/1/89, (PB89-218481).
- NCEER-89-0008 "Fundamentals of System Identification in Structural Dynamics," by H. Imai, C-B. Yun, O. Maruyama and M. Shinozuka, 1/26/89, (PB89-207211/AS).
- NCEER-89-0009 "Effects of the 1985 Michoacan Earthquake on Water Systems and Other Buried Lifelines in Mexico," by A.G. Ayala and M.J. O'Rourke, 3/8/89, (PB89-207229/AS).
- NCEER-89-R010 "NCEER Bibliography of Earthquake Education Materials," by K.E.K. Ross, Second Revision, 9/1/89, (PB90-125352/AS).
- NCEER-89-0011 "Inelastic Three-Dimensional Response Analysis of Reinforced Concrete Building Structures (IDARC-3D), Part I - Modeling," by S.K. Kunnath and A.M. Reinhorn, 4/17/89, (PB90-114612/AS).
- NCEER-89-0012 "Recommended Modifications to ATC-14," by C.D. Poland and J.O. Malley, 4/12/89.
- NCEER-89-0013 "Repair and Strengthening of Beam-to-Column Connections Subjected to Earthquake Loading," by M. Corazao and A.J. Durrani, 2/28/89, (PB90-109885/AS).
- NCEER-89-0014 "Program EXKAL2 for Identification of Structural Dynamic Systems," by O. Maruyama, C-B. Yun, M. Hoshiya and M. Shinozuka, 5/19/89, (PB90-109877/AS).
- NCEER-89-0015 "Response of Frames With Bolted Semi-Rigid Connections, Part I - Experimental Study and Analytical Predictions," by P.J. DiCorso, A.M. Reinhorn, J.R. Dickerson, J.B. Radzimirski and W.L. Harper, 6/1/89, to be published.
- NCEER-89-0016 "ARMA Monte Carlo Simulation in Probabilistic Structural Analysis," by P.D. Spanos and M.P. Mignolet, 7/10/89, (PB90-109893/AS).
- NCEER-89-0017 "Proceedings from the Conference on Disaster Preparedness - The Place of Earthquake Education in Our Schools," Edited by K.E.K. Ross, 12/31/89.
- NCEER-89-0018 "Multidimensional Models of Hysteretic Material Behavior for Vibration Analysis of Shape Memory Energy Absorbing Devices, by E.J. Graesser and F.A. Cozzarelli, 6/7/89, (PB90-164146/AS).

- NCEER-89-0019 "Nonlinear Dynamic Analysis of Three-Dimensional Base Isolated Structures (3D-BASIS)," by S. Nagarajaiah, A.M. Reinhorn and M.C. Constantinou, 8/3/89.
- NCEER-89-0020 "Structural Control Considering Time-Rate of Control Forces and Control Rate Constraints," by F.Y. Cheng and C.P. Pantelides, 8/3/89, (PB90-120445/AS).
- NCEER-89-0021 "Subsurface Conditions of Memphis and Shelby County," by K.W. Ng, T-S. Chang and H-H.M. Hwang, 7/26/89, (PB90-120437/AS).
- NCEER-89-0022 "Seismic Wave Propagation Effects on Straight Jointed Buried Pipelines," by K. Elhadi and M.J. O'Rourke, 8/24/89.
- NCEER-89-0023 "Workshop on Serviceability Analysis of Water Delivery Systems," edited by M. Grigoriu, 3/6/89, (PB90-127424/AS).
- NCEER-89-0024 "Shaking Table Study of a 1/5 Scale Steel Frame Composed of Tapered Members," by K.C. Chang, J.S. Hwang and G.C. Lee, 9/18/89.
- NCEER-89-0025 "DYNA1D: A Computer Program for Nonlinear Seismic Site Response Analysis - Technical Documentation," by Jean H. Prevost, 9/14/89.
- NCEER-89-0026 "1:4 Scale Model Studies of Active Tendon Systems and Active Mass Dampers for Aseismic Protection," by A.M. Reinhorn, T.T. Soong, R.C. Lin, Y.P. Yang, Y. Fukao, H. Abe and M. Nakai, 9/15/89.
- NCEER-89-0027 "Scattering of Waves by Inclusions in a Nonhomogeneous Elastic Half Space Solved by Boundary Element Methods," by P.K. Hadley, A. Askar and A.S. Cakmak, 6/15/89, (PB90-145699/AS).
- NCEER-89-0028 "Statistical Evaluation of Deflection Amplification Factors for Reinforced Concrete Structures," by H.H.M. Hwang, J-W. Jaw and A.L. Ch'ng, 8/31/89.
- NCEER-89-0029 "Bedrock Accelerations in Memphis Area Due to Large New Madrid Earthquakes," by H.H.M. Hwang, C.H.S. Chen and G. Yu, 11/7/89.
- NCEER-89-0030 "Seismic Behavior and Response Sensitivity of Secondary Structural Systems," by Y.Q. Chen and T.T. Soong, 10/23/89.
- NCEER-89-0031 "Random Vibration and Reliability Analysis of Primary-Secondary Structural Systems," by Y. Ibrahim, M. Grigoriu and T.T. Soong, 11/10/89.
- NCEER-89-0032 "Proceedings from the Second U.S. - Japan Workshop on Liquefaction, Large Ground Deformation and Their Effects on Lifelines, September 26-29, 1989," Edited by T.D. O'Rourke and M. Hamada, 12/1/89.
- NCEER-89-0033 "Deterministic Model for Seismic Damage Evaluation of Reinforced Concrete Structures," by J.M. Bracci, A.M. Reinhorn, J.B. Mander and S.K. Kunnath, 9/27/89, to be published.
- NCEER-89-0034 "On the Relation Between Local and Global Damage Indices," by E. DiPasquale and A.S. Cakmak, 8/15/89.
- NCEER-89-0035 "Cyclic Undrained Behavior of Nonplastic and Low Plasticity Silts," by A.J. Walker and H.E. Stewart, 7/26/89.
- NCEER-89-0036 "Liquefaction Potential of Surficial Deposits in the City of Buffalo, New York," by M. Budhu, R. Giese and L. Baumgrass, 1/17/89.



National Center for Earthquake Engineering Research
State University of New York at Buffalo