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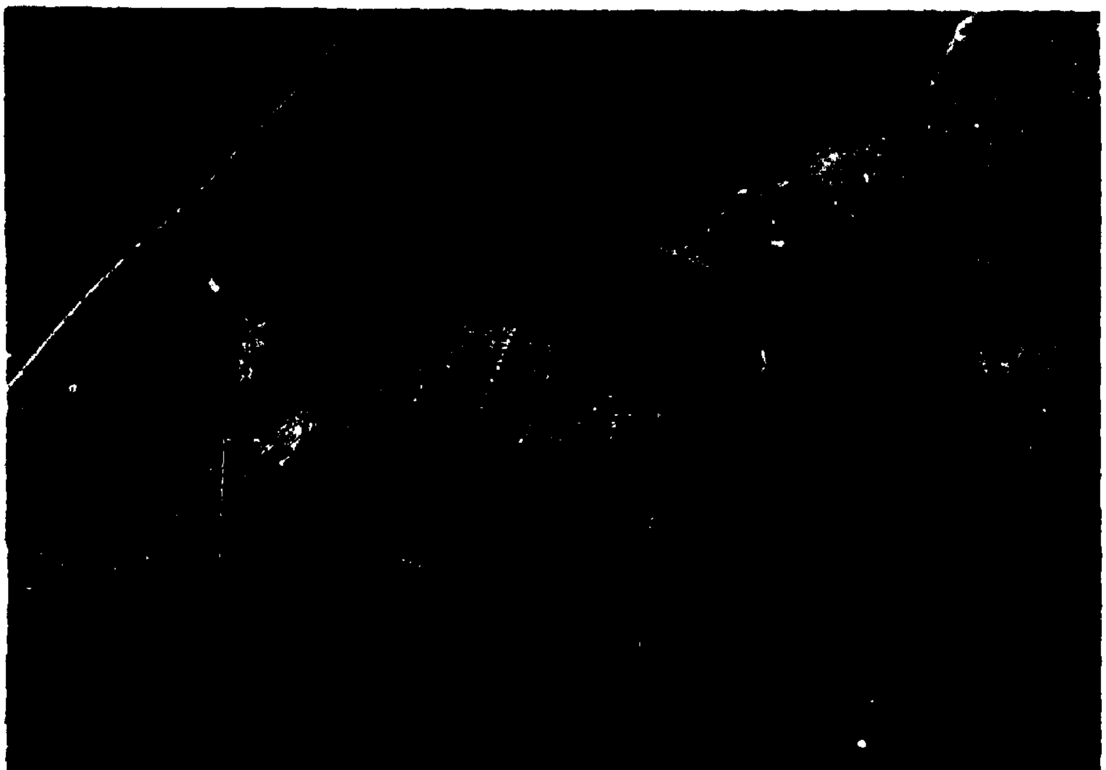

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Reconnaissance Report

MIYAGI-KEN-OKI, JAPAN EARTHQUAKE

June 12, 1978

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The Miyagi-Ken- ki, Japan earthquake caused considerable damage in the city of Sendai and its surrounding areas. As information became available, it became obvious that Sendai constituted a good model of a modern city in the United States such as San Francisco or Seattle. The city has modern, instrumented, steel and reinforced concrete buildings up to 20 stories high and has an operating nuclear power plant complex, consisting of six units, located nearby at Fukushima. The areas surrounding the city were subjected to peak ground accelerations in the range of 1/5g, 1/4g, and 1/3g. There were failures of large tanks, oil spills, dike and bridge failures, a gasholder failure, disruption of utility service, and landslides. The reports compiled here are of a reconnaissance nature only and are not intended to analyze or to reach conclusions about what was seen but rather to report by photos, words, and numbers what happened and what did not happen. Reports cover the following topics: Seismicity; strong-motion earthquake records; liquefaction and damage to dikes; landslides resulting from the earthquake; engineering aspects; architectural aspects; and social effects and government response.

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EARTHQUAKE ENGINEERING RESEARCH INSTITUTE
RECONNAISSANCE REPORT

MIYAGI-KEN-OKI, JAPAN EARTHQUAKE
JUNE 12, 1978

PREFACE AND INTRODUCTION BY JOHN A. BLUME
PRESIDENT, EERI

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Earthquake Engineering Research Institute
with support from
The National Science Foundation

ACKNOWLEDGMENTS

Grateful acknowledgment is made to the many people who made the investigation possible.

The visit of the team was planned and coordinated by Dr. Tadayoshi Okubo, Chief of the Department of Planning and Research Administration, Public Works Research Institute, Ministry of Construction, who also serves as Secretary of the Japan panel of UJNR. He made the basic arrangements for our visit to Japan and our generous reception; for meetings with officials and scientists in Tokyo and in Sendai and tours of the damaged area; and for the valuable exchange of scientific information that resulted.

Mr. Toshio Iwasaki, Mr. Eiichi Kuribayashi, Mr. Tadayuki Tazaki, and Dr. Masamitsu Ohashi of the Earthquake Disaster Prevention Division, Public Works Research Institute, Ministry of Construction, guided the team through the damaged region and provided much insight into the effects of the earthquake.

The following Japanese scientists and engineers assisted the team. Mr. Kazuto Nakazawa, Mr. Yoshito Takeuchi, Mr. Ken Nagai, Mr. Nobuyuki Narita, and Mr. Kazuhiko Kawashima of the Public Works Research Institute, Ministry of Construction; Mr. Y. Tsuruya, Mr. Hajime Tsuchida, and Mr. Yoshi Koshi of the Ministry of Construction; Dr. Makoto Watabe, Dr. Shinsuke Nakata, and Dr. Yoshihiro Sugimura of the Building Research Institute, Ministry of Construction; Mr. Jusaku Funita, Dr. Toshio Fujii, and Dr. Hiroshi Tanaka of the Tokyo Electric Power Company; Mr. Takeshi Miyashita, Mr. Toshiro Yamada, Mr. Toyokazu Shimizu, Mr. Yasuo Watanabe, and Mr. Kunimatsu Hoshihata of the Tohoku Regional Construction Bureau; Mr. Tatsuji Ohshima, Mr. Kunio Isago, and Mr. Hajime Goto of the Tohoku Electric Power Company; Mr. Shigeharu Naribu, and Mr. Makoto Kogo of the Japan Highway Public Corporation; Mr. Masaomi Akabane of the Tohoku Oil Company; Mr. Shiro Hirade of the Sendai Higashi Doboku Office; Professor Nagatomo Oshiage of the Tohoku Institute of Technology; Mr. Tsunehiko Tatebe, Mr. Hiroaki Tsuruta, Mr. Kurihara, Mr. Tadayoshi Ishibashi, Mr. Morio Nishiyama, and Mr. Masaaki Inoue of the Japanese National Railways; Professor Shiga, Professor Akenori Shibata, Professor Akio Takagi, Dr. Ishii, and Professor Hisao Nakagawa of Tohoku University; Professor Kiyoshi Muto, Dr. Kazuyoshi Uchida, Dr. Tsunehisa Tsugawa, Dr. Tadashi Sugano, and Mr. Masayuki Nagata of the Muto Institute of Structural Mechanics; Dr. Yoichi Fujii and Mr. Noburu Inouchi of the Geographical Survey Institute; Mr. Keiichi Ontani of the National Research Center for Disaster Prevention.

The staff of the U.S. Embassy in Tokyo, and particularly Mr. Bruce Carter, also helped with some of the arrangements for the visit.

The help of Dr. Edward O. Pfrang and Dr. H. S. Liu of the National Bureau of Standards, who made arrangements with Dr. Okubo for EERI participation in the reconnaissance, was invaluable.

Participation of the U.S. Geological Survey members was on behalf of the Seismic Engineering and Earthquake Hazard Reduction Programs of the U.S. Geological Survey.

The National Science Foundation contributed part of the funds for publication of this report. Additional funding was provided by URS/John A. Blume & Associates, Engineers. Mary T. Stauduhar of URS/John A. Blume & Associates, Engineers edited much of the report and coordinated its publication.

PREFACE

by

John A. Blume

President, EERI

This is a special reconnaissance report, published and distributed by EERI, on the June 12, 1978, Miyagi-Ken-oki, Japan earthquake, which caused considerable damage in the city of Sendai and its surrounding areas. The earthquake data from U.S. Geological Survey (USGS) sources are:

M_s = 7.4

Time: 08:14:27.0 GMT (17:14 local)

Location: 38.2°N, 142.2°E

Depth: 30 km

Approximate epicentral distance to Sendai: 100 km

Approximate epicentral distance to Fukushima Nuclear Power Plant: 120 km
(As noted in the report, some of the points where energy was released were very likely much closer to Sendai than the hypocenter was to Sendai.)

The report consists of the collected reports of individuals whose participation in the reconnaissance was made possible by their respective agencies and organizations and by their own great personal energy and hard work. Publication funds were provided by the National Science Foundation. We have attempted to acknowledge all those who were of assistance, but there are no doubt some omissions, and for these we apologize.

No attempt is made to reach conclusions or to find the reasons for what happened or did not happen; that constitutes another phase of investigation, a large part of which will no doubt be well documented by Japanese scientists and engineers and by others. For example, a more detailed report will be published by the National Bureau of Standards, under the auspices of the United States-Japan Natural Resources Panel on Wind and Seismic Effects.

In general, the report covers as well as possible within the limitations of time, scope, cost, and space what happened to an area of some million or so people in and about a core city that has hundreds of modern buildings up to 20 stories high, a harbor, oil refineries, power stations, bridges, dikes, distribution systems, etc., under peak horizontal ground accelerations in the range of 1/5g, 1/4g, 1/3g. The Sendai area provides an excellent model for some United States communities.

All information provided is the best available to us at this time. Some variations in data may be expected in more detailed future reports.

CONTENTS

INTRODUCTION

by

John A. Blume
President, EERI and
URS/John A. Blume & Associates, Engineers
San Francisco, California

Each damaging earthquake is different from its predecessors, and the investigation of each also varies. There are many reasons for the latter, including the expertise already available in the country in which the disaster occurs, the types of structures affected by the earthquake, the geologic environment, the amount and type of damage, the possible engineering and other lessons to be learned, the cost of investigation, political conditions, and, of course, the availability of funds and volunteers for field work.

When data on the Miyagi-Ken-oki earthquake of June 12, 1978, started to come in, our first reactions were that Japan has experienced many earthquakes (including one of 6.7 magnitude on February 20, 1978, which because of its location and depth was not disastrous) and has many experts in all aspects of seismology and earthquake engineering as well as ample funds for earthquake investigations of all types. On the other hand, EERI funds for such field efforts had essentially been depleted and at that time did not appear likely to be replaced in the immediate future. Furthermore, travel to and subsistence in Japan is quite costly.

As more information became available, however, it became obvious that Sendai constituted a good model of a modern city in the United States such as San Francisco or Seattle. The city has modern, instrumented, steel and reinforced concrete buildings up to 20 stories high and has an operating nuclear power plant complex, consisting of six units, located nearby at Fukushima. The areas surrounding the city were subjected to peak ground accelerations in the range of 1/5g, 1/4g, and 1/3g. There were failures of large tanks, oil spills, dike and bridge failures, a gasholder failure, disruption of utility service, and landslides. Given all these conditions, we felt that, in spite of all the talent of the Japanese, we should see this model city with our own eyes and with our own point of view. Along these lines, I have previously noted that the Japanese, in one sense at least, learned more from the 1906 San Francisco earthquake than we did: they put some static design codes into effect early while we procrastinated until 1933, two damaging earthquakes later.

It was clear that our company should finance a trip for EERI, but we could send only one engineer. I wanted to go to Japan myself but could not do so because of fixed commitments here, including important EERI matters. The man we were able to spring loose and who had the necessary background and was ready and eager to make the trip was Peter Yanev. He had previously covered the Managua, Nicaragua and Lice, Turkey quakes. But things were not quite that simple. The U.S. Geological Survey (USGS) by then had decided to send a team; we wanted to join them, and USGS concurred. However, there were certain agreements between Japan and the United States that control such matters. Persons planning to go to the affected areas had to be individually approved in advance and to be guided on the tour. Various sorts of approval were required for different matters. To make a long story short, after some 20 or more telephone calls and through the courtesy of Dr. Edward O. Pfrang of the National Bureau of Standards (NBS) and Dr. Jerry Harbour of the Nuclear Regulatory Commission (NRC), not to mention all those involved in USGS, the team, including Peter, was cleared for rendezvous on June 22, 1978, in Tokyo. From there they would be escorted to various places of interest, including the Fukushima Nuclear Power Plant complex. I armed Peter Yanev with credentials, the EERI manual, and a long checklist of things to look for, to do, and not to do. He did a great job, including taking 1,400 photographs and telephoning back preliminary data that were published in the July, 1978, EERI Newsletter.

As is clear by now, this was not the usual, more direct procedure of sending an EERI reconnaissance team to a foreign country. I am pleased to report, however, that in spite of the many complications, and because of the cooperation of a great many agencies and persons, the mission was a success. Much valuable material, documented in this report, is being sent to all EERI members. There are new lessons to be learned, and it was indeed a worthwhile effort.

The reports compiled here are of a reconnaissance nature only and are not intended to analyze or to reach conclusions about what was seen but rather to report by photos, words, and numbers what happened and what did not happen. No doubt there will be, and there should be, many other more detailed studies and reports by the Japanese and others. Among these is an in-depth report being planned by NBS that will include contributions by members of the reconnaissance team.

The funds for publishing this EERI report were provided by the National Science Foundation (NSF) and, as the report shows, USGS, UJNR, NBS, FHA, HUD, and URS/John A. Blume & Associates, Engineers contributed personnel and covered the costs of the trip. There is a separate section of the report for acknowledgement of others to whom we owe thanks for helping us all to learn from earthquakes. The team spirit among agencies, organizations, companies, and individuals was most heartening, and it is that fact which makes progress possible in this complex field.

General Perspective

The following map (Figure 1) may look a little odd at first glance, but it is quite interesting. A reversed outline of California has been superimposed (by C. Arnold) over a map of Japan of the same scale. If the total land area of Japan were consolidated, it would be a little less than that of California, yet the population of Japan is about 113 million, compared with 21 million in California. Human density is a factor to be considered in earthquake risk. Sendai and Tokyo are about as far apart as half the distance between Los Angeles and San Francisco. The Japanese scale intensities (0 to 7) for the Miyaki-Ken-oki earthquake are also shown on the map. Figure 2 compares the Japanese scale with the Modified Mercalli scale.

Fortunately, many of the severe Japanese earthquakes originate offshore and at some depth. In general, California's major shocks tend to be close to shore or on the land and are usually shallower. One can not, however, judge exposure, in the sense of proximity to the source of the earthquake, on the basis of epicentral distance alone. The moving fault or zone of energy release may, in fact, be much closer than the original hypocenter. For example, the epicentral distance from Sendai is about 100 km, but as Carl Wentworth points out in his report, the damaged land area (Sendai, etc.) lies in the down-dip direction of the probable rupture plane, and the surface distance from Sendai to some of the energy release could have been as short as 55 km.

Most Japanese strong-motion instruments are somewhat different from ours in that their

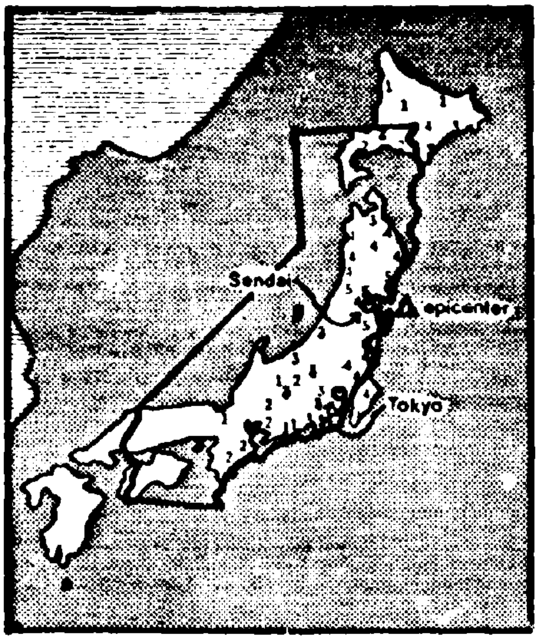

Figure 1 Miyagi-Ken-oki earthquake intensity (Japanese scale: 0-7). A reversed outline of California is superimposed to indicate scale, with San Francisco at the epicenter. The distance between Sendai and Tokyo is about half the distance between Los Angeles and San Francisco. The land area of Japan is approximately equivalent to that of California. Base map data: Building Research Institute, Ministry of Construction, Japan.

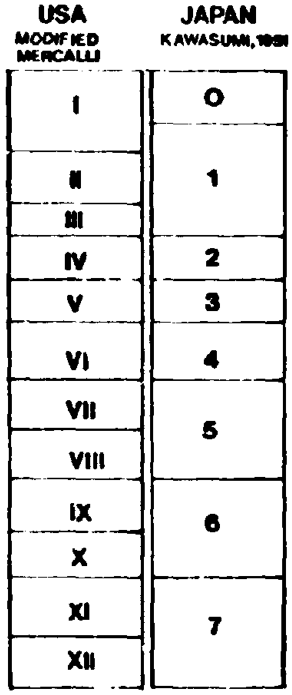

Figure 2 Comparison of United States (MMI) and Japan Meteorological Agency (JMA) intensity scales

frequency-response recordings do not extend to as high a range as that recorded by United States instruments. Another difference is that, at the greater amplitudes, the Japanese traces have an arc shape due to their being drawn by pens of constant radius (see A. Gerald Brady, herein). The records can be reconciled for true comparisons of motion, but care is needed.

General Statistics

It is estimated that 27 people were killed by the earthquake; about half of them died because of falling walls. This is, fortunately, a small number of fatalities for such a heavily shaken, densely populated area; however, more than 1,000 others were injured. Tsunami effects were negligible, but there was some flooding, and many houses were destroyed. Fire was contained locally, and in some places this must have represented heroic efforts. The preliminary total estimated loss is more than $830,000,000 (June, 1978, U.S. dollars). (See Hugh Fowler herein for more detailed statistics.)

Some Highlights

Highlights of this earthquake, in my opinion, include:

- good general performance of modern, engineered buildings up to 20 stories high (there were none higher: the early report on this, in July, was in error)
- failure of three out of more than 80 oil storage tanks and the consequent great oil contamination in the area
- collapse of a typical telescoping gasholder and burning of its contents
- loss of gas distribution for several weeks because the collapsed gasholder caused adjacent main gaslines to go out
- failure of dikes, and the many resulting landslides
- failure of the anchorage of precast exterior wall panels from a low building and crushing of automobiles by the falling units
- damage to certain types of steel frames
- damage to electrical switchgear, breakers, transformers, etc., in spite of earthquake bracing (the porcelain was very vulnerable)
- damage and shutdown of fossil-fueled boilers at the local power plant, apparently caused by the failure of minor secondary pipes
- excellent performance of the Fukushima Nuclear Power Plant, which apparently did not shut down (the motion was somewhat less than that specified by the design criteria)
- recording of 1.0g at the top of a building that survived without heavy damage in spite of the fact that a peak response acceleration of 0.5g had previously been recorded for it
- the dropping of a whole section of a bridge deck
- control of fire
- the ability of the Japanese people to recover rapidly, repair important damage, and carry on.

SEISMICITY AND GEOLOGIC SETTING

by Carl M. Wentworth
U.S. Geological Survey
Menlo Park, California

The off-Miyagi earthquake of June 12, 1978, occurred on the subduction zone that inclines westward beneath Honshu, the main island of Japan. Here the western margin of the great Pacific plate, which consists of the oceanic lithosphere beneath the northern Pacific Ocean, is plunging slowly beneath Japan. A great many earthquakes result from this deformation, including many damaging ones (Figure 1). These differ from damaging earthquakes in California -- along the San Andreas fault system at the eastern margin of the Pacific plate -- in being more frequent and generally farther from the cities and engineering structures at risk.

The damaged area lies on the east coast of northern Honshu about 300 km north of Tokyo, in a region of low, flat alluvial plains, local alluvial terraces, and steep bedrock terrain of moderate relief.

This paper reports information gained largely from discussion with Japanese officials and scientists (see acknowledgments) and from unpublished materials provided by them. Original observations made in the damaged region and some published materials are also used. The information is necessarily incomplete, because only two weeks had been available for study of the earthquake by the Japanese at the time of the visit to Japan by the U.S. team, and time for the discussion during the visit was brief. The more thorough accounts expected from the Japanese studies should be consulted when they become available.

Seismicity

The earthquakes along the western margin of the Pacific occur in bands that follow the paired deep-sea trenches and adjacent island chains. The earthquakes, trenches, and islands have a common origin, the subduction of the westward-moving Pacific plate. The west-dipping subduction zones along which the plate plunges into the earth's mantle are delineated by the earthquakes, which increase in depth westward. They range from shallow near the trench to greater than 500 km in depth well behind the island arcs (Figure 2). Earthquakes are most abundant at depths less than 70 to 100 km.

Damaging earthquakes are frequent in this tectonic setting. The historic record of damaging earthquakes off northern Honshu includes tens of events in the past 500 years, and Tarr (Figure 1) shows five great earthquakes in that region since 1897. Four of these occurred in the first five years of that period, and one in 1933, although all of the earlier ones may not have been as large as is shown (Tarr, oral communication, August 1978).

Microearthquake studies more precisely define the upper part of the subducting plate and the geometry and styles of the earthquakes. A seismic network operated in northern Honshu by the Observation Center for Earthquake Prediction at Tohoku University in Sendai has produced extensive information about the seismic and tectonic setting of the off-Miyagi earthquake of June 12 (Takagi, Hasegawa, and Umino, 1977; Hasegawa, Umino, and Takagi, 1978). The network consists of 15 stations with a spacing of about 60 to 80 km. Hasegawa and others (1978) indicate that hypocenters are located to within 2 to 3 km within the network but that locations are less accurate offshore to the east.

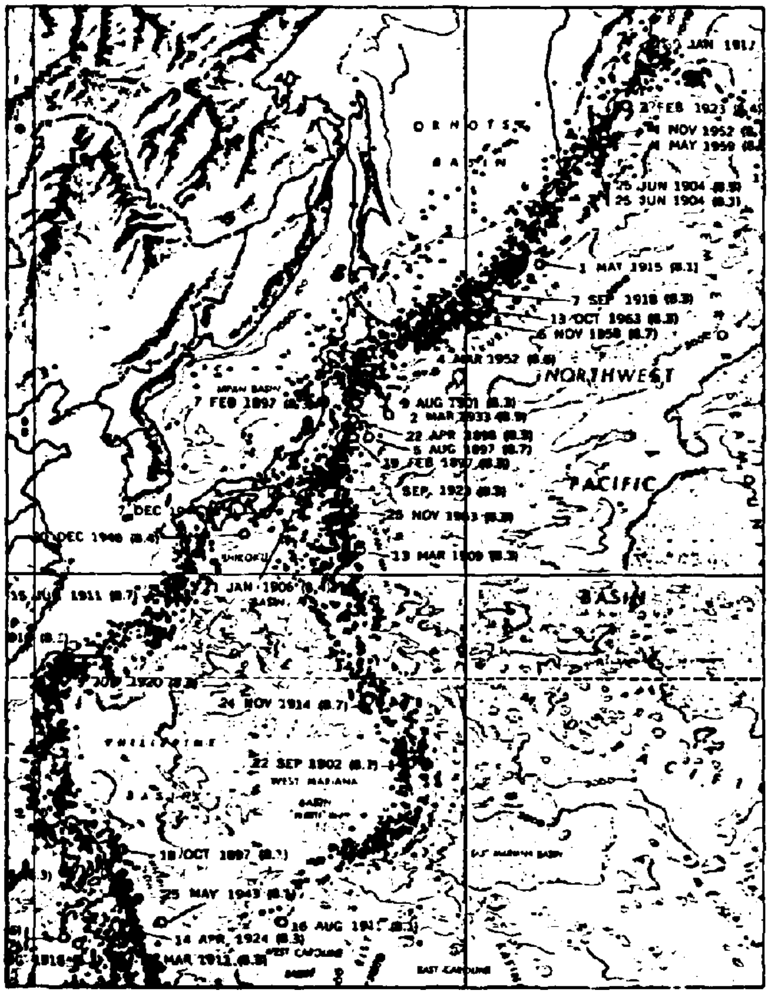

Figure 1 Earthquake epicenters along the northwest margin of the Pacific tectonic plate. Dots show earthquakes greater than magnitude 4.5 for the period July 1963-December 1972; open circles show great earthquakes for the period 1897-1972 with date and magnitude. From Tarr, 1974.

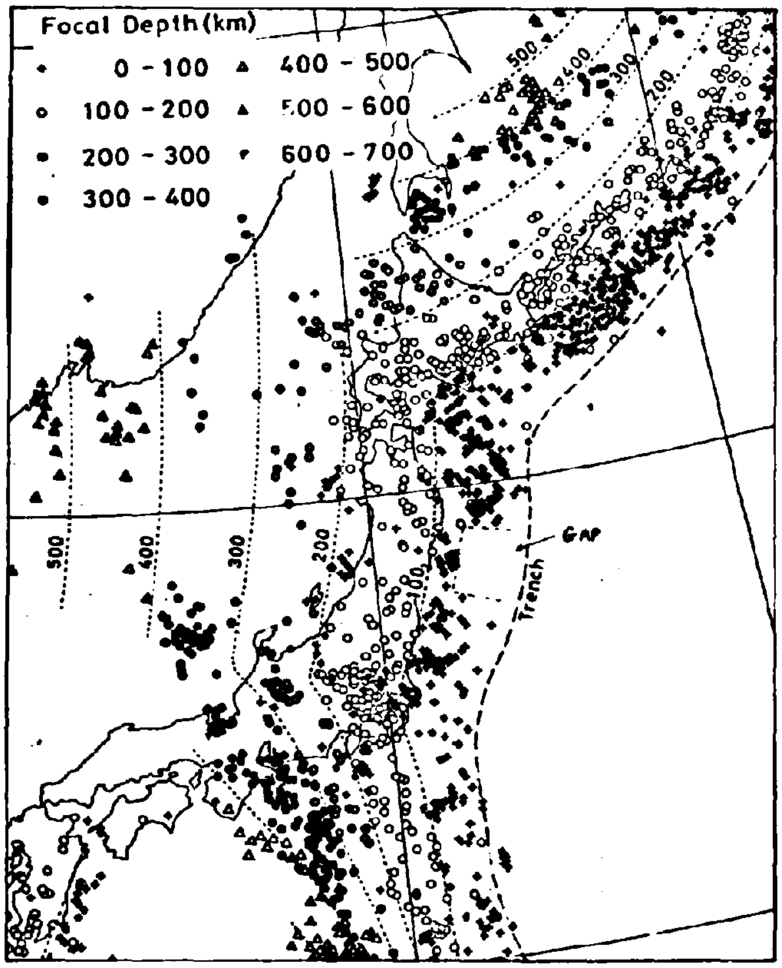

Figure 2 Earthquake hypocenters beneath Japan for the period 1964-1974. Epicenter symbols show depth of hypocenter, depth contours in km. From Coordinating Committee on Earthquake Prediction, 1978.

Figure 3 Distribution of microearthquakes beneath northern Honshu, Japan, in vertical, east-west section (shown by dots) and subducting oceanic lithosphere. Horizontal line above section represents land, the upright triangle the volcanic front, and the overturned triangle the Japan Trench. Copied from Figure 6 of Takagi and others, 1977.

The microearthquakes clearly define the upper boundary of the subducting slab as dipping westward at about 30° to a depth of about 150 km beneath the western side of northern Honshu (Figure 3). A second westward-dipping band of earthquakes lies about 40 km beneath the first and within the subducting slab. A zone of abundant activity is also shown that extends above the slab from beneath the east coast of Honshu eastward toward the trench.

Analysis of the sense of first motions at the various seismometers in the network from groups of earthquakes in these three zones has been made by Hasegawa and others (1978) to determine the style of faulting associated with their generation. These composite focal-mechanism solutions indicate that thrust faulting, with compression nearly perpendicular to the trench, is under way at and above the upper boundary of the subducting slab, as would be expected. In contrast, the band of seismicity within the slab involves extension along its dip direction.

Seismic Gap and Precursors

The absence of both current seismicity and recent large earthquakes in an area off northern Honshu has suggested that an earthquake near magnitude (M) 8 could be expected there. A gap in the 10-year pattern of earthquakes shown in Figure 2 coincides with a gap in the pattern of source areas of major earthquakes since 1923 (Figure 4), in an area where the last major earthquake occurred in 1897. Strain resulting from continued deformation along the subduction zone has been relieved along much of the zone in the major earthquakes shown in Figure 4, but the existence of the seismic gap suggests an area where this strain has yet to be relieved. The off-Miyagi earthquake of June 12 occurred adjacent to, but not within, this gap, so that a major earthquake is still anticipated there.

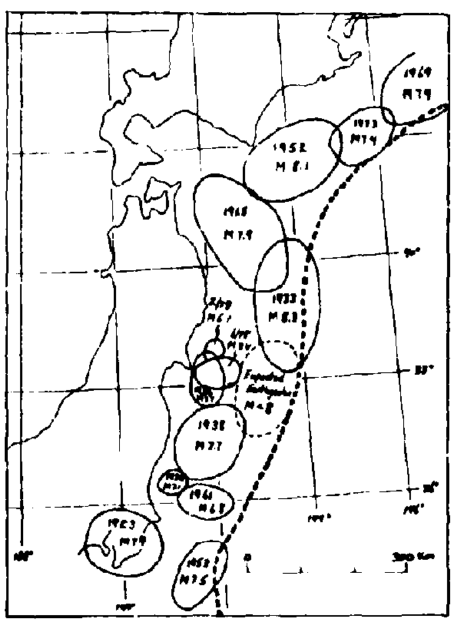

Figure 4 Source areas of recent major earthquakes along the subduction zone off Japan, with date and magnitude. From Coordinating Committee on Earthquake Prediction, 1978.

Particularly because of the seismic gap, other indications of an imminent large earthquake have been of interest. Spirit leveling had demonstrated an eastward tilt of the land opposite the gap, but no short-term precursors were recognized prior to the June 12 earthquake. Abundant data from the seismic network of Tohoku University showed no clear change in seismic velocities. Similarly, no indications of imminent earthquakes were evident from the extensometers and tiltmeters that are part of each station in that network.

Comparisons along two east-west level lines that end at Sendai and Kamaisi, run by the Geographical Survey Institute, show relative downward tilt to the east of 2 to 5 cm between the center of the island and the east coast in a 7-to-8-year period beginning in 1966. The tilt is greater at Sendai than farther north, and an additional 3 centimeters of decline at Sendai may be related to withdrawal of ground water. Detailed tidal records in the area showed no evident changes within hours after the main shock of June 12, with a resolution of a few centimeters, so that little or no coastal uplift accompanied the earthquake. As a result of the earthquake, releveling of the survey lines before year-end is now planned by the Geographical Survey Institute of Japan.

1978 Earthquakes

The main shock of June 12 resulted from thrusting in the deformation zone along or above the upper boundary of the subducting slab off the coast of northern Honshu. It was preceded by an M 6.7 earthquake nearly four months earlier.

Earthquake of February 20. The M 6.7 earthquake occurred on February 20, 1978, at 1:37 P.M. local time with a depth of 60 km and epicenter at latitude 38.7° north, longitude 142.2° east (National Research Center for Disaster Prevention, 1978a). This is about 65 km north of the epicenter of the June 12 earthquake (Figure 5). According to a preliminary report of the Building Research Institute, the focal mechanism involved failure on a near-vertical focal plane. This suggests that the earthquake was associated with the zone of seismicity within the subducting slab where extension in the dip direction is occurring (Figure 3). The February earthquake has its own pattern of aftershocks, distinct from that of the June 12 earthquake, and therefore was not simply a foreshock of the larger earthquake.

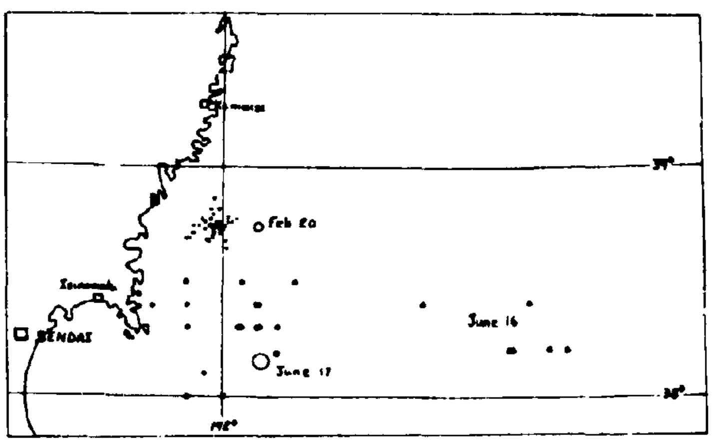

Figure 5 Epicenters of the earthquakes of February 20 and June 12, 1978 and principal aftershocks. From Coordinating Committee on Earthquake Prediction, 1978.

Off-Miyagi Earthquake of June 12. The off-Miyagi earthquake (Figure 6) occurred on June 12, 1978, at 5:14 P.M. local time with its hypocenter at a depth of 30 km at latitude 38.2° north, longitude 142.2° east, according to the Prompt Report (National Research Center for Disaster Prevention, 1978b). It was preceded by one foreshock a few minutes earlier. Many aftershocks were recorded by the seismic network of Tohoku University. Figure 6 shows the hypocenter of the main shock and aftershocks through the first seven hours (6a) and aftershocks for the first 10 days following the main shock (6b).

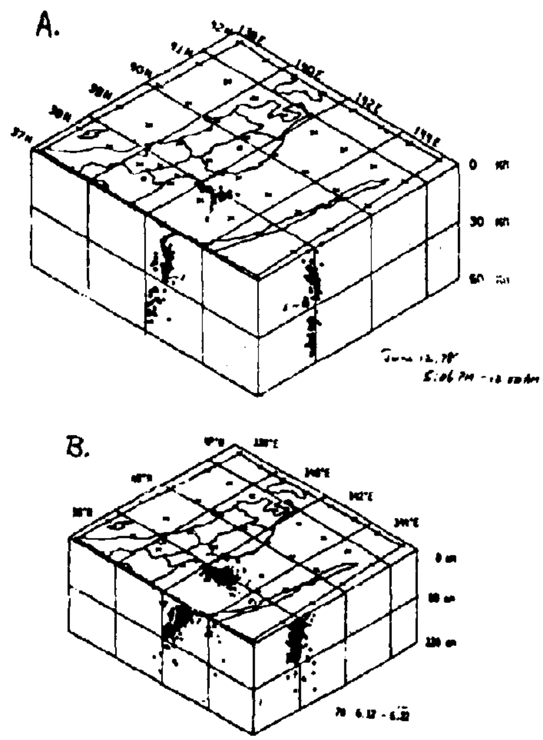

Figure 6 Hypocenters of June 12 main shock and aftershocks through June 22. Block diagram shows projections of hypocenters in map view (epicenters), east-west vertical section; and north-south vertical section. Figure 6a shows main shock (X) and aftershocks through midnight of June 12 to 60-km depth (from Coordinating Committee on Earthquake Prediction, 1978). Figure 6b shows aftershocks through June 22 to 120-km depth (from figure provided by Observation Center for Earthquake Prediction, Tohoku University).

The June 12 earthquake, in contrast to the February 20 earthquake, was the result of thrust faulting along a west-dipping rupture associated with the top of the subducting slab. The two aftershock patterns of Figure 6 are nearly identical and suggest main shock rupture on a west-dipping plane extending from a shallow depth to nearly 60 km. The aftershock pattern of Figure 6b lies entirely within the equivalent pattern of Figure 3, at and above the top of the subducting slab above a depth of 60 km, and a focal mechanism solution using worldwide data (Otsuka and others, 1978) indicates that the main shock was associated with thrust movement along a preferred plane dipping to the west northwest at 20°.

The epicenter of the June 12 earthquake and its aftershock pattern lie west of the seismic gap, so that this rupture event did not encroach upon the area of unrelieved strain suggested by the existence of the gap. This location of the June 12 earthquake and the nearby smaller earthquake four months earlier raised the possibility that they were precursors of a larger earthquake that would fill the gap. On June 16 several earthquakes as large as M 5.9 did occur in the gap area (Figure 5). The aftershock train of the June 12 earthquake decayed rapidly, however, perturbed only by one aftershock somewhat larger than M 6 and an associated increase in activity on June 14 (Figure 7).

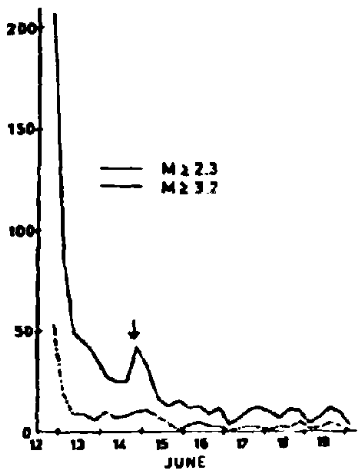

Figure 7 Numbers of aftershocks of the June 12, 1978, earthquake through time. Arrow shows time of largest aftershock. From Coordinating Committee on Earthquake Prediction.

<u>Location of Source of Energy</u>. The location of the source of energy is an important parameter in studies of the attenuation of seismic shaking. The earthquake epicenter is commonly used as the point from which to measure distances for this purpose. This practice can lead to problems, however, as pointed out by Youd and Perkins (1978) in their discussion of the distance to which significant liquefaction occurs in earthquakes. Strike-slip rupture can pass close to a site of interest although the epicenter is more distant. This is easily accommodated by using the shortest distance to the rupture trace, rather than the epicentral distance. In the reverse faulting at San Fernando, California, in 1971, the epicenter lay far to the north of the damaged area in the San Fernando Valley. The rupture surface extended up the dip of the fault to the ground surface within the damaged area, however, so that distances to the rupture surface could be measured.

The off-Miyagi earthquake is more complicated, because the epicenter is offshore and the damaged area on land lies in the down-dip direction. The epicenter is about 115 km east of the city of Sendai. The down-dip end of even the early aftershock pattern, however, lies 60 km west of the epicenter at a depth of 45 to 55 km directly beneath the Ojika Peninsula (Figure 6a). If these early aftershocks delineate the main-shock rupture plane, then the faulting reached within about 75 km of Sendai in three dimensions and within 55 kilometers in plan view.

<u>Geology of the Damaged Region</u>

The damaged region consists of three north-trending topographic zones containing different kinds of geologic materials. Most of the damaged buildings and engineered structures lay in the central alluvial lowland, which is flanked by hilly bedrock terrain of Cenozoic volcanic and sedimentary rocks on the west and older slates on the east (Figure 8).

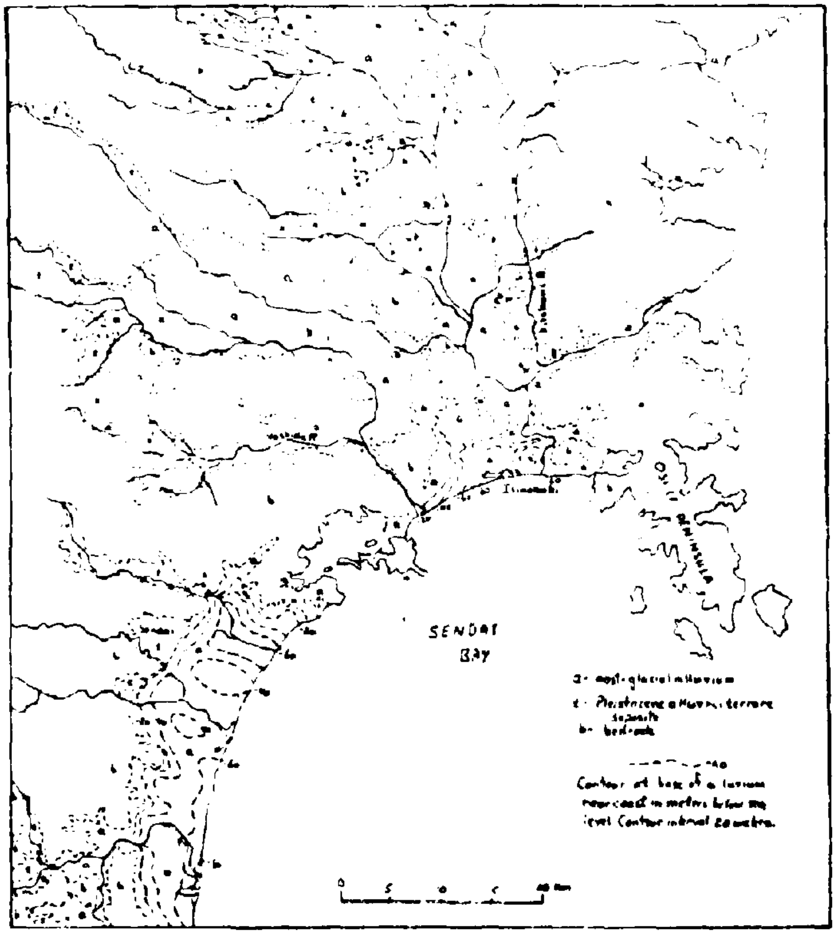

Figure 8 Geology of the damaged area, earthquake of June 12, showing bedrock areas, surficial deposits, and depth to rock in the coastal area. Compiled from 1:200,000-scale topographic maps published by the Geographical Survey Institute of Japan, Geologic Map of Miyagi Prefecture at 1:200,000, and Hydrogeologic Map of the Coastal Region of Bay of Sendai at 1:100,000 (Geological Survey of Japan, 1968).

The eastern zone consists of rather intricate, steep-sided hills 200 to 300 m high. These form a southward-pointing range about 20 km wide that terminates in the Ojika Peninsula. Bedrock here is largely hard, fractured slate of Mesozoic age. Cursory views of quarry exposures revealed little difference between rock near the ground surface and deeper fresh rock, and intact rock on the ubiquitous steep slopes was overlain only by a thin root zone supporting grass and trees.

On the west, the central mountain crest of Honshu drops eastward to steep-sided foothills. The hills flanking the city of Sendai consist of a complex Miocene and Pliocene section of sandstone and shale with intercalated volcanic layers.

The central lowland is about 40 km wide, and consists of extensive flat alluvial plains containing scattered steep-sided hills locally as high as 200 m. In the Matsushima area between Sendai and Ishinomaki these hills consist largely of Miocene volcanics that include much tuff and agglomerate. These rocks stand in vertical natural cliffs but are soft enough to have cavities dug with hand tools.

Sendai Bay occupies most of this lowland zone south of Ishinomaki and is bordered on the west by a delta plain that is as wide as 1 km at the city of Sendai. Where not used for housing, much of this delta plain and the plains west and north of Ishinomaki are covered with rice paddies.

The alluvial deposits were formed during the past 18,000 years as the continental ice sheets of the last glaciation melted and sea level rose to its present position. Rivers draining the adjacent highland found their progress gradually blocked by the rising sea and deposited sediment along their lower courses, particularly at times of flood. An intricate assemblage of sediment types is produced by rivers in an aggrading regime, here accompanied by an adjacent rising shoreline. Broad ribbons of channel sand and gravel are left as the river changes its position from time to time; finer sand and silt are deposited in flanking natural levees in times of flood; and organic silt and clay accumulate in the intervening back marsh areas. Ridges of beach sand form along the shore.

The surface of the alluvial deposits is quite flat and is still crossed by the several rivers responsible for depositing the sediment. Frequent flooding of these rivers has led to construction of many dikes, some of which were damaged in the June 12 earthquake. The sediment is soft and water saturated, because it is young and the water table is very shallow. Depth below sea level of the base of the alluvial fill over bedrock is shown for the coastal areas in Figure 8.

A series of alluvial terraces that extend in age back to Pliocene occur in the Sendai area. The old section of Sendai City is built on a late Pleistocene alluvial terrace some 10 to 20 m above the younger delta plain to the east, on which part of the new city is built. In contrast to the younger alluvium, these terrace deposits undoubtedly are slightly cemented and therefore are firmer than the younger sediments.

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STRONG-MOTION EARTHQUAKE RECORDINGS

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Introduction

In Japan, several government agencies are responsible for independent networks of strong-motion instruments located throughout the country. Among the larger of these accelerograph networks are those operated by the following agencies:

- Railway Technical Research Institute (RTRI), Japanese National Railways
- Strong Earthquake Motion Observation Center, Earthquake Research Institute (ERI), University of Tokyo
- Port and Harbor Research Institue (PHRI), Ministry of Transport
- International Institute of Seismology and Earthquake Engineering, Building Research Institute (BRI), Ministry of Construction
- Public Works Research Institute (PWRI), Ministry of Construction

Other organizations with interest in strong-motion recording include:

- National Research Institute of Agricultural Engineering, Ministry of Agriculture and Forestry
- Nippon Telegraph and Telephone Public Corporation
- Japan Building Center Foundation (JBC)

The Strong-Motion Earthquake Observation Council was established in 1967 within the National Research Center for Disaster Prevention (NRCDP) of the Science and Technology Agency. Records recovered from particular earthquakes by the various government agencies are made available to the public in the council's "Prompt Report" publication, which describes the records, gives peak accelerations and epicentral distances, and contains copies of some of the more interesting records. These and other earthquake records are published in the council's annual report. The agencies responsible for the accelerograph networks also report on digitization and analysis of the records collected by them that they consider significant.

The data contained in Figures 1 and 2 and Tables 1 and 2 were obtained from Reference 1 and from the Prompt Report for this earthquake of June 12, 1978.[2]

Stations and Recordings

Figure 1 shows the northern part of Japan and the locations of the strong-motion accelerograph stations that provided records of the June 12, 1978, earthquake. The codes for the stations, and their pertinent characteristics, appear in Reference 1 and are reproduced in Table 1. In addition to the records shown on the map, there exist 61 additional records taken at basement, first-floor, or ground level, mostly in Tokyo or its vicinity. Of these 61 records, the peak acceleration is .045g at an epicentral distance of 305 km. A 19th-floor record had a peak acceleration of 0.23g at a 422-km epicentral distance.

Two epicenters are shown, one provided by the Japan Meteorological Agency (JMA) and published by the National Research Center for Disaster Prevention,[2] the other provided by the U.S. Geological Survey on June 30, 1978. In the sections of this report that discuss the epicenter and epicentral distances, we have chosen to use the epicenter coordinates given in Reference 2.

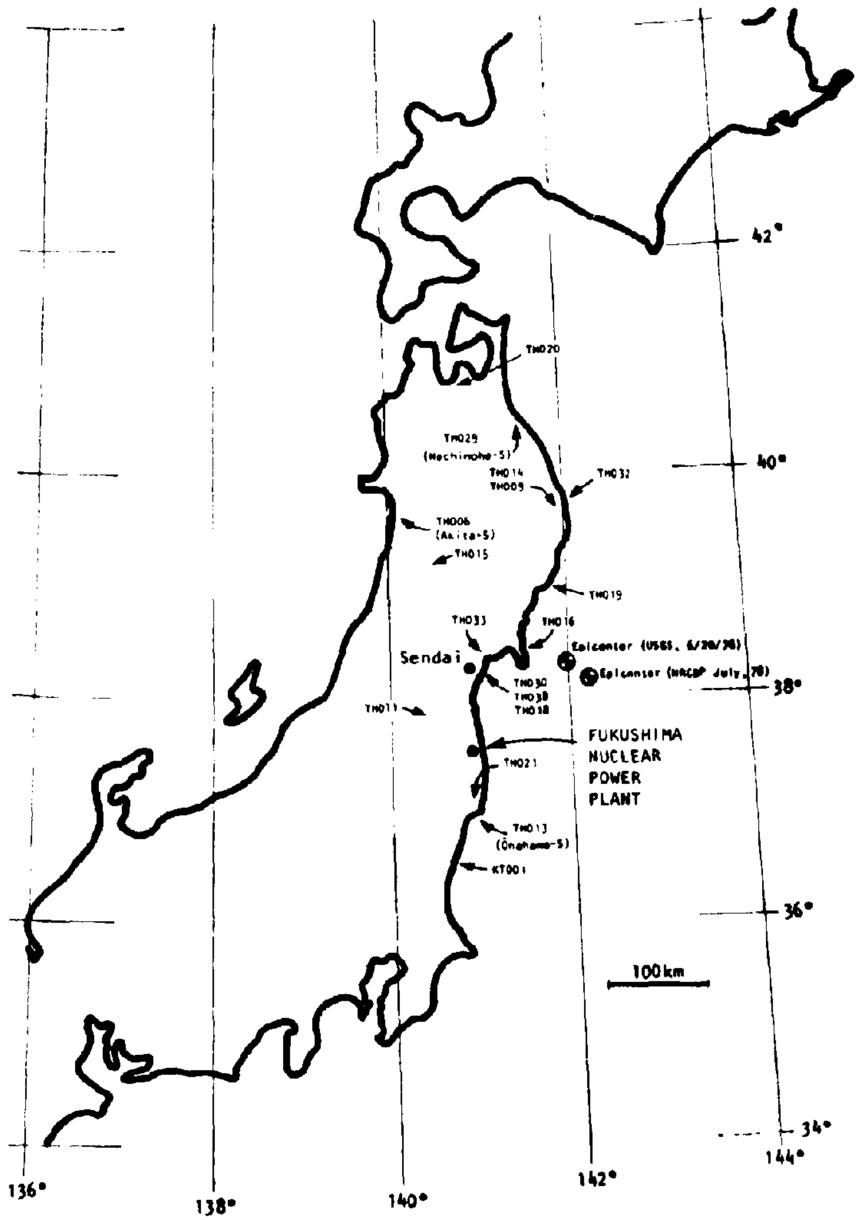

Figure 1 Locations of accelerograph sites providing significant recordings of June 12, 1978, earthquake.

Table 1 Station Details

Site No.	Name	Address	Lat. & Long.	Number of Stories (above/below the G.L.)	Location
TH 002	Akita Prefectural Office	Sanno 4 chome, Akita City		6/1	B1F
TH 003	Sendai Steam Power Plant, Tohoku Electric Power Co.	Shichigahama Town, Miyagi Prefecture		11/0	1F, 5F
TH 006	On the Premises of Akita Harbour Works Office	Tsuchizakiminato-Nishi 1-chome, Akita City	140°09'E 39°45'N		Ground
TH 007	Oya Bridge	Otomachi-Oya, Aizuwakamatsu City	139°55' 37°22'	ℓ=150m, w=8m	Crest of pier No. 2, ground
TH 008	Kahoku Bridge	Kahoku Town, Yamagata Prefecture	140°09' 38°26'	ℓ=441.7m, w=6m	Crest of pier No. 7, ground
TH 009	Schoolhouse of Atago Middle School, Miyako City	Nakasatodaochi, Miyako City	141 58' 39 38'		1F
TH 011	Date Bridge	Date Town, Fukushima Prefecture		ℓ=208m, w=7m	Crest of pier No. 2, ground
TH 012	On the premises of Hikarigaoka Residence	Hikarigaoka 5-chome Sakata City	139°50' 38°54'		Ground
TH 013	On the premises of 2nd Wharf, Onahama Harbour	Tatsumimachi, Iwaki City	140°54' 36°57'		Ground
TH 014	On the Premises of Construction Section Miyako Harbour Works Office	Minatomachi, Miyako City	141°58' 39°38'		Ground
TH 015	Yuhoi Bridge	Jumonji Town, Akita Prefecture	140°28' 39°12'	ℓ=456m, w=6m	Crest of pier No. 8, ground
TH 016	Kaihoku Bridge	Inai, Ishinomaki City	141°18' 38°26'	ℓ=285m, w=6m	Crest of pier No. 2, ground
TH 017	Fukushima Atomic Power Plant, Tokyo Electric Power Co.	Okuma Town, Fukushima Prefecture	141°02'E 37°25'N	5/1, 1/0	Garret, B1F, 1F, 5F
TH 018	Sendai Kakutetsu Building	No. 20, Shimizukoji, Sendai City	140°55' 38°15'	6/1	B1F, 6F
TH 019	Breakwater of Ofunato Harbour	Akasakikicho, Ofunato City	141°44' 39°00'		On the Jetty, ground
TH 020	On the premises of Aomori Harbour Works Office	Honcho 3-chome, Aomori City	140°49' 40°49'		Ground
TH 021	Taira Bridge	Taira-Kamada, Iwaki City	140°54' 37°03'	ℓ=141.6m, w=14m	Crest of abut, ground
TH 022	Hachinohe Steam Power Plant, Tohoku Electric Power Co.	Kawaragi, Hachinohe City	141°30' 40°31'	7/0	1F
TH 023	Asanuma Elevated Bridge, (J.N.R.)	Rokunohe Town, Aomori Prefecture			Ground
TH 024	Onagawa Atomic Power Plant, Tohoku Electric Power Co.	Onagawa Town, Miyagi Prefecture	141°24' 38°24'		Ground, ground
TH 025	Koyohawa Bridge	Matsuyama Town, Yamagata Prefecture	140°01' 38°47'	ℓ=391.8m, w=6m	Crest of pier No. 5, ground
TH 026	Hachirogata	Akita Prefecture			Ground
TH 027	Heiwa Bridge	Waga Town, Iwate Prefecture	141°13' 39°15'	ℓ=155m, w=7m	Crest of pier No. 3, ground
TH 029	On the premises of Hachinohe Factory, Hachinohe Harbour Works Office	Kawaragi, Hachinohe City	141 3[illegible] 40 3[illegible]		Ground
TH 030	Faculty of Engineering, Tohoku University	Aramaki, Sendai City		9/0	1F
TH 031	Tsugaru Bridge	Nakasato Town, Aomori Prefecture		ℓ=550m, w=6.5m	Crest of pier No. 9, ground
TH 032	Masaki Bridge	Taro Town, Iwate Prefecture	141°57'E 39°44'N	ℓ=190m, w=8m	Crest of pier No. 1, ground
TH 033	On the premises of Shiogama Harbour Office	Teizandori 1-chome, Shiogama City	141°02' 38°19'		Ground
TH 036	Zuikoji Bridge	Yanaizu Town, Fukushima Prefecture	139°43' 37°32'	ℓ=148.5m, w=10m	Crest of pier, ground ground
TH 037	Aomori City Office	Uramachi, Aomori Prefecture	140°45' 40°48'	2/0	1F, 1F, 1F
TH 038	Sumitomo Sendai Building	Chuodori, Sendai City		18/2	B2F, 9F, 18F
TH 902	Akita Prefectural Office	Sanno 4-chome, Akita City		6/1	P2F
TH 903	Faculty of Engineering Tohoku University	Aramaki, Sendai City		9/0	9F
KT 001	Meteorological Laboratory, Japan Atomic Energy Research Institute	Tokai Village, Ibaraki Prefecture	140°37' 36°28'	1/0	1F

The section on seismicity indicates that, although the epicentral distance to Sendai is about 115 km, it might be inferred from the aftershock pattern that the main shock rupture plane actually reached a point within about 75 km of Sendai, measured in three dimensions, or within an epicentral distance of 55 km, measured in plan. Such a conclusion would play a significant part in studies of the attenuation of peak accelerations for this earthquake, particularly for those stations within latitude 37.5° and 38.5° north that lie approximately due west of both the epicenter and the closest point on the rupture plane. Other stations on the east coast would not be affected because, for each of these, the epicentral distance is approximately equal to the distance to the closest point of the inferred rupture surface.

Figure 2 shows the northern part of Japan, with peak accelerations recorded at ground level, or at the basement or first-floor level in structures, at stations in the geographic area shown in Figure 1. In two instances more than one recording is made at a single location. Each set of the three numbers shown gives the peak acceleration recorded in the two horizontal directions and in turn that recorded in the vertical direction. For most ground-level stations the two horizontal directions referred to are north-south and east-west, in that order, whereas the instruments at the lowest level of a structure are generally aligned in the longitudinal and transverse directions of the structure and acceleration values are reported in that order. The acceleration units used are cm/sec/sec, commonly called a gal. Conversion to g units is simply, if slightly inaccurately, accomplished by dividing by 1,000. Epicentral distances are indicated from both estimated epicenters. An (F) following the acceleration levels indicates that the recording could be considered a free-field recording, although it must be realized that any instrumental housing disturbs the true free-field motion. Table 2 contains a more complete list of peak accelerations, including those for significant upper stories.

Figure 3 is a highly idealized isoseismal map constructed from the plotted Japan Meteorological Agency intensities at specific locations. The boundary between JMA 4 and 5 is reasonably well constrained to the north and west but less so to the south. The other isoseismals are more arbitrarily chosen. If a circular area were approximated to the JMA 5 region, its center would lie close, in plan, to the westernmost down-dip end of the inferred rupture surface mentioned above. This lends credence to the conclusion that for this earthquake the distance from points on the ground surface to the nearest point of the rupture surface is the distance of importance in attenuation and related studies.

The SMAC Accelerograph

The SMAC strong-motion accelerograph in its various versions has been the main Japanese strong-motion recording instrument since its development between 1951 and 1953 by the Japanese Committee for the Standard Strong Motion Accelerograph. In its earliest form (the SMAC-A), it consisted of a set of three mechanical oscillators which, through a series of linkages, scribed analog traces on a waxed-paper record that was driven past the recording pens at 1 cm/sec by a hand-wound spring motor. The natural period of the transducer was 0.1 sec (frequency, 10 cps), and critical damping was provided with an air piston mechanism. A sensitivity of 25 gal/mm (i.e., 25 cm/sec/sec per mm), corresponding to approximately 4 cm/g, was arranged for in the mechanical linkage and allowed recording of accelerations of 1g amplitude without the pens moving off-scale. Some of the models developed after the SMAC-A, are listed with their important characteristics in the following table.

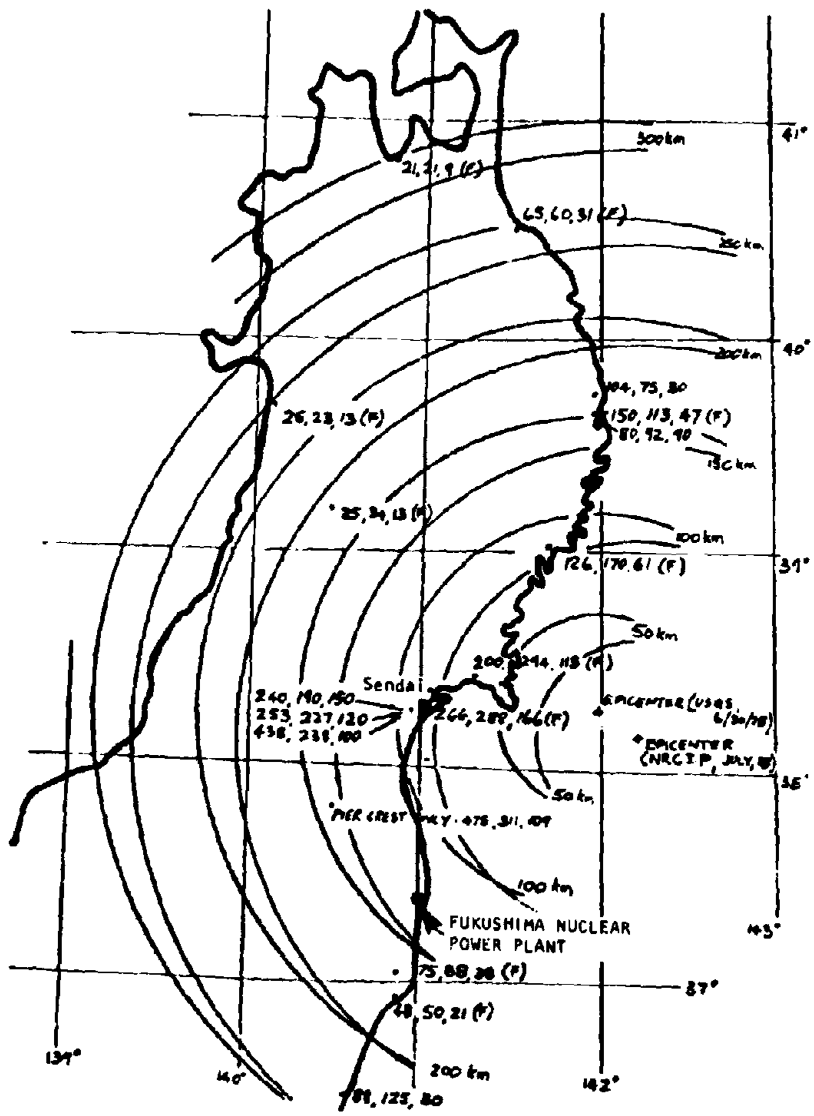

Figure 2 Peak accelerations at ground level (or basement or first-floor level in structures).

Table 2 List of Strong-Motion Accelerograms

*1	*2	*3	*4	*5	*6	*7	*8	*7	*9	*7
TH038-1	SUMITOMO	SENDAI	SUMITOMO Bld.	B2F	253.3	0.59	226.7	0.2	120.	0.45
-2				9F	393.3	0.32	520	0.29	206.7	0.49
-3				18F	486.7	0.32	553.3	0.29	226.7	0.13
TH030	BRI	SENDAI	TOHOKU Univ.	1F	240		190		150	
TH903				9F	980		480		300	
TH009		MIYAKO	ATAGO Shi	1F	80		92		90	
TH018-1	MTRI	SENDAI	SENDAI Office	B1F	306	0.8	238	0.54	100	0.2
TH028	PHRI	SHIOGAMA	SHIOGAMA Off.	GL	266		280		166	
TH014		MIYAKO	MIYAKO Off.	GL	150		113		47	
TH029		HACHINOHE	HACHINOHE Off.	GL	65		31		60	
TH020		AOMORI	AOMORI Off.	GL	31		21		9	
TH013		IWAKI	ONAHAMA Off.	GL	48		50		21	
KT050		IBARAKI	KASHIMA Off.	GL	40		39		9	
TH016-1	PWRI	ISHINOMAKI	KAIHOKU Brg.	GL	200		294		113	
-2				BP	>500		330		188	
TH011-1		FUKUSHIMA	DATE Brg.	GL	475		319		109	
KT014		CHIBA	PWRI	GL	15		25		7.5	
KT030-1			TONE Riv.	GL	45		37		15	
-2				DAM	83		89		10	
TH021-1		IWAKI	TAIRA Brg.	GL	75		86		38	
-2				B	56		38		25	
TK034	MRCDP	SUMIDA	AZUMABASHI St.	GL	20	1.0	13	0.5	4	0.35
TK058-1	FUJI FILM	MINATO	FUJI FILM Bld.	B3F	0.6	0.7	11	1.0	0.3	0.5
-2				7F	25	0.6	23	0.5	6	0.3
-3				13F	39	1.8	40	1.2	0.5	0.25
TK055-1	FUJI TV	SHINJUKU	FUJI TV Bld.	B2F	18	0.4	13	0.45	3	0.4
-2				14F	75	1.3	-		5	0.2
TK070-1	KEIHIN EW	MINATO	Hotel PACIFIC	B3F	19		13		13	
-2				8F	44	0.68	19	0.43	6	0.25
-3				30F	94	0.58	38	0.18	38	0.25
TK083	JBC	CYUO	JBC Bld.	B1F	27	0.7	16	0.6	4	0.55
TK090-1	NHK	SHIBUYA	NHKBld.	B1F	13		6		6	
-2				11F	19	0.63	19	0.63	9	0.13
-3				23F	31	0.63	19	0.83	13	0.45
KT012-1	KANAGAWA	YOKOHAMA	KANAGAWA Off.	B2F	20	1.0	18	1.2	-	
-2				6F	44	1.0	34	0.8	6	0.3
•	MITSUBISHI	MINATO	MITA Bld.	B3F	13	0.8	3	0.75	0.3	0.35
				1F	24	0.5	19	0.5	0.6	0.3
				P1F	34	0.9	29	1.0	19	0.35

*1 Site No. (This number corresponds with that in "List of the sites where strong-motion seismographs are installed".)

*2 Organization which collected original record and reported maximum accelerations, etc.

*3 Prefecture or city where instrument is installed.

*4 Location or structure where instrument is installed.

*5 Installation condition GL: on ground; BP: bridge pier; F: floor; B: basement; P: penthouse

*6 Maximum acceleration of north-south component in gals.

*7 Period of wave which gives maximum acceleration in sec.

*8 Maximum acceleration of east-west component in gals.

*9 Maximum acceleration of vertical component in gals.

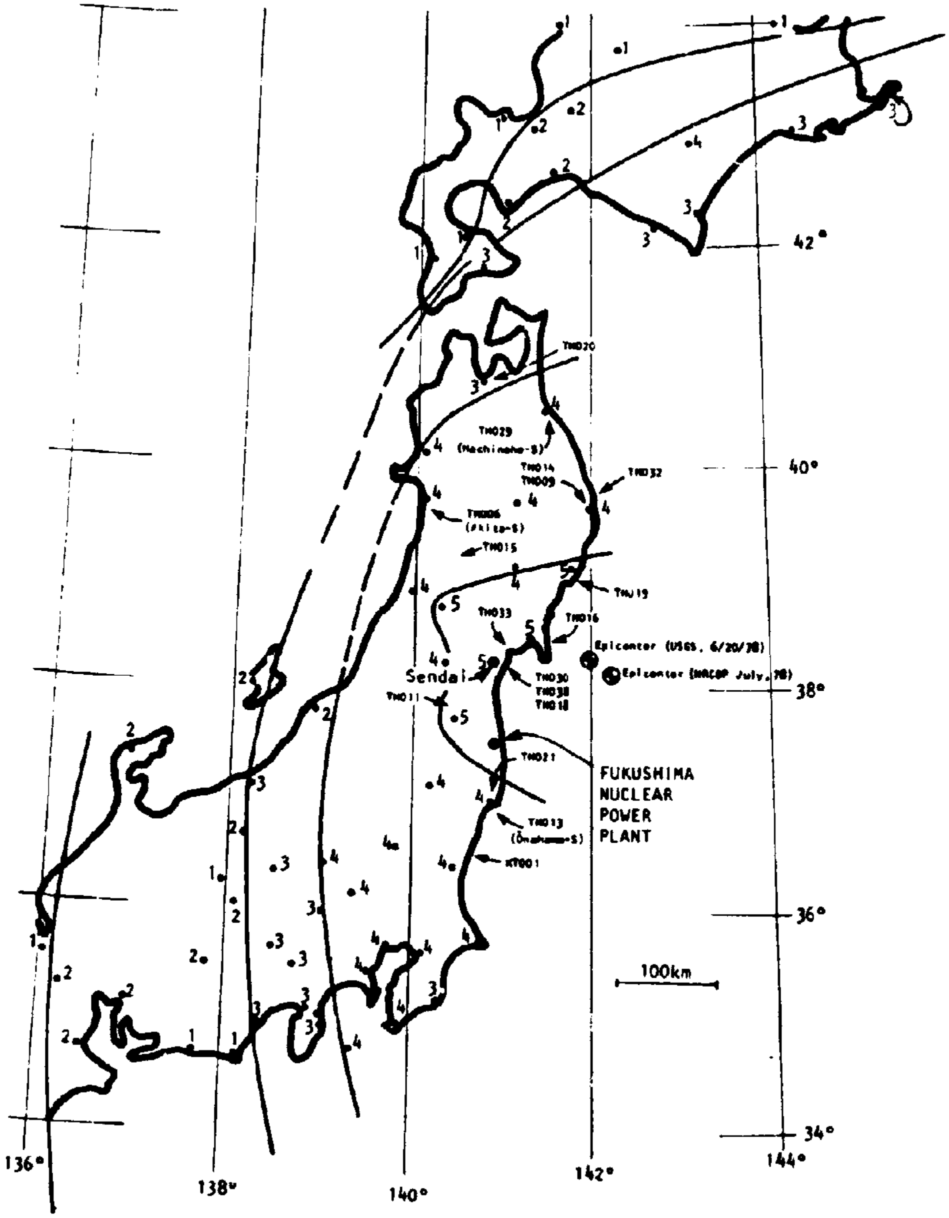

Figure 3 Idealized isoseismal map constructed from JMA-recorded intensities. (JMA 5 approximates range covered by MMI VII and VIII.)

	Damping (fraction of critical)	Natural period (sec)	Sensitivity (cm/g)	Recording speed (cm/sec)	Approximate Number in 1975
SMAC-A	1.0	0.1	4.0	1.0	33
SMAC-B	1.0	0.1	4.0	1.0	90
SMAC-B2	1.0	0.14	8.0	1.0	240
SMAC-C	1.0	0.1	4.0	1.0	18
SMAC-D	1.0	0.05	1.0	0.5	21
SMAC-E2	0.60	0.05	1.0	0.25	45
SMAC-Q	0.60	0.05	0.5	0.5	11

It is important to note from this table that the majority of the instruments of the SMAC type that are operated in Japan at this time have frequency-response characteristics that are different from the most common, modern United States instruments that record on 70-mm or 6-in. film. In particular, the SMAC response at frequencies higher than 7 cps (for the SMAC-B2) or 10 cps (for the SMAC-A, -B, and -C) has been designed to be much less than we are used to seeing with United States instruments such as the SMA-1 or RFT-250. A glance at recordings from these earlier SMAC instruments confirms this lack of high-frequency content.

Another feature of the records made by SMAC-type instruments is that the pens draw arc-shaped curves that have constant radius in the higher-amplitude motions. Although peak accelerations can be scaled off without requiring significant correction, it is evident that, after digitizing a record with high amplitudes, correction procedures must be adopted to handle this instrumental behavior before arriving at true time histories.

Recent developments in Japanese instrumentation have included higher natural frequencies (in the SMAC-D, -E2, and -Q instruments), the use of moving-coil electromagnetic transducers (in the ERS accelerograph developed by the Earthquake Resistant Structures Laboratory, Port and Harbor Research Institute), and recording on analog magnetic tape (in the SMAC-M instrument). The two instruments in the Engineering Building at Tohoku University, which record 240 gal (240 cm/sec/sec, or 0.24g) and 980 gal (1g) at ground level and at the 9th floor, respectively, are SMAC-M instruments operated by the Building Research Institute.

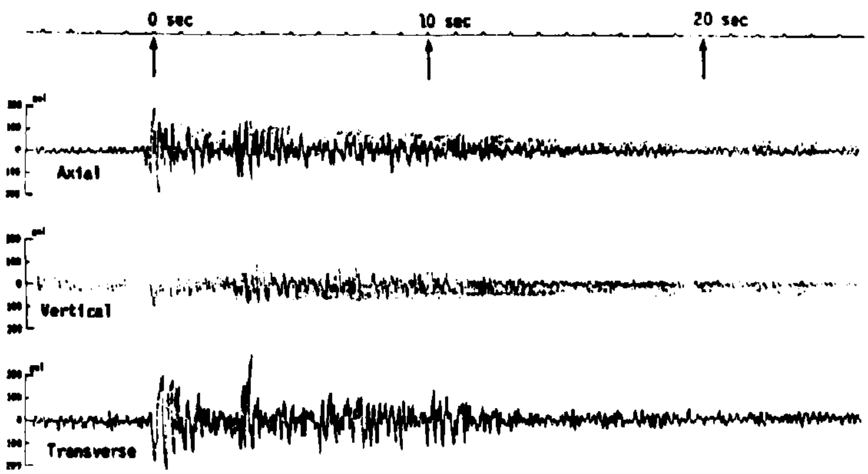

Figure 4 Kaihoku Bridge: Ground-level record, SMAC-B2, peak accelerations: 0.20g, 0.29g.

Note: A SMAC-B2 example. The vertical trace is legible on the original. The two horizontal traces clearly show arc-shaped curves.

Records reproduced in this report are copies of original records. Digitization and preliminary corrections will be performed by the Japanese agencies responsible for the instruments.

Figure 4 is a reproduction of the ground-level record at the Kaihoku Bridge site (TH016 in Figure 1). The instrument, an SMAC-B2, is placed sufficiently far from the bridge abutment to be considered a free-field instrument. The vertical trace -- legible on the original and on prints designed to reproduce that particular trace -- is in the center of the record. The arc-shaped curves on the visible horizontal traces confirm the statements made about concerning the need for care in digitizing these records. Figure 5 shows a SMAC-E2 tracing.

Figure 6 shows the central tower of the 9-story Engineering Building at Tohoku University. Two SMAC-M instruments, at the ground-floor and ninth-floor levels, are operated by the Building Research Institute (TH030 in Figure 1; the 9th-story instrument in TH903).

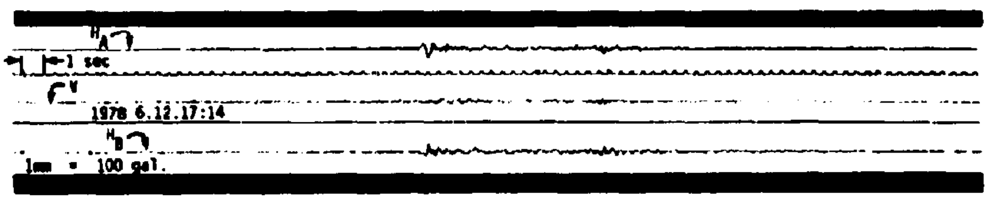

Figure 5 SMAC-E2 35mm film tracing.

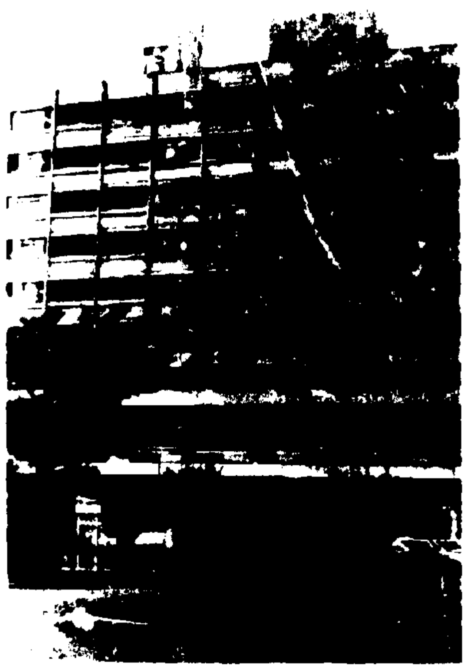

Figure 6 Faculty of Engineering Building, Tohoku University. A 9-story reinforced concrete building, with instruments at the first and ninth floors recording on magnetic tape. Motion at threshold of structural damage. Window glass broken, bookshelves emptied.

Plots of both records, computed after analog-to-digital conversion, are shown in Figures 7 and 8, which were reproduced from a report in Japanese containing the results of analysis by the BRI.

Figures 9 and 10 contain further results of BRI analysis of one horizontal component of motion recorded at the first-floor level. Corrected accel[illegible]tion, velocity, and displacement were obtained by procedures developed in Japan. A pre[illegible]inary analysis of the high-amplitude (1g) oscillations in the north-south direction a[illegible] the upper level indicates that the displacements involved are ±10 in. (±25.4 cm). This appears to be consistent with the damage found in the interior of the building (bookcases, in particular) and also indicates that the building was approaching the structural damage state although the only evidence of external damage was some broken glass from windows (Figure 5) and architectural brick veneer that had come loose from the foyer wall.

<u>References</u>

1. National Research Center for Disaster Prevention; Science and Technology Agency [Japan], March 1975, Strong-motion earthquake records in Japan, 1974, vol. 19.
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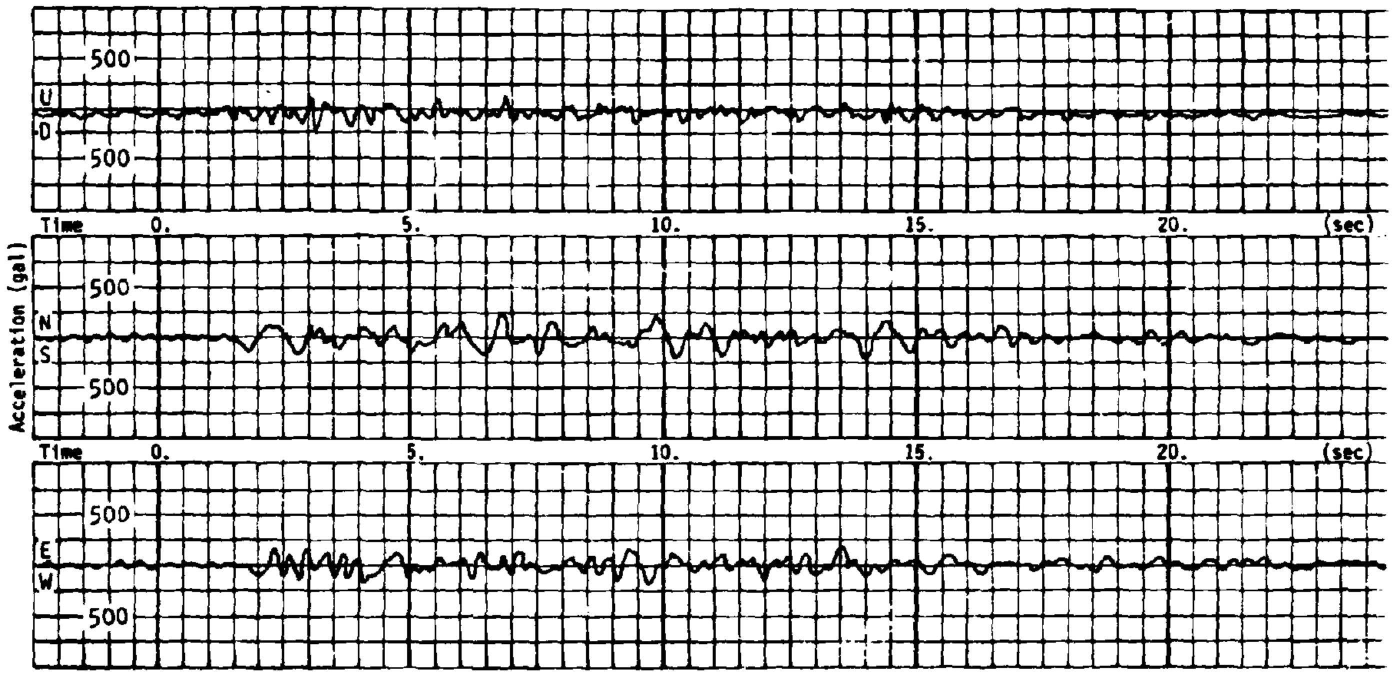

Figure 7 Three components at first-floor level.

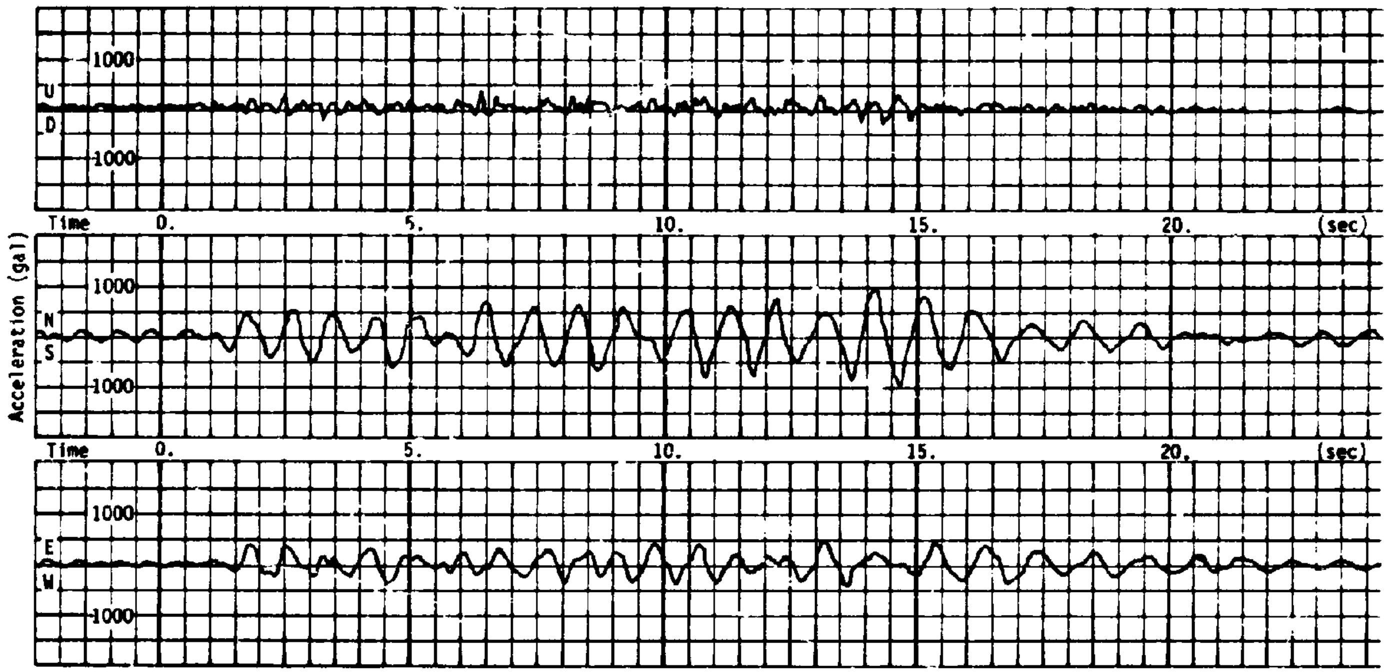

Figure 8 Three components at ninth-floor level.

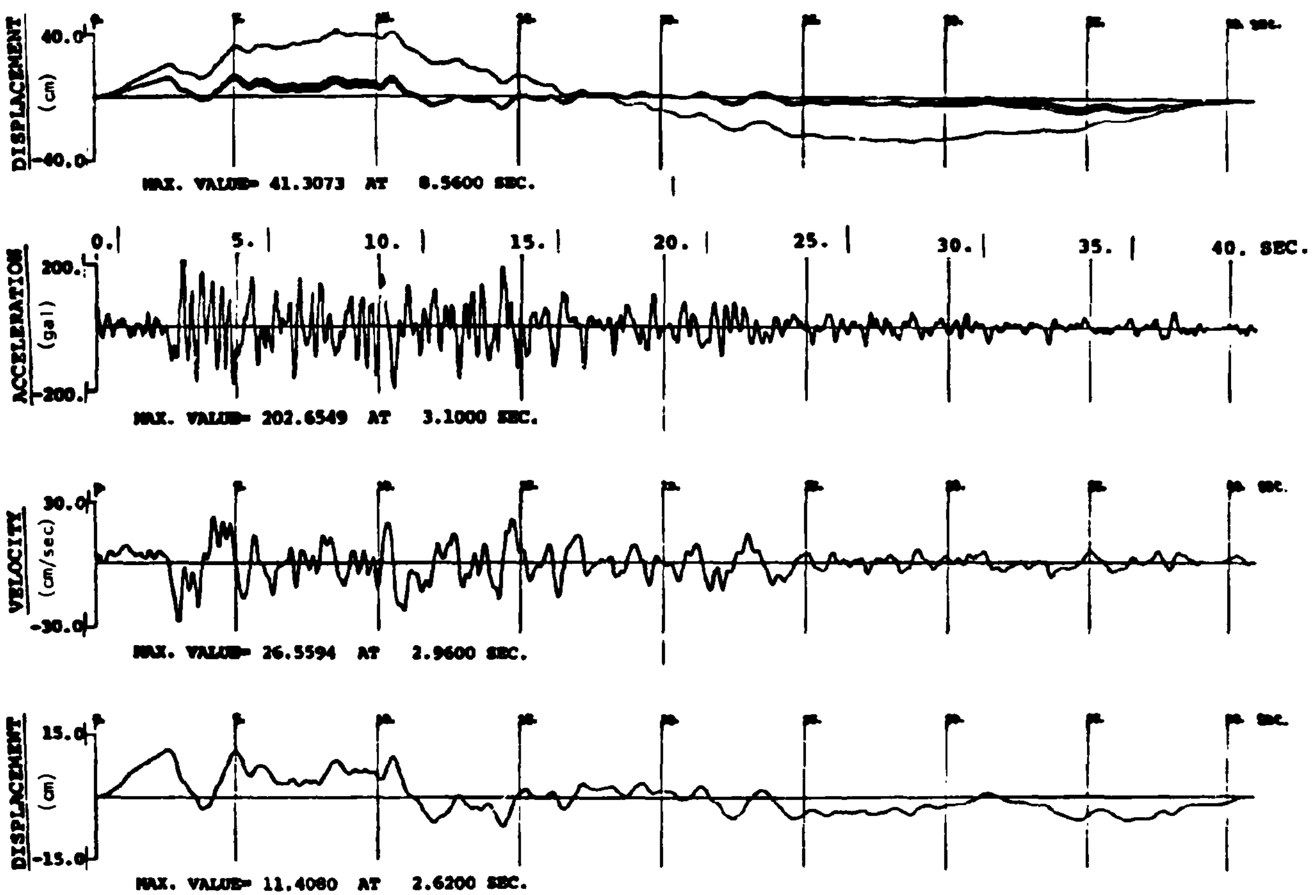

Figure 9 Analysis for corrected acceleration, velocity, and displacement of first floor, east-west component.

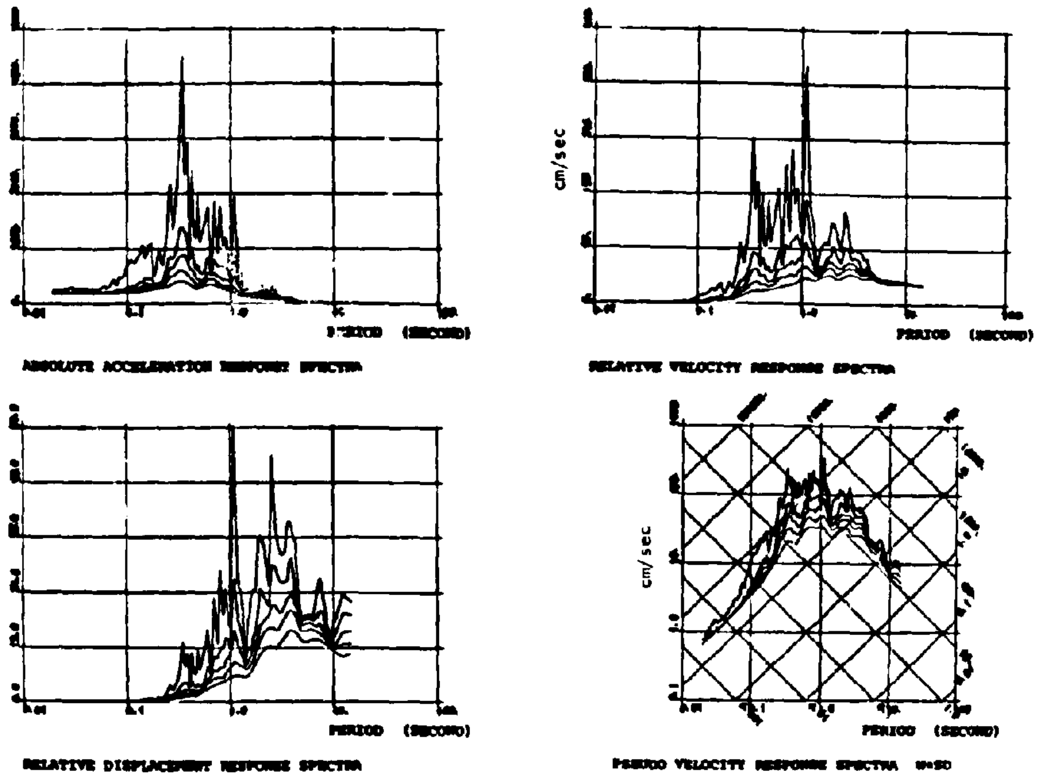

Figure 10 Spectral analyses of first floor, east-west component.
(Damping values are 0%, 2%, 5%, 10%, and 20% of critical.)

LIQUEFACTION AND DAMAGE TO DIKES

by David K. Keefer
U.S. Geological Survey
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Introduction

The June 12, 1978, earthquake caused soils to liquefy at several sites on the coastal flood plain bordering the Bay of Sendai. The engineering structures most extensively damaged by liquefaction were flood-control dikes composed of earth fill. The damage consisted primarily of cracking, settlement, and minor lateral spreading and slumping. During a trip to Miyagi Prefecture on June 26-28, 1978, I was shown six sites where dike damage had occurred (Figure 1). Additional information on earthquake-induced dike damage was provided by officials of the Public Works Research Institute (PWRI), the Japanese government agency charged with building and maintaining river works. Liquefaction-induced damage also occurred in an uncompacted sand fill in the port of Ishinomaki.

Summary of Dike Damage

Reported sites of damage are scattered in an arc extending from the Abukuma River on the southwest to the mouth of the New Kitakami River on the northeast (Figure 1). Within this region, damage occurred along parts of the Abukuma, Natori, Hirose, Yoshida, Eai, Naruse, Old Kitakami, and New Kitakami rivers (Figure 1, Table 1). All sites are underlain by unconsolidated Holocene coastal flood plain or alluvial fan deposits (Geological Survey of Japan, 1968; Geologic Map of Miyagi Prefecture). Many of the damaged dikes are founded on historically active river channels. A total of 28 linear kilometers of dikes was damaged in this earthquake, and total repair costs of dikes and other river works amounted to 1,328,500,000 yen (approximately $6,700,000) (M. Takahashi, National Land Agency of Japan, unpublished data). Most of this damage was caused by liquefaction.

The dikes are composed chiefly of compacted sand. They are built directly on alluvial fan or flood plain sediments with little or no ground improvement. Most dikes are several meters high, several meters wide at the crest, and have side slopes of 2 Horizontal : 1 Vertical or less. At the time of my visit, repairs to the dikes were already well advanced. The repairs consisted of regrading and filling cracks, placing sand bags, and driving steel-sheet pile walls between severely damaged dike sections and the rivers in order to reduce seepage.

Geologic Setting

Most sites of damage are on the coastal plain bordering the Bay of Sendai; a few are on the Natori River alluvial fan (Geological Survey of Japan, 1968; Geologic Map of Miyagi Prefecture). The coastal plain sediments are unconsolidated Holocene gravels, sands, silts, and clays primarily deposited by rivers; beneath most dikes these deposits are several tens of meters thick (Hase, 1967). The river deposits are of three main types: channel, natural levee, and back marsh deposits (Tohoku Regional Construction Bureau, PWRI, unpublished data; H. Nakagawa, Tohoku University, unpublished data). Structures including dikes founded on channel or back marsh deposits performed relatively poorly during the June 12 earthquake. Liquefaction occurred most commonly in channel deposits. Performance of structures founded on natural levee deposits varied from place to place. These deposits are generally thin, and the performance of engineering structures was therefore strongly influenced by the materials

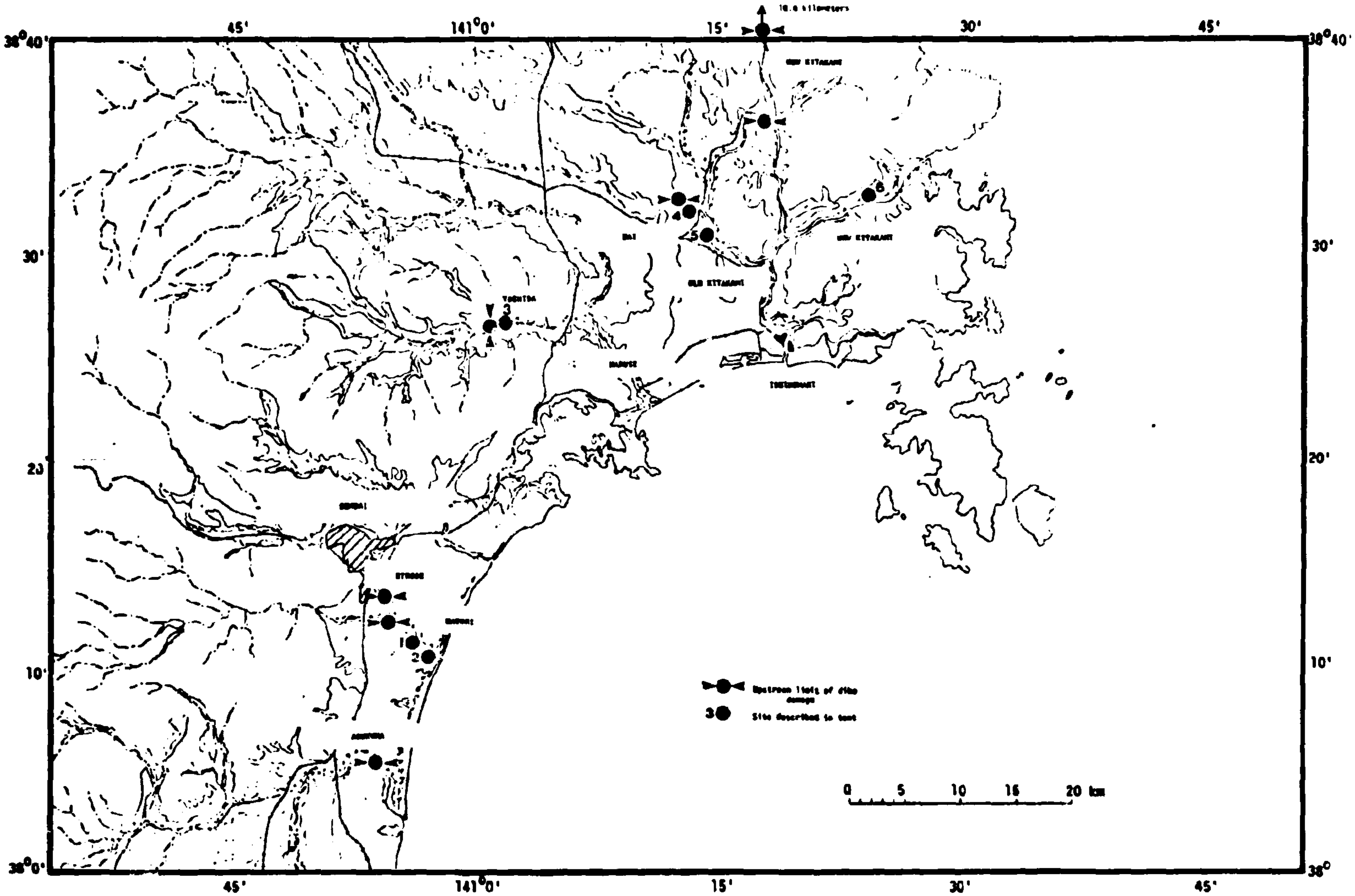


Figure 1 Dike damage in Miyagi Prefecture

TABLE 1

DIKE DAMAGE IN MIYAGI PREFECTURE

River	Bank[1]	Number of damage sites	Total length of dike affected by cracking, settlement, lateral spreading, or slumping (km)
Abukuma	left	2	0.38
	right	5	0.68
Natori	left	11	1.87
	right	6	2.17
Hirose	left	0	0
	right	5	0.38
Yoshida	left	9	0.51
	right	12	5.50
Eai	left?	5	2.90
	right?	6	0.21
Naruse	left	13	0.79
	right	10	1.08
Old Kitakami	left	3	0.15
	right	9	0.29
New Kitakami	left	16	7.13
	right	17	4.13
TOTAL		129	28.17

Information furnished by the Tohoku Regional Construction Bureau.

[1]Right or left relative to an observer facing downstream.

underlying the natural levees (H. Nakagawa, Tohoku University, oral communication). Near the coast, there are beach ridge and dune deposits, and sand in these deposits is relatively firm. Structures founded on them sustained little damage in the June 12 earthquake. Natori River alluvial fan materials are relatively coarse grained, consisting primarily of gravel but also containing a few thin layers of sand and silt (Hase, 1967).

Natori River (Sites 1 and 2). Lateral spreads, fissures, and sand boils were apparently widespread along the Natori River for 3 km upstream from its mouth (T. Tazaki, PWRI, oral communication). There the flood plain is underlain mainly by fluvial sand that extends to a depth of 15 m or greater (Hase, 1967). I visited two damaged dikes in this area (Figure 1).

At Site 1, liquefaction affected a 160-m-long section of dike. The configuration (Figure 2) and composition of this dike are typical of those I saw throughout Miyagi Prefecture. The dike is composed primarily of compacted, fine-to-medium sand. It rises 2 m above the high water level of the river and is 4 m wide at its crest. Its riverward flank has a slope of 2H:1V. The opposite flank descends as a series of slopes (again 2H:1V) and benches to the agricultural land beyond the dike.

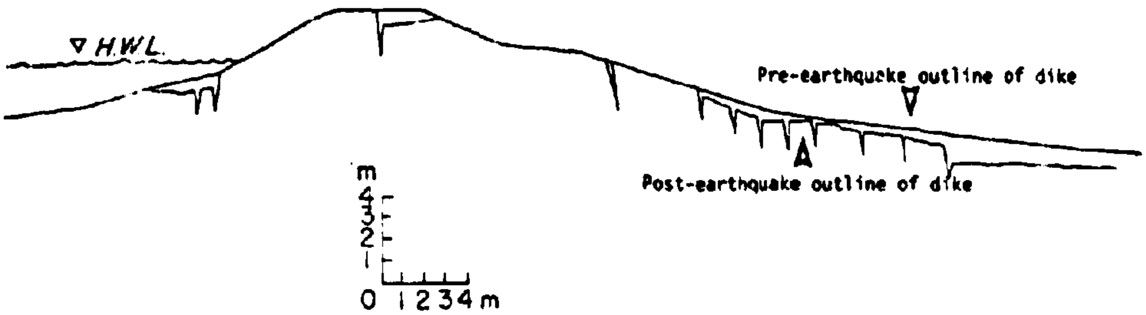


Figure 2 Site 1, Natori River: Cracking, settlement, slumping, and lateral spreading induced by liquefaction. (From Tohoku Regional Construction Bureau, PWRI, unpublished data)

As a result of the earthquake, slumping, lateral spreading, and settlements of up to 1.5 m occurred (Figure 3). Longitudinal fissures several tens of meters long opened in the dike crest. Between the dike and the river, fissures striking obliquely to the dike formed, and sand was ejected from them (Figure 3b). Other fissures trending parallel to the dike and the river formed near the river bank, more than 100 m from the base of the dike. The occurrence of fissures and sand boils in ground away from the dike indicates that liquefaction took place primarily in material beneath the dike and not in the dike material itself.

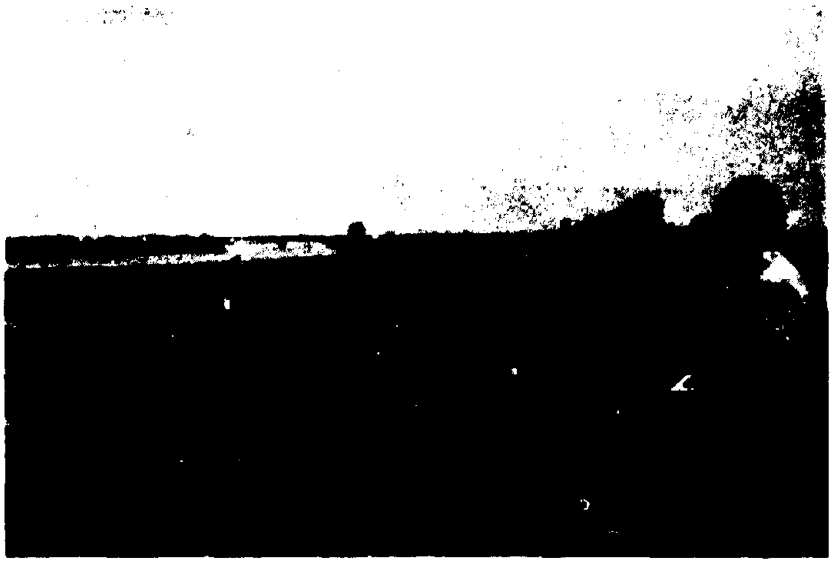
The damaged section is built on a former channel abandoned by the river less than 500 years ago. Beneath the dike, fluvial sand extends to a depth of at least 60 m (Hase, 1967), and much of the top 15 m of sand is fine grained, loose, and well sorted (poorly graded) (Tohoku Regional Construction Bureau, PWRI, unpublished data). Because of the proximity of this site (and all other sites of dike damage) to a river, the water table is close to the ground surface at all times.

Liquefaction previously took place at this site during a magnitude (M) 6.7 earthquake in February 1978 (T. Tazaki, PWRI, oral communication). The same section of dike was affected, and the same materials liquefied in both the February and June earthquakes.

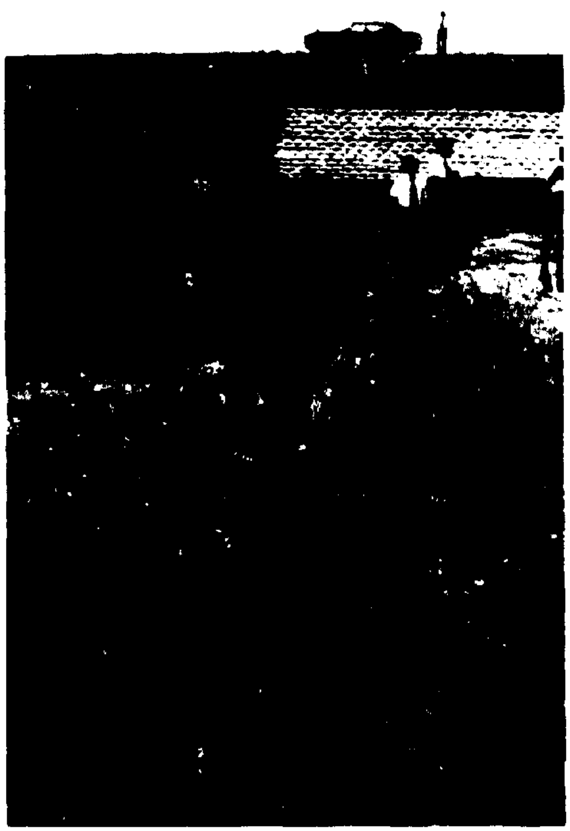
At Site 2 (Figure 1), the dike is contained by a concrete retaining wall (Figures 4 and 5). A section of the retaining wall several hundred meters long moved about 30 cm toward the river. Longitudinal fissures opened in the dike behind the retaining wall and in a concrete pavement along part of the dike (Figure 5c). The dike also settled by as much as 30 cm. This site, which is at the mouth of the river, is underlain by at least 20 m of sand (Hase, 1967).

Yoshida River (Site 3). This was one of the most severely damaged sections of dike in Miyagi Prefecture. Settlements of up to 1 m occurred over a distance of 5 km, longitudinal fissures opened (Figure 6), bulges appeared in some of the lower slopes, and sand boils were associated with fissures in some places. The fissures and bulges indicate that lateral spreading and slumping took place. The damaged section rests on the fan-delta of a small stream, and a boring near this site penetrated 15 m of silt, 2 m of fine sand, and 5 m of coarse sand (Tohoku Regional Construction Bureau, PWRI, unpublished data; Hase 1967). Bedrock lies at an average depth of 35 m.

Figure 3 Site 1, Natori River



3a View downstream (southeast) along repaired portion of dike. Dike is made of compacted sand. It rises 2 m above the high water level of the river and has side slopes of 2H:1V. Natori River in center-left background.



3b Liquefaction-induced cracks and sand boils in ground between river and dike indicate that liquefaction took place in materials beneath the dike. Sand in center distance to left of crack is from sand boil. Sand bags on dike were placed after the earthquake as a repair measure. View south. (Photo courtesy E. L. Harp)

Figure 3 Site 1, Natori River

3c Liquefaction-induced slumping of dike on flank away from river. View north. (Photo courtesy Tohoku Regional Construction Bureau)

Figure 3 Site 1, Natori River

3d Cracking and settlement of dike crest caused by lateral spreading. View southeast. (Photo courtesy Tohoku Regional Construction Bureau)

Figure 3 Site 1, Natori River

3e Cracking of roadway on dike caused by slumping or lateral spreading. View southeast. (Photo courtesy Tohoku Regional Construction Bureau)

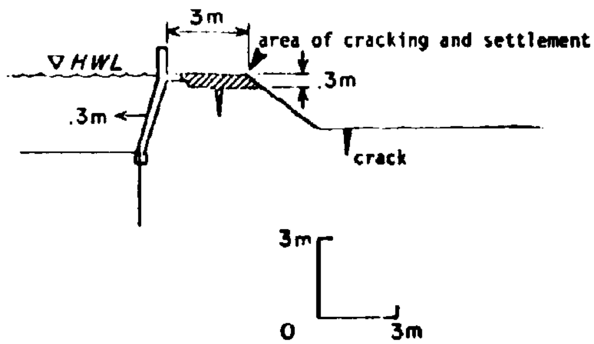


Figure 4 Site 2, Natori River: Retaining wall moved laterally, and dike crest settled. (From Tohoku Regional Construction Bureau, PWRI, unpublished data)

Eai River (Site 4). Sand boils were common in an old river channel at Site 4, on the right bank of the Eai River (Figure 7). A concrete block fence near this channel was cracked by lateral spreading toward the old channel bank (Figure 8). Damage to the dike on this side of the river was minor. Across the river from Site 4, cracks up to 80 cm deep and 10 cm wide affected a 2-km-long section of the dike. In this area, the foundation material apparently contains much soft clay. Some layers of silt and sand may also be present. The dike was built relatively slowly, and significant settlement took place during construction (K. Kawashima, PWRI, oral communication).

Old Kitakami River (Site 5). Sand boils occurred in the rice field adjacent to the dike (Figure 9), but damage to the dike itself was apparently minor. Subsurface material at Site 5 consists of alternating layers of silty sand and clay to a depth of 15 m (T. Tazaki, PWRI, oral communication).

New Kitakami River (Site 6). The dike and paved roadway at Site 6 settled a maximum of 1.5 m and cracked over a distance of 4 km (Figure 10), and sand boils formed on both flanks of the dike. This dike, too, is built over an old river channel. According to data from borings completed by the Tohoku Regional Construction Bureau, PWRI, the soil under the damaged part of the dike is similar to the soil under an adjacent, undamaged section. The soils consist of gravels, sands, and silts with a few thin layers of clay to a depth of approximately 8 m. N-values (blows/ft from a standard penetration test) for most soil layers under both sections are less than 10. Reasons for the differences in behavior between the damaged and undamaged sections are currently under study by Japanese engineers.

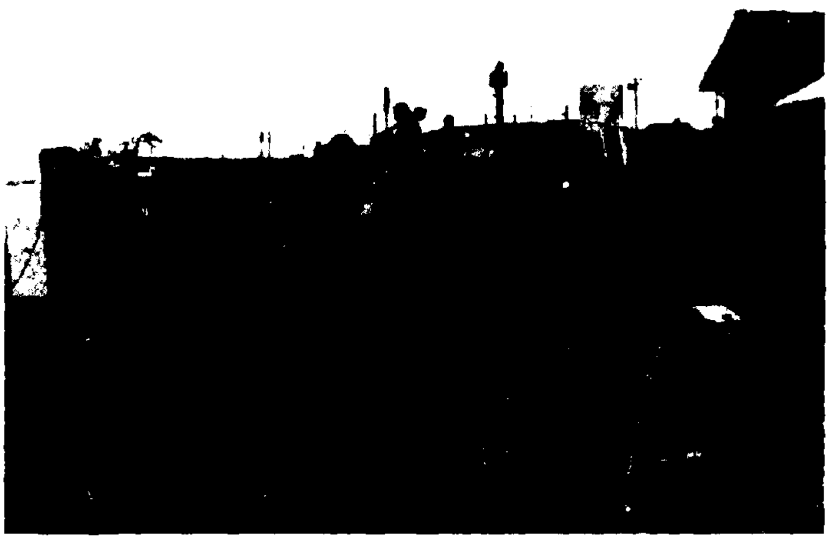
Liquefaction in the Port of Ishinomaki*

In the port of Ishinomaki, a fill composed of fine sand liquefied, causing severe damage to anchored steel sheet pile bulkheads. The fill material had been dredged from the seafloor and placed hydraulically with no compaction. It was placed next to old beach deposits, and the boundary of the liquefaction damage followed the contact very closely; the natural material was not involved in the liquefaction.

*Data kindly provided by Mr. Hajime Tsuchida, Chief, Earthquake Resistant Structures Laboratory, Port and Harbor Research Institute, Ministry of Construction.

Figure 5 Site 2, Natori River

5a View west along repaired portion of dike. Note patch across offset in retaining wall caused by differential lateral movement during earthquake. Retaining wall rises approximately 1 m above roadway.

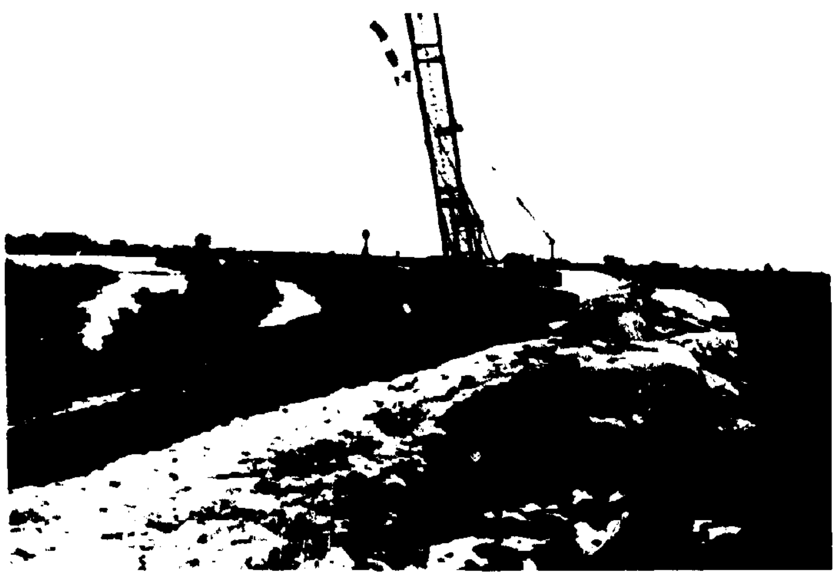


5b Settlement, lateral movement, and longitudinal cracking of dike. View east. (Photo courtesy Tohoku Regional Construction Bureau)

Figure 5 Site 2, Natori River

5c View west across tributary of Natori River. Dike section shown in Figures 5a and 5b is to right of houses in background of this figure. Note crack in concrete pavement in foreground is aligned with crack in retaining wall in background.

Figure 6 Site 3, Yoshida River



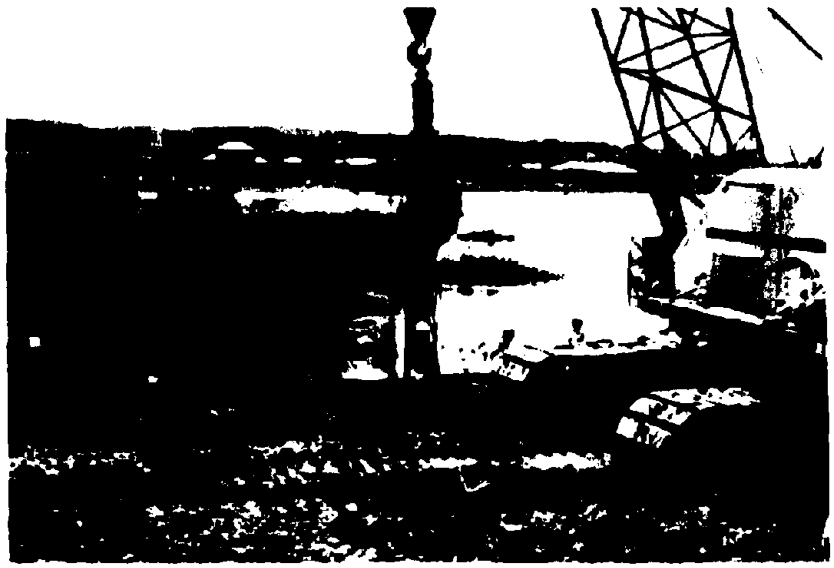
6a View east (downstream) along section of dike where repairs are under way. Dike crest settled as much as 1 m over a length of 5 km. Note sand bags used in repair process.

Figure 6 Site 3, Yoshida River

6b Cracks in dike caused by slumping and lateral spreading. Cracks are 10-30 cm wide. View west. (Photo courtesy K. Kawashima, PWRI)

6c Scarps in dike caused by slumping. For scale, note man in background. (Photo courtesy K. Kawashima, PWRI)

Figure 6 Site 3, Yoshida River



6d Steel sheet piles being placed by vibratory driver as part of repair process. Purpose of sheet piles is to reduce seepage into part of dike weakened by earthquake.

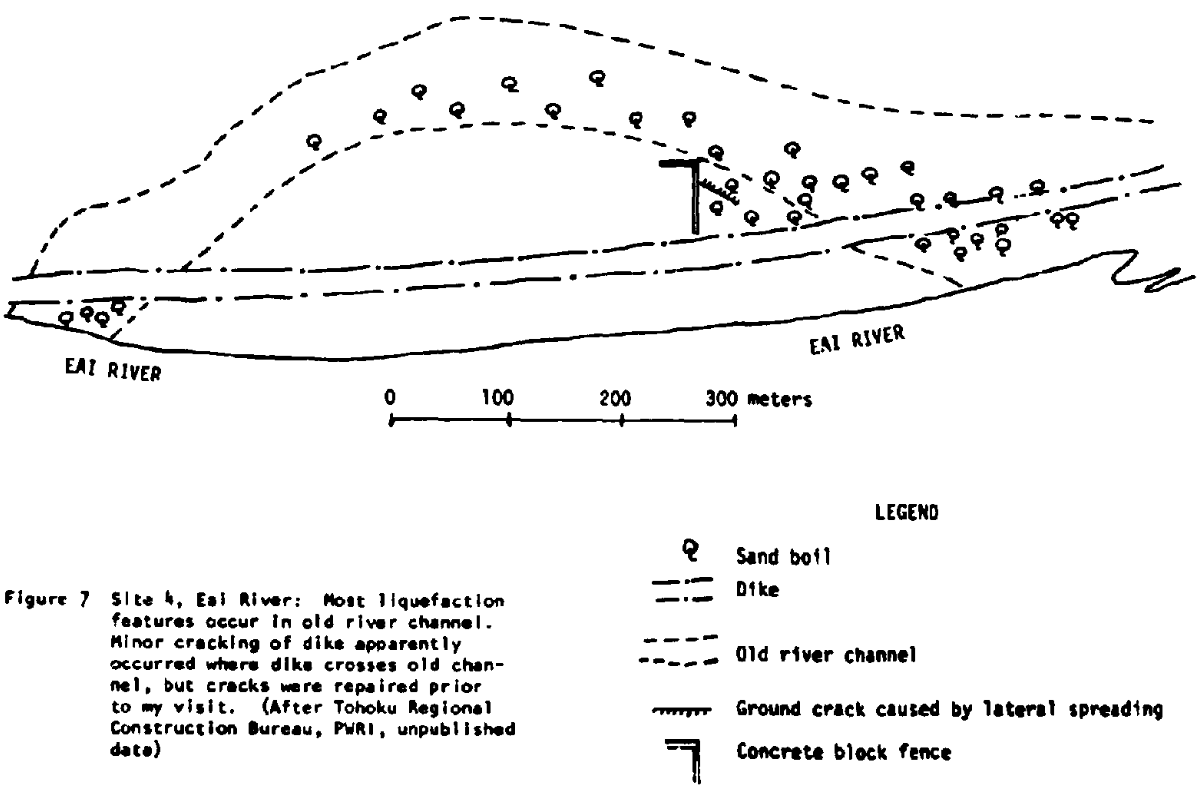


Figure 7 Site 4, Eai River: Most liquefaction features occur in old river channel. Minor cracking of dike apparently occurred where dike crosses old channel, but cracks were repaired prior to my visit. (After Tohoku Regional Construction Bureau, PWRI, unpublished data)

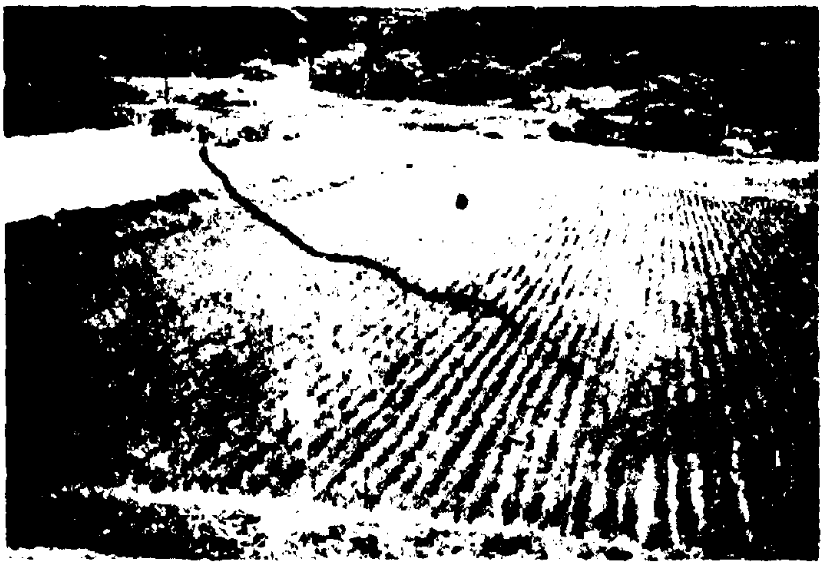
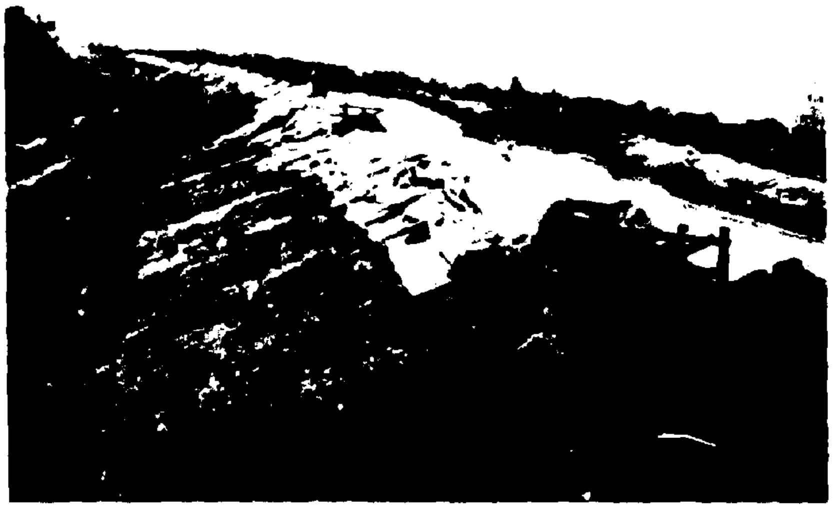


Figure 8 Site 4, Eai River: View southwest from crest of dike. Crack (indicated by heavy line) in fence and rice field caused by lateral spreading toward bank of old channel in background.

Figure 9 Site 5, Old Kitakami River: Sand boils in rice field. Plants are several centimeters tall. Damage to the dike at this site was minor. (Photo courtesy K. Kawashima, PWRI)

Figure 10 Site 6, New Kitakami River



10a View east along crest of dike and highway that are being repaired. Uneven nature of highway surface is due to liquefaction-induced differential settlement. Settlements of up to 1.5 m occurred over a distance of 4 km.

10b Cracking of dike crest and roadway due to liquefaction-induced slumping. (Photo courtesy K. Kawashima, PWRI)

Conclusion

The off-Miyagi-Prefecture earthquake caused cracking, settlement, and minor lateral spreading and slumping of man-made dikes along several rivers in the prefecture. A total of 28 km of dikes was affected, and total damage to dikes and other river works was approximately $6,700,000. The damage was apparently all repairable. Most of the damage was due to liquefaction. Liquefaction also occurred in hydraulic fill composed of fine sand in the port of Ishinomaki. These effects are currently being investigated by several Japanese scientists and engineers, and their reports should be forthcoming in the near future.

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Hase, Kotaro, 1967, Geology of the Alluvial Plains of Miyagi Prefecture (in Japanese with English figure captions), Contributions from the Institute of Geology and Paleontology, Tohoku University, No. 64, 45p.

LANDSLIDES RESULTING FROM THE EARTHQUAKE

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Several thousand landslides were triggered by the June 12, 1978, off-Miyagi Prefecture earthquake. From our field observations and from data supplied by Japanese scientists and engineers, the landslides appear to have been confined mainly to the Miyagi Prefecture and the northern part of the Fukushima Prefecture. The landslide distribution was densest along the coast nearest the epicenter from Sendai northeast to the area around Matsushima. Landslides were responsible for 1 injury, 11 houses partially destroyed, 2 houses completely destroyed, and 2 houses partially damaged (Y. Tsuruya, 1978, unpublished data).

Most numerous of all landslides were small rockfalls and rockslides issuing from steep slopes. Landslides of these types were numerous along the mountainous roads of the Ojika Peninsula. They were generally less than 10 m^3 in volume and occurred in heavily fractured Triassic and Jurassic slate and interbedded quartzite. The largest rockfalls and rockslides occurred on natural slopes near Matsushima town and eastward along slopes near the mouth of the Naruse River.

Although fewer in number, rotational slumps in artificial fill were larger than most rockfalls and rockslides and caused severe damage to highways and buildings. Two such sites were visited within the city limits of Sendai where houses were destroyed or severely damaged. The seismic performance of these fills suggests that they may be hazards in future earthquakes.

Approximately three days were spent surveying ground failure from south of Sendai northeast to the mouth of the New Kitakami River. Although a detailed picture of the regional landslide distribution was not obtained, the observations throughout the area surveyed afforded a good estimate of the size ranges and types of landslides that occurred. The following description of seismic-induced landslides is presented as site observations along this route, referring to Figure 1 for locations of individual landslide sites and areas of interest. They depict the most noteworthy as well as representative examples of the different kinds of landslides that occurred in this earthquake.

Rockfalls and Rockslides in Natural Slopes

Site 1. Two of the largest rockfalls from the earthquake occurred near Matsushima town west of the Takagi River as failures on steep (greater than 45°) natural slopes. The larger of these (Figure 2) occurred in an extensively weathered and jointed Miocene pumice tuff breccia (from Geologic Map of Miyagi Prefecture, legend in Japanese) exposed in a 45-m scarp. The slope affected is approximately 110 m wide, and the volume of debris produced is about 6,000 m^3. The rockfall damaged four houses built next to the slope (Y. Tsuruya, 1978, unpublished data). As seen two weeks after the earthquake, the landslide had clear plastic tarps stretched across the upper parts of the scarp to protect against rainfall infiltration and possible further movement.

About 0.5 km to the north, a smaller rockfall occurred on a steep slope in dark brown volcanic rock of Miocene age (possibly andesite or andesitic sediments). The scarp is about 20 m high

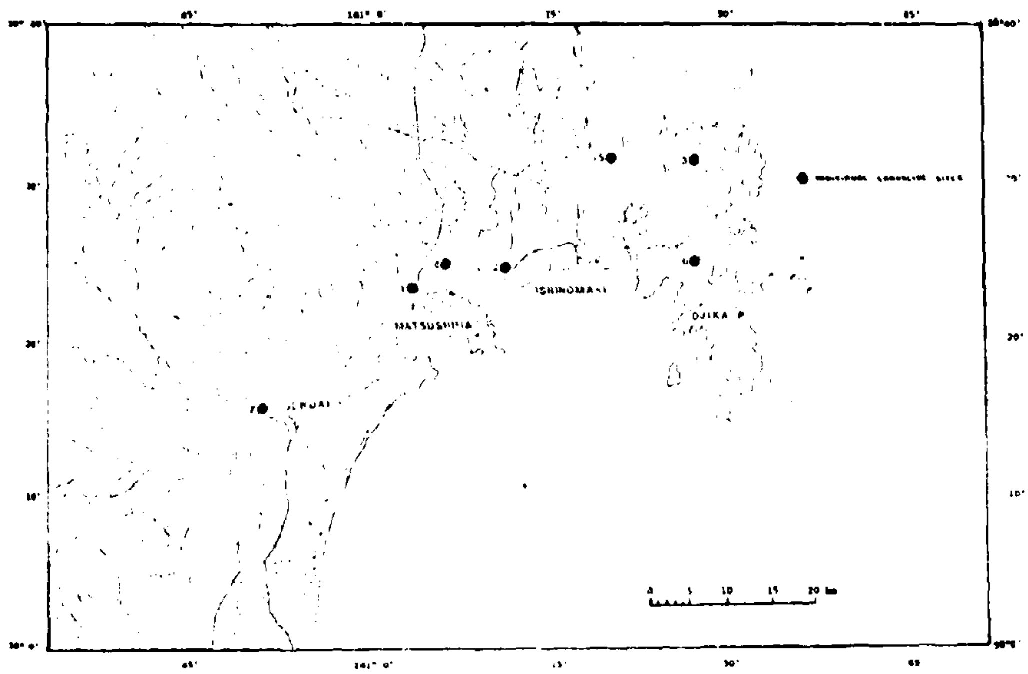

Figure 1 Landslide sites visited during reconnaissance survey.

Figure 2 Rockfall on steep slopes near Matsushima town. Failure is in Miocene pumice. Photograph was taken approximately two weeks after the earthquake. Tarps were already stretched over most of the slope to protect against further movement arising from rainfall infiltration (photograph by David Keefer).

and about 50 m wide (Figure 3). This rockfall produced blocky debris with boulders up to 0.5 m in diameter. The scarp reveals extensively fractured bedrock. The fracture surfaces probably provided planes of weakness along which the rock failed.

Site 2. Three rockslides occurred in steep east-facing bluffs flanking a broad plain near the mouth of the Naruse River. All three were narrow slides about 15 m wide that occurred in a dark brown volcanic clastic rock similar to the smaller slide at Site 1. The slides extended from near the crest of the bluffs to the base, a height of approximately 30 m as shown in Figure 4.

Site 3. A small rockfall (Figure 5) south of the New Kitakami River occurred on the end of a narrow ridge of Triassic slate and quartzite. Slopes adjacent to this end of the ridge showed no failure, suggesting that this point, which was the narrowest part of the ridge, experienced stronger shaking than adjacent slopes. This phenomenon has been documented in other earthquakes (Bonilla, 1959, Nason, 1971, Harp and others, 1978) and is probably due to topographic focusing of seismic energy.

Rockfalls and Rockslides in Cut Slopes

Ojika Peninsula. The reconnaissance of the Ojika Peninsula and area immediately to the north was along winding mountain roads that traversed slopes of Triassic and Jurassic metamorphic rocks (slate and quartzite, see Wentworth, this report), which were heavily vegetated but had a thin soil mantle, generally less than 0.5 m thick. Numerous small rockfalls were derived from near-vertical roadcuts. None of these failures appeared to have produced more than several cubic meters of debris.

Site 4. A typical roadcut failure, shown in Figure 6, is derived from weakly cemented sandstones along a valley west of the Naruse River. The rockfall is less than 1 m thick, and slope height is about 10 m.

Site 5. A rockfall in Triassic slate and fine-grained quartzite occurred along a steep cut slope on the north side of the New Kitakami River. The scarp of the rockfall is inclined at about 60° and is formed by prominent slaty cleavage planes (Figure 7). Figure 8 shows the blocky rockfall debris, which has been broken into pieces of up to 30 cm in longest dimension. Almost all of the debris appeared to have broken along preexisting fractures.

Landslides in Artificial Fill

Site 6. Several artificial fill failures occurred on roads crossing the Ojika Peninsula, one of which is shown in Figure 9. The fill material in the center foreground of the photograph has slumped away from beneath the road surface, cutting about 2 m into the highway. The fill appeared to be either uncompacted or poorly compacted sandy clay derived from adjacent bedrock and soil.

This particular failure occurred at a site where rainfall-induced sliding has repeatedly taken place in the past (T. Tazaki, 1978, oral communication). At the time the photograph was taken, tarps had been spread over the extensively cracked pavement to prevent or minimize rainfall infiltration into the scarp area. During observation, heavy rainfall was mobilizing the debris into small, active mudflows.

Figure 3 Rockfall on steep slopes in volcanic clastic sediments (photograph by David Keefer).

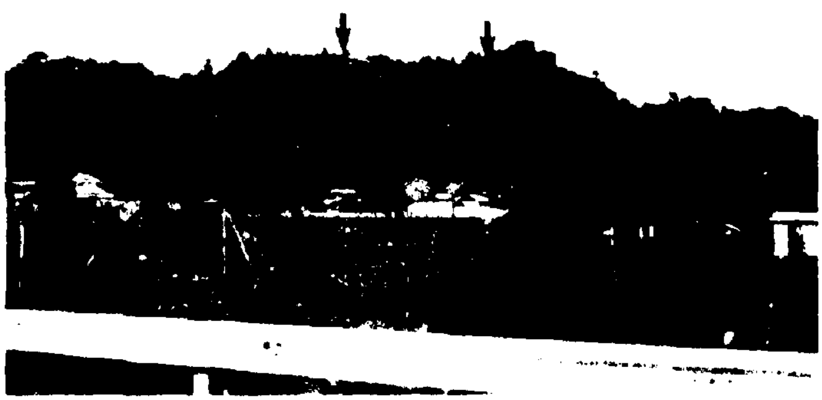

Figure 4 Rockslides (arrows) in steep bluffs bordering flood plain near mouth of Naruse River (photograph by David Keefer).

Figure 5 Small rockfall in slate and quartzite on the spur of a narrow ridge.

Figure 6 Rockfall from roadcut in weakly cemented sandstone.

Figure 7 Rockfall in roadcut. Note slaty cleavage planes that form the rockfall scarp.

Figure 8 Debris from rockfall shown in Figure 7 showing pieces up to 30 cm.

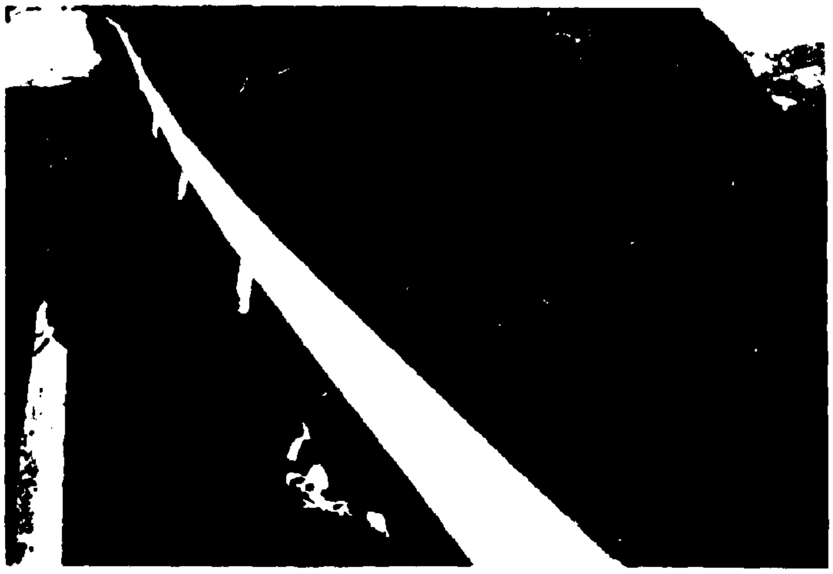

Figure 9 Slump in artificial fill along a highway on the Ojika Peninsula.

Site 7. Many slope failures took place in artificial fill within the city limits of Sendai. These were mainly rotational slumps. In the neighborhood of Midorigaoka, a large rotational slump occurred in a fill slope of about 15°, composed of gravelly clay. From headwall scarp to toe, the slide extends approximately 70 m horizontally and 20 m vertically (Y. Matsuzaki, 1978, unpublished data); it is approximately 30 m wide and about 14 m in maximum thickness, and the volume is thus approximately 30,000 m^3. The bulk of the slide occurred above and to the right of one of the 1,400 concrete slope-protection dams (sabo works) in Sendai (Figure 10). The entire slide had been covered with nylon tarps at the time the photograph was taken to prevent rainfall infiltration. Many houses had been removed from this slope in past years due to rainfall-induced slumping; as a result, only one house, near the headwall scarp, was severely damaged by the seismic-induced sliding. Figure 11 shows the area originally occupied by this house, which was removed. The fence in the figure clearly shows the rotational component of slide movement. About 5 m of horizontal displacement (Y. Matsuzaki, 1978, unpublished data) occurred, placing the toe of the landslide mass no more than several meters from houses below, as shown in Figure 12. The house shown in Figure 12 was subsequently evacuated because of the threat of recurrent movement of the landslide mass.

Engineers from the Sabo Section of the Miyagi prefectural government were engaged in an extensive geotechnical investigation of the landslide mass and surrounding area. Many boreholes had been drilled in the slide material, as shown in Figure 13, to establish the depth of the failure surface, to provide samples for strength testing, and to emplace slope inclinometers to monitor any continuing movement. Adjoining areas were also being drilled and monitored to detect any movement that might be precipitated by the slide, such as deformation downslope from the toe in response to the weight of the encroaching slide mass and retrogressive slumping upslope from the headwall scarp.

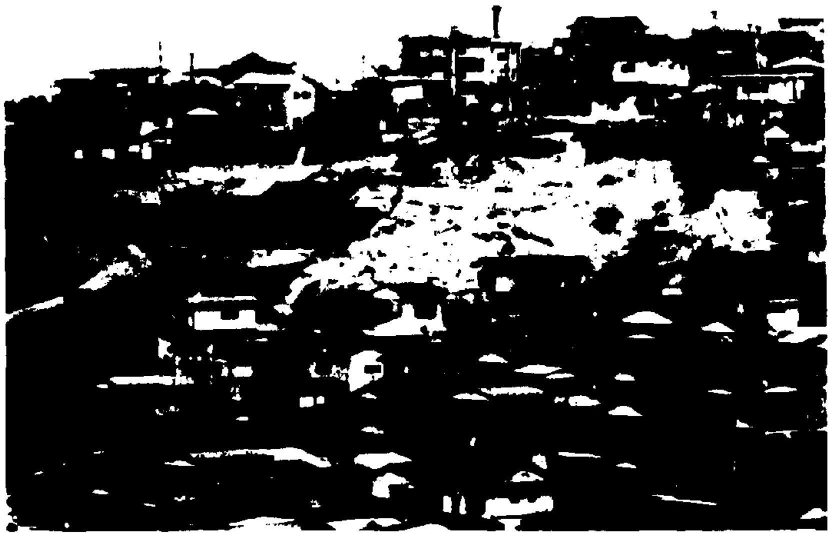

Figure 10 Rotational slump in artificial fill in Sendai (area covered by tarps), which destroyed one house and is threatening others. To left of slump is concrete slope-protection dam (sabo works) (photograph by David Keefer).

Figure 11 Area near head of rotational slump where a severely damaged house had to be removed. Fence shows rotational component of slump movement.

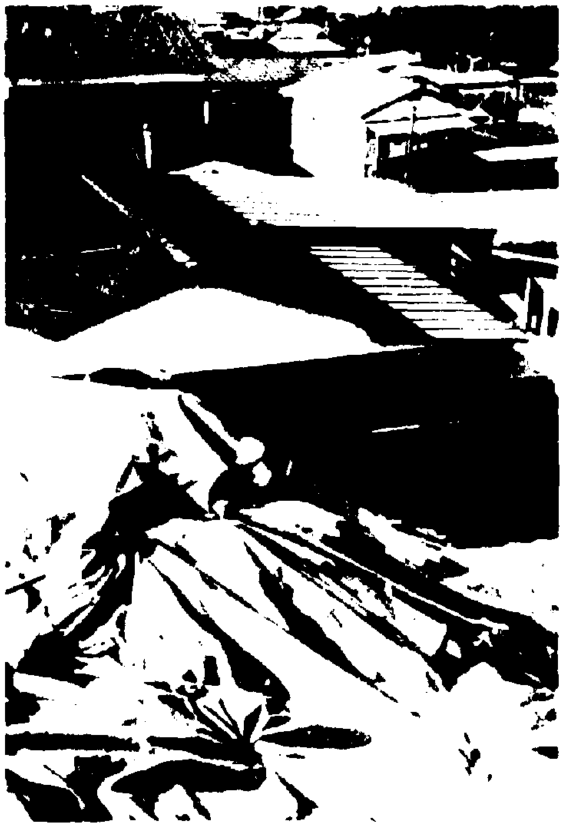

Figure 12 Toe of slump and house below in danger of being overridden by slide mass. House had been evacuated.

Figure 13 Area near slump toe showing borehole being drilled as part of geotechnical investigation of the failure and surrounding area.

Many other hillside slopes in Sendai underwent similar failure. At another site on artificial fill about 0.5 km to the east of Midorigaoka, six houses were condemned by the Mayor of Sendai because of cracking beneath and around the houses within the fill area. The decision to destroy the houses was made to protect the houses downslope. It was decided that collapse of the slope was imminent unless the weight of the houses was removed (T. Tazaki, 1978, oral communication).

Judging from the extensive failure of artificial fill in many slopes in Sendai, as compared with few noticeable landslides on the many steep natural slopes in the same area, the artificial fill appeared to be particularly susceptible to seismic-induced failure. Artificial-fill slopes may prove to be a seismic hazard in future earthquakes.

Conclusions

The June 12, 1978, off-Miyagi earthquake triggered several thousand landslides in Miyagi and Fukushima Prefectures. A field reconnaissance two weeks after the earthquake of the coastal region nearest the epicenter supported the following general conclusions:

(1) Most of the landslides were rockfalls and rockslides originating on steep natural and cut slopes, generally steeper than 45°.

(2) Many slopes and roadways constructed with artificial fill behaved poorly during the earthquake, forming rotational slumps and extensive ground cracks. The heaviest damage from these failures occurred in areas occupied by housing developments in Sendai.

(3) Many slopes composed of artificial fill were more susceptible to seismic-induced failure than steeper natural slopes. This was probably a result of insufficient compaction of the fill material.

Japanese scientists and engineers are continuing studies and will most likely combine the data gathered by different government agencies to produce a more comprehensive report of the regional landslide distribution, landslide mechanisms, and other important factors related to this potentially devastating category of seismic-induced ground failure.

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Geologic Map of Miyagi Prefecture, legend in Japanese.

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ENGINEERING ASPECTS

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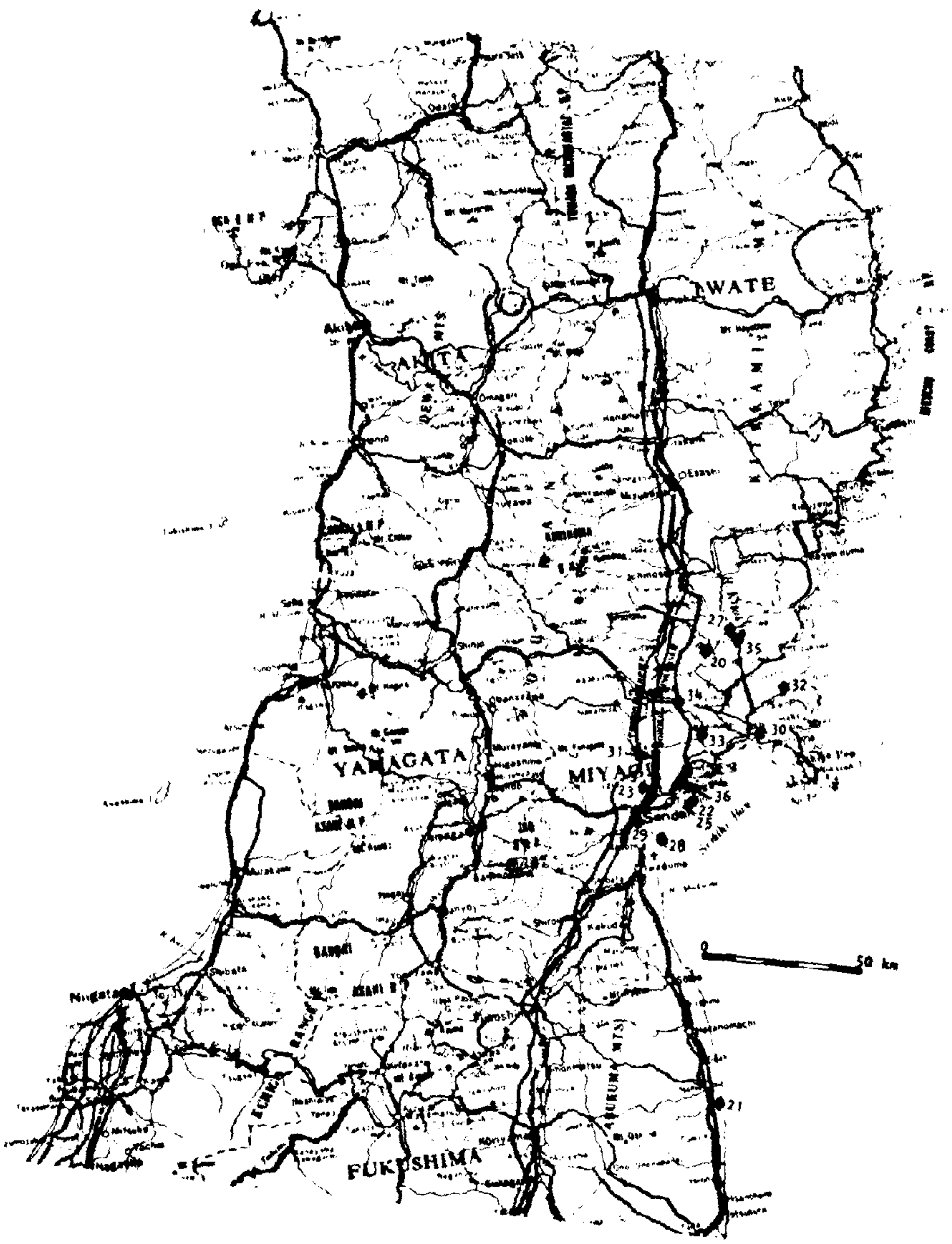
Introduction

This section reports the observations of the civil and structural engineer members of the reconnaissance team for the June 12, 1978 Miyagi-Ken-oki earthquake. No attempt is made here to analyze the structures or their performance; detailed reports are in preparation by Japanese engineers and authorities, and a report by the U.S. National Bureau of Standards, under the auspices of the United States-Japan Natural Resources Panel, is also planned.

The primary objective of the reconnaissance investigation, and of this report, was to observe the performance of earthquake-resistant buildings and other structures, including industrial complexes and some equipment items. Because of the time constraints of the investigation, effects on nonstructural items in buildings and on the numerous building service systems could not be observed. Another objective was to report on the general performance of critically needed utility systems.

Figure 3a

Figure 1b



-57a-

KEY:

1 City Center, Sendai
2 Minami Machidori Building, Sendai
3 Second Sendai Government Building, Sendai
4 Sumitomo Life Insurance Building, Sendai
5 Second Eastern Building Company Building, Sendai
6 Steel Framed 4-Story Building, Sendai
7 Steel Framed Furniture Warehouse, Sendai
8 Oroshicho Area of Sendai
9 Maryuyoshi Building, Oroshicho, Sendai
10 Obisan Building, Oroshicho, Sendai
11 Kinoshita Building, Oroshicho, Sendai
12 Maruhong Building, Oroshicho, Sendai
13 9-Story Building, Oroshicho, Sendai
14 Yazaki Industries Buildings, Oroshicho, Sendai
15 Paloma Building, Sendai
16 Engineering Faculty Building, Tohoku University, Sendai
17 Tohoku Institute of Technology, Sendai
18 Tonan High School, Sendai
19 Izumi High School, Izumi
20 Town of Hazama
21 Fukushima Nuclear Power Plant Complex, Namie, Fukushima Prefecture
22 New Sendai Power Plant, Tagajyo
23 Sendai Substation of Tohoku Electric Power Co., Izumi
24 Haranomachi Plant, Sendai City Gas Bureau, Sendai
25 Sendai Refinery, Tohoku Oil Co., Ltd., Tagajyo
26 Concrete Batch Plant, Sendai
27 Kin-noh Bridge
28 Yuriage Bridge
29 Sendai Ohashi Bridge
30 Kaihoku Bridge
31 JNR New Sendai Shinkansen Trunkline
32 Kitagami Ohashi Bridge and Dike
33 Kimazuka Bridge
34 Eai River Rail Bridge
35 Maiya Ohashi Bridge
36 Tunnels, National Highway Route 45 (Shiogama to Matsushima)
37 77 Bank Building, Sendai

Figure 1 Buildings and other structures in Sendai and in other parts of Miyagi Prefecture.

Buildings in the Sendai Metropolitan Area

Sendai is a large, modern city, with a population of more than 615,000 (1975 data). Its metropolitan area has a population of more than 1.2 million. Many hundreds of buildings in the city are at least five stories high and can be considered to be modern highrise structures. The central downtown area, in particular, has a great many modern buildings in the 10- to 20-story range. A large proportion of them are steel frame; many others use the Japanese steel-reinforced concrete (SRC) system, in which embedded structural steel shapes, in conjunction with conventional reinforcing steel, constitute the reinforcement.

The total damage from the June 12, 1978, earthquake constituted only a small percentage of the total capital investment in buildings and structures, despite the recorded high ground accelerations (generally between 0.25g and 0.40g).

Upon entering the city, it was difficult to believe that a significant earthquake had occurred. Closer inspection revealed minor facade damage, but even that was not widespread; many modern buildings showed no damage to their architectural veneer or glazing. However, as the investigation proceeded, it became obvious that pockets of damage, apparently correlated to local geologic and soils conditions, existed throughout the city.

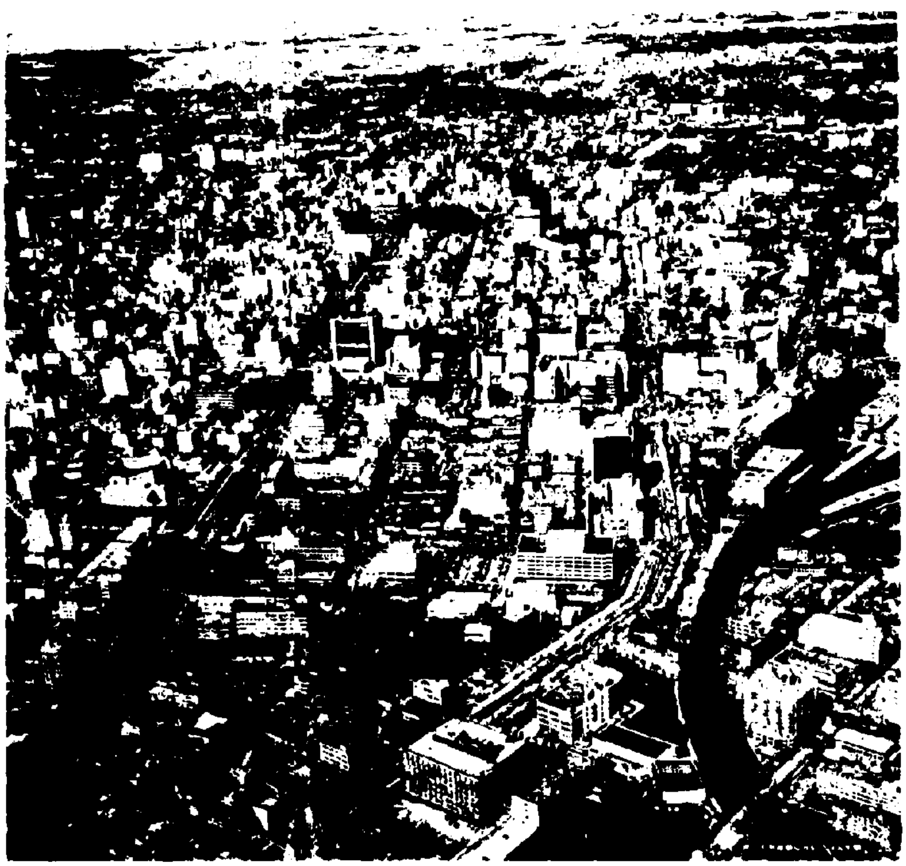


Figure 2 A general view of the downtown area of Sendai. (Tohoku Electric Power Company photograph)

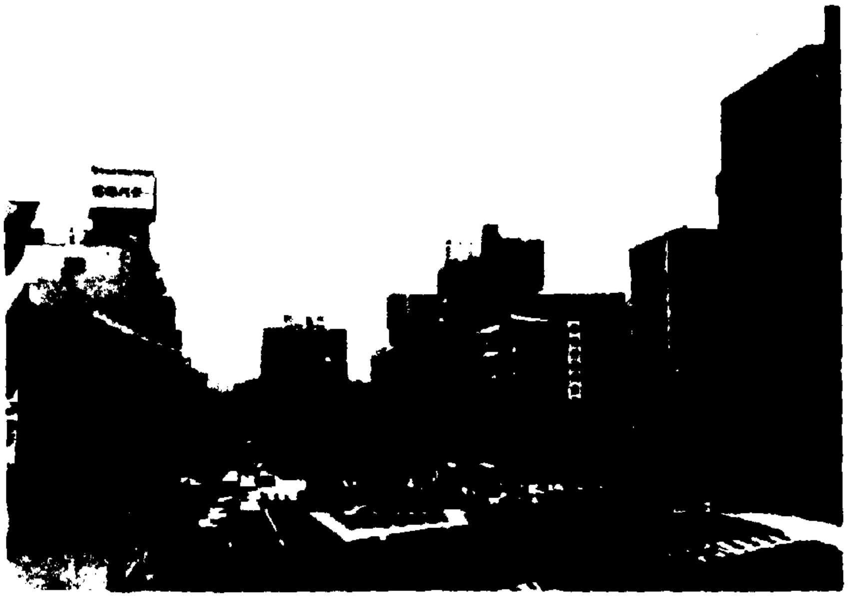


Figure 3 A typical view of the downtown area of Sendai.

Figure 4 Downtown Sendai: chimney damage (under repair) to the Mitsukoshi department store building. Many similar chimneys appear to have been damaged.

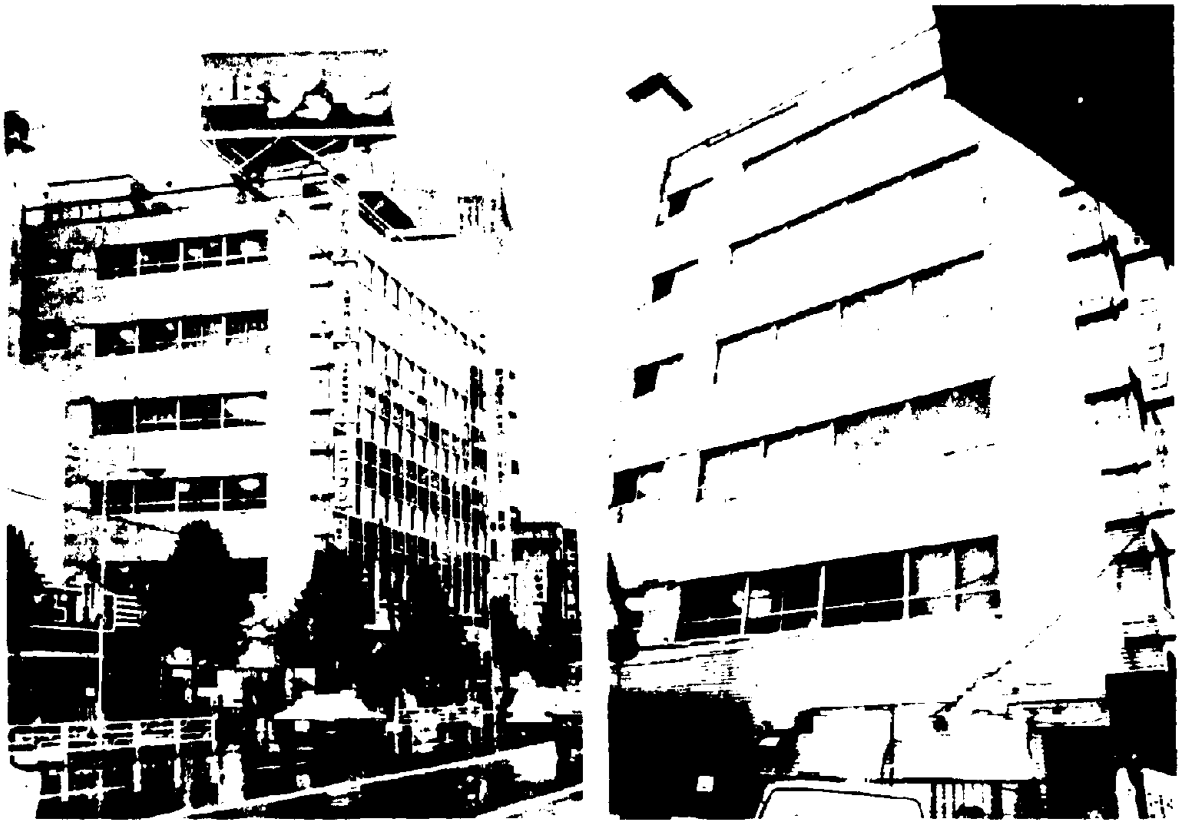


Figure 5 Minami Machidori building, Sendai. This 6-story reinforced concrete building in downtown Sendai suffered extensive cracking to its brick veneer facing and shows signs of possible structural damage as well. The damage is typical for many similar buildings in the city.

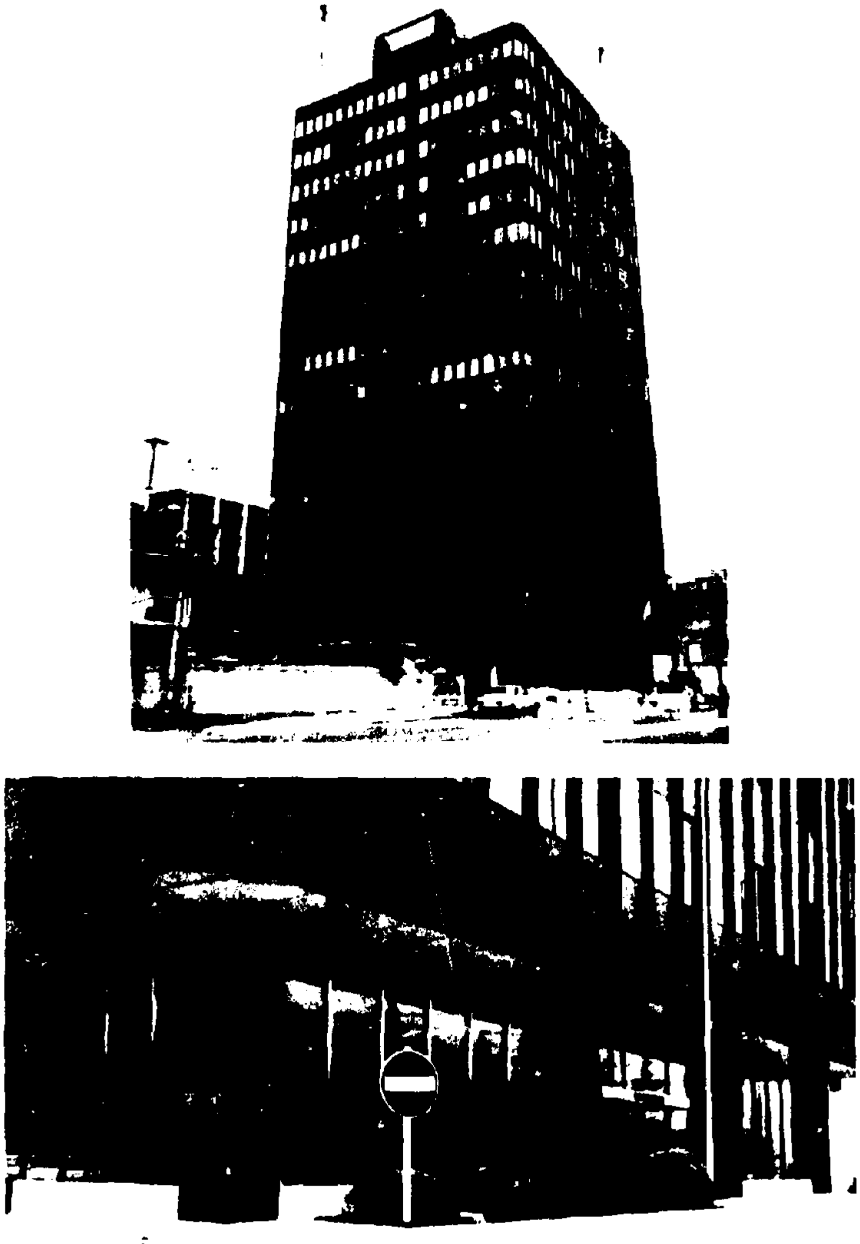


Figure 6 Sendai Second Government building. This 17-story, steel frame structure in downtown Sendai was built in 1973. The building was designed using dynamic analysis and has a raft foundation. Ground conditions are considered to be good. The building is instrumented (fifteenth floor, second basement, and downhole at -40 m). There was no apparent structural damage.

Figure 7 Sumitomo Life Insurance building. This modern, 18-story steel and reinforced concrete building, in downtown Sendai, has continuous shear walls around the elevator core and on the transverse outside walls. The interior shear walls around the elevator core and some of the construction joints in the stairwells show minor cracking. Some of the cracks were caused by the February 20, 1978, earthquake and apparently were widened by the most recent earthquake. The other main structural elements are believed to be undamaged. The building is instrumented on the second basement level and on the ninth and eighteenth floors. A peak ground acceleration of 0.26g and a peak response acceleration of 0.56g (eighteenth floor) were recorded.

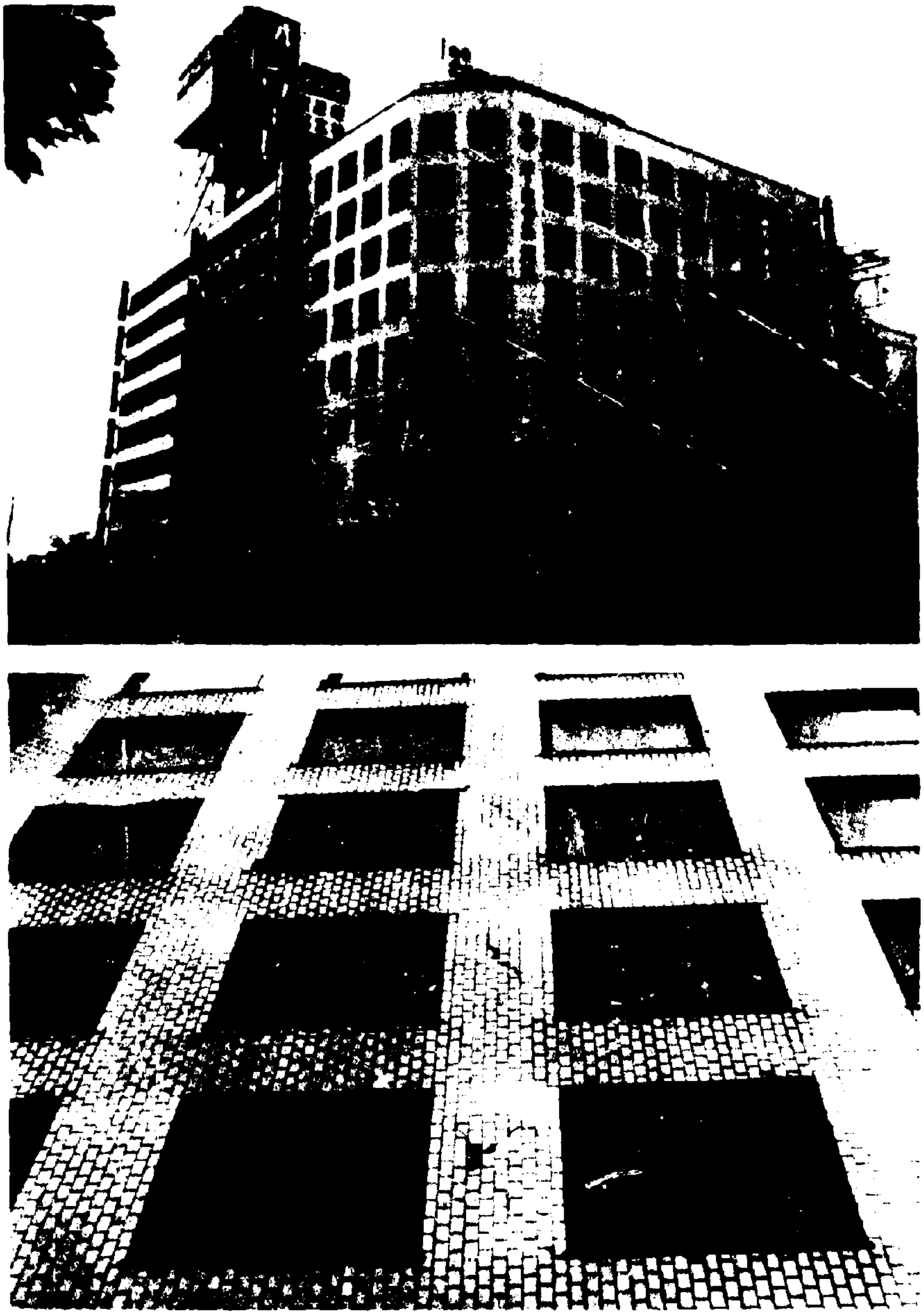


Figure 8 Second Eastern Building Company building: a typical modern, 8-story building in downtown Sendai. The only apparent damage to the exterior, which is veneered with glazed tiles, was cracking through the spandrels and the shear walls (on the sides opposite those illustrated).

Figure 9 Sasaki building, outskirts of Sendai: a damaged 4-story steel-framed building. The exterior precast concrete panel anchorages failed. (Kawahoku Newspaper Co. photograph)

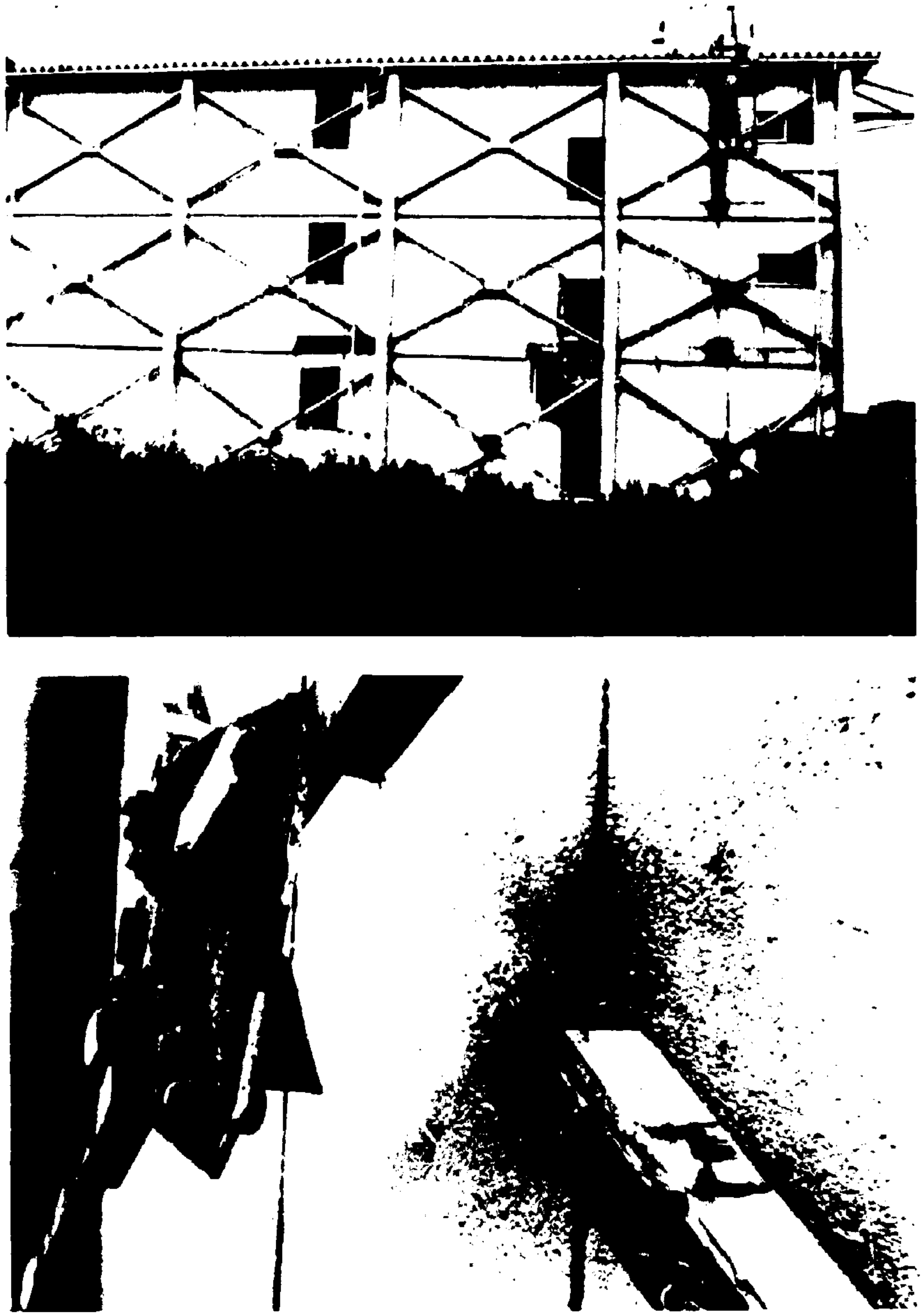


Figure 10 Outskirts of Sendai: a damaged steel-frame furniture warehouse. Some of the transverse diagonal braces failed at their midheight connections. Generally, rupture occurred at the bolt holes. (Courtesy of Professor Iemura, University of Kyoto)

Buildings in the Oroshicho Area of Sendai

Oroshicho (Site 8 of Figure 1a), on the eastern edge of Sendai, was once an area of rice paddles. It was developed about 10 to 12 years ago, with zoning equivalent to U.S. medium-density residential and commercial classifications. The soil conditions for construction needs are poor, and earthquake damage was extensive. At least 10 buildings were damaged seriously; four of them, reinforced concrete structures, suffered collapse.

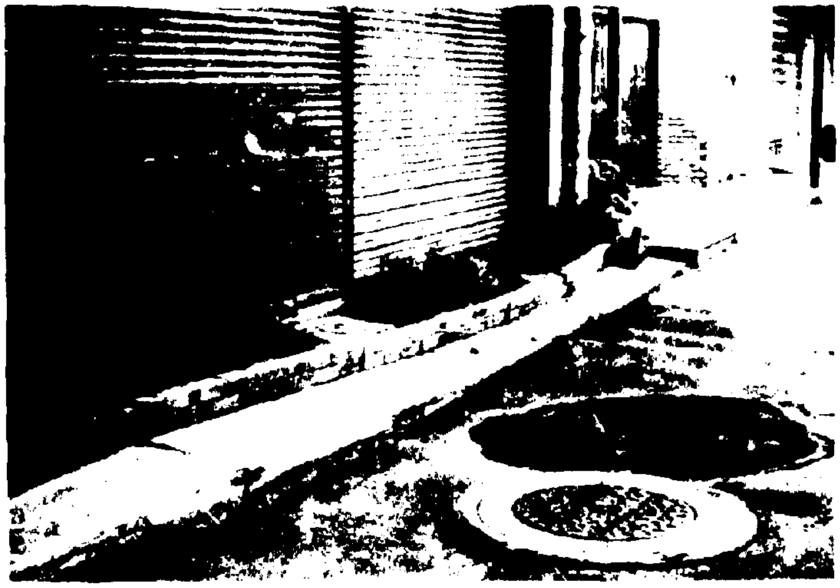


Figure 11 Oroshicho area, Sendai: sidewalk and other damage from ground settlement and deformation.

Figure 12 Maruyoshi building, Oroshicho area, Sendai: view from the north. This 3-story reinforced concrete frame building, one span by three, suffered almost total collapse of the first floor.

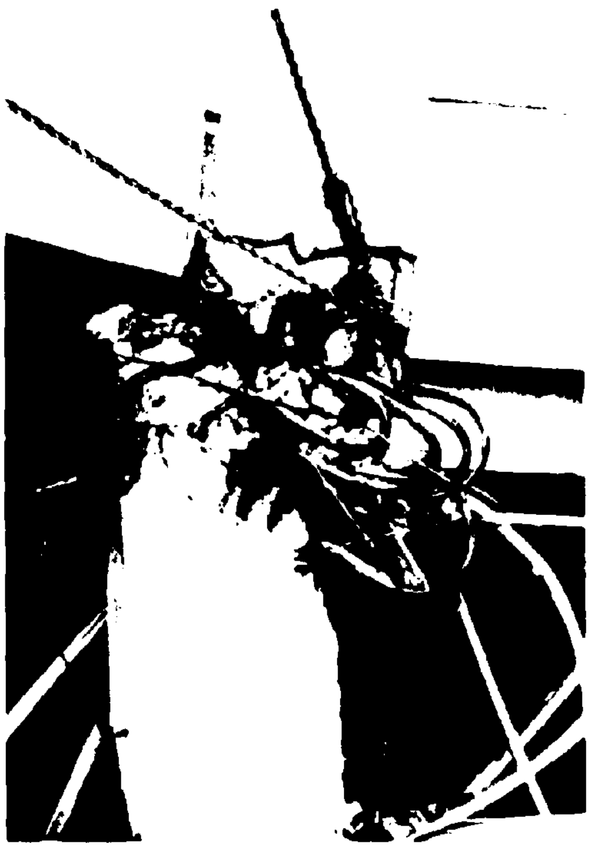


Figure 13 Maruyoshi building, Oroshicho area, Sendai: view from the east. Failure of the first-story columns in shear caused the collapse. The end walls (the shear walls on the ground floor) are being demolished. Detail photograph of joint at top of first-story column shows shortening and the use of undeformed bars, a common practice in the Oroshicho area.

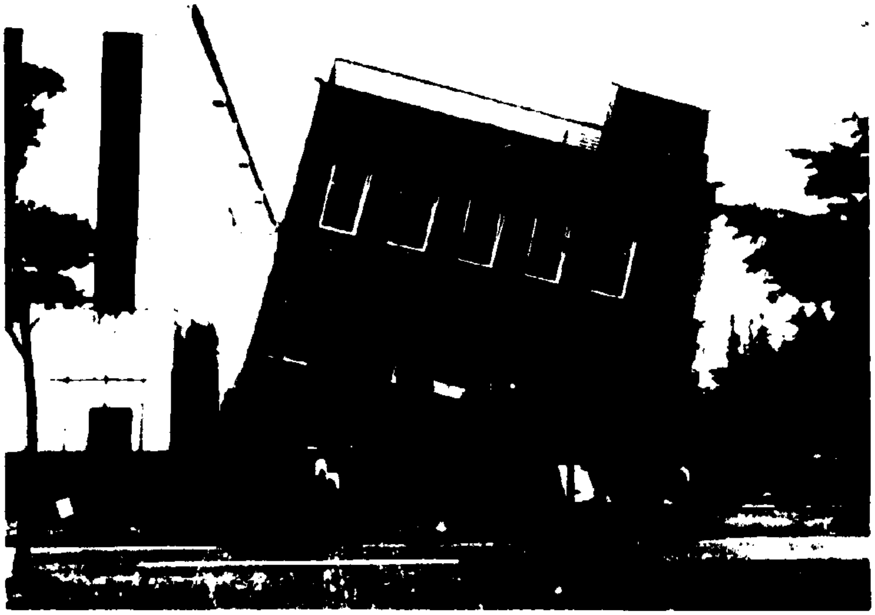


Figure 14 Obisan building, Oroshicho area, Sendai: view from the northwest. This is a 3-story reinforced concrete frame building with a soft first story, one span in each direction. The columns were inadequate to resist the torsional force caused by a heavy eccentric stairwell that cantilevered over the column line at the right end of the building.

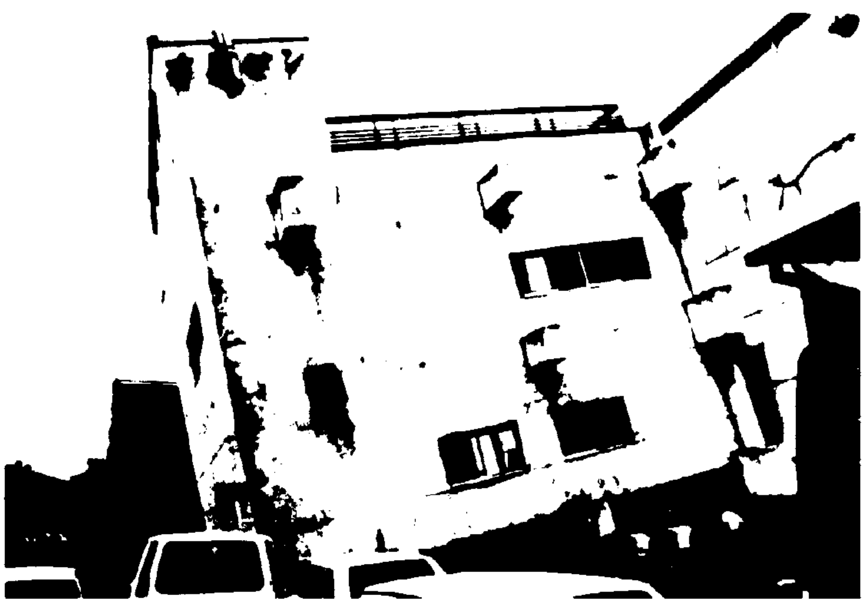


Figure 15 Obisan building, Oroshicho area, Sendai: view from the south. The upper stories rotated as a rigid body when the first-floor column support was lost.

Figure 16 Obisan building, Oroshicho area, Sendai. Rotation of the structure led to a disintegration of the four corner columns. The reinforcing bars that can be seen are undeformed.

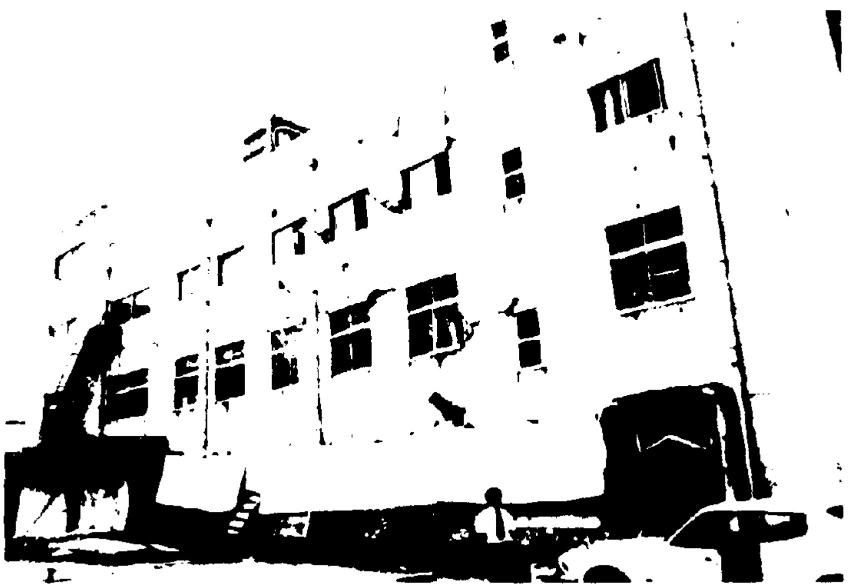


Figure 17 Kinoshita building, Oroshicho area, Sendai: view from the east (rear). This 3-story reinforced concrete building is two spans by six. The transverse foundation of the structure settled 10 to 15 cm along a middle column line, contributing to the extensive diagonal cracking.

Figure 18 Kinoshita building, Oroshicho area, Sendai: west face. This face suffered less apparent damage. The 2-story reinforced concrete penthouse also suffered extensive damage.

Figure 19 Maruhong building, Oroshicho area, Sendai: east building, east face. This 6-story reinforced concrete building shows extensive shear cracking in the panels between window openings. The east and west buildings are separated by a 3-cm construction gap; there is no evidence of pounding between the buildings.

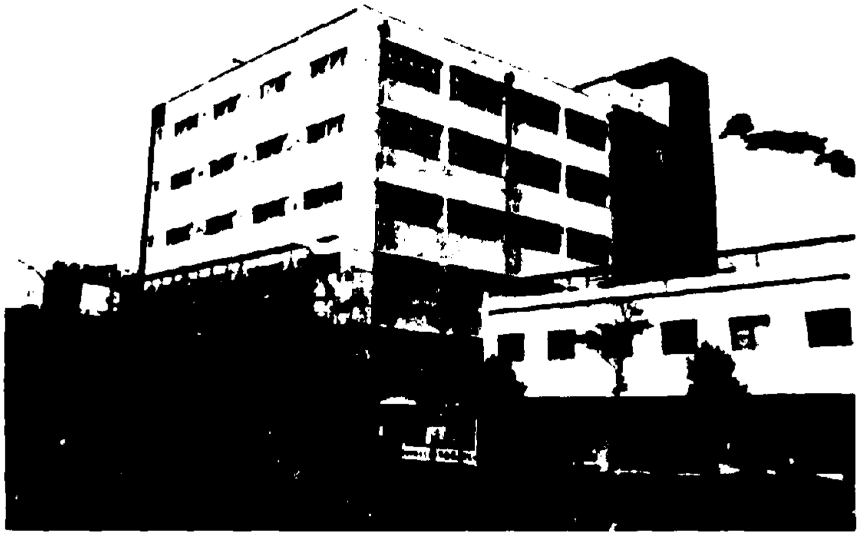


Figure 20 Maruhong building, Oroshicho area, Sendai: west building, west face. Extensive cracking of nonstructural curtain wall panels and shear cracking between windows was observed. The decorative ceramic brick facing on the north wall did not appear to have been damaged.

Figure 21 Maruhong building, Oroshicho area, Sendai: west building, west face. Details of damage to the nonstructural window spandrels can be seen.

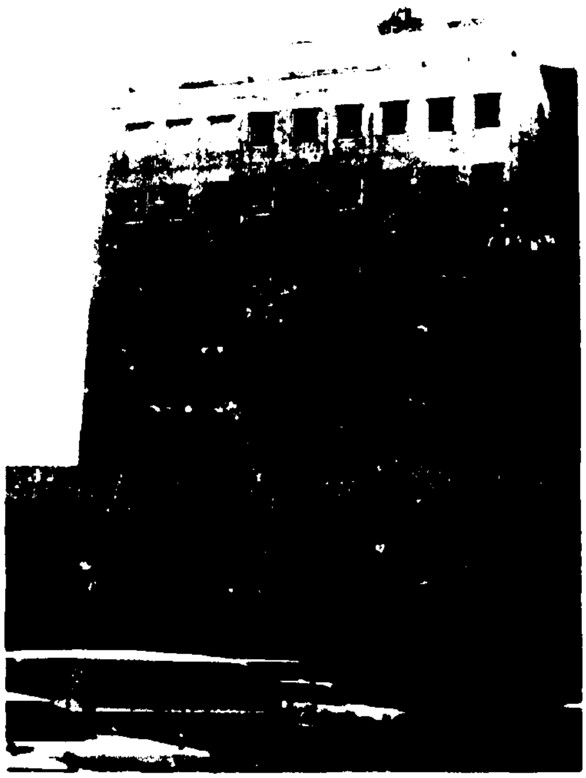


Figure 22 Oroshicho area, Sendai: 9-story building, lightly damaged.

Figure 23 Yazaki Industries buildings, Oroshicho area, Sendai: portions of three of the five Yazaki Industries buildings. The lower building on the left is a steel-frame warehouse. The middle building is a 4-story reinforced concrete frame structure, three spans by five. Adjacent to it is a 2-story steel-frame building (foreground). Failure of the reinforced concrete columns of the middle building caused a general collapse of the ground floor. The building fell against the front steel structure, causing extensive damage.

Figure 24 Yazaki Industries buildings, Oroshicho area, Sendai: Interior damage in the steel-frame 2-story building; caused by the collapse and impact of the failed 4-story concrete structure shown in Figure 23.

Figure 25 Yazaki Industries buildings, Oroshicho area, Sendai: view of the failed ground floor of the 4-story concrete building.

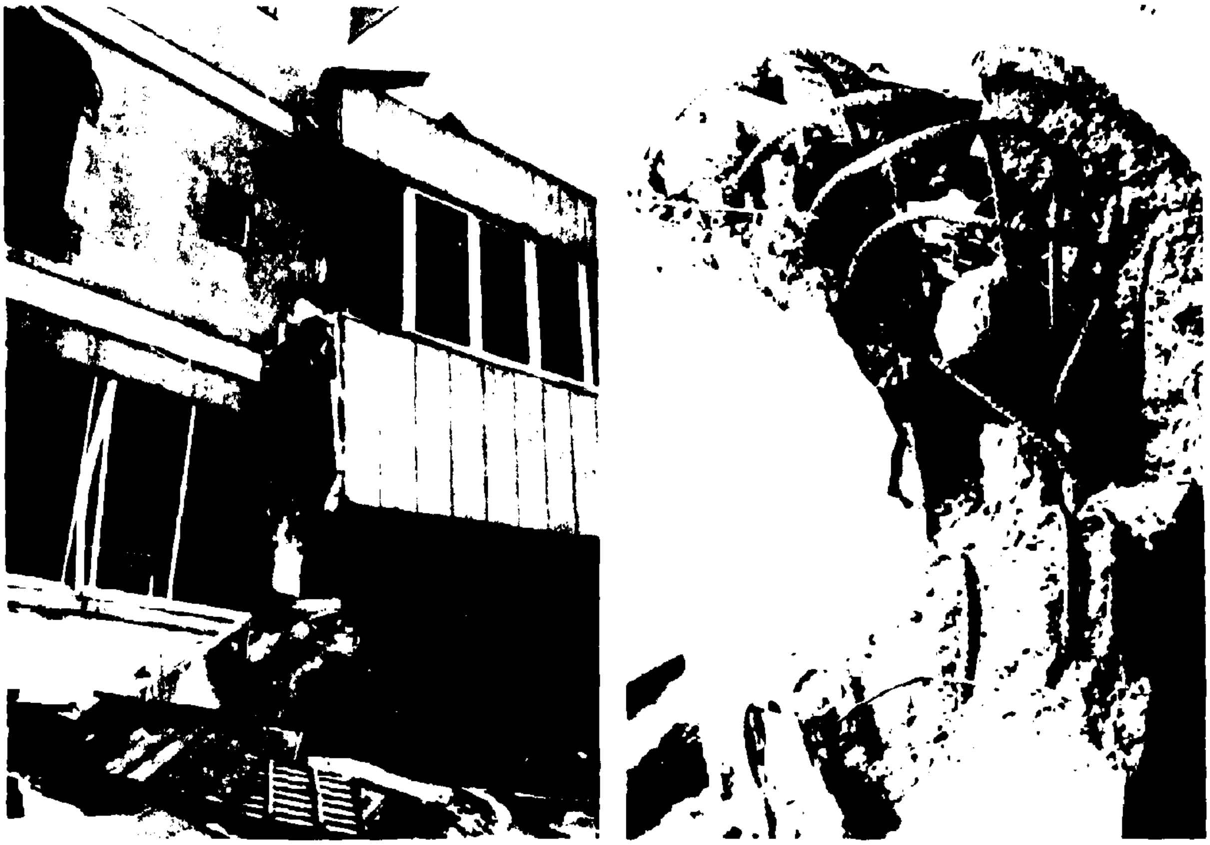


Figure 26 Yazaki Industries buildings, Oroshicho area, Sendai: details of damage to the concrete structure. The photograph to the left shows the impact area between the concrete building and the steel frame building. Deformed bars were used in this building, as shown in detail photograph, right.

Figure 27 Yazaki Industries buildings, Oroshicho area, Sendai: a failed beam-column connection. The expansion connection to the adjacent steel warehouse prevented damage to the latter structure.

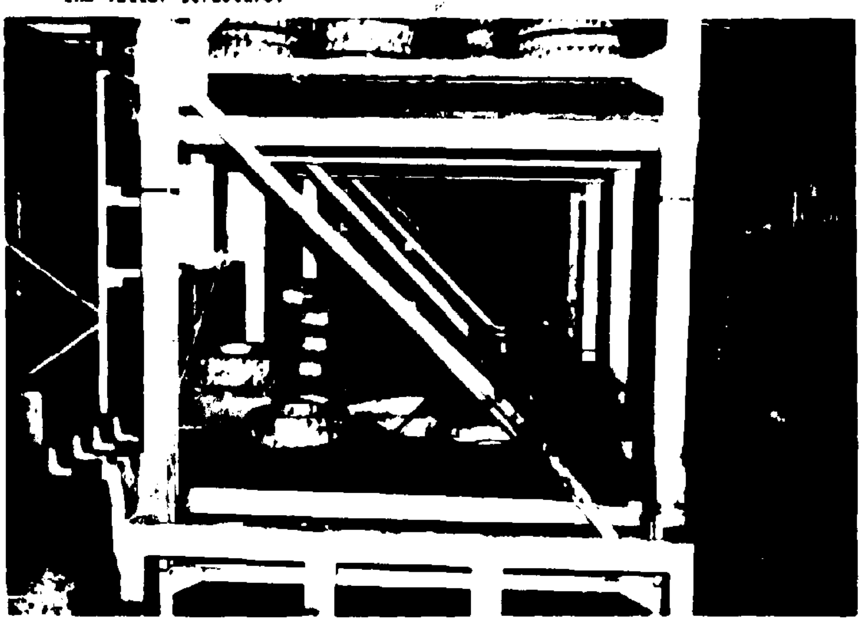


Figure 28 Yazaki Industries building, Oroshicho area, Sendai. The steel-frame warehouse contains a number of multilevel, tubular-steel storage racks for storing heavy gas-metering equipment. They are either bolted down or are welded to steel plates embedded in the concrete floor. The racks were damaged at the ground-level, transverse braces, but none collapsed, probably because of the extensive use of diagonal bracing.

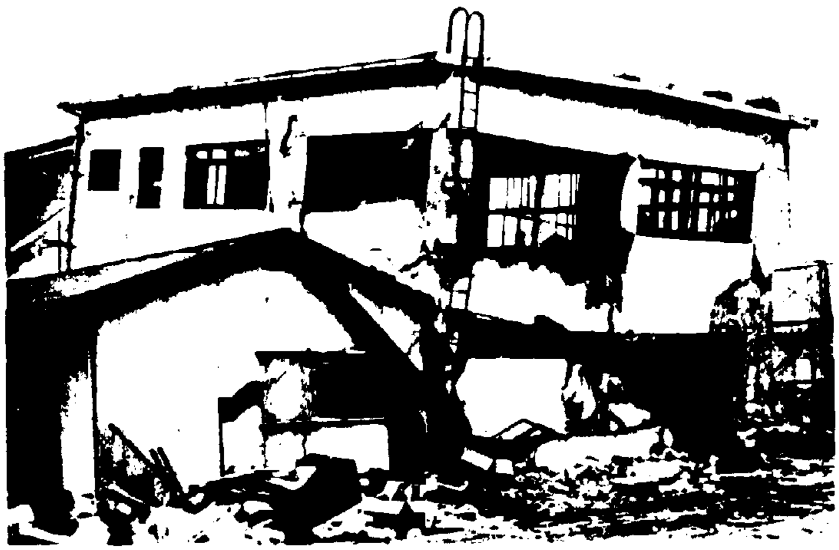


Figure 29 Paloma Building, near the Oroshicho area of Sendai: a 2-story, reinforced concrete building. The structure has two spans by three. There is a shear wall at one end; failure occurred at the opposite end, which is supported only by columns. The exposed concrete in the failed columns appeared to be of inferior quality. Column stirrups, 9 mm in diameter, were spaced 30 cm on centers.

Figure 30 Paloma Building, near the Oroshicho area of Sendai: detail of the failed wall.

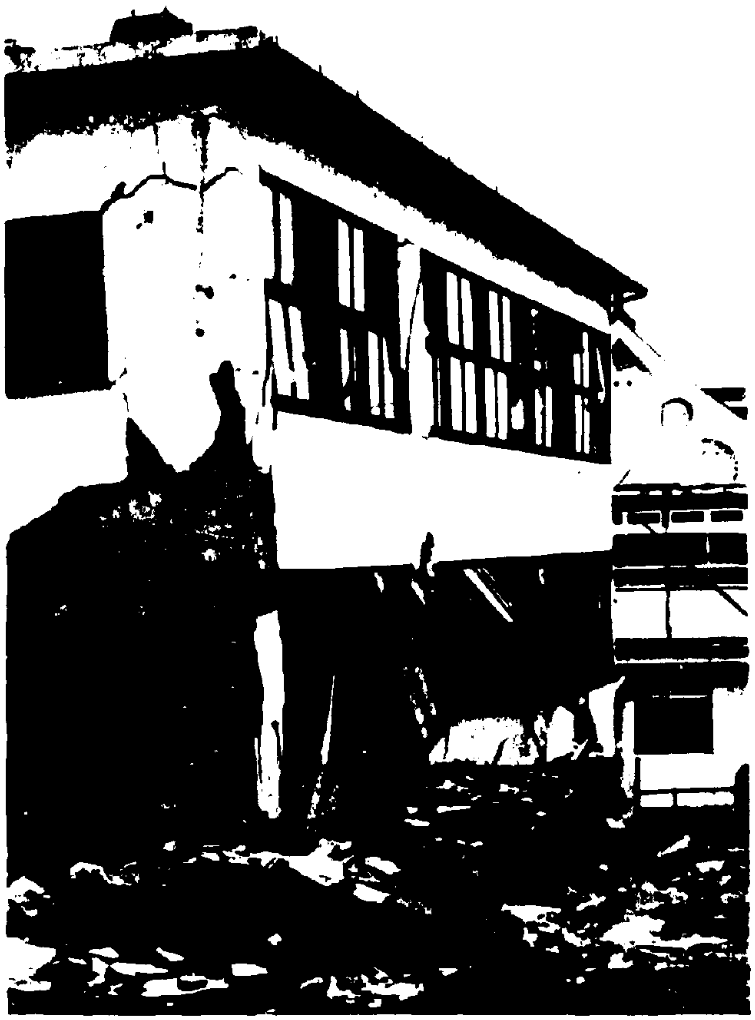


Figure 31 Paloma Building near the Oroshicho area, Sendai.

School and University Buildings

The following campuses were visited: (1) Tohoku University (two buildings), (2) Tohoku Institute of Technology (two buildings), (3) Tonan High School (two buildings), and (4) Izumi High School (four buildings).

The engineering faculty building of Tohoku University represents a unique case in earthquake engineering. This 9-story, reinforced concrete frame building with shear walls has successfully withstood two strong earthquakes and several small ones. The building is instrumented with two SMAC instruments: in the basement (ground level) and on the ninth floor. (The records are discussed by Brady in a separate section of this report.) The February 20, 1978, earthquake apparently caused some damage to the structure (cracking of shear walls, window breakage) and lengthened its period. The June 12, 1978, earthquake apparently a plified the damage caused by the February shock: the width of the diagonal cracks in the shear walls increased, and additional windows were broken (mostly by falling bookcases and other falling objects). The following table summarizes the recorded peak accelerations from the two earthquakes.

		Peak Acceleration (g)		
Earthquake	Floor	North-South	East-West	Up-Down
Feb 20, 1978	1	0.17	0.11	0.09
	9	0.37	0.26	0.08
June 12, 1978	1	0.24	0.19	0.15
	9	1.00	0.49	0.31

The building experienced about 15 sec of motion at the ninth floor between 0.50g and 1.00g, and about 20 sec of motion in excess of 0.25g.

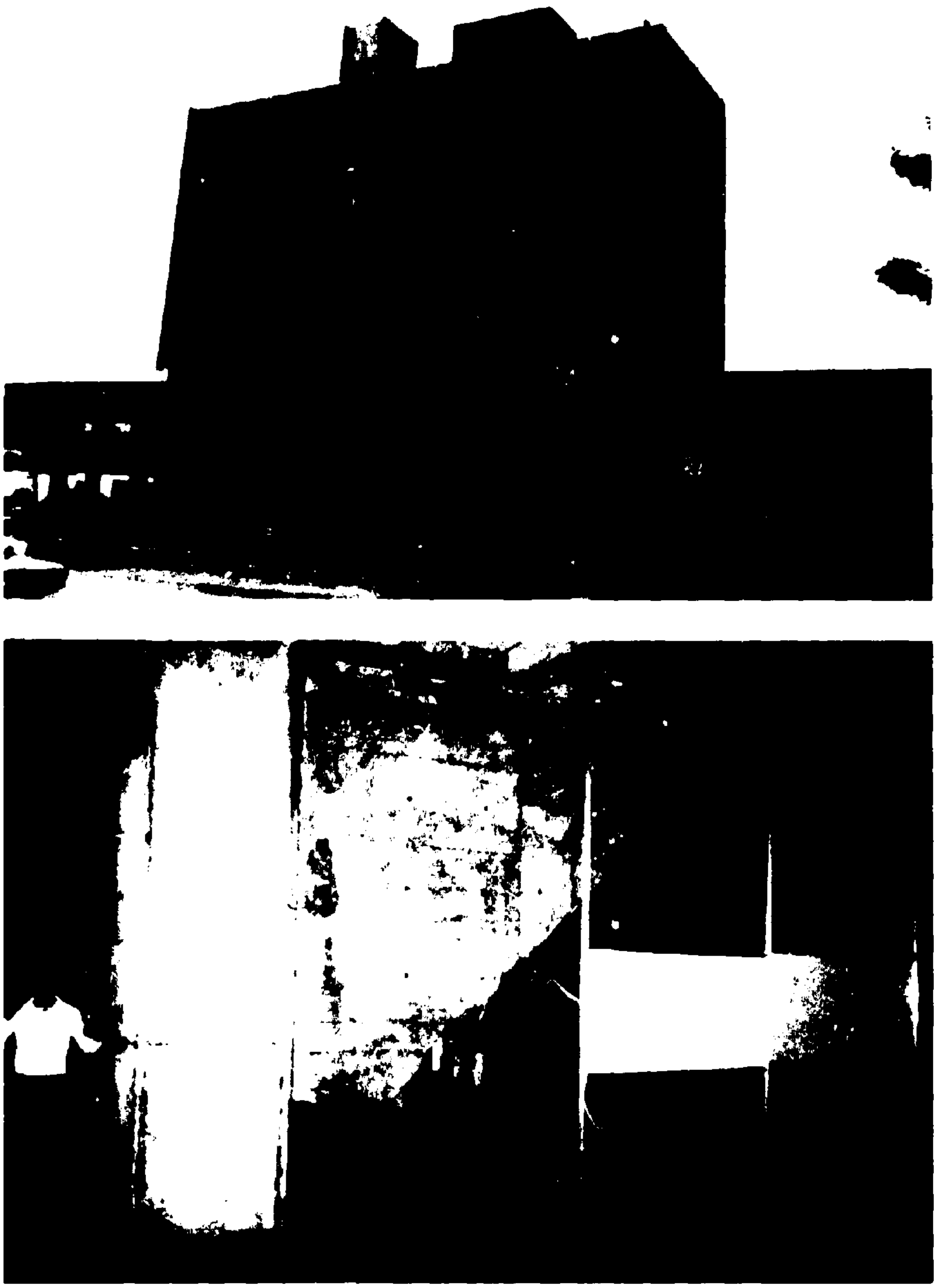


Figure 32 Engineering Faculty Building, Tohoku University: a general view of the 9-story reinforced concrete frame building and damaged transverse shear wall at the ground floor. Some of the glazed tile veneer has spalled along a diagonal crack.

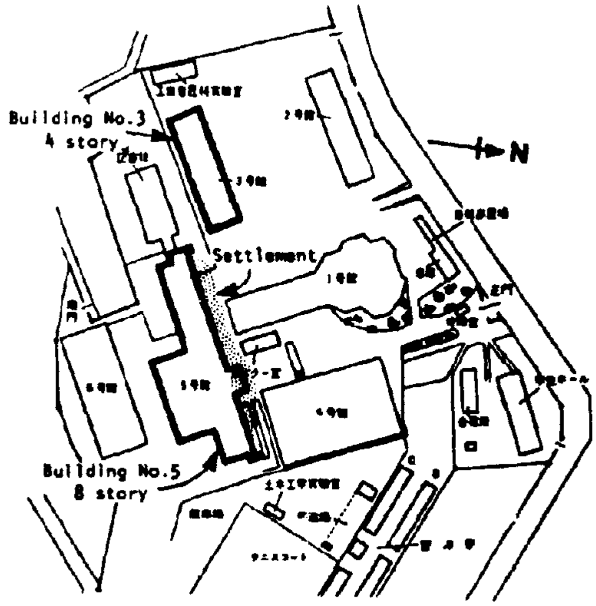


Figure 33 Tohoku Institute of Technology: plan of the campus showing the two buildings that were investigated (Buildings 3 and 5). Building 3 is a 4-story building on a level foundation. Building 5, located on a steep slope, is an 8-story building with the three lower floors built into the hill on the north elevation.

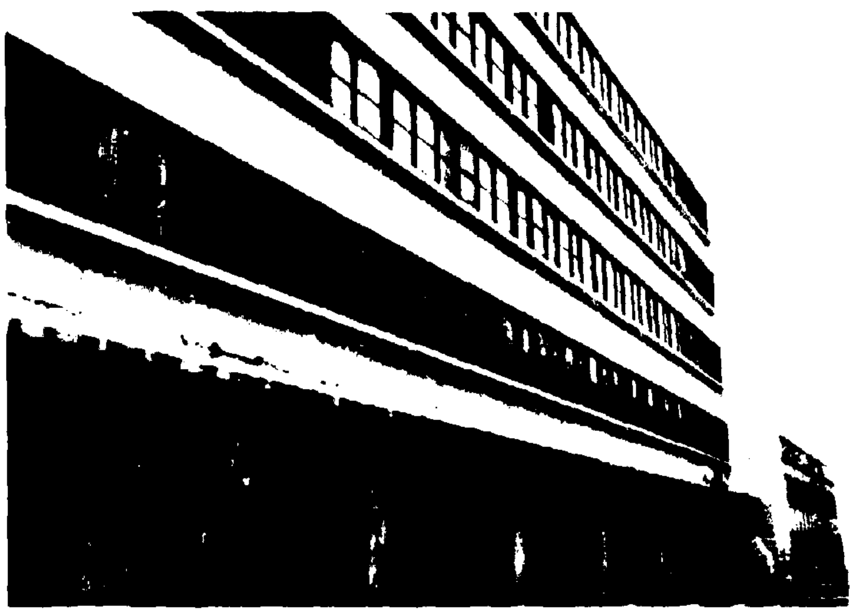


Figure 34 Tohoku Institute of Technology, Building 5: partial view of the north facade. The most serious damage to the framing occurred on this side; most columns have failed in shear.

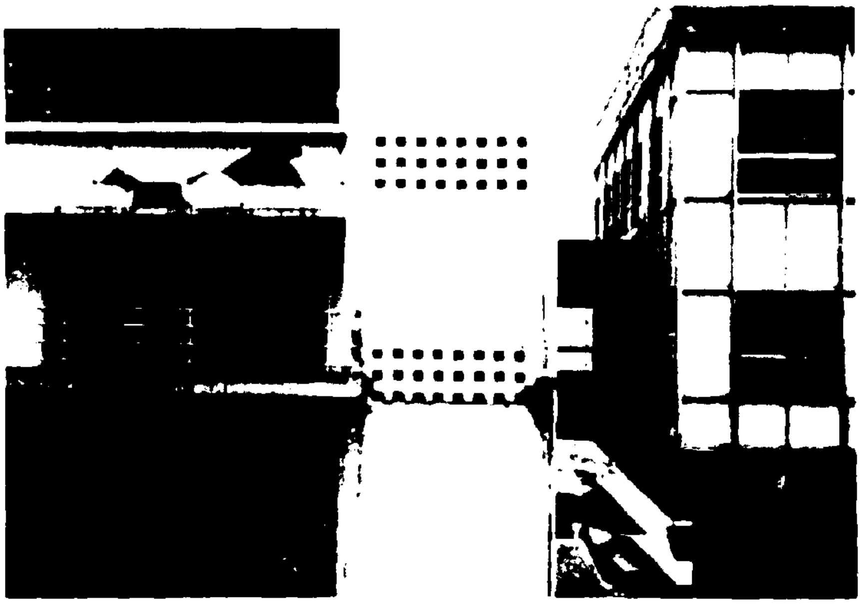


Figure 35 Tohoku Institute of Technology, Building 5: damage to the north facade of Building 5 and to the passageway to an adjacent building to the east. The latter building was constructed about 1972, under the provisions of the present building code, for an equivalent peak ground acceleration of 0.20g. Under the present code, deformed bars are used, and the stirrup spacing is 10 cm. A cursory visual examination of the exterior revealed no apparent damage.

Figure 36 Tohoku Institute of Technology, Building 5: detail of typical damage at midheight to a column in the north facade. The stirrup spacing is 25 cm (10.25 in.). The bars are undeformed.

Figure 37 Tohoku Institute of Technology, Building 5: view of an upper floor interior, looking toward the slightly damaged southern exterior frame. The interior columns generally did not exhibit damage, whereas interior shear walls, such as that in left center, were generally cracked extensively. In addition, tensile cracks were evident throughout the floor diaphragms, particularly near the shear walls of the stairway tower along the north frame.

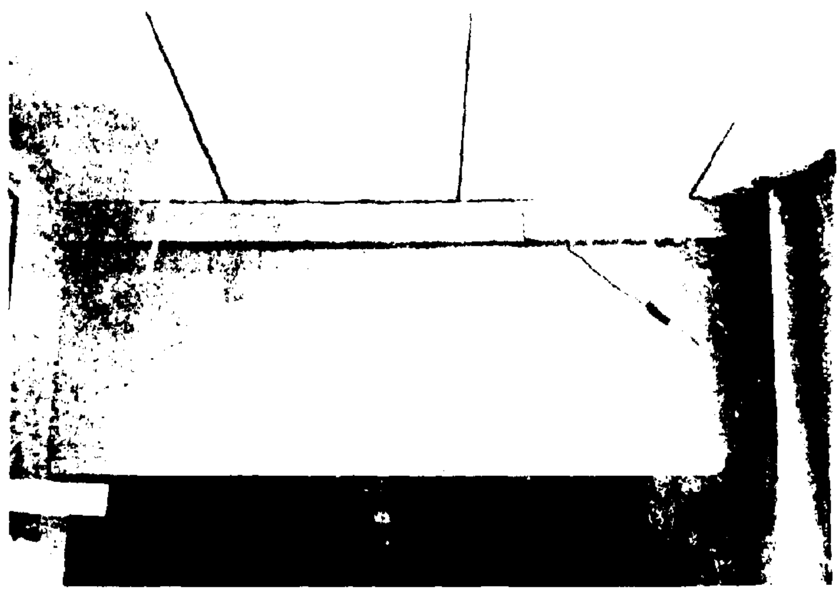


Figure 38 Tohoku Institute of Technology, Building 5. A header (spandrel beam) over a corridor on the sixth floor that connects two transverse shear walls exhibits a classical compression arch failure. Note the diagonal cracks on both ends.

Figure 39 Tohoku Institute of Technology, Building 5: a view of the entrance area of the north entrance to Building 5 showing settlement of backfill along most of the length of the building. The settlement caused extensive damage to the stairs and to the adjacent retaining walls.

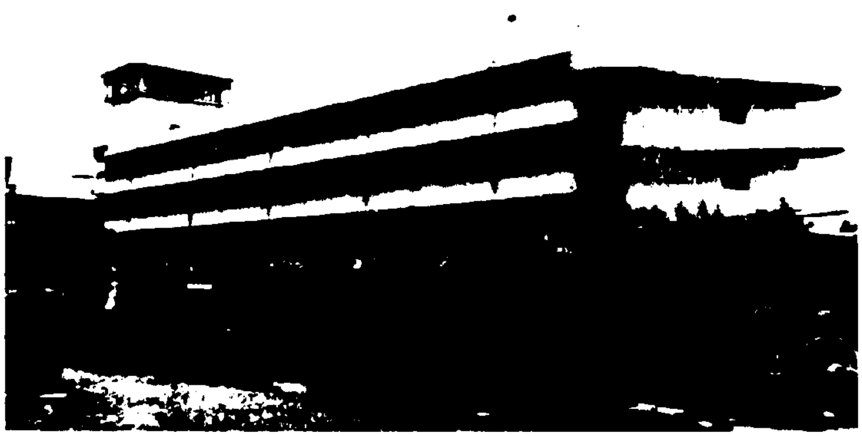


Figure 40 Tohoku Institute of Technology, Building 3: a general view of the 4-story building that was damaged severely. It was designed under the pre-1972 code for a ground acceleration of 0.20g.

Figure 41 Tohoku Institute of Technology, Building 3: damage to the ground floor columns. Similar damage is present all along the opposite (north) side of the building.

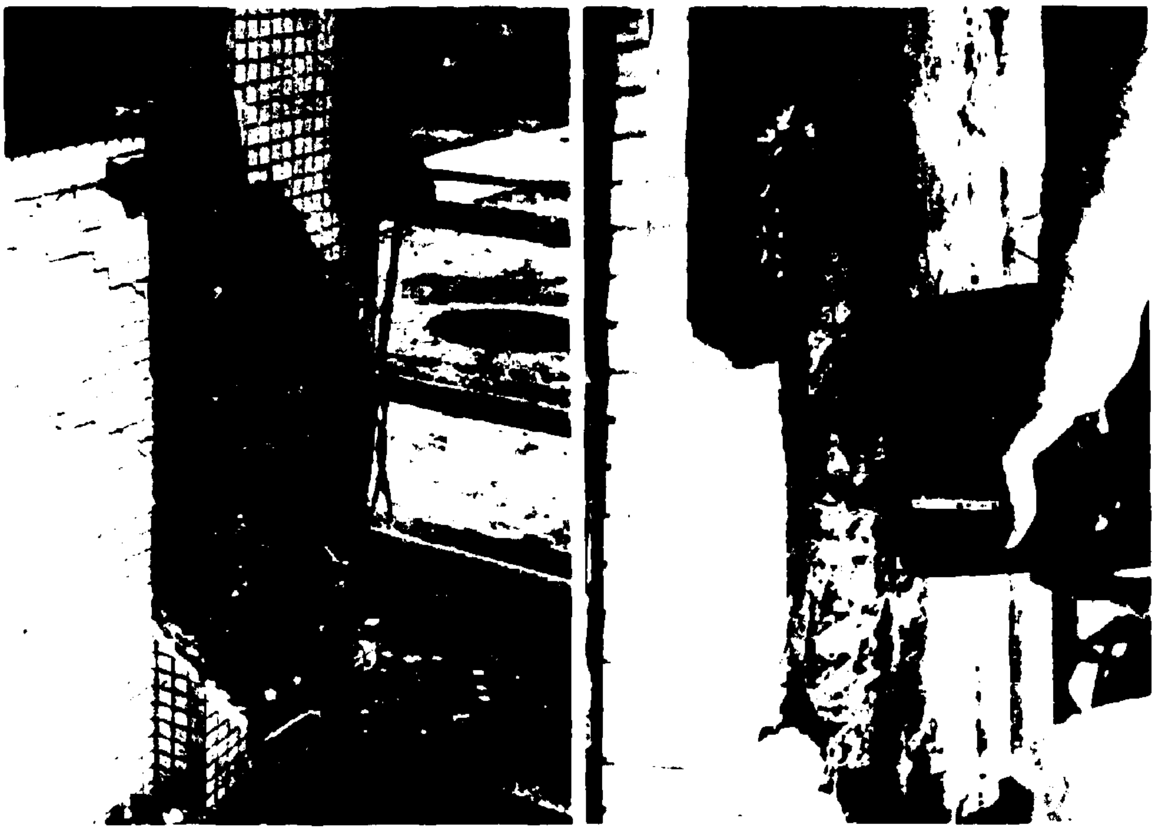


Figure 42 Tohoku Institute of Technology Building 3: a detail (left) of one of the damaged columns of the south exterior frame showing the reinforcing details. The stirrups are undeformed and are spaced at 25 cm (10.25 in.) on centers. The vertical bars at the bare of the column were bent during construction to fit within the column. Damage (right) to a south-facing ground-floor exterior column: the plaster facing and some of the st-uctural concrete has been spalled. The reinforcing steel appeared to have lsss than 2.5 cm (1 in.) of cover.

Figure 43 Tohoku Institute of Technology, Building 3: typical damage to a column on the ground floor of the north-facing exterior frame. The interior shear walls in the transverse (north-south) direction also suffered extensive damage.

Figure 44 Tunan High School: west face. This reinforced concrete building frame with shear walls is about 12 years old. It suffered extensive damage, due in part to the unfavorable orientation of the shear walls with respect to strong shaking. An adjacent structure, oriented at right angles to the high school, was undamaged. The high school stands adjacent to a small bluff which may have amplified the ground motion.

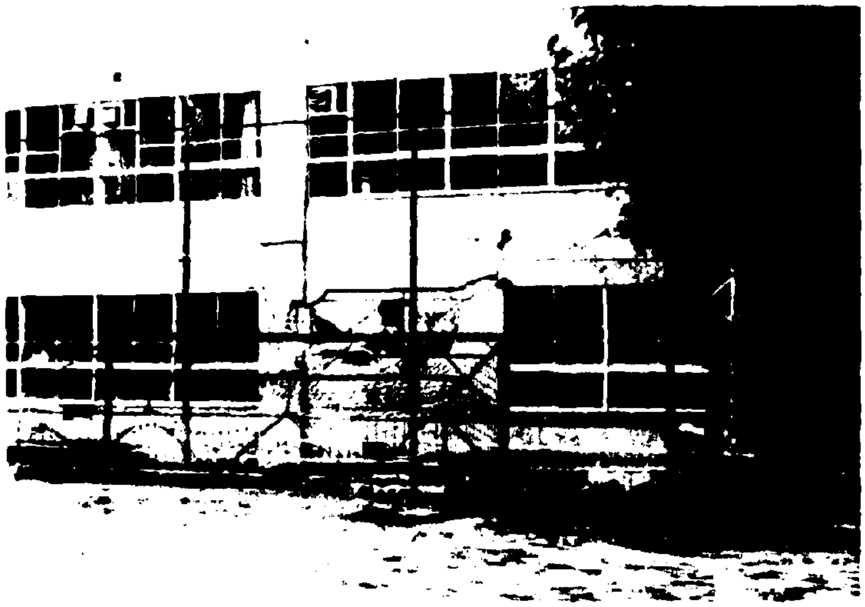


Figure 45 Tonan High School: detail of damage to the west face.

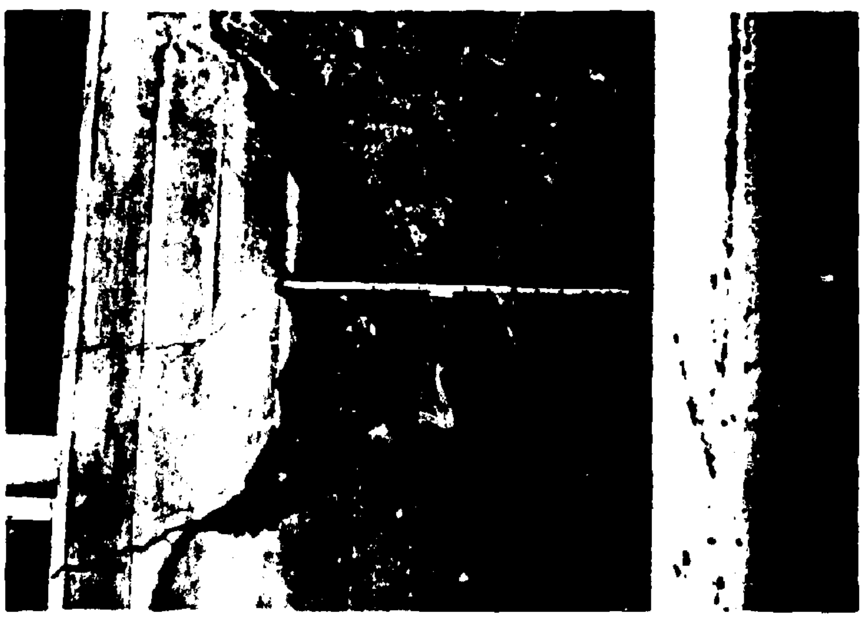


Figure 46 Tonan High School: west face. Partial-infill panels caused adjacent columns to be extensively damaged. Slender interior columns showed little damage. The concrete appeared to be of questionable quality.

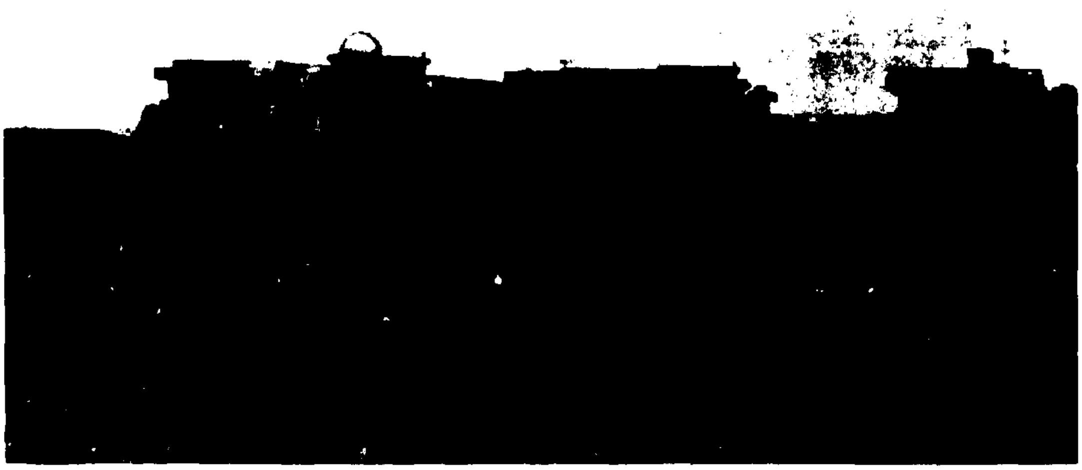


Figure 47 Izumi High School. Izumi, to the north of Sendai, is a city with a population of 70,000. Three adjacent reinforced concrete frame structures with shear walls were damaged, but the school remained functional. The buildings were constructed after 1971.

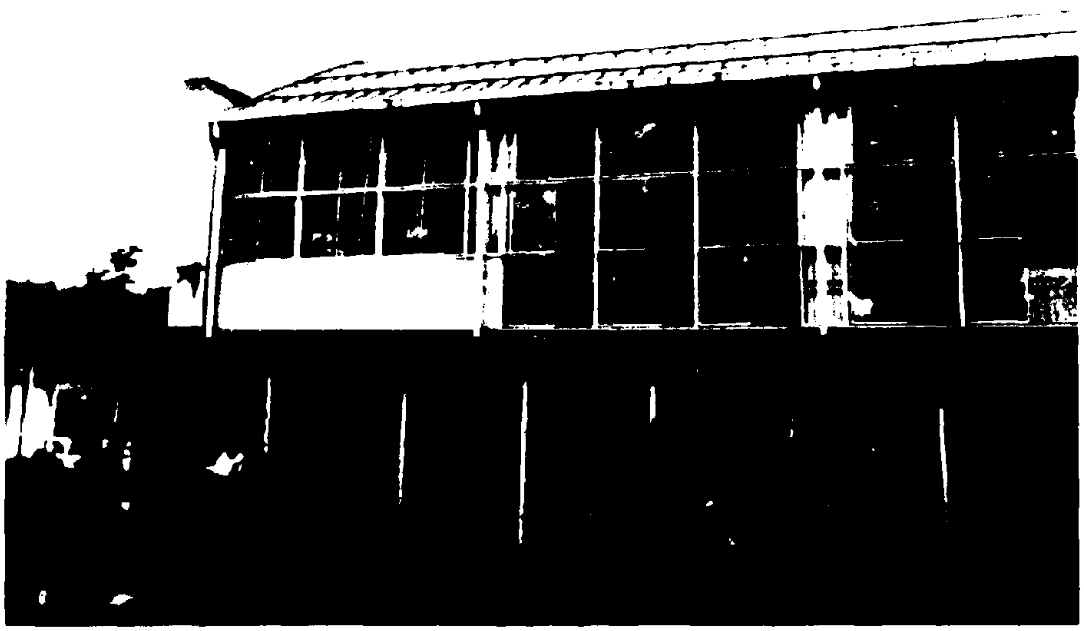


Figure 48 Izumi High School: partial view of the slightly damaged, steel-frame auditorium.

Figure 49 Izumi High School. An interior corridor wall aligned in the longitudinal direction of the building shows extensive shear cracking.

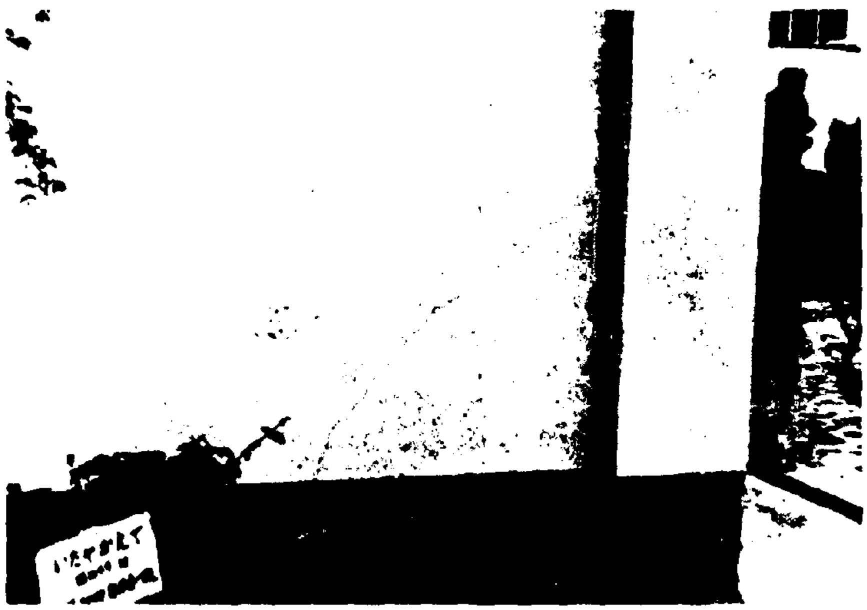


Figure 50 Izumi High School. The diagonal crack along an exterior transverse shear wall was caused either by uplifting or by settlement of the foundation.

Figure 51 Izumi High School. The two illustrations show, respectively, two sides of a typical building. The rear of the building (left), which is relatively open, suffered little apparent damage; damage was heavier on the side with partial-infill wall panels (right). In addition, the interior transverse shear walls frame into the columns on the rear but do not frame into the columns on the front because of a longitudinal corridor. All of the buildings experienced this type of damage.

Single-Family Dwellings

A reported 803 dwellings were destroyed or very severely damaged by the earthquake. Most of the damage was due to foundation failures, such as landslides and rockfalls, and to inadequate lateral bracing. Most of the houses in this part of Japan have glazed-tile roofs. Thousands of roofs were damaged, and additional damage was probably caused by the ingress of water: the earthquake occurred at the start of the monsoon (rainy) season. The following illustrations show some damage typical to houses. Detailed data will probably be available from the Japanese authorities in the near future.

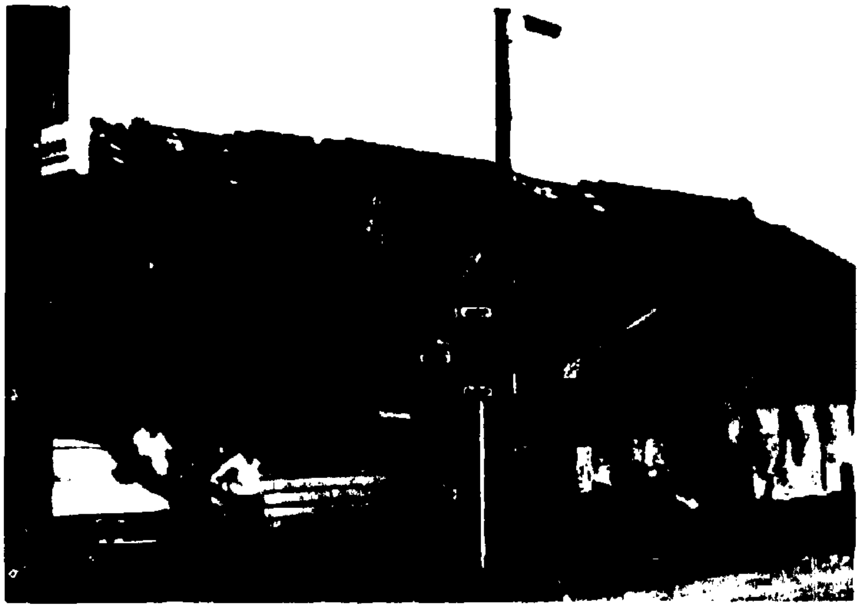


Figure 52 Town of Hasama, northern Miyagi Prefecture: almost total damage to a typical older, single-family dwelling. The damage is probably due to inadequate lateral bracing and the presence of a heavy glazed-tile roof. The house is in a pocket of damage that was possibly due to the response of local soft soils.

Figure 53 Typical roof damage. The damaged area has been covered with plastic sheets to protect the structure and its contents against rain.

Figure 54 A collapsed older, wood-frame temple building with a tile roof. (Kawanoku Newspaper Co. photograph)

Industrial Facilities and Lifelines

Our reconnaissance team made a brief inspection of several industrial facilities and lifeline structures. Sendai is a large industrial city with more than 6,500 business and manufacturing firms; the facilities investigated represent only a small sample of the structures that were damaged by the earthquake. The degree of damage observed ranged from negligible (at the Fukushima Nuclear Power Plant) to severe (at the Sendai Gas Facility). Japanese engineers were conducting thorough investigations at some of the same facilities. The power facilities in and near Sendai (most of which are owned by the Tohoku Electric Power Company) that suffered damage were being given particularly close attention. Detailed reports are expected to be published soon.

Fukushima Nuclear Power Plant Complex. The Fukushima Nuclear Power Plant complex is owned and operated by the Tokyo Electric Power Company. It is located on the Pacific coast of the Fukushima Prefecture, about 7 km south of the town of Namie, and is southeast of the town of Fukushima. The original earthquake design criteria and dynamic analyses were performed by URS/Blume Engineers. The following table summarizes some of the pertinent data for this six-unit complex:

	Net MWe	Type	Reactor Supplier	Generator Supplier	Architect Engineer	Constructor	Construction stage (%)	Commercial Operation: orig. schedule†	Commercial Operation: actual or expected
Fukushima One 1 (Fukushima)	460	BWR†	GE/Toshiba	GE/Hitachi	Ebasco	Kajima	100		3/71
Fukushima One 2 (Fukushima)	784	BWR	GE	GE/Toshiba	Ebasco	Kajima	100		7/74
Fukushima One 3 (Fukushima)	784	BWR	Toshiba	Toshiba	Toshiba	Kajima	100		3/76
Fukushima One 4 (Fukushima)	784	BWR	Hitachi	Hitachi	Hitachi	Kajima	92	6/76	10/78
Fukushima One 5 (Fukushima)	784	BWR	Toshiba	Toshiba	Toshiba	Kajima	96	12/75	4/78
Fukushima One 6 (Fukushima)	1100	BWR	GE	GE/Toshiba	Ebasco	Kajima	78	10/76	10/79

†BWR = Boiling Water Reactor

(Source: Nuclear News Buyers Guide, mid-February 1978)

At the time of our visit, June 23, 1978, 11 days after the earthquake, Units 1 through 5 were operating; Unit 6 was still under construction. We inspected the exterior of Unit 1 and the exterior and interior of much of Unit 6, including the containment structure and the reactor vessel pedestal, the reactor building, the turbine building, and various ancillary structures.

Units 1 and 6 are heavily instrumented, and more than 20 strong-motion records were obtained. The maximum recorded ground acceleration was approximately 0.12g; the maximum peak response acceleration of the structures was about 0.25g. The duration of the records was somewhat longer than 30 sec.

Figure 55 Fukushima Nuclear Power Plant: a general view showing the six units. They are, from right to left, Unit 6, Unit 5, Unit 1, Unit 2, Unit 3, and Unit 4. (Tokyo Electric Co. photograph)

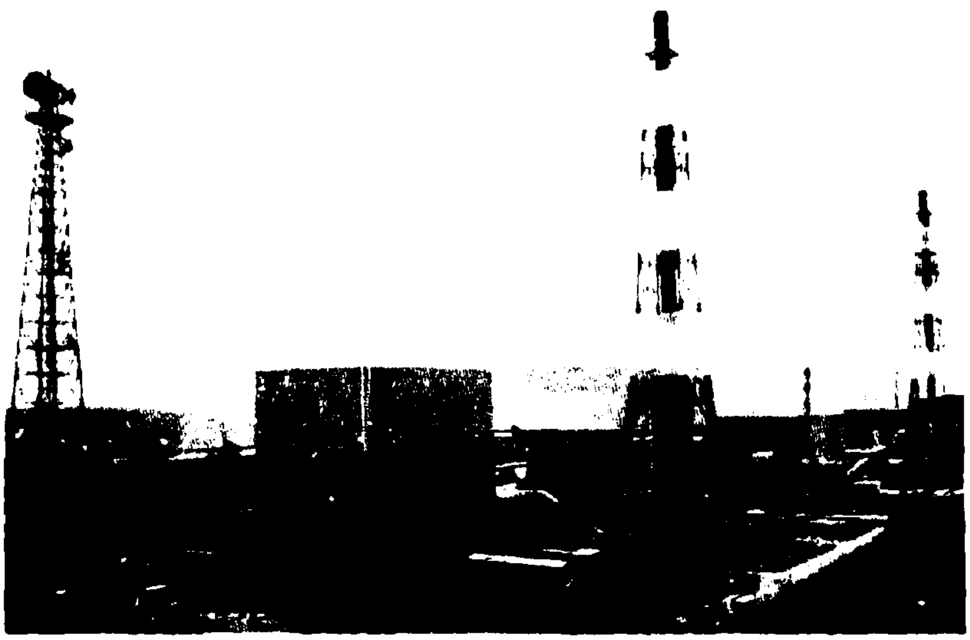


Figure 56 Fukushima Nuclear Power Plant: the containment structures of Units 1 through 4. None of these structures showed damage. (Tokyo Electric Co. photograph)

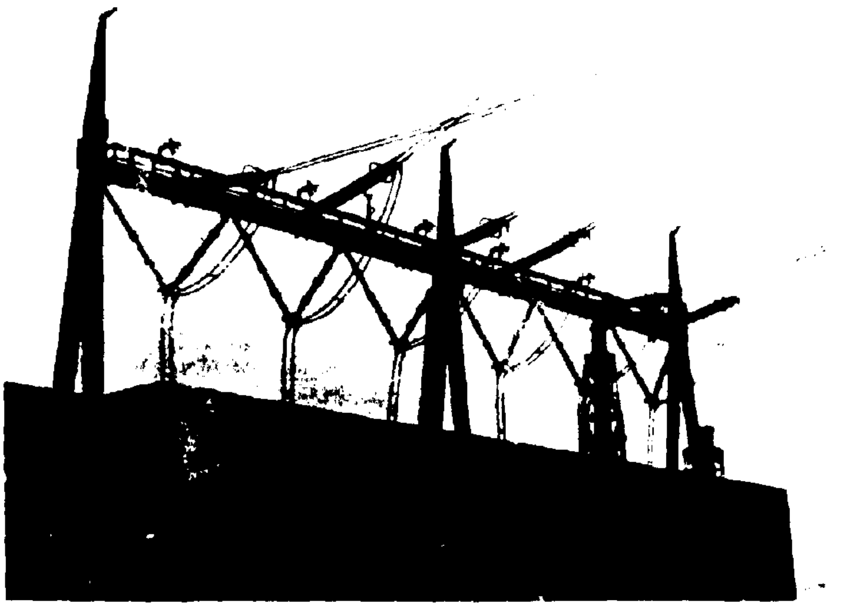


Figure 57 Fukushima Nuclear Power Plant. A broken ceramic insulator in Unit 1 was the only damage reported for the site. The damaged insulator had been replaced, as illustrated above, before the reconnaissance visit.

Figure 58 Fukushima Nuclear Power Plant: a view of some of the auxiliary structures to the north of Unit 1. Free-field acceleration was recorded in the water treatment building (the white, 1-story building in the middle of the photograph), which is located approximately 100 m from the Unit 1 containment structure. The SMAC instrument recorded a peak ground acceleration of approximately 0.12g.

Figure 59 Fukushima Nuclear Power Plant: a partial view of the control room of Unit 5. At the time of the visit on June 23, 1978, 11 days after the earthquake, this unit was operating.

Figure 60 Fukushima Nuclear Power Plant: a partial view of the Unit 6 control rod drive and its supports. The unit is still under construction and was more than 95% completed at the time of the reconnaissance. There was no apparent damage or any evidence of working connections at this system or at the other systems of Unit 6 that were examined.

New Sendai Power Plant, Tohoku Electric Power Company, Sendai. The New Sendai Power Plant, owned and operated by the Tohoku Electric Power Company, is located on the Pacific shore, 15 km east of the center of Sendai. The plant has two Mitsubishi oil-fired boilers: Unit 1 was completed in 1971 and has a capacity of 350 MW; the 600-MW Unit 2 was completed in 1973. The total capacity of the Tohoku Electric Company is 5,715 MW, this plant representing about 17% of that capacity.

Both Unit 1 and Unit 2 suffered damage to tubing inside the boilers. The suspended units and their structural supports pounded against one another and also sustained some damage. The plant was shut down for six days for repairs.

Because the SMAC accelerograph at the station was being inspected at the time of the earthquake, no records were obtained. However, the plant's seismic alarm, located at the level of the turbine operating floor, was triggered at approximately 0.15g.

Total damage to the facilities of the Tohoku Electric Company is approximately $15 million; estimated damage to the plant accounts for about 10% of the loss. The total assets of the company in property, plant and equipment for Fiscal Year 1976 were $3,840 million. Damage from this earthquake caused a loss of about 0.4% of those assets.

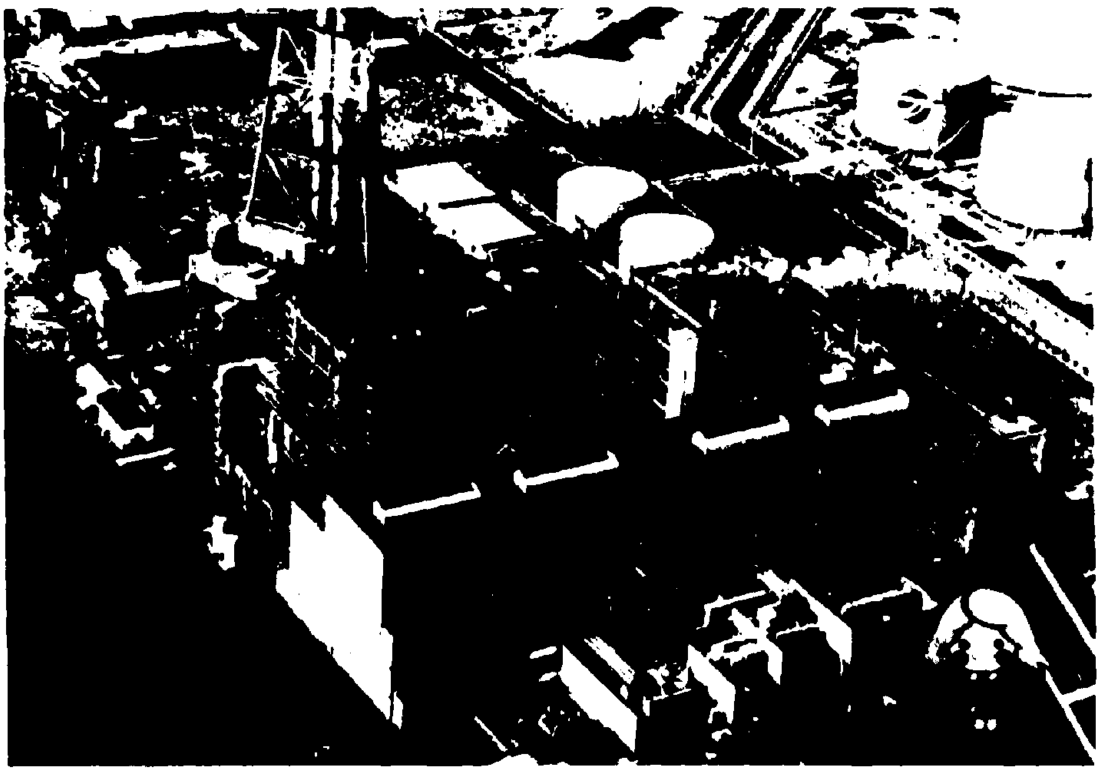


Figure 61 New Sendai Power Plant, Tohoku Electric Power Company: a general view of the two-unit, oil-fired power plant. The turbine building is in the foreground, and the two boiler structures are in the background. Unit 2, the large unit, has a 600-MW capacity. Unit 1 has a capacity of 350 MW. (Tohoku Electroc Power Co. photograph)

Figure 62 New Sendai Power Plant, Tohoku Electric Power Company: a loosened exterior facing panel in the turbine building. This was the only obvious damage to the exterior of the structure. The shear walls of the adjacent administration building showed cracking.

Figure 63 New Sendai Power Plant, Tohoku Electric Power Company: damage to the two boilers consisted of shearing of spacer tubes for the furnace platen cooler tubes inside the boiler. (Tohoku Electric Power Co. photograph)

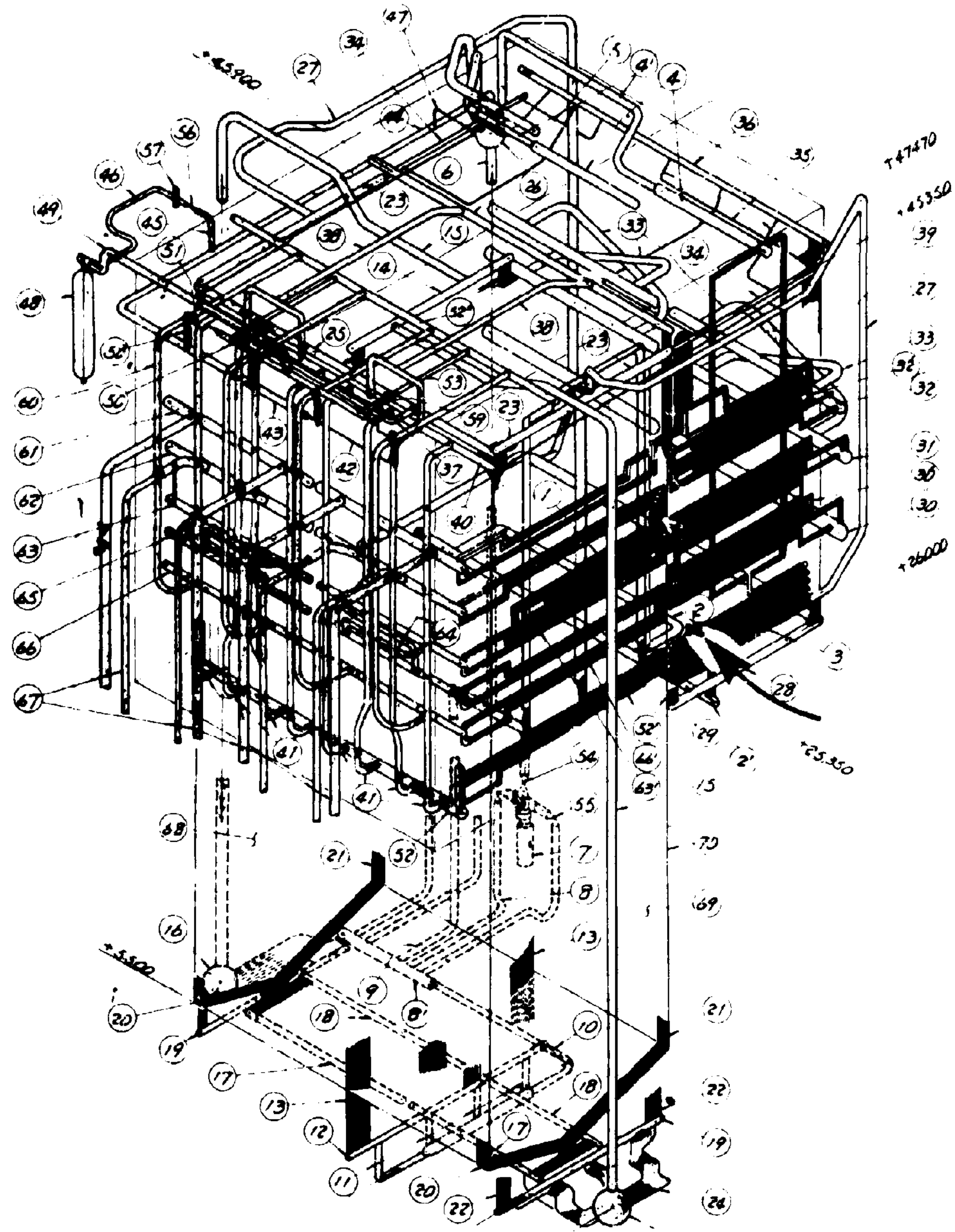


Figure 64 New Sendai Power Plant, Tohoku Electric Power Company. The arrow points to the location of the damaged horizontal spacer tubes in the 600-MW boiler of Unit No. 2. See Figure 63.

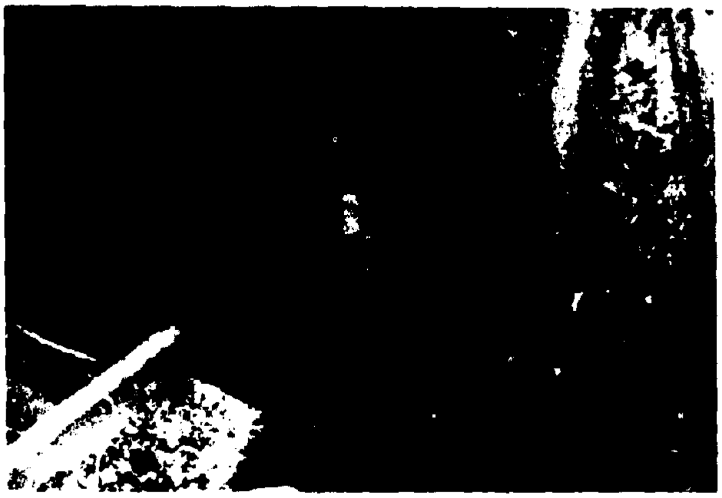


Figure 65 New Sendai Power Plant, Tohoku Electric Power Company: a view of the exterior of the boiler walls showing evidence that the suspended boiler had pounded against the surrounding support structure. (Tohoku Electric Power Co. photograph)

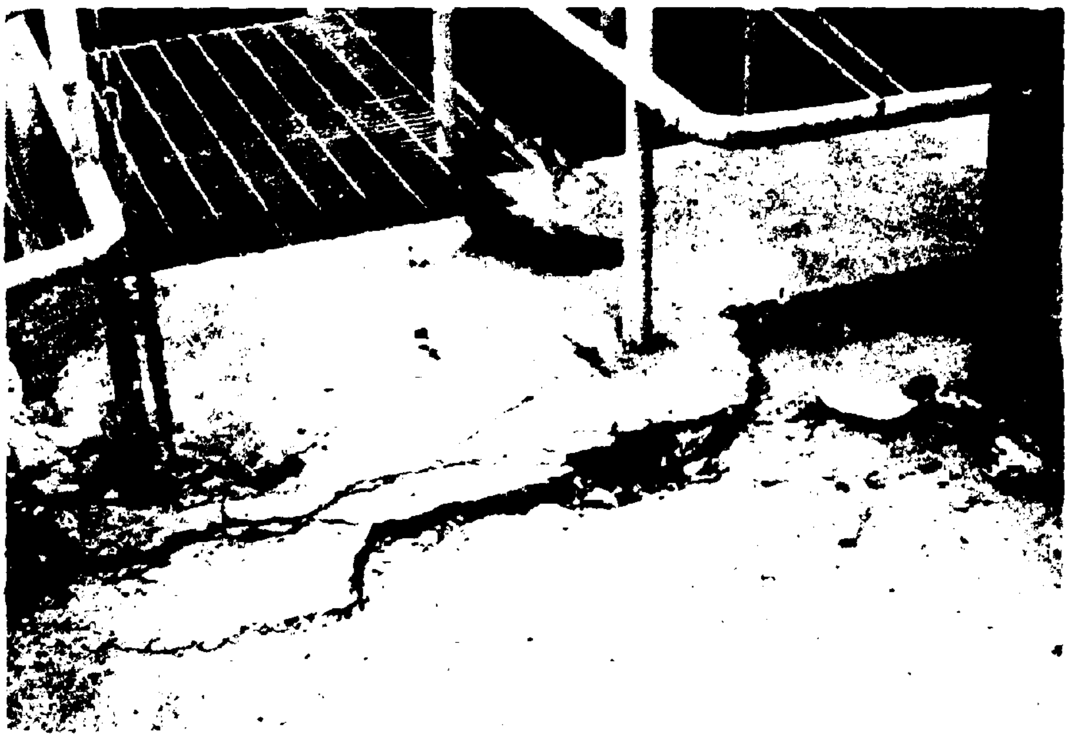


Figure 66 New Sendai Power Plant, Tohoku Electric Power Company: damage around the water intake structure from minor settlement. Other examples of minor settlement were observed throughout the site.

Sendai Substation, Izumi. The Sendai Substation of the Tohoku Electric Power Company is located on a low hill in the town of Izumi, about 7 km north-northeast of the center of Sendai. The substation is a multilevel complex. Extensive cuts and fills were necessary for its construction. The most important components of the station were placed on the cut portions of the site, over a competent soft mudstone formation. However, because the fills were engineered, there seemed to be no difference in the amount of damage sustained by equipment whether on fills or on cuts: there was extensive damage to equipment in all parts of the facility. Most of it occurred to various ceramic insulators, lightning arrestors, circuit breakers, and transformers. At the time of our visit, June 24, 1978, 12 days after the earthquake, much of the damage had been repaired. It had taken 10 days to repair the essential equipment and to restore power. Power to the City of Sendai was restored about five hours after the earthquake; presumably the Sendai Substation was bypassed.

A Japanese team has been assembled to conduct a special investigation of the performance of the substation during the earthquake.

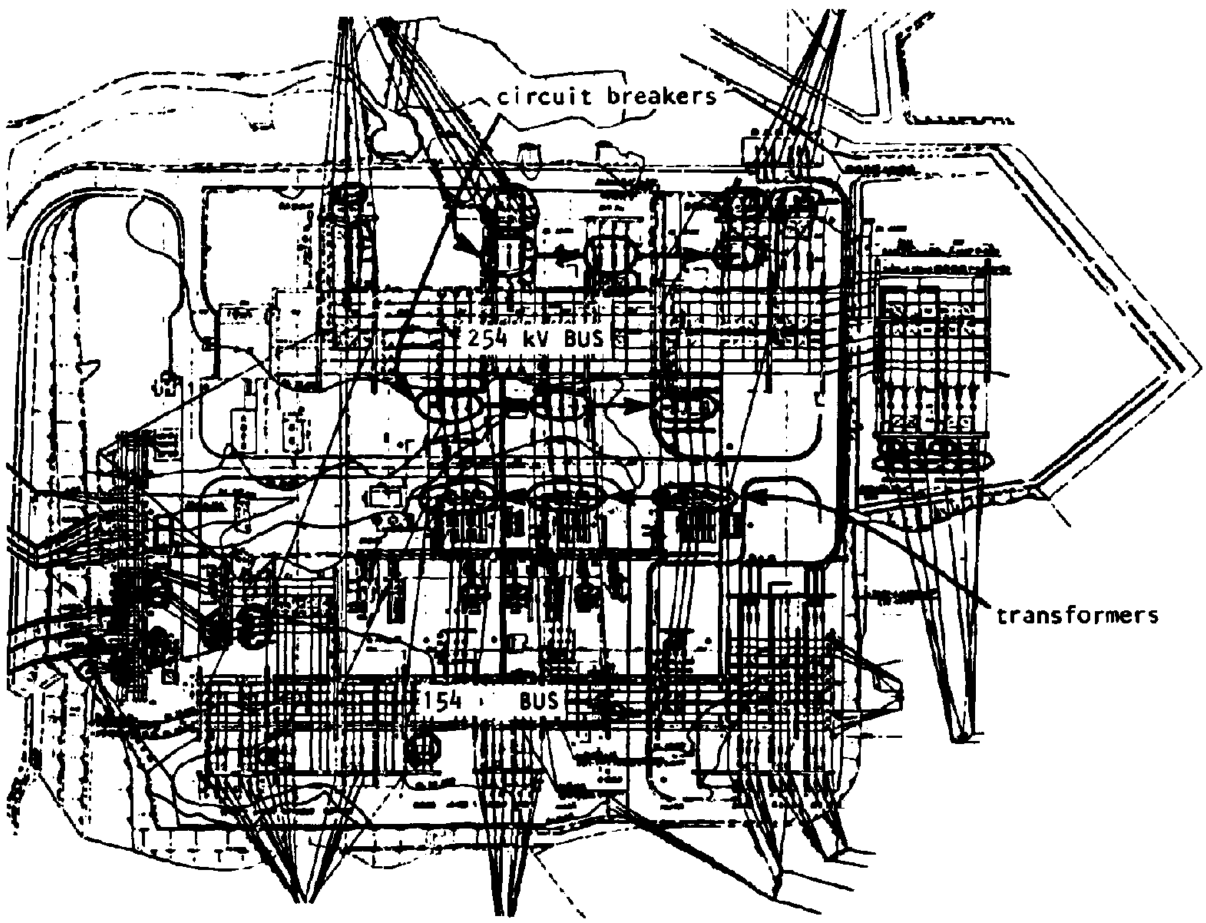


Figure 67 Sendai Substation, Tohuku Electric Power Company, Izumi: plan of the facility showing the location of damaged equipment (circled).

Figure 68 Sendai Substation, Tohoku Electric Power Company, Izumi: one of many broken T-shaped, three-phase circuit breakers. The photograph was taken immediately after the earthquake, before repairs were initiated. (Tohoku Electric Power Co photograph)

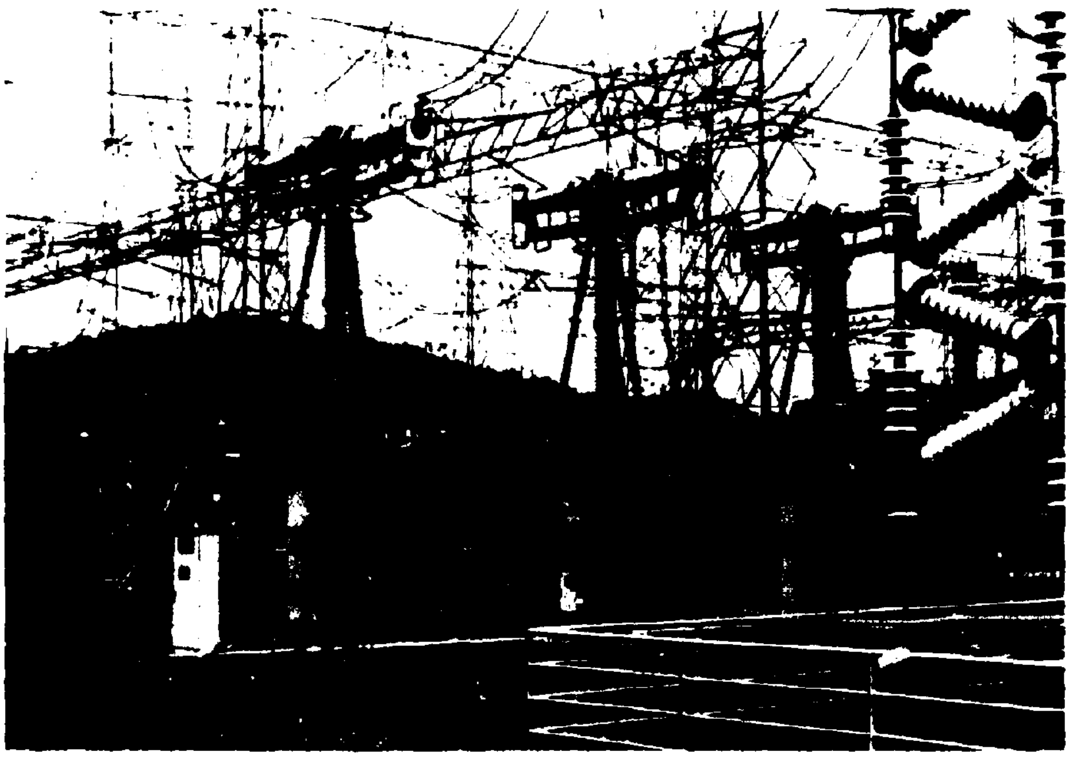


Figure 69 Sendai Substation, Tohoku Electric Power Company, Izumi: three circuit breakers, like the one illustrated in Figure 68, that have been repaired.

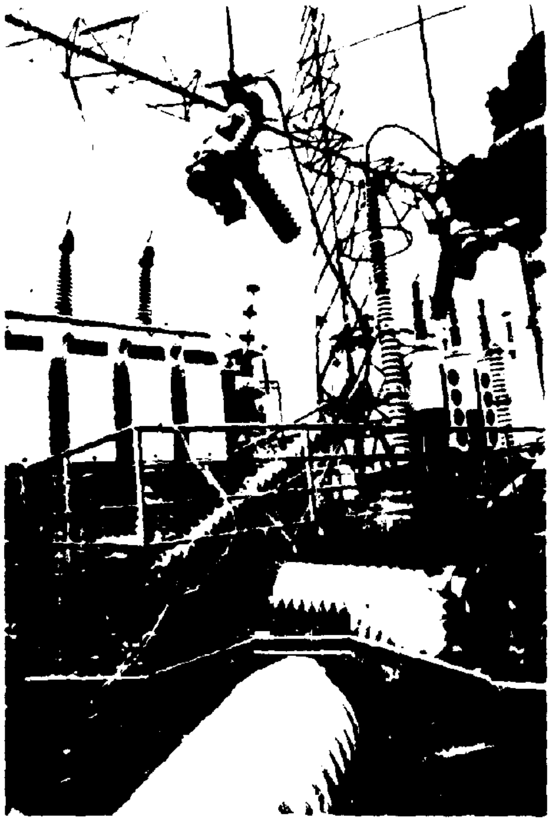


Figure 70 Sendai Substation, Tohoku Electric Power Company, Izumi. damaged equipment, including circuit breakers (with the porcelain broken through) and a lightning arrestor in the background.

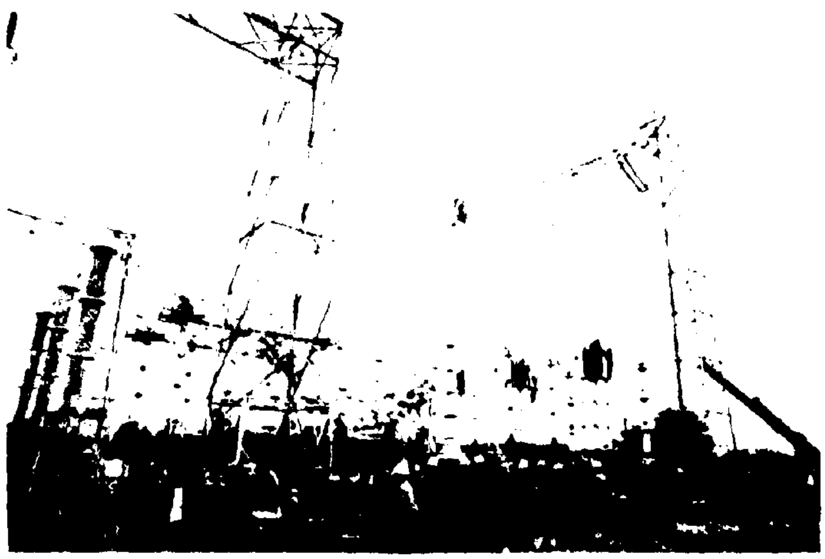


Figure 71 Sendai Substation, Tohoku Electric Power Company, Izumi: damaged equipment at the substation, including potential devices, current transformers, circuit breakers, and reactors. (Tohoku Electric Power Co. photograph)

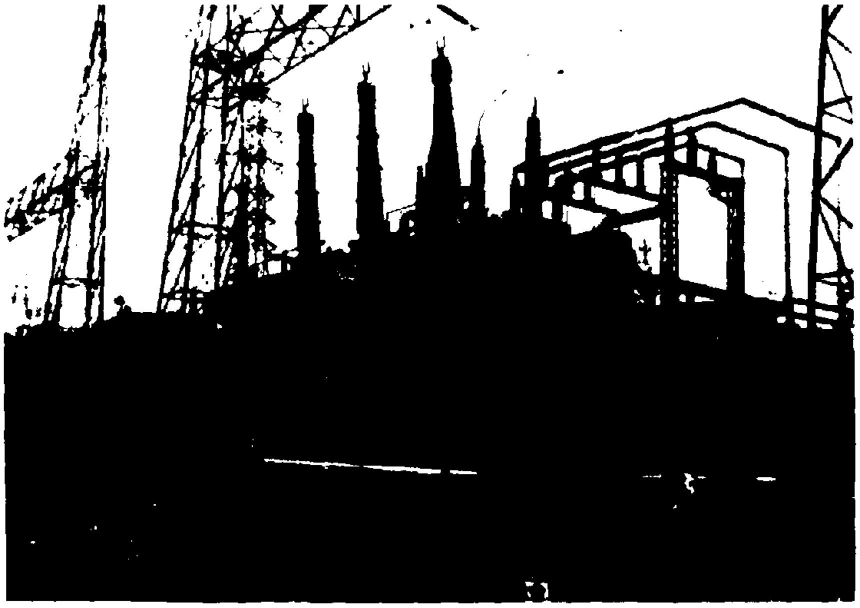


Figure 72 Sendai Substation, Tohoku Electric Power Company, Izumi. One of the repaired main transformers. The bushings illustrated were damaged during the earthquake and have since been replaced. Note the stains from spilled oil. Many bushings and lightning arrestors were damaged.

Figure 73 Sendai Substation, Tohoku Electric Power Company, Izumi. One of several piles of broken equipment.

Haranomachi Plant of Sendai City Gas Bureau, Sendai. The Sendai City Gas Bureau's Haranomachi Plant, located approximately 3.7 km northwest of the center of Sendai, suffered major damage. The total collapse of a large propane gas holder was primarily responsible for the stoppage of gas service for the city. It was estimated that gas service for the city would not be restored until the end of June, some three weeks after the earthquake.

The holder diameter was 38 m; its height was 27 m. At the time of the earthquake, the holder contained 14,000 m^3 of propane gas, at the relatively low pressure of 1 kg/m^2, and held water in a 9-m section at the bottom of the structure. The tank had at least two, but more probably three, telescoping sections constructed of riveted plate, 1 cm (3/8 in.) thick, stiffened with ring stiffeners at approximately 2 to 3 m.

The collapsed tank caught on fire shortly after failure, and all of the stored gas was consumed. The fire was extinguished about 25 minutes later. The collapsing tank struck nearby pipeways and other piping systems and equipment, causing much additional damage to the facility. There was evidence of other kinds of damage throughout the facility; however, none of the other tanks at the facility are believed to have suffered major damage.

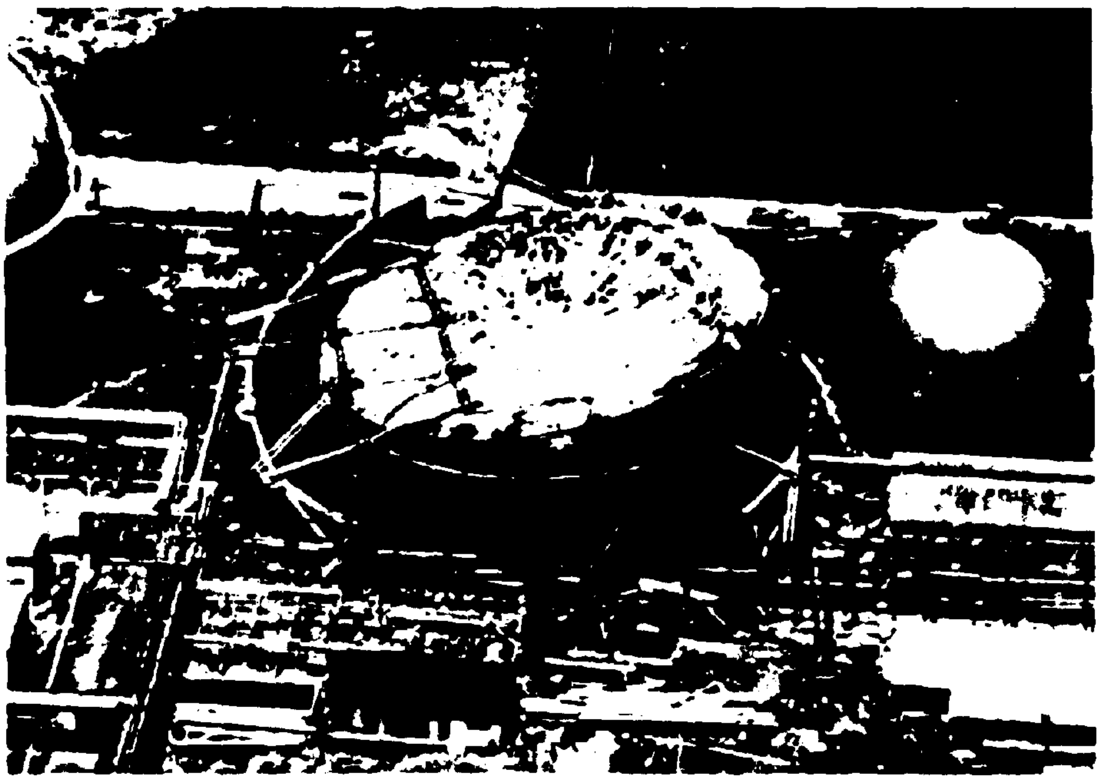


Figure 74 Haranomachi Plant, Sendai City Gas Bureau: an overall view of a collapsed propane gas holder and some of the surrounding propane storage tanks and affected pipeway and equipment. (Kawahoku Newspaper Co. photograph)

Figure 75 Haranomachi Plant, Sendai City Gas Bureau: collapsed gas holder and the damaged adjacent pipeway structure. At the time of the investigation, the severely damaged steel pipeway structure had been removed, and a replacement structure was under construction, as illustrated.

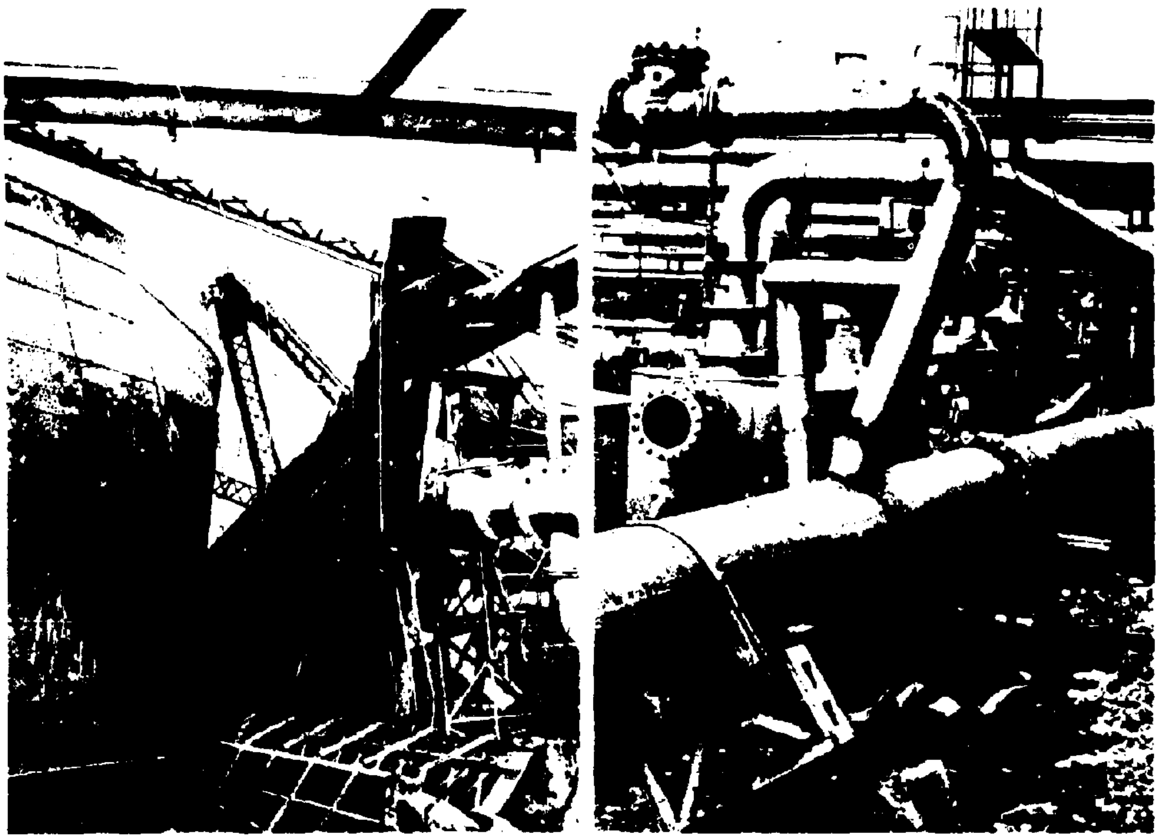


Figure 76 Haranomachi Plant, Sendai City Gas Bureau: damage (left) to the telescoped gas holder and to some of the nearby pipeways and equipment. The holder plate is approximately 3/8 in. thick. Note the stiffeners on the interior of the collapsed tank. The trusses are portions of the original support structure that had surrounded the tank. Typical damage (right) to pipe systems in the vicinity of the collapsed gas holder.

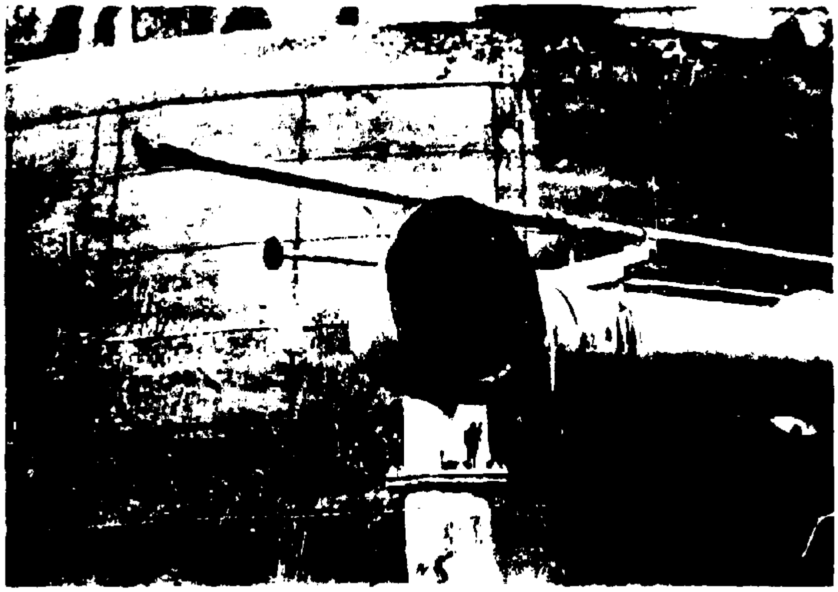


Figure 77 Haranomachi Plant, Sendai City Gas Bureau: sheared pipe flange connections in the pipeway structure in the vicinity of the collapsed gas holder.

Figure 78 Haranomachi Plant, Sendai City Gas Bureau: a brittle fracture of the 3/8-in. plate wall of the collapsed gas holder. The leng h of the fracture is approximately 1.5 m (5 ft).

Sendai Refinery, Tohoku Oil Company, Ltd. The Sendai Refinery of the Tohoku Oil Company, Ltd. is located onshore, about 15 km east of the center of Sendai and adjacent to the New Sendai Power Plant. The refinery covers an area of 1,600,000 m^2. Its capacity is approximately 100,000 barrels/day. There is a total of 87 storage tanks in the facility. The western portion of the complex suffered little damage; all of the major damage was concentrated on the east side.

Three large tanks containing topped refined fuel called Top Crude (TC) failed, spilling approximately 68,100 kl of oil. The surrounding dike could accommodate only 35,000 kl. The oil overtopped the dike, inundated much of the refinery area, and spilled over into the port. Three other tanks suffered damage but did not fail. Many parts of the facility were still covered with oil at the time of the investigation. The refinery was not in operation because of the very great danger of fire. The facility had been shut down for annual maintenance and checkup and had not yet resumed operation at the time of the earthquake. Thus a serious fire hazard from the spilled oil fortuitously was averted

During the investigation, the company was checking much of the equipment throughout the complex for damage, and a large scale clean-up effort was under way. The seriously damaged tanks were still not approachable because of the spilled oil. The gas handling and distribution system was considered to be hazardous.

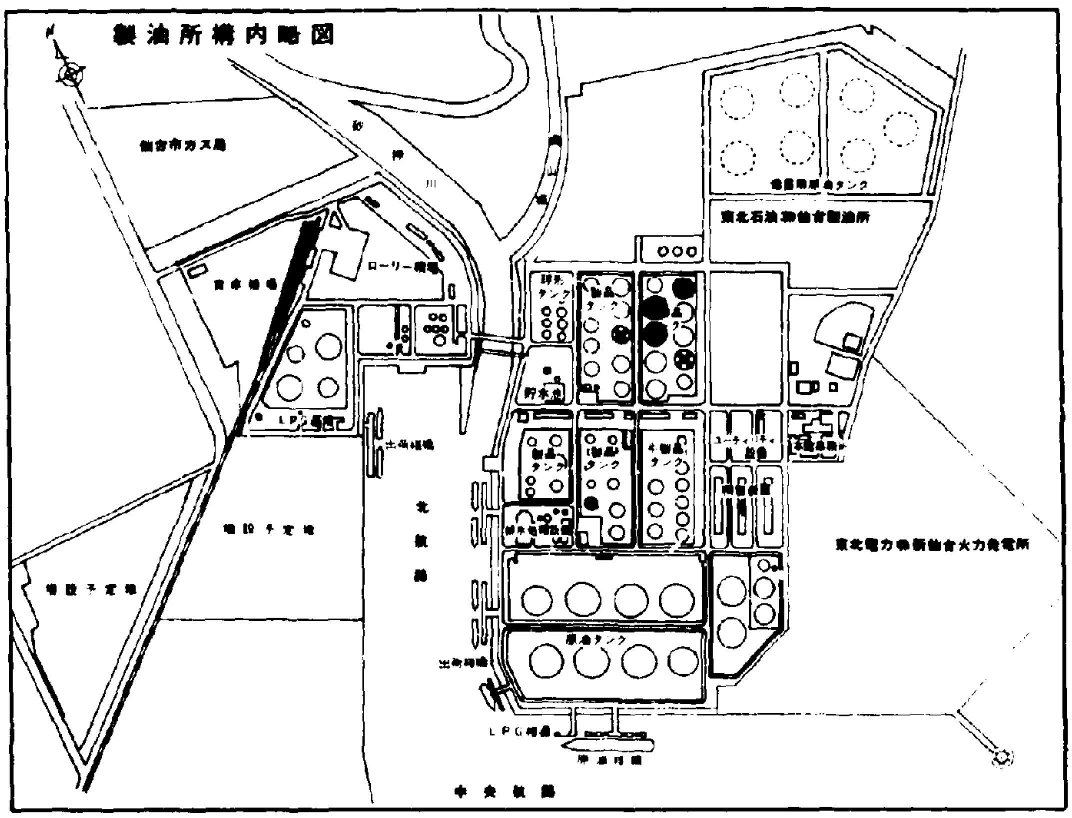


Figure 79 Plan of the Sendai Refinery, Tohoku Oil Company, Ltd. The New Sendai Power Plant is shown on the lower right in the plan. Tanks are shown as circles in the plan. The circles that represent the three failed TC tanks have been blackened; ones that represent the three other damaged tanks are marked with an X. The refinery structures are located to the right of the tank farms.

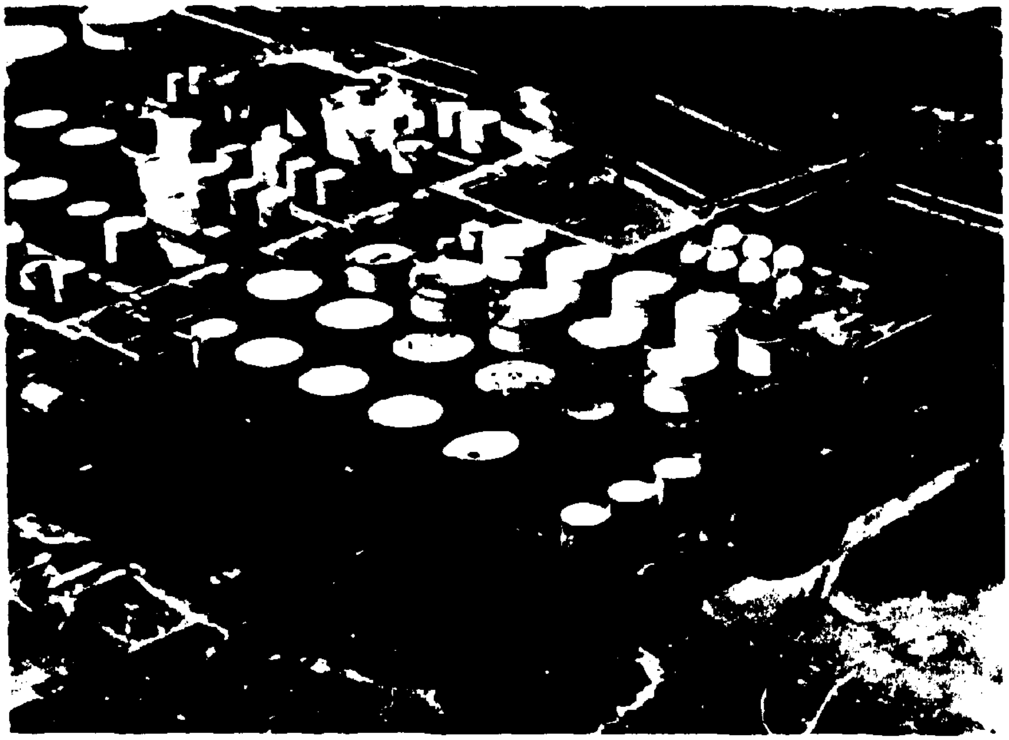


Figure 80 Sendai Refinery, Tohoku Oil Company, Ltd.: an overall view of the refinery's tank farm. The spilled oil appears as the dark area of the photograph.

Figure 81 Sendai Refinery, Tohoku Oil Company, Ltd.: a partial view of the refinery. There is no apparent damage from this distance; however, at the time of the reconnaissance, most of the equipment within the refinery complex had not yet been checked for operability.

Figure 82 Sendai Refinery, Tohoku Oil Company, Ltd.: one of the three failed storage tanks. This tank has an approximate volume of 23,000 kl. The damage illustrated is due to suction caused by rapid evacuation of the oil through the ruptured connection of the base and wall of the tank. The several tanks, of similar size, in the foreground are thought to be undamaged.

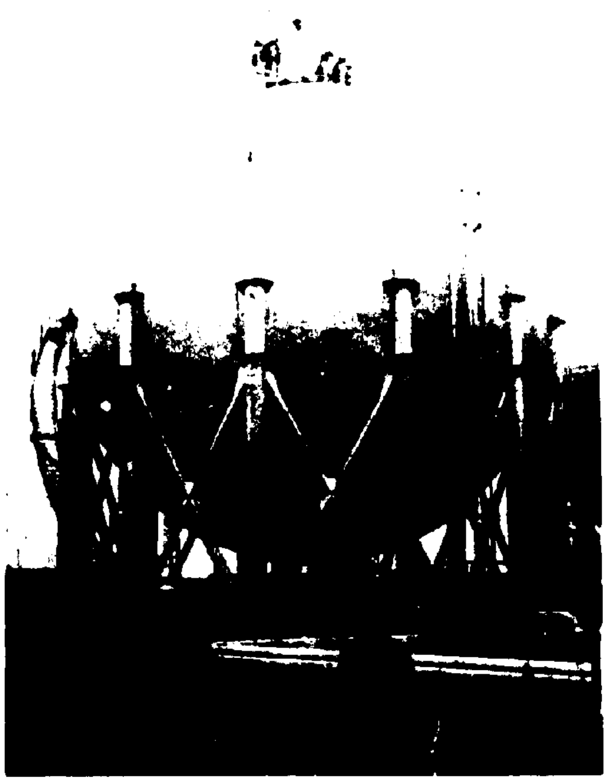


Figure 83 Sendai Refinery, Tohoku Oil Company, Ltd.: an undamaged gas storage tank. Note the heavy diagonal bracing in the supporting structure.

Figure 84 Sendai Refinery, Tohoku Oil Company, Ltd.: ground settlement at the refinery.

Figure 85 Sendai Refinery, Tohoku Oil Company, Ltd. A large water storage (left) tank near the main refinery complex appeared to have experienced significant rocking. The anchor bolts stretched, or pulled out, from 1 to 6 in. Detail (right) of one of the pulled-out, or stretched, anchor bolts of the water storage tanks shown at left.

Concrete Batch Plant, Sendai. A small concrete batch plant is located about 2.7 km south of the Sendai-Ohash. Bridge, on National Highway No. 4. Except for some of the foundations and lower supporting structures, all of the structures, tanks, and equipment at the site are made of steel. This was the only small manufacturing or industrial facility that was investigated in any detail. The facility sustained various types of structural damage to equipment and tank supports, buckling of storage tank walls, damage to structural steel framing, etc. It was inoperable for two days after the earthquake while repairs were being carried out. The most serious structural damage had not yet been corrected at the time of the investigation.

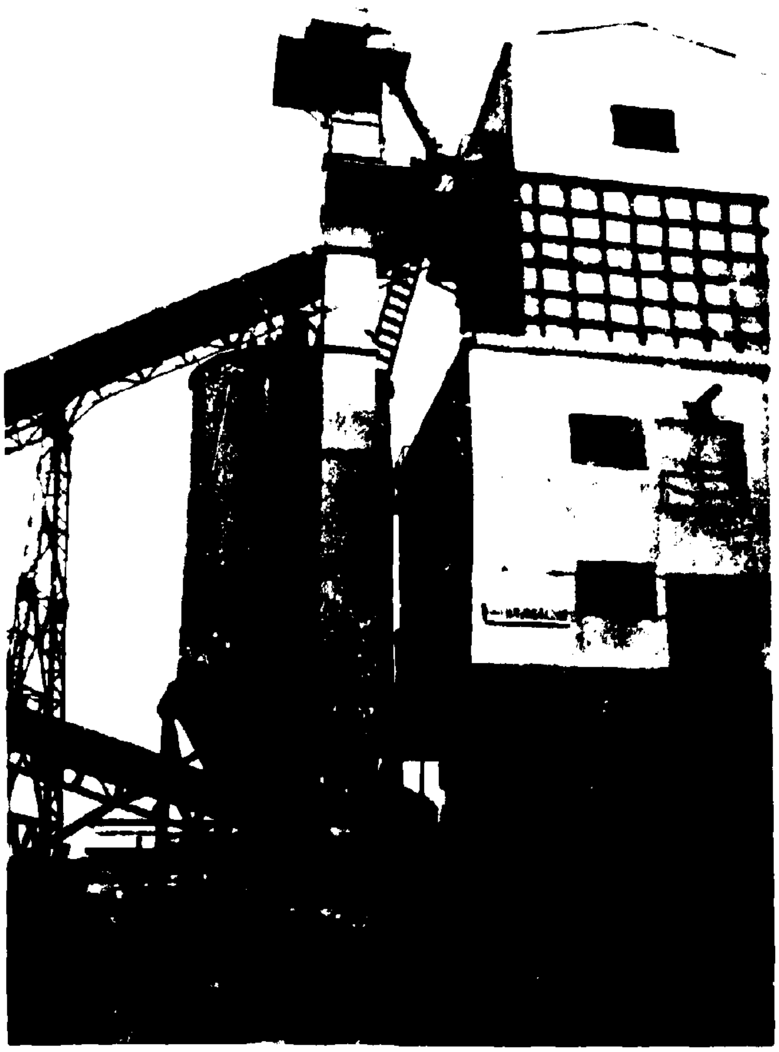


Figure 86 Concrete Batch Plant, Sendai. Differential motion of the upper (light steel) structure and the conveyor belt structure damaged the vertical stack and was responsible for extensive damage to the light steel structure. The stiffer reinforced concrete substructure was not damaged.

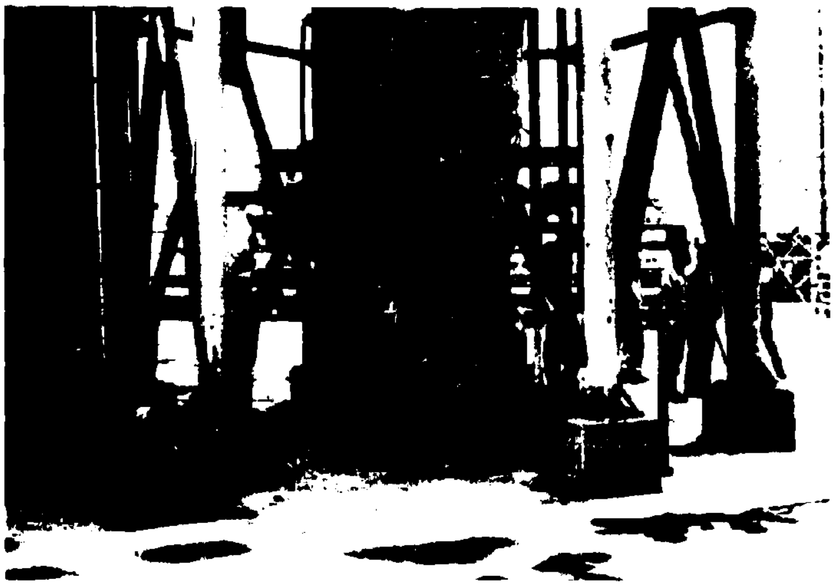


Figure 87 Concrete Batch Plant, Sendai: view of the supporting substructure of a cement bin and related equipment. By the time of the investigation, the damage had been repaired by replacing a number of the diagonal braces and by welding the sheared bolt connections between the diagonal braces and the vertical pipe columns.

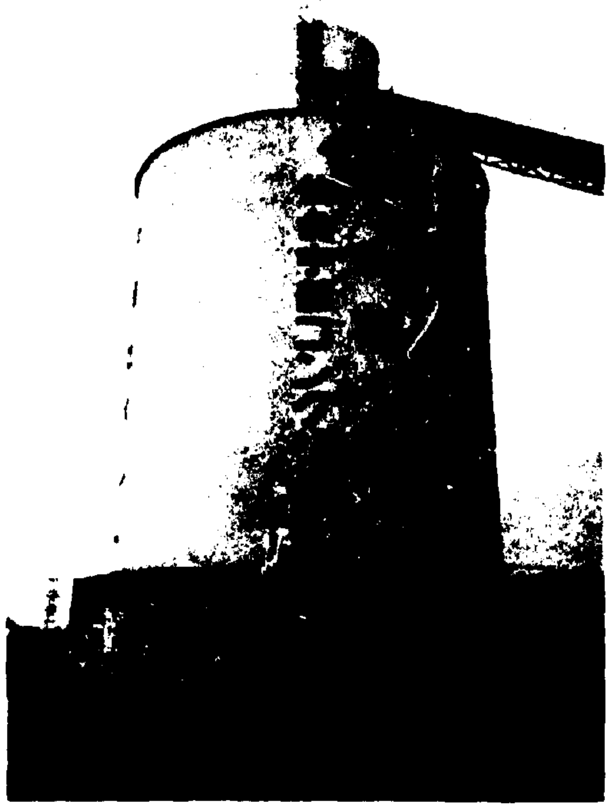


Figure 88 Concrete Batch Plant, Sendai. A large gravel-and-sand-storage tank experienced buckling of the steel plate at its base--at the extreme left side and at two separate locations on the right side.

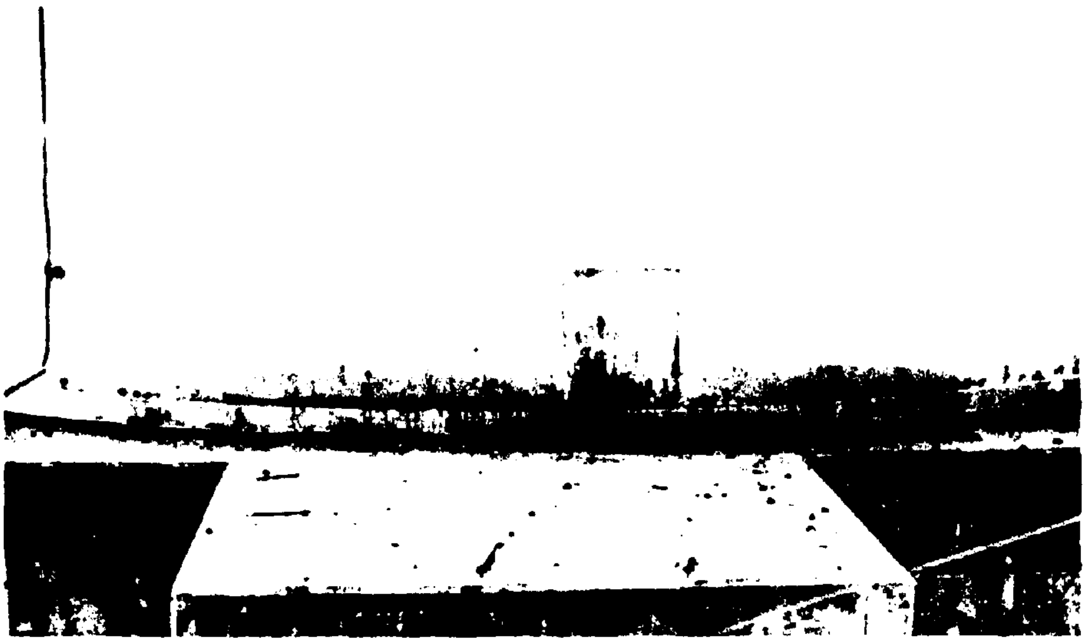


Figure 89 Concrete Batch Plant, Sendai: a detailed view of the damaged supports of the tank shown in Figure 88. There were several such buckles at the base of the tank. The tank and its superstructure and support structure did not experience any other damage. The tank was full of sand and gravel during the earthquake.

Bridges and Transportation Structures

The Japanese Ministry of Construction reported that 78 highway bridges had been damaged as a result of the June 12, 1978, earthquake. An inventory of damaged highway structures included only those bridges having an estimated repair cost of 1 million yen ($5,000) or more. (There were no reported cases of significant damage to the many steel pedestrian bridges in Miyagi Prefecture.) Bridge damage was confined principally to structures within Miyagi Prefecture. Of approximately 100 bridges in Sendai, only four were reported to have been damaged; two of these were inspected by members of the reconnaissance team. Most of the damaged bridges were within an area extending about 90 km northeast from Sendai.

The reconnaissance team visited the sites of 13 highway bridges and 4 rail bridges to view representative damage. Cracked concrete piers and columns, displaced or dislodged girder-bearing devices, settlement of abutments and piers, and vibration-induced settlement of fills at bridge approaches are typical examples of the damage that was observed.

Records of significant strong motion were obtained from the Kaihoku Bridge, 65 km northeast of Sendai, and from the Datē Bridge, about 75 km southwest of Sendai and just north of Fukushima. The team members visited only the Kaihoku Bridge site. The maximum ground acceleration at Kaihoku was 0.31g; the maximum pier acceleration was greater than 0.50g. No ground record was obtained from the Datē Bridge site; the peak pier acceleration was 0.49g.

There was no reported damage to highway tunnels in Miyagi Prefecture. Only one railway tunnel, on the New Sendai Shinkansen line -- the bullet (fast) train -- northeast of Sendai, was reported to have suffered damage. There was minor, hairline cracking in its concrete lining.

After the earthquake, the Japan National Railway Corporation stopped all trains until safety inspections could be made. Most train service was restored within three days following the earthquake. The public bus system in Sendai was not adversely affected by the earthquake. It was reported that airline traffic to and from Sendai was interrupted only briefly while a rapid inspection of the airport was made by airpor officials.

No major damage at Shiogama Port, 18 km northeast of Sendai, was reported. One free-field strong-motion record, obtained from a SMAC-B2 instrument at the port, recorded peak accelerations of 0.28g in the north-south direction, 0.20g in the east-west direction, and 0.17g for the vertical component of the earthquake.

Kin-Noh Bridge. The Kin-Noh Bridge, located about 65 km northeast of Sendai on the National Highway, Route 346, is a 2-lane, 25-span multiconfiguration structure that is 575 m long. It was constructed in 1956 and is made up of nine simply supported plate-girder spans, each 28 m long. Four of the spans are totally suspended; five are simply supported through-truss spans, each 60 m long; one is a simply supported plate-girder span that is 23 m long.

Three major earthquakes have occurred in this region since the bridge was constructed: one in 1962; another on February 20, 1978, which caused significant damage at one of the abutments and to the girder-bearing devices; and the June 12, 1978, earthquake, during which one of the suspended spans collapsed. Repair work to damage from the February 1978 earthquake was under way at the time of the most recent earthquake. The repairs included replacing bearings on the five truss spans and tying the truss spans together with restrainers. The abutment at the end of the nine plate-girder spans had been shored but had not yet been repaired. The bridge will be replaced at an estimated cost of 3.2 billion yen ($16 million).

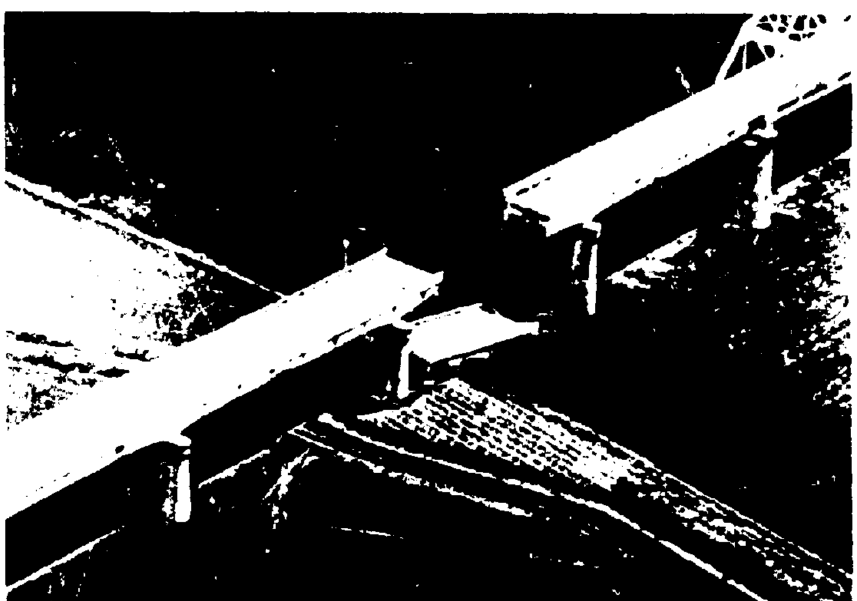


Figure 90 Kin-Noh Bridge: view of the collapsed suspended plate-girder span. (Kawahoku Newspaper Co. photograph)

Figure 91 Kin-Noh Bridge: the only visible pier damage occurred at Pier 8, which is adjacent to the collapsed suspended span. Shear cracking extended 12 cm through the 152-cm-deep pier, approximately one-fourth of the way up the column from grade.

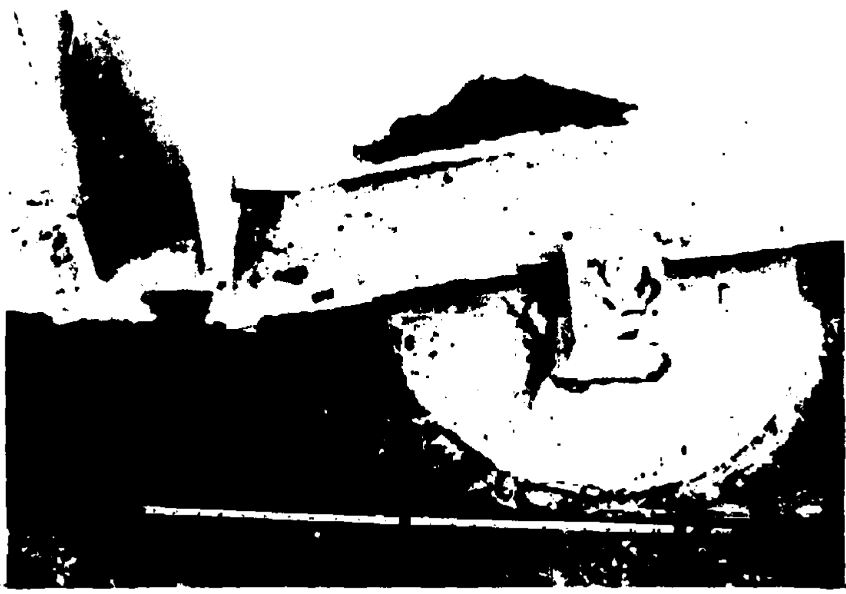


Figure 92 Kin-Noh Bridge: the girders at Pier 8 displaced 55 cm longitudinally toward the abutment, allowing the unrestrained suspended span to drop off the 45-cm hinge seat. The movable girder-bearing plate came to rest at the edge of the pier cap. The fixed bearing on Pier 7, at the opposite side of the suspended span, displaced longitudinally 0.5 cm.

Figure 93 Kin-Noh Bridge: extension of anchor bolts at Pier 6. The foreground shows a portion of a repaired lower chord truss member.

Figure 94 Kin-Noh Bridge: bearing restraining device used on the repaired bearing supports of the truss spans. The restrainers had been placed before the June 12 earthquake.

Yurlage Bridge. The 10-span Yurlage Bridge, constructed in 1962, is located 1.2 km from the mouth of the Natori River on the outskirts of Sendai and is 107 km from the epicenter. It has seven prestressed-concrete T-girders, each 45 m long, and three main spans. The spans are twin-cell, segmentally constructed, post-tensioned concrete box girders. The center span, which is 90 m long, has a 60-m span at either end. The bridge was open to only one lane of traffic because of heavy column damage. No damage was reported to the three-span box structure. Excavation at the first pier at the opposite side of the bridge to investigate possible foundation damage was in progress.

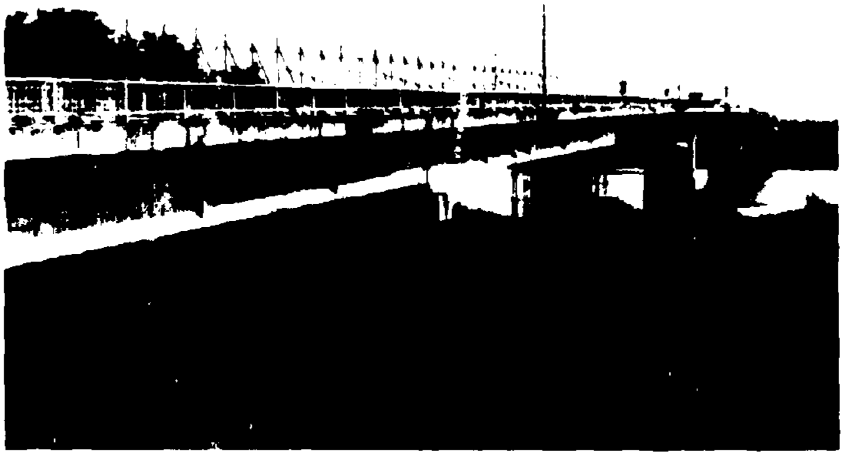


Figure 95 Yurlage Bridge: general view showing the first two columns, which were heavily damaged.

Figure 96 Yurlage Bridge: liquefaction in the flood plain below the bridge.

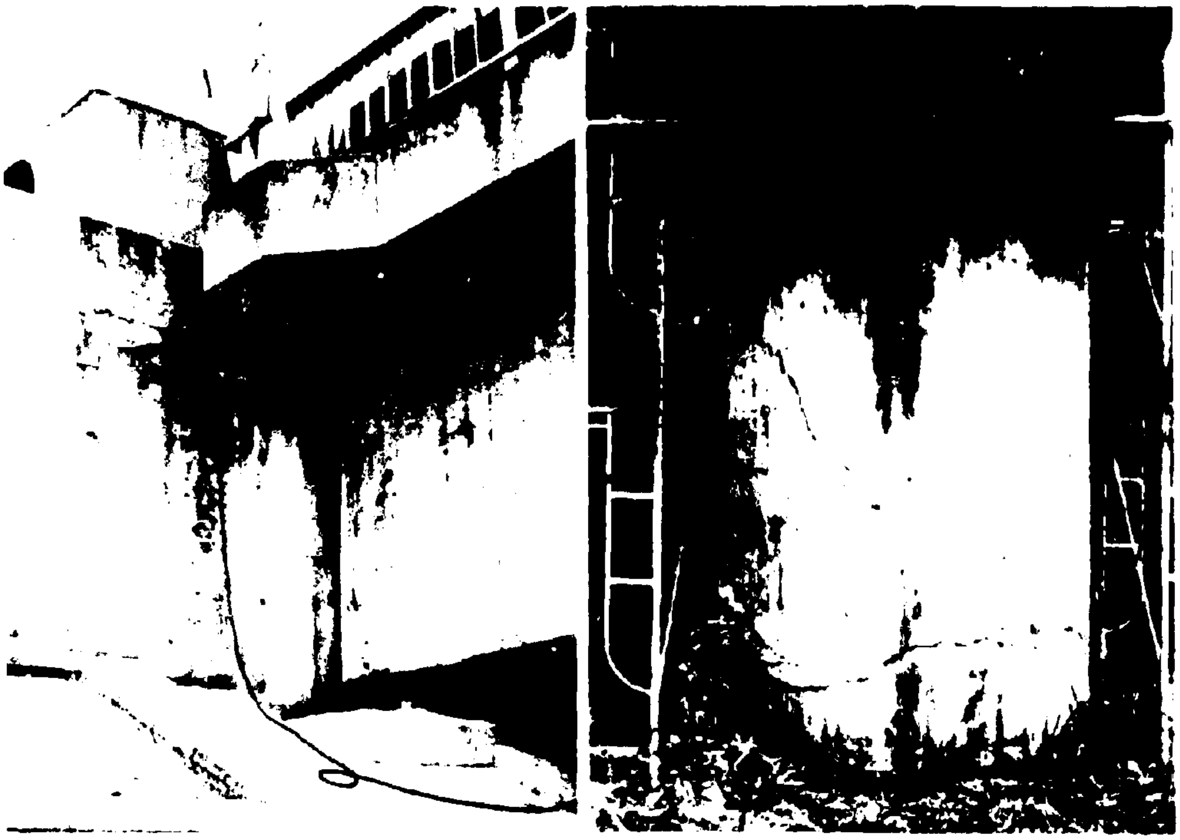


Figure 97 Yuriage Bridge: evidence (left) of light girder impacting with the abutment and pronounced shear cracking of the exterior girder at the bearing. Pier 1 (right), founded on a caisson 19 m deep and 2 m by 4 m in plan, suffered heavy shear cracking. The pier cap was reported to have settled 5 cm uniformly.

Figure 98 Yuriage Bridge: the face of Pier 1, showing severe distress. The plaster-of-paris patchwork is used to determine whether additional pier cracking is occurring under service loads.

Sendai Ohashi Bridge. The Sendai Ohashi Bridge over the Hirose River on the National Highway, Route 4, was constructed in 1965. It suffered heavy pier damage during the June 1978 earthquake. The structure is a nine-span, simply supported, composite concrete-and-steel plate-girder bridge with 34 m span lengths. The bridge was retrofitted across the joints, with steel restraining plates bolted to the girder webs. Although the reconnaissance team inspected the bridge site only 11 days after the earthquake, repair efforts were well under way, making it impossible to view much of the original damage.

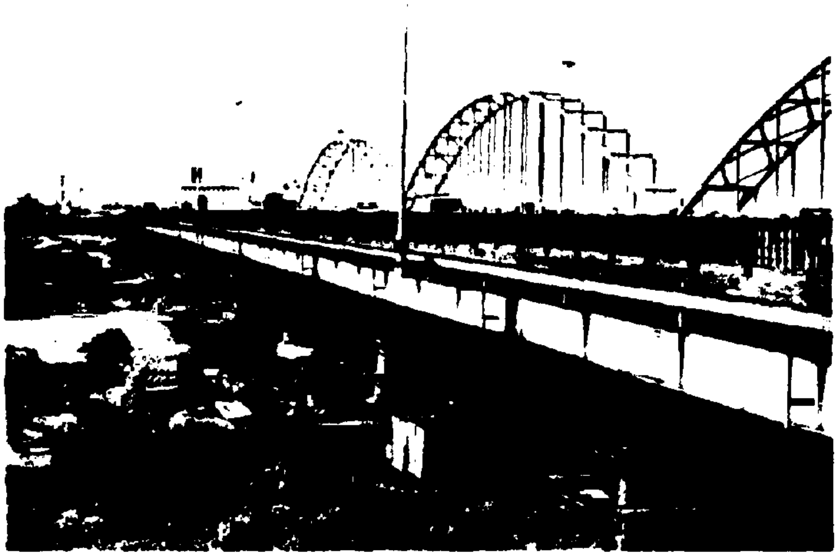


Figure 99 Sendai Ohashi Bridge: general view. The arch bridge in the background, which is made up of two steel plate girders with cross-bracing and is supported on slender circular columns, carries an industrial water pipeline. The bridge was not reported to have been damaged.

Figure 100 Sendai Ohashi Bridge: temporary cribbing used to support the steel plate girders.

Figure 101 Sendai Ohashi Bridge: typical pier configuration. The cross-pier dimensions are approximately 5 m by 2 m. The piers have massive caps.

Figure 102 Sendai Ohashi Bridge: typical pier damage at the construction joint between pier and cap. The vertical reinforcing bars have buckled across the joint. Significant concrete spalling is evident. Horizontal concrete cracking around the pier was discovered upon excavation of soil around the piers. (Ministry of Construction photograph)

Figure 103 Sendai Ohashi Bridge: typical damage to the base of a pier before repair.

Figure 104 Sendai Ohashi Bridge: typical damage being repaired at the base of the pier. Note the outward buckling of the undeformed vertical rebar. The concrete cover had been roughened, the footing strengthened, and additional rebars placed to strengthen the pier.

Figure 105 Sendai Ohashi Bridge: details showing the added reinforced concrete form work. The thickness of the piers will be increased on each side by 50 cm at the top, tapering to 70 cm at the base.

Kaihoku Bridge. The Kaihoku Bridge, located on Principal Route 51 approximately 45 km northeast of Sendai, is a two-lane, five-span, continuous, single-cell steel box girder. Its total length is 285 m.

The bearings are movable at all piers except Pier 2, where an SMAC-B strong-motion accelerograph is located. Hydraulic dampers acting in the longitudinal direction have been incorporated into the bearing system. All piers and their abutments are skewed. A free-field SMAC-B instrument was located on rock between Pier 1 and Pier 2, approximately 30 m from the structure. The axes of the pier and the free-field instruments were aligned with the principal axes of the bridge. The peak recorded accelerations are:

	Longitudinal	Vertical	Transverse
Free Field	0.20g	0.12g	0.30g
Pier	0.50+ g (off scale)	0.19g	0.34g

The only damage noted was minor settlement of the wing wall of an abutment. There was no visible damage to the piers or bearings and no evidence of the girders' having impacted with the east abutment. (See Figure 4 of the contribution by A. G. Brady in this report for the free-field (ground) record.)

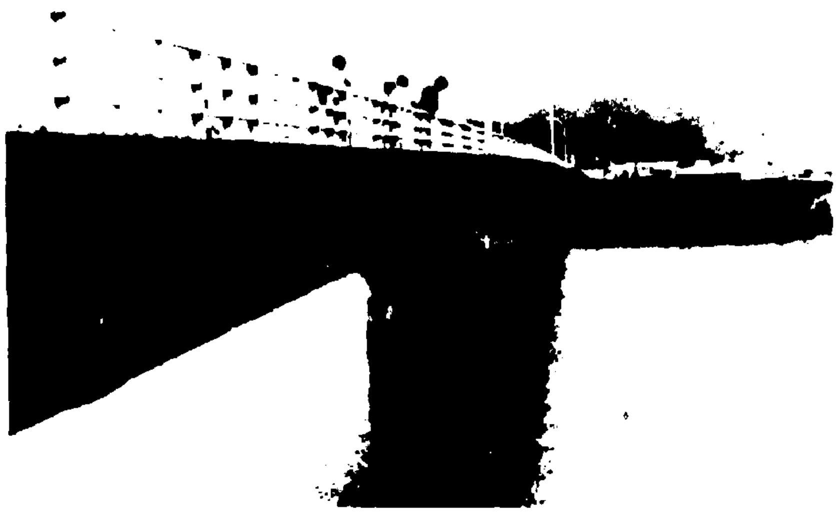


Figure 106 Kaihoku Bridge: general view. (Ministry of Construction photograph)

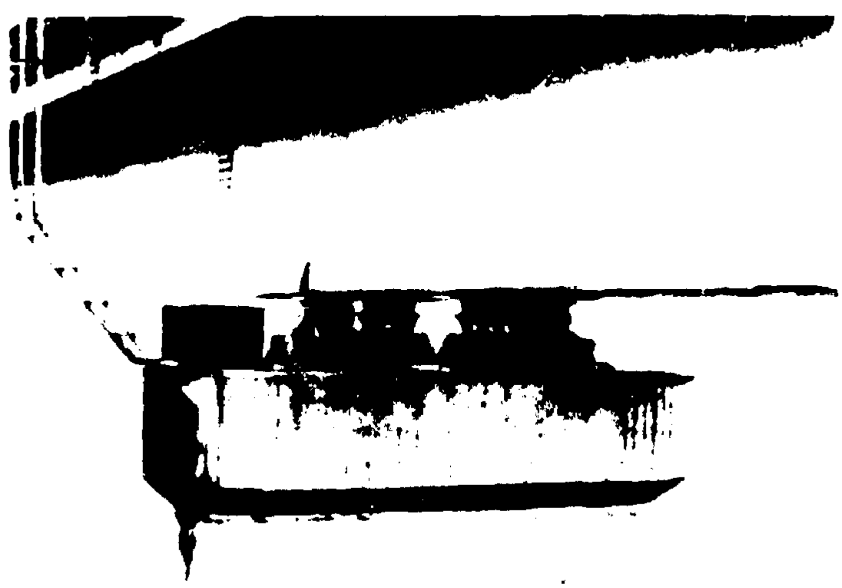


Figure 107 Kaihoku Bridge: Pier 2, showing the SMAC-B_2 instrument (which recorded a peak acceleration greater than 0.50g in the longitudinal direction) and the fixed bearing and hydraulic damper system.

The New Sendai Shinkansen Trunkline of the Japan National Railway. The Japan National Railway Corporation (JNR) is constructing the New Sendai Shinkansen Trunkline, a series of elevated structures for the fast train. The line will extend through Miyagi Prefecture and is scheduled for completion in 1981. The majority of the elevated structures, a series of prestressed concrete T- , I- , and box girders with varying configurations of single and multiple column bents, had been completed at the time of the June 12, 1978, earthquake and experienced varying degrees of damage to the bearing shoes and columns. Damage was concentrated to structures located approximately 30 to 40 km northeast of Sendai. All structures were designed under the 1971 Japanese seismic code.

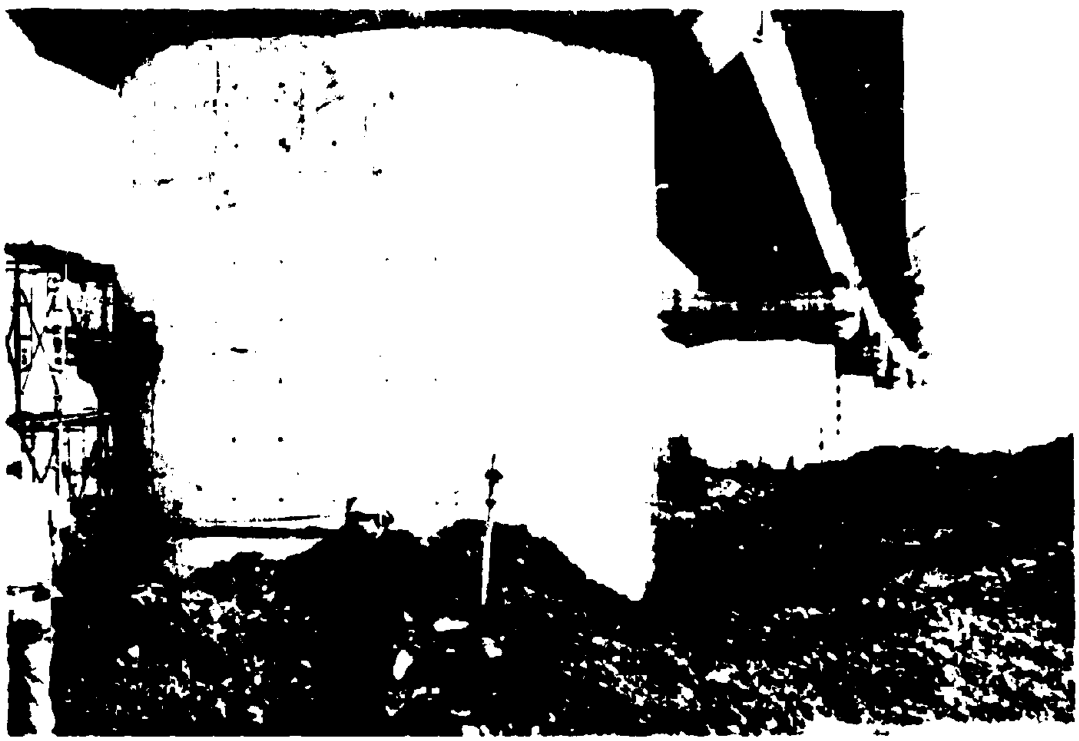


Figure 108 Natori River Bridge: this is a three-span continuous single-cell, reinforced cast-in-place concrete box girder structure, on 3 m by 6 m piers approximately 8 m above grade. Typical damage included cracking in the central part of the pier, where the gross cross-sectional area of vertical steel was reduced.

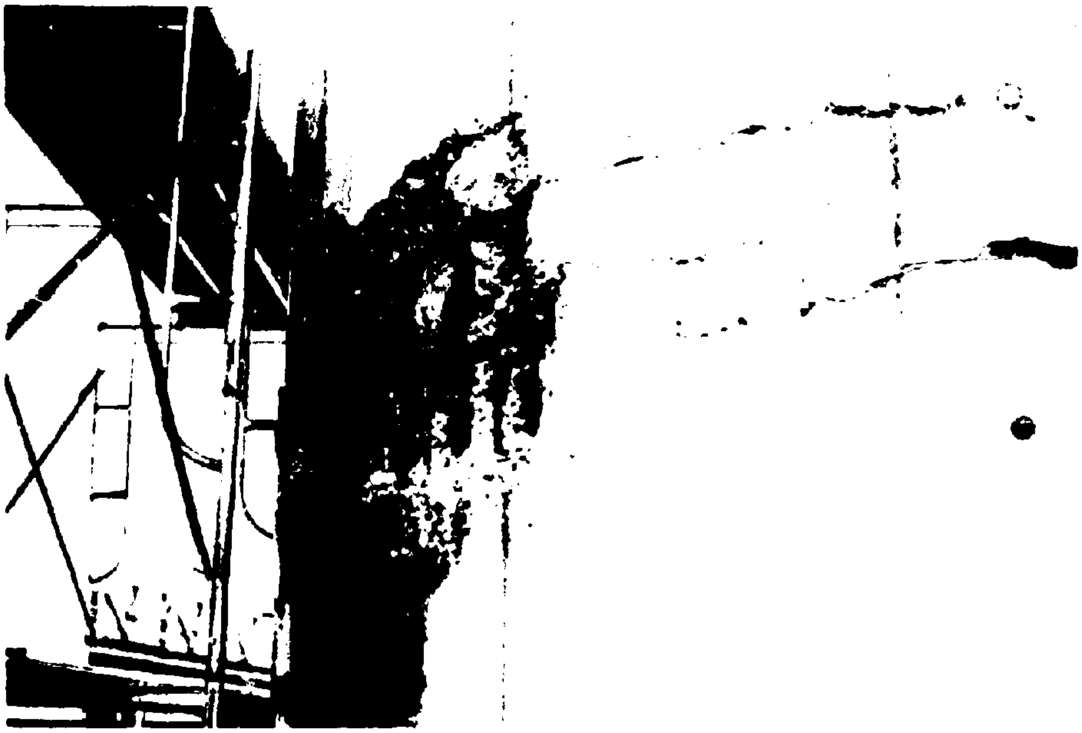


Figure 109 Natori River Bridge: detail of spalled concrete, showing the buckled vertical rebar.

Figure 110 Natori River Bridge: shear cracking in the relatively lightly reinforced upper portion of a pier near the Rifu construction office of JNR.

Figure 111 Cracking of space frame tie beams near the Rifu Construction Office.

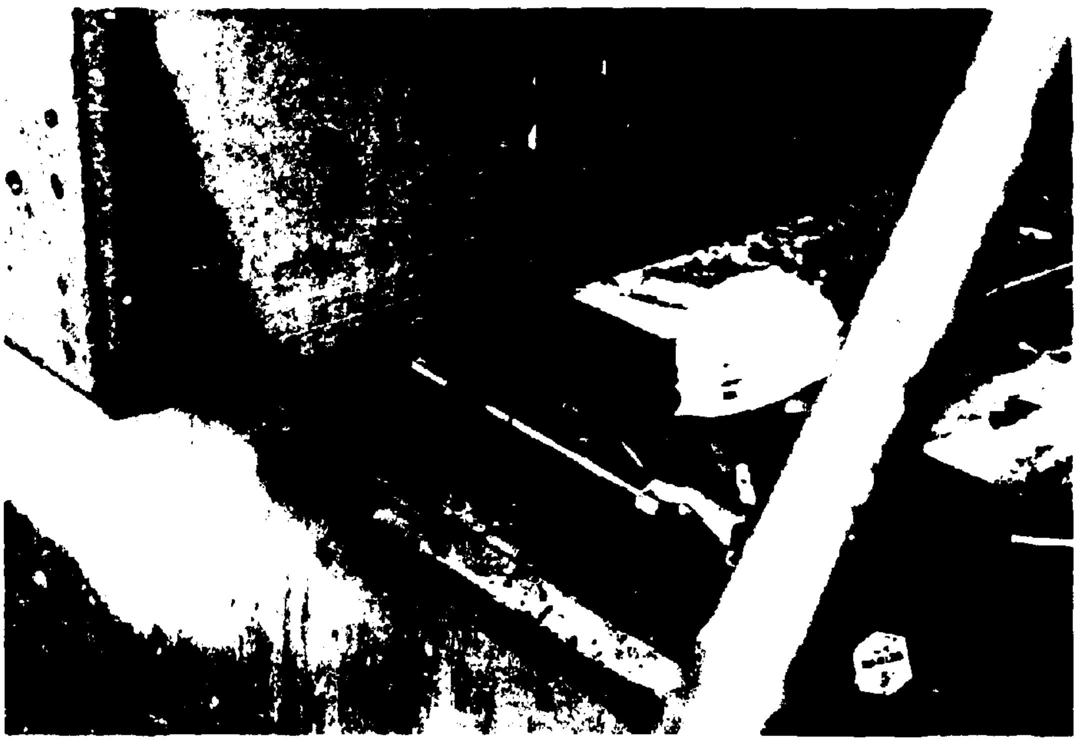


Figure 112 Failure of a bearing plate supporting a single cell box girder near the Higashi Sendai Construction Office. The girder displaced laterally 50 cm.

Kitagami Ohashi Bridge and Dike. The Kitagami Ohashi Bridge, completed in 1976, crosses the Kitagami River 60 km northeast of Sendai on Principal Route 23. The seven-span, 400-m deck-truss structure suffered no visible structural damage, although there was minor settlement of the abutment apron. The bridge was designed with the latest Japanese criteria and incorporated new abutment bearing details. Significant damage occurred to the dike and roadway along the Kitagami River south of the bridge site, particularly to a 1/2-km-long section in which the roadway on top of the dike settled about 1.5 m. Continuous steel sheet piling was being driven to stabilize the dike.

Figure 113 Kitagami Ohashi Bridge. No structural damage was reported.

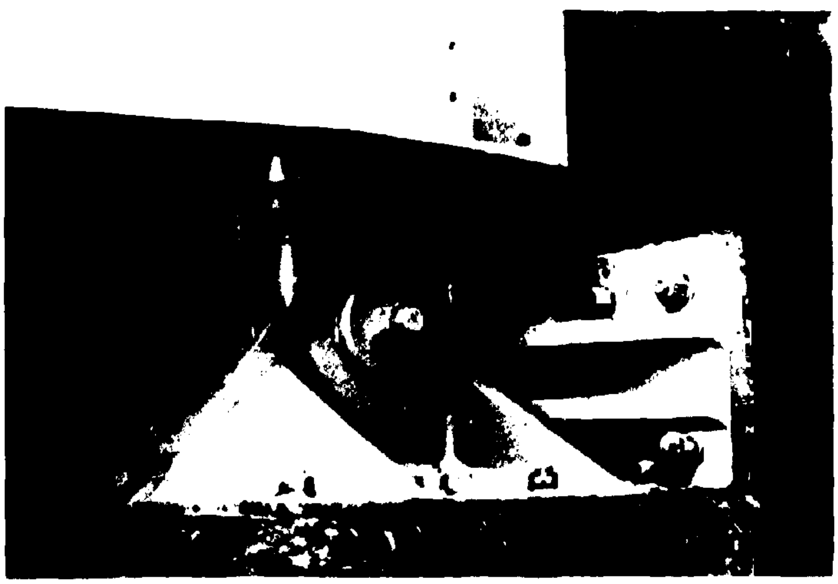


Figure 114 Kitagami Ohashi Bridge: detail of a seismic bearing device at the abutment.

Figure 115 Kitagami Dike: road damage and temporary stabilization of the dike near the Kitagami Ohashi Bridge site.

Maiya Ohashi Bridge. The Maiya Ohashi Bridge is a three-span Gerber-truss bridge located on the National Highway, Route 342, approximately 62 km northeast of Sendai. The 181-m-long truss bridge, constructed in 1928, was closed to traffic because of a brittle fracture through the rivet holes of the top chord channel members at the first pier. Four steel plates had been welded around the top chord members. Some of the small steel angle members in the top lateral bracing were buckled in the vicinity of the pier. No damage was reported to either the piers or the abutments.

Figure 116 Maiya Ohashi Bridge.

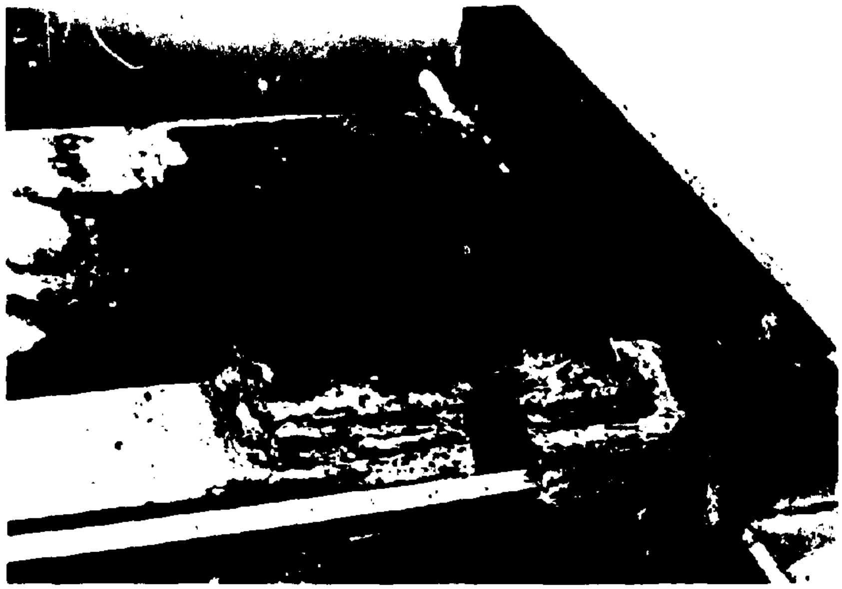


Figure 117 Maiya Ohashi Bridge: steel plates welded to the top chord channel members. Note the clean fracture at a line passing through the centerline of the rivet holes of the lattice bracing and the permanent 2.5-cm separation.

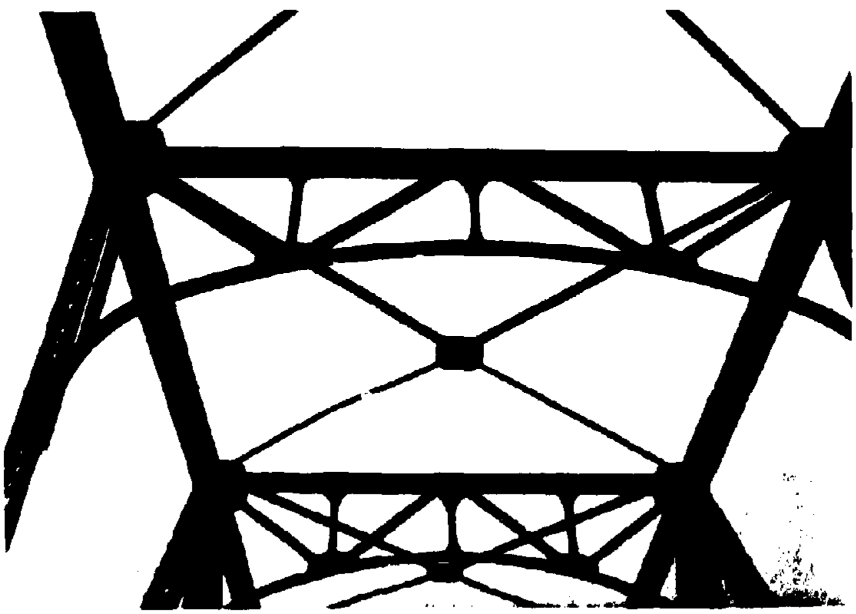


Figure 118 Maiya Ohashi Bridge: buckled diagonal braces of the overhead trusses.

Tunnels. Five short, unreinforced-concrete-lined highway tunnels through rock, located about 20 km northeast of Sendai on the National Highway Route 45, suffered no apparent damage. The Japan National Railway Corporation reported that one concrete-lined tunnel, about 40 km northeast of Sendai on the New Sendai Shinkansen Line, had hairline cracking.

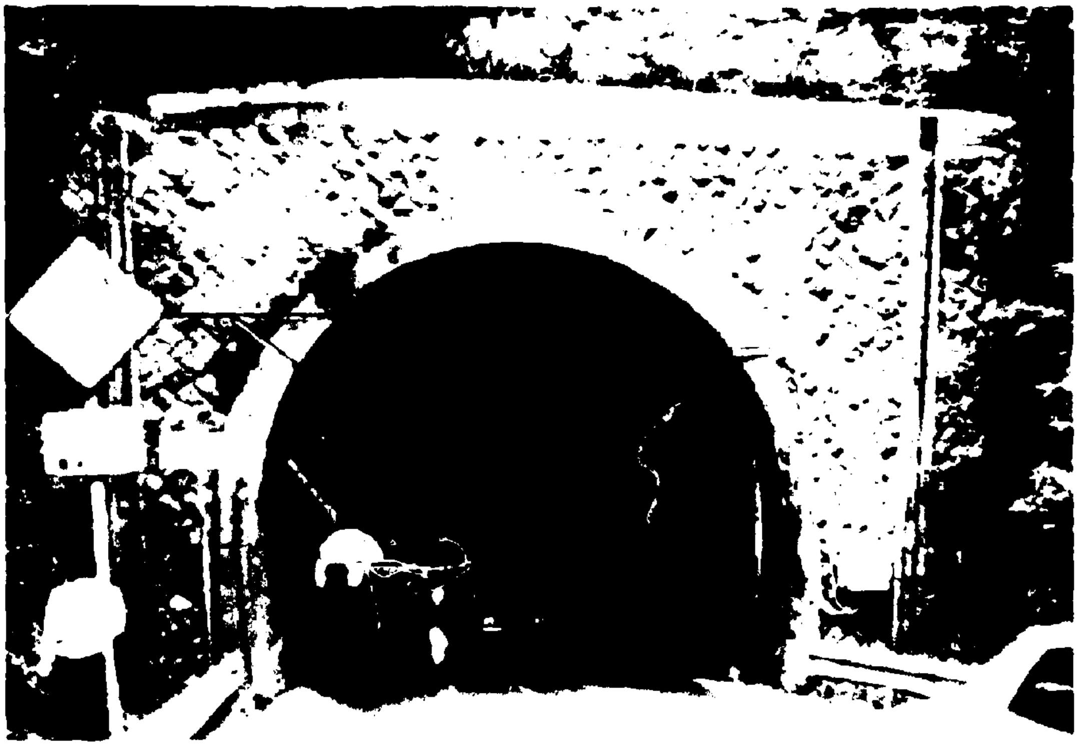


Figure 119 Typical Undamaged Highway Tunnel. This tunnel is on Route 45, which runs along the coast between Sendai and Ishinomaki (north of Sendai).

ARCHITECTURAL ASPECTS

by Christopher Arnold, Architect
Building Systems Development, Inc.
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Introduction

This section of the report provides observations by the architect member of the team of National Science Foundation researchers that visited Sendai from July 6 through July 9, 1978. The notes are of two main types: (1) direct observation of architectural damage particularly to ceilings, partitions, exterior walls, and glazing, and (2) an attempt to identify the contribution of architectural configuration to the seismic resistance of a building. In the latter case, less attention is focused on the failure of details than on an attempt to assess the underlying causes of failure, which may result from the shape of the building as a whole or from details of building form that cause extreme forces to be imposed on specific resistant elements.

Observations are also made on emergency and temporary operational issues of facilities, and some attention is directed towards undamaged buildings that revealed interesting architectural aspects.

In the attempt to broaden the observation and diagnosis of earthquake damage, this section of the report necessarily indulges in some speculation, for which the author takes full responsibility.

Architectural Damage

In general, architectural damage was minimal. High-rise buildings behaved particularly well. Although glass breakage was fairly extensive, replacement glass in the many windows damaged by the February 20, 1978 earthquake generally performed well during the June 12 earthquake. This experience showed that glass performance depended on the way in which the glass had been fixed; glass that had been fixed with dried-out caulking tended to break. This is clearly an architectural problem that merits the close attention of glass installers as well as those specifying architectural details.

Figure 1 Ceiling damage to Second Government building (see Engineering Aspects, Figure 6). Note that this was in the 2-story wing of the building, probably a more flexible structure than the main tower. Although not clearly obvious from the picture, the ceiling hangers are much stouter than comparable members in standard U.S. construction.

Figure 2 Yasaki building (see Engineering Aspects, Figures 23-28). Interior damage of the 2-story steel frame portion of the Yasaki building complex; a flexible structure.

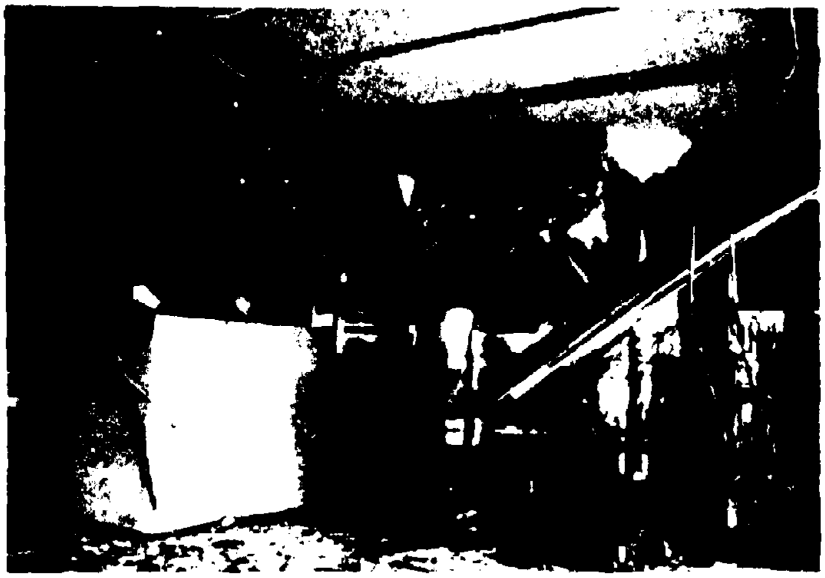

Figure 3 Yasaki building: open showroom floor, with large glass windows to street. Severe interior damage.

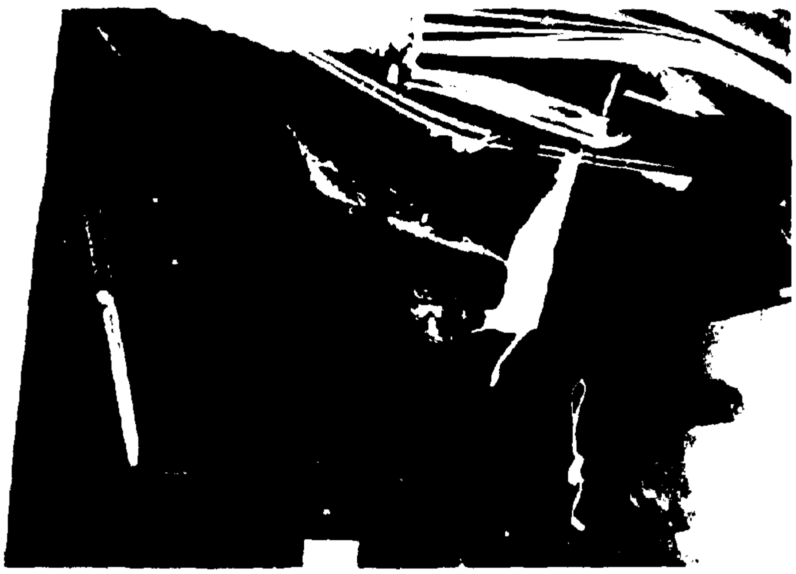

Figure 4 Yasaki building, interior.

Figure 5 Yasaki building, interior.

It is apparent that architectural damage is related to the flexibility of the building. The illustrations below show another flexible frame structure.

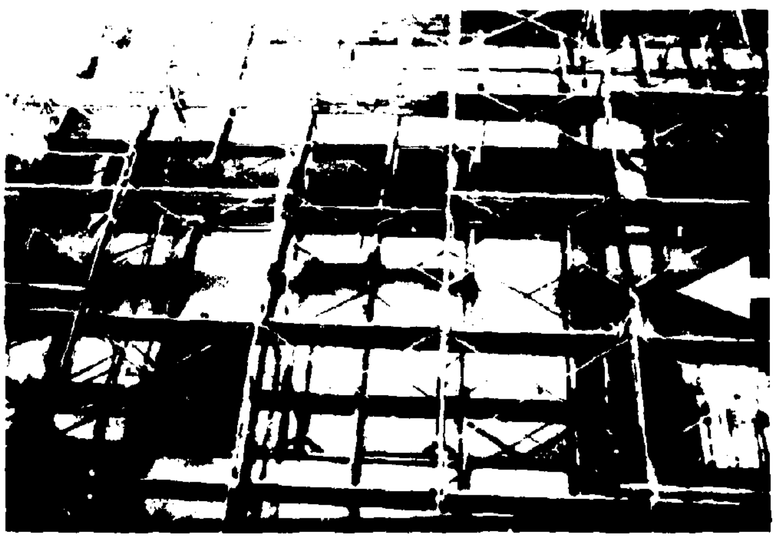

Figure 6 Morisada Kosyo Building, a 4-story steel frame office building located in the Oroshicho area. Columns have deformed along the line of the third floor (arrow), where the column section was reduced for the top two floors. Scaffolding was erected after the earthquake.

Figure 7 Morisada Kosyo Building. Column deformation resulted in major interior architectural damage.

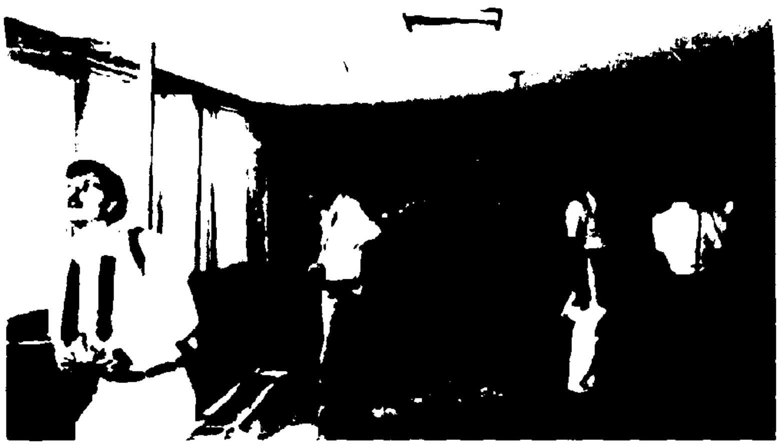

Figure 8 Morisada Kosyo Building. Interior damage. Diagonal brace installed after earthquake.

Figure 9 Exterior cladding failure. Detail of Sasaki home center shown in the Engineering Aspects section, Figure 9. These panels are of very light-weight concrete; however, their large size (most are approximately 15 ft high by 4 ft by 1 ft) results in a heavy panel. Panels shown were flush before the earthquake.

Architectural Configuration

Underlying some of the failures of structural details are some architectural issues. Although the direct cause of failure may be in the detail design and construction of column reinforcement, the indirect cause originates in building configuration. The architectural configuration is such that earthquake forces are concentrated into certain structural details that become overstressed and fail. The failure of the Obisan building (Engineering Aspects, Figure 14) originates in the torsion caused by the architectural planning of staircase location. The shear failures in the Kinoshita building (see Engineering Aspects, Figure 17) occurred along a face with no shear walls at a point where a heavy concrete canopy cantilevers over the building corner.

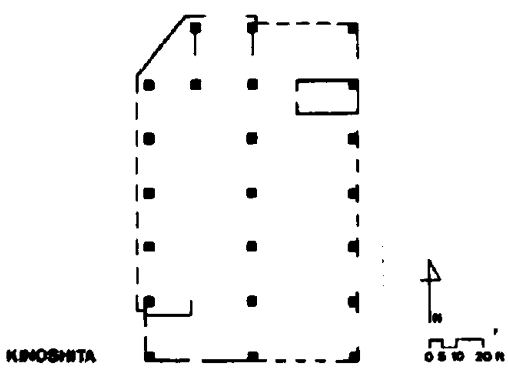

Figure 10 Kinoshita Building: plan. Note disposition of solid walls, open front, and canopy cantilever at corner.

Shear failures in columns at Tonan High School, Tohoku Institute of Technology, and Izumi High School (Engineering Aspects, Figures 46, 43, and 51, respectively) occurred where the architectural configuration created short columns due to deep infill concrete spandrels and where this condition occurred on one facade of the building but not the other. In addition, these heavy, frame buildings had limited (or no) shear walls in the north-south direction (the direction of main emphasis of the earthquake) because of the architectural need for full daylighting to classrooms. The interaction of architectural and structural factors is very clear in these examples.

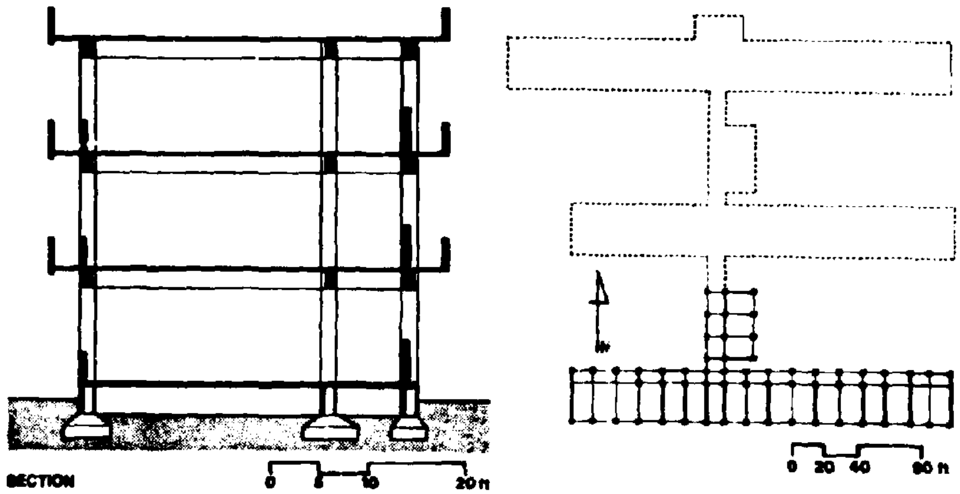

Figure 11 Plan and section of Izumi High School. Note in plan the absence of shear walls in the east-west direction and the termination of north-south shear walls at the corridor. The section shows how deep poured concrete spandrels on the right create short columns, which failed. Even though the main emphasis of the earthquake was in the north-south direction, in this instance failure occurred in the east-west direction.

It is interesting that both Tonan High School and Izumi High School suffered column failures even though the latter was built after a code change that resulted in increased shear reinforcing. Although the failures at Izumi were much less severe than at Tonan, it is clear that the basic problem lies in the configuration rather than in the structural detailing.

Identical Configurations, Selective Failure. An interesting case was observed in two buildings of identical configuration, one of which failed completely, the other showing incipient failure.

Figure 12 Sendai Unyu Soko warehouse, a 2-story steel frame warehouse, suffered complete first-floor collapse.

Figure 13 Sendai Unyu Soko warehouse. Warehouse crushed truck at loading dock; the driver escaped.

Figure 14 Sendai Unyu Soko warehouse: detail of column failure.

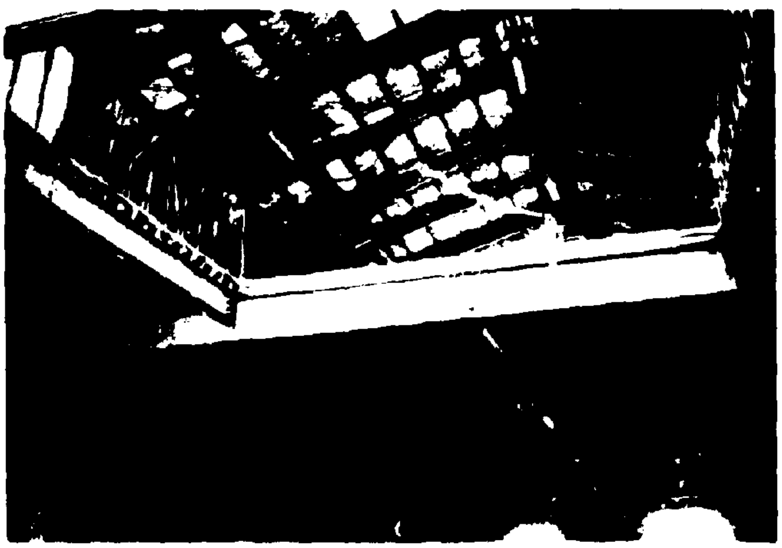

Figure 15 Sendai Unyu Soko warehouse. Adjoining warehouse shows type of construction similar to collapsed warehouse.

Figure 16 Sendai Unyu Soko warehouse: bracing failure. Warehouse braced only at perimeter, with unbraced center bays.

In these storage building, the live loads may vary and may be very large. Possibly the collapsed warehouse was heavily loaded on the second floor.

<u>Chance</u>. The next two pictures show column failure in a market south of downtown Sendai. The detail shows that this heavy concrete building was close to collapse. At the time of the earthquake, the store was crowded with about 300 shoppers; if the building had collapsed, casualties would have been very heavy, and the importance of this Sendai earthquake in relation to causualty statistics might have changed dramatically.

Figure 17 Toko store: general view. Note shear failures at first-floor columns. These failures occurred at short columns created by deep poured-in-place spandrels.

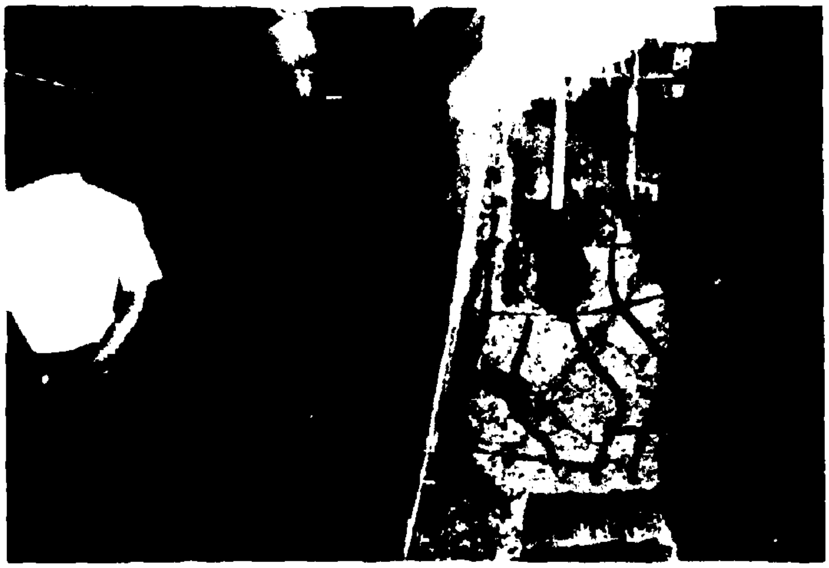

Figure 18 Toko store: detail of interior column failure.

Figure 19 Midorigaoka residential area, south west Sendai: typical concrete-block screen walls. Such walls were responsible for many casualties: at the time of the earthquake, many people were walking home alongside screen walls. Note light braced-frame carport.

Figure 20 Midorigaoka residential area: concrete-block screen walls, and typical new dwellings. Wood-frame house, exterior plywood or stucco on wood lath. Note smaller scale of house relative to U.S. practice, r^sulting in closer interior cross walls and shorter spans, a beneficial scale effect for seismic resistance.

Figure 21 Grand Bowl, east Sendai. Complete collapse of wide-span roof trusses, which are similar in type and construction to those of U.S. bowling alleys. In Senoai, bowling alleys, after an initial popularity, have fallen out of fashion, and this alley was closed and hence unoccupied.

Figure 22 Grand Bowl, east Sendai: collapse of exterior canopy and glass wall.

An L-Shaped Building. The Sunnyheights condominium project is a 17-story L-shaped reinforced concrete building. The building is separated by a seismic joint into two rectangular buildings. The apartment party walls act as effective shear walls in one direction, but in the other the concrete wall is perforated by doors, windows, etc. The building with its shear walls aligned with the north-south axis was virtually unscathed. This building is a good example of the principle of separation of the elements of an L-shaped building to eliminate torsion.

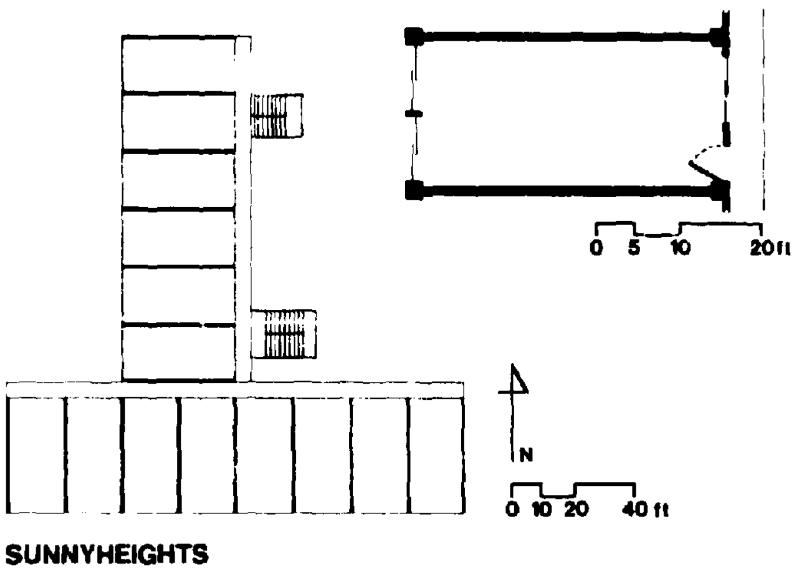

Figure 23 Plan of Sunnyheights apartments.

Figure 24 Sunnyheights building: general view.

Figure 25 Sunnyheights building: elevation of damaged wall. Shear failure caused distortion that resulted in inoperable doors for 57 of the 190 units.

Seismic Joints. In the building pictured below, the seismic joint suffered some damage, but major structural damage through pounding at this point was avoided. Essentially, only architectural trim and flashing are in need of repair.

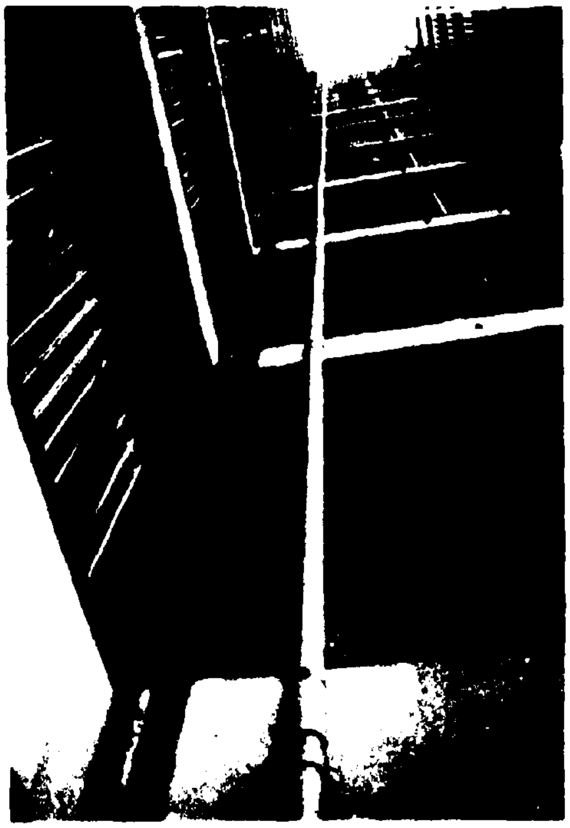

Figure 26 Sunnyheights building: seismic joint between two wings.

Figure 27 Sunnyheights building: seismic joint detail.

Figure 28 Yasaki building. Large seismic joint protects light steel frame building on left while concrete structure on right suffers major collapse.

Figure 29 Izumi High School: seismic joint at 2-story connection between main wings of school. Minor architectural damage only.

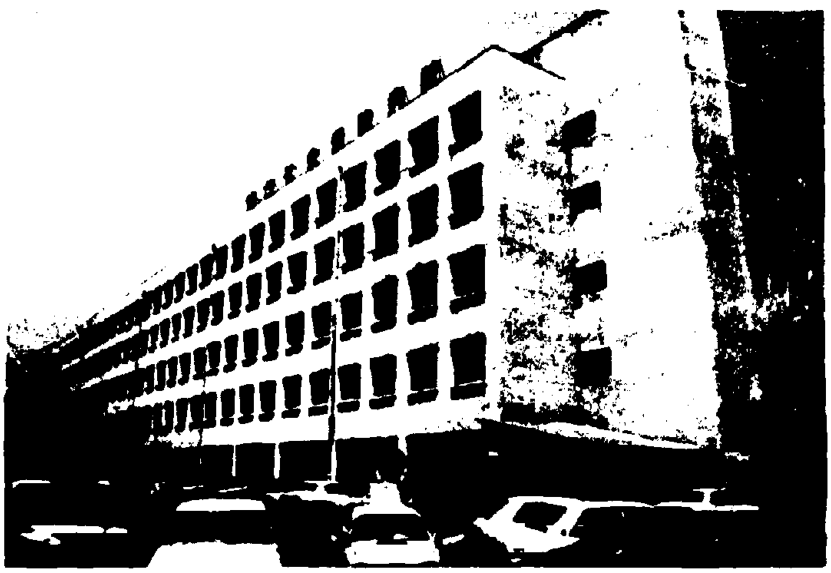

Figure 30 Sendai Social Insurance Hospital.

The main building of the Sendai Social Insurance Hospital is a 5-story reinforced concrete frame structure built in 1968. Administration is housed in a temporary 2-story light steel prefabricated building while a new building is under construction. The building is owned by the government; a private organization runs the hospital.

No damage beyond slight cracks along the staircase was suffered by the building. Elevators suffered no damage although they stopped because of power failure. (No one was in the cars at the time.) The building's emergency power system is sufficient for lights and for the operating room but not for the elevators. Because of the earthquake, two additional emergency patients entered the hospital. Electricity was available for life support systems. In the pharmacy, some bottles and an ice maker fell down and were damaged, but no dangerous items were involved.

The hospital draws two-thirds of its water supply from wells and one-third from the city supply. The well pumps did not operate due to power failure, and power was not restored until 12:45 am, so water usage was cut back one-third. The supply pipe for city water was not damaged; however, there is an emergency tank on the roof, adequate for five hours of limited usage. No drain damage was experienced: some sewer damage was caused by ground settlement, but the sewer remained usable.

The hospital administrator said he was considering three changes in safety procedures: to increase emergency electrical supply, to increase the emergency water supply, and to provide larger battery capacity in the emergency panel.

Miscellaneous Observations on Configuration

The buildings pictured below were damaged slightly or not at all by the earthquake. In each case, the building exhibited interesting architectural treatment.

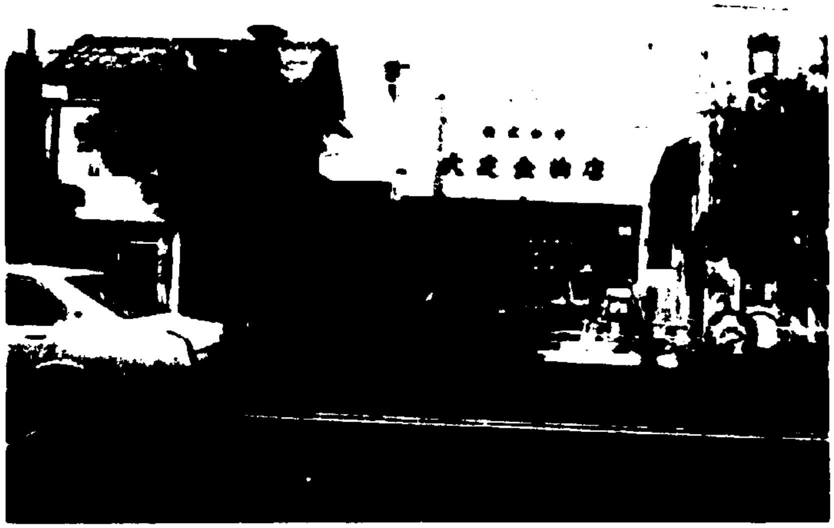

Figure 31 Distortion of open store front (opposite Toko Store, Figure 17), showing classic effect of open, unbraced elevation in light-weight building.

Figure 32 Gasoline station, downtown Sendai, undamaged. Building is highly asymmetric because of party wall and allowance for pump access. Note stout, closely spaced columns; building may well be dynamically symmetrical.

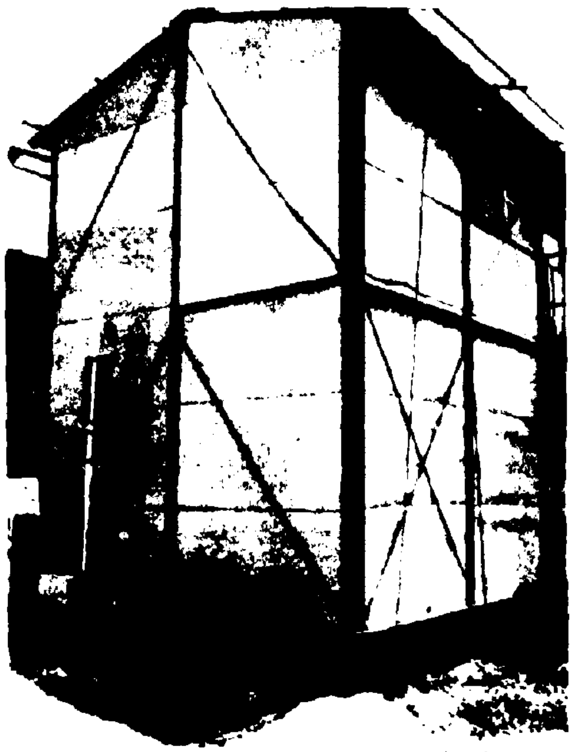

Figure 33 Temporary structure, Sendai Social Insurance Hospital. Note distortion of bracing and foundation posts.

Structures similar to those shown in Figure 33 were in frequent use as construction shacks around Sendai. The demountable light steel frame is wire braced and has a nonstructural infill panel. The structure shown at the Social Insurance Hospital was a contractor's shack. A similar structure was in use as a 2-story administration wing for the hospital while a new building is being completed.

Figure 34 Fire station, Tohoku Oil Co. Typical fire station with open front and solid sides. Note that sides are built as braced-frame structures rather than with heavy shear walls.

Figure 35 U.S. Embassy, Tokyo. During the Sendai, and other earthquakes, eyewitnesses who were inside the Embassy reported large (estimated 12-inch) movements of this building. Note that this building has a partially open first floor with long columns. However, the columns are tied at each floor, which results in a stiffness comparable to that of the shorter columns at the other end of the site.

Acknowledgements

The author would like to acknowledge the invaluable assistance received from Dr. Makoto Watabe of the Building Research Institute, Ministry of Construction, Tokyo, host of our visit, and from his colleagues. In addition, at Sendai, Professor Akenori Shibata and his colleagues at Tohoku University provided invaluable assistance. Dr. Yuji Ishiyama, from the Building Research Institute, stayed with us during the entire visit, acting as organizer and interpreter, and we were also accompanied for two days in Sendai by Dr. Shunsuke Sugano, Chief Research Engineer of the Second Research Department, Technical Research Laboratory, Tanaka Komuten Co., Ltd. Dr. Ebert A. Ashby, National Science Foundation representative at the American Embassy, Tokyo, and his staff, were most effective in handling logistical arrangements. Finally, I would like to acknowledge the technical guidance of my U.S. colleagues on the visit, Drs. Mete Sozen, Steven Mahin, Anshel Schiff, and Robert Waller.

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SOCIAL EFFECTS AND GOVERNMENT RESPONSE

by Hugh H. Fowler
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Department of Housing and Urban Development
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Population

Miyagi Prefecture has a population of about 1.9 million, of which approximately 650,000 reside in Sendai. Another million people live in the suburbs of Sendai or in nearby cities and villages. This section of Japan is quite mountainous, and only the coastal plains and mountain valleys are inhabited. The population is much more densely concentrated than is common for cities in the United States. The City of Sendai, with a population of 650,000, is compressed into an area that is probably about one-third the size of Seattle, Washington, which has about the same population.

Casualties

The earthquake caused 27 deaths: 17 resulted from falling rock or cinder block from fence walls or from collapse of the fences, 7 more were caused by other falling objects or collapsing structures, and 3 were the result of physiological effects such as shock and heart failure. Nearly all fatalities occurred in or near Sendai.

As of June 28, 1978, records showed that 1,590 injuries had been caused by the earthquake. Injuries such as cuts and broken bones accounted for more than half of the total. More than 200 of the injured were treated by doctors on the spot. The others were taken to hospitals and clinics by ambulance or in private cars. Because treatment facilities available were able to accommodate all of the injured, triage was not necessary.

Damage

There are about 6,500 business and manufacturing firms and about 452,000 households (homes and apartments) in Miyagi Prefecture. In Miyagi Prefecture, 803 dwellings were destroyed (309 in Sendai). Major causes of the destruction were landslides, inadequate foundations, and inadequate lateral bracing. A number of 2- to 4-story apartment buildings were rendered uninhabitable when their first floors, which housed shops or parking space, collapsed.

According to data compiled by the National Land Agency, the earthquake caused damage amounting to 166 billion yen ($830 million). A detailed outline of the various types of damage and the economic loss that resulted is presented at the end of this chapter. In some cases the amounts listed represent the cost of replacing a building or facility with a modern structure even though the damage caused by the earthquake could be repaired at a lower cost. Almost half of the total damage estimate represents the cost of repairing or replacing factories, stores, and other business establishments.

Most buildings in Japan have tile roofs. Literally thousands were damaged this was the most apparent type of damage in the area. (Tile falling from roofs caused a number of injuries.) Item 9 of Table 1 indicates that 20,634 structures were flooded. Sendai City and Miyagi Prefecture officials reported that only four homes were flooded as a direct result of the earthquake. Because of the extensive roof damage, and because the area received heavy rains after June 12, it may be that secondary water damage is reflected in the table.

In considering the damage, one must understand the topography and construction siting areas in and near Sendai. Sendai has three distinct areas: the old (original) city, which is centrally situated on solid level ground; a newer section on the eastern side, toward the coast, much of which is constructed on soft, flat ground (some of which includes fill areas); and an area of hills to the north and west, where people have constructed homes and buildings on terraces. Damage and losses were much greater in the soft and hill areas than in the old section.

In the hill areas, unstable fill surfaces in combination with saturated soil caused many landslides. Cracks, mostly associated with the landslides, formed in the terraced ground where houses and apartment buildings were built. According to officials, a total of 337 landslides occurred throughout the Prefecture.

Liquefaction in conjunction with inadequate foundations contributed to heavy damage in the flat (soft) area. Reports of dike and levee subsidence were verified in many areas along streams. At Nokahura, which is near Sendai, a dike that was originally 7 to 8 m high settled 1.5 m because of liquefaction.

Reinforced concrete buildings, bridge piers, and bridge abutments settled and sustained damage in many areas due to liquefaction and inadequate footings. Soft soil layers under reinforced concrete structures contributed to much of the damage. It is interesting to note that damage to buildings from north-south shaking motion was often noticeably more severe and extensive than damage from east-west movement. Steel-frame buildings by and large survived the earthquake better than reinforced concrete structures. Some lost facades and windows, and only one collapsed. Older buildings constructed of wood frames were damaged because of inadequate lateral bracing.

A major oil refinery in the port area of Sendai, containing 98 storage tanks of varying sizes, suffered damage when three large tanks containing fuel oil sprang leaks. Several million gallons of oil flooded the refinery area, and some reached the waterway serving the port.

The major cause of deaths and injuries from the earthquake was collapsing or falling walls made of stone or cinderblock. These structures serve as fences, privacy walls, and noise barriers. There is a National Code that requires that walls of this kind that are over 1-1/2 m high must be reinforced in both directions with steel rod. (The rod must be at least 9 mm in diameter and must consist of an 80-cm grid across and down the wall.) Some of the walls that fell contained reinforcing that did not meet the code. More fatalities resulted from walls that contained inadequate reinforcing than from those with none: those with no reinforcement tended to crumble, while those with inadequate reinforcing toppled on people who were nearby or who held onto them for stability as the earthquake occurred.

Public Facilities, Services, and Lifelines

Effects of the earthquake on so-called critical facilities, on public services, and on other vital activities were varied. In some cases, functioning was interrupted only temporarily, in other cases, the impact on segments of the population lasted for several weeks.

Law Enforcement and Emergency Services. Only slight damage was sustained by police facilities. The police communication system played a vital role in maintaining order and dispersing factual information immediately after the earthquake. Fire service facilities, also, received little damage, and units had no difficulty coping with the few (10) fires that started.

Of the 41 hospitals in the prefecture (27 in Sendai), several sustained varying amounts of damage. The natural gas and electricity outage interfered with medical services. However, there were no reported problems with overloading because of the influx of injured to the city for treatment.

Transportation. The National Railway stopped all train service in the area immediately after the earthquake to insure against accidents and to assess damage to the system. Service was restored quite soon, after repairs were made and the safety of the line and its control systems was ascertained. Public bus service in Sendai was hampered in the hours immediately following the earthquake because of traffic light failure. Air service between Sendai and other points was quickly restored after airport officials assessed damage and found that safe service could commence.

Utilities. Damage to the natural gas distribution system in Miyagi Prefecture was a major recovery problem. Gas distribution systems in six cities were severely affected. About 60% of the 200,000 households in Sendai are dependent on gas for heating and cooking. As of June 28, 1978, 22,000 of those households as well as 10,419 households in other cities of the prefecture were still without gas.

Electrical service to 419,100 homes in the prefecture was interrupted. For the most part, service was restored within a day or two. Few distribution line poles were toppled. Two electrical generating plants serving Sendai were out of operation. One of those plants, located near the oil refinery at the port, depended upon fuel from the one refinery that was rendered inoperative. The other, located in north Sendai, was rendered inoperative when the city's storage plant for low-pressure gas caught fire and service had to be terminated. Electrical power from other areas and facilities was diverted and at the time of the reconnaissance was meeting the needs of Sendai, although several factories in the prefecture were still without power.

Within the prefecture, there are about 50 separate water and sewage conveyance systems, most of which are publicly owned. Prefecture officials estimated the damage to these systems, all of which had been restored by June 25, 1978, at about $30,000,000. Several lift station pumps had to be replaced. Damage to sewer lines in Sendai was minimal; however, until electricity had been restored, the system was partially inoperative. Several nuclear electrical generating plants are located near Miyagi Prefecture. It is interesting to note that none experienced any significant earthquake-related problems or damage.

Communications. All telephone service in Sendai and in the surrounding areas was interrupted from 5:14 p.m. until 8:00 p.m. on June 12, 1978. By 8:00 p.m., 50% of the service in the Sendai area and 75% of the service in areas north of Tokyo had been restored. The disruption extended as far south as Tokyo.

With the loss of electricity, all television and radio stations were unable to broadcast. Several came back on the air soon afterwards by using emergency generators and performed an important service by broadcasting factual information provided by the police and local government officials. However, because most of the population was without electrical service, only those people with battery-powered transistor radios could receive emergency information. (No formal emergency broadcast system exists in Japan.)

Response

Immediately after the earthquake, government officials in Tokyo (national), in Sendai (prefectural and city), and in other affected communities met to take emergency-response action and to plan recovery measures. Sendai established a Disaster Countermeasures Headquarters headed by the Mayor. Included in this group were representatives of the National Railway; water, gas, and electric utilities; the police and fire departments; the Red Cross; and others. This headquarters remained operational for 24 hours a day immediately after the earthquake. It was still in operation on June 27, 1978. Actual response activities are the City of Sendai's responsibility. If an emergency is beyond the means of their resources, City officials may request additional services or financial help from the prefectural or national government.

With regard to food supplies and distribution of emergency rations, the Governor of the Prefecture activated a Headquarters for Self-Sufficiency for the purpose of monitoring food supplies and prices as well as to insure the availability of other items necessary for the populace to survive and recover. Among the tasks the Headquarters performed were:

- Checking on regional and central wholesale markets
- Checking on bread and diary products
- Checking department and food stores
- Arranging for additional propane bottles and burners
- Monitoring the supply of electric cells (batteries) for flashlights
- Requesting cooperation from the sales industry to maintain stable prices (prices of some critical items actually were lowered during the emergency period)
- Receiving and considering consumer complaints
- Providing propane burners and fuel to handicapped centers
- Providing coordination with producers and suppliers of lumber, glass, concrete, and other building supplies to insure that adequate stocks were available where needed
- Coordinating with National Government officials in Tokyo when necessary

The headquarters used the media to the fullest extent possible to broadcast factual information concerning supplies and prices. Close daily contact was maintained with 30 designated stores in the area to monitor events.

The police force played a key role in maintaining order and providing information to the populace. Because the lack of electric power limited the effectiveness of the mass media, police used loudspeakers on vehicles. By 8:30 p.m. on June 12, more than 7,000 people had gathered at the Sendai train station (all trains had stopped after the earthquake). The police moved in portable generators, set up lights, and used loudspeakers to provide information. By keeping them informed about the likelihood of tsunami or another earthquake and about the damage situation, authorities were able to calm the public and avert panic. By 9:30 p.m., all but 600 of the crowd had dispersed.

A traffic control center was set up immediately after the earthquake to handle the severe traffic problem. Crowds of people and vehicles had gathered at crossings. To deal with this the following measures were taken:

- All available police were ordered to duty.
- The traffic control center monitored critical areas and dispatched police to handle problems.

- Loudspeakers were used effectively to inform the public.

The damage caused by the earthquake had been judged not great enougn for the Prime Minister to issue a National State of Emergency declaration for the Miyagi Prefecture. Article 105 of the Disaster Countermeasures Basic Law provides the basis for issuance of such a declaration. Officials of the Ministry of Construction have visited Miyagi Prefecture to assess the damage caused by the earthquake. On the basis of their assessment, the National Government will determine the amount of national funds to be provided (usually two-thirds of the cost, with the remaining third to be borne by the prefecture).

Japan has a Disaster Relief Act, which is administered by the Ministry of Health and Welfare. Under this authority, which does not require a declaration by the Prime Minister of a National State of Emergency in order to act, relief was approved for two cities and four towns. Each municipality (or prefecture) submits a request, accompanied by data, photographs, and loss statistics, to the National Government. Included as benefits under the Act are low-interest loans (5.05%) to replace buildings of wood construction. The period of repayment can be extended to 25 years. Homeowners with existing loans on their property are not eligible for much assistance under the Disaster Relief Act other than a low-interest loan. This means that they would need to carry two loan payments. City of Sendai and Miyagi Prefecture officials are trying to get national funding to cover the initial loan balance.

The prefecture disaster plan provides that local government heads can request military support and assistance (from the Self-Defense Force). Between June 12 and June 19, such help was requested by and provided to six cities and seven towns. A total of 2,117 military personnel were involved in supplying water to people in areas where normal systems were not operative. They were also instrumental in saving three lives.

Two factors influenced the need for evacuation: the danger of a tsunami and the unsafe conditions caused by the earthquake damage.

A tsunami warning was issued at 5:21 p.m. on June 12. The actual order to evacuate must be given by a mayor or other head of government. The Sendai mayor did not order an evacuation but did issue a warning. Local officials in other coastal communities did issue evacuation orders, and more than 20,000 people moved inland. The "all clear" was received at 8:15 p.m., and those who had left their homes were permitted to return.

Evacuation was necessary to protect people whose homes had been destroyed or judged unsafe for habitation. Approximately 70 families were ordered from their homes in the hill areas of Sendai because of continuing danger of landslides.

Most displaced, evacuated individuals and families stayed with relatives and friends. However, the City and Prefecture response plans provide for the use of schools, hospitals, and other public buildings as shelters. Under extreme conditions, the National Defense Force can provide tents or other types of shelter for transient population.

Little search-and-rescue activity was associated with the earthquake. Lifesaving measures were performed as necessary by fire and police forces working in the Fire Defense Headquarters, established in affected municipalities immediately after the quake. Two apartment buildings were involved when their first floors collapsed, and evacuation of the occupants of other floors required the assistance of fire departments. The National Self Defense Force assisted in locating the body of a missing person. Two other bodies were recovered by neighborhood groups.

The City of Sendai has five rescue teams on alert at all times. When the earthquake occurred and electrical power was lost, the traffic signal system (there are more than 400 signals in the city) became inoperative. Major traffic congestion developed at most intersections, and ambulances were able to respond to only 24 of the more than 200 calls for aid. A central emergency facility, where people could obtain medical treatment, was quickly established in Sendai. Hospitals activated an emergency medical information center, which consisted of computerized data on doctors, hospital bed space, ambulances, etc.

On June 25, only 705 people (in three cities and nine towns) remained in shelters. Sites used for shelters included school gymnasiums, citizens halls, and other public facilities. Emergency rations were distributed by volunteer agencies. The Japanese Red Cross was not asked to participate in the emergency-response or recovery phases of this disaster.

Because both gas and electricity were lacking in many homes, people bought food that did not require cooking. Stores received additional quantities of precooked foods from areas not affected by the earthquake. Fortunately, most grocery stores and markets in the area remained intact, and there was ready access for shopping. Food prices remained stable despite the heavy demand for particular types of food. Because most homes depend upon gas for cooking and heating, the Sendai Gas Company (public) distributed portable gas heaters for purchase at less than cost.

More than 300 homes in Sendai were destroyed. Under certain conditions, the local and prefectural governments may construct prefabricated dwellings for those who lose their homes.

Approximately 70 such dwellings were under construction in Sendai to provide shelter to those who did not have other means.

Neither the City of Sendai nor Miyagi Prefecture attempted to establish or maintain a locater service for missing persons. As soon as the radio and television stations resumed service, selected stations set aside an hour each day to broadcast names and messages. The telephone company also liberalized its use of phones to assist victims.

Reconstruction

New construction in Japan must conform with the Architectural Law, which contains special requirements to mitigate earthquake damage and is administered by the Ministry of Construction. Builders must submit plans to prefectural or larger municipal governments for review and approval before starting construction. With very few exceptions, buildings destroyed or seriously damaged had been constructed before the law was in effect.

The Sendai City and Miyagi Prefecture government formed a Reconstruction Planning Committee to insure that building replacement and repair will contribute toward safety. The committee includes representatives of higher education institutions, commercial and business concerns, industry, and the architectural profession. The Sendai Construction Bureau will insure that new construction in the City meets the requirements of the National Building Code.

Insurance

Unemployment Insurance. Although manufacturing firms and business were hard hit by the earthquake, a large majority of those whose jobs were affected were back at work soon after the earthquake. Some manufacturers who were operating on a marginal basis had not reopened at the time of the reconnaissance; the workers affected were drawing unemployment insurance.

Earthquake Insurance. There are at least two types of earthquake insurance available in Japan. Both are expensive.

One type of protection, available to a farmers association, covers 100% of the damage up to a maximum of 25,000,000 yen. Lesser amounts of coverage can be obtained.

The other (major) type of earthquake insurance is a plan that is endorsed and guaranteed by the government. This program was initiated five years ago but has not met with general acceptance. What appear to be major limitations are its high cost and the limitations on coverage. The maximum coverage for goods is 1.5 million yen ($7,500); the maximum coverage for homes is 2.4 million yen ($12,000). (The average home in Japan costs 15 to 20 million yen.) Both city and prefectural officials in Sendai stated that they felt there is a need to equalize the program. It was their consensus that the insurance program will become popular if coverage can be increased and rates adjusted. This type of insurance is required of those who request and receive low-interest disaster-relief loans.

Conclusions

The 1977 Disaster Countermeasures Act of Japan, administered by the National Land Agency, requires that each level of government have a plan and a competent organization for dealing with disasters. The rapid and effective response by all levels of government (national, prefectural, and municipal) towards alleviating the affects of the earthquake was the result of a unified, integrated program of disaster preparedness and response.

The amount of recovery work accomplished or under way within two weeks after the earthquake occurred was impressive. The speed and efficiency with which a vast amount of work had been performed was most admirable. Officials responsible for directing operations and others working to accomplish the monumental task of recovery exhibited unusual industry and knowledge about the problems they faced and how to solve them. All, without exception, devoted their efforts exclusively to serving the needs of the people and communities that were adversely affected.

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Table 1 Outline of Preliminary Damage from June 12, 1978, Miyagi-Ken-oki Earthquake

		Quantity	Value (million $)	
1.	Dead	27	--	
2.	Missing	0	--	
3.	Injured	1,052	--	
4.	Households suffering damage	3,477	--	
5.	Individuals suffering damage	13,768	--	
6.	Buildings wholly destroyed or burned or washed away	803	--	
7.	Partially destroyed buildings	5,227	108.0	
8.	Partially damaged buildings	58,927	--	
9.	Flooded buildings	20,634	31.0	
	Subtotal			139.0
10.	Hospitals	119	1.7	
11.	Clinics	194	0.2	
12.	Medical equipment	735	1.0	
13.	Water works	--	4.8	
14.	Sanitation facilities	29	5.3	
15.	Other sanitation facilities	33	7.4	
	Subtotal			20.4
16.	Factories and stores	55,078	455.0	
17.	Other business establishments			
	Subtotal			455.0
18.	Paddy fields (ha)	5.5	0.3	
19.	Fields or farms (ha)	--	--	
20.	Agricultural facilities	535	24.1	
	Subtotal			24.5
21.	Farm produce (ha)	541.1	1.1	
22.	Joint-use facilities	424	5.8	
	Subtotal			6.9
23.	Livestock	2,100	--	
24.	Livestock facilities	35	0.6	
25.	Livestock products	3	--	
	Subtotal			0.6
26.	Sericultural (silkworm) facilities	12	--	
27.	Fishing boats	17	--	
28.	Fishing port facilities	109	13.5	
29.	Fishery and aquaculture facilities	341	5.0	
30.	Fishery products	--	0.2	
31.	Fishing equipment	64	--	
	Subtotal			18.9
32.	Forest land, roads	56	1.6	
33.	Forestry facilities	38	0.9	
34.	Forestry products	6	0.1	
	Subtotal			2.6
35.	Primary schools	367	7.0	
36.	Middle schools	170	2.1	
37.	High schools	102	7.0	

		Quantity	Value (million $)	
38.	Other schools	323	14.7	
39.	Cultural assets	22	1.2	
	Subtotal			33.2
40.	Roads (s .es of damage)	720	16.8	
41.	Bridges	65	32.1	
42.	Rivers (sites of damage)	115	6.6	
43.	Shores	5	1.1	
44	Erosion control facilities	12	1.7	
45.	Ports and harbors	85	7.6	
	Subtotal			66.0
46.	Railways	--	34.8	
47.	Electrical facilities	--	13.7	
48.	Communications facilities (sites of damage)	2,660	2.3	
49.	Social welfare facilities	166	3.0	
50.	Urban facilities	76	4.1	
51.	Gas facilities	53	2.0	
52.	Other facilities	231	3.1	
	Subtotal			62.8
	Total loss			830.0

Number of people evacuated by order or recommendation	26,017
Number of communities where headquarters for disaster countermeasures were set up	56