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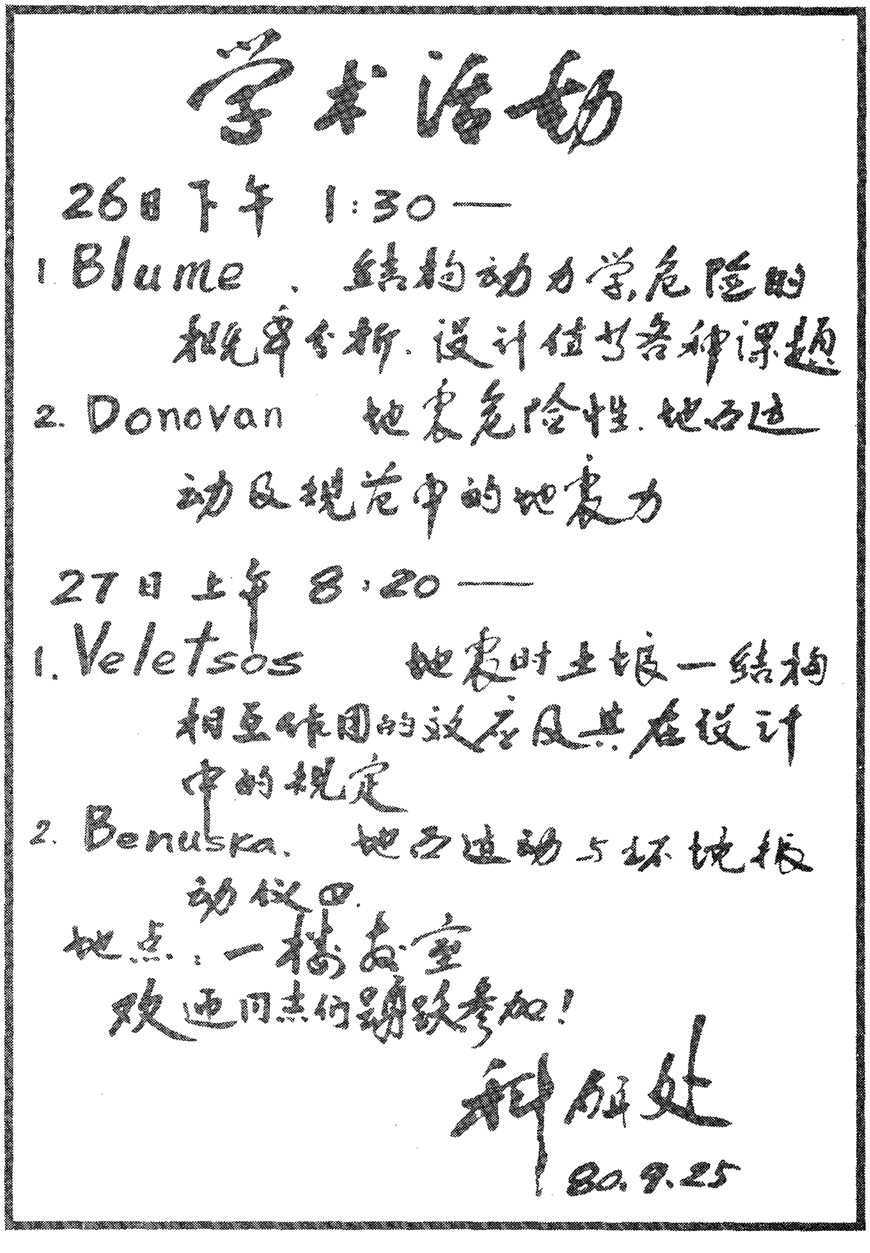
**Earthquake Engineering
Research Institute**



学术活动

26日下午 1:30—

1. Blume、结构动力学危险的概率分析．设计值与各种课题

2. Donovan 地震危险性．地面运动及规范中的地震力

27日上午 8:20—

1. Veletsos 地震时土壤—结构相互作用的效应及其在设计中的规定

2. Benuska. 地面运动与环境振动仪器．

地点：一楼会室

欢迎同志们踊跃参加！

科研处

80.9.25

EERI DELEGATION TO THE PEOPLE'S REPUBLIC OF CHINA

(September 19 to October 6, 1980)

January 1982

INFORMATION RESOURCES
NATIONAL SCIENCE FOUNDATION

Note: The photo on the front cover is an announcement of the lectures given at the Institute of Engineering Mechanics, Harbin. The translation is given below.

SEMINAR

26 September at 1:30 p.m.
1. Blume: Structural Dynamics, Risk Analysis, Design, and Other Discussions
2. Donovan: Earthquake Hazards, Ground Motion, Building Code Requirements

27 September at 8:20 a.m.
1. Veletsos: Soil-Structure Interaction and Design Specifications in the Building Code
2. Benuska: Ground Motion Instrumentation

Published by

The Earthquake Engineering Research Institute, a nonprofit corporation for the development and dissemination of knowledge on the problems of destructive earthquakes.

Copies of this report may be obtained from:

Earthquake Engineering Research Institute
2620 Telegraph Avenue
Berkeley, California 94704

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16. Abstract (Limit: 200 words)

A tour taken by American earthquake engineering experts to the People's Republic of China (PRC) in September and October of 1980 is documented. The objective of the visit was to implement the Agreement on Cooperation in Science and Technology between the U.S. and the PRC. An itinerary and a list of tour members are provided. Earthquake engineering education, research, and practice in the PRC were studied. Considerable emphasis in the PRC is placed on practice-oriented research that permits immediate application of research results to ground motion and structural response evaluations, engineering designs, and construction practices. In building research, improving the design and construction of single-story and multistory brick and reinforced concrete buildings is stressed. A large amount of research is conducted on cyclic response characteristics of reinforced concrete elements and structures as well as on precast, prestressed beam and slab elements, and their connections to either precast or cast-in-place columns. A partial list of experts met during the tour in the PRC is included.

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Reinforced concrete
Masonry
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People's Republic of China
PRC
J.A. Blume, /PI

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EERI DELEGATION TO THE PEOPLE'S REPUBLIC OF CHINA

(September 19 to October 6, 1980)

An Information Exchange in Earthquake Engineering and Practice

Roger E. Scholl
Editor

January 1982

Earthquake Engineering
Research Institute

with support from
The National Science Foundation

CONTENTS

APPENDICES

ACKNOWLEDGMENTS

The success of the Earthquake Engineering Research Institute (EERI) delegation's tour of the People's Republic of China (PRC) is a result of the cooperative effort of several persons representing several organizations. Dr. S. C. Liu of the U.S. National Science Foundation deserves special credit for first envisioning this exchange and for making the initial contacts with officials in the PRC. Special credit is also due the National Science Foundation, through the office of Dr. William W. Hakala, for providing the financial support necessary.

Several people at the State Capital Construction Commission (SCCC) in the PRC deserve special acknowledgment. Mr. Li Jingzhou, Vice Minister of the SCCC extended the invitation to EERI and hosted the delegation in the PRC. Mr. Ye Yaoxian, Vice Director of the Office of Earthquake Resistance of the SCCC, and Mr. Lin Li, a staff interpreter for the SCCC, provided competent and courteous guidance during the entire tour of the PRC. Mrs. Nie Fenglan and Mrs. Ning Ho interpreted for the delegation during our week-long stay in Beijing.

Finally, we extend our appreciation to the EERI Board of Directors for making this tour possible and to the EERI Ad Hoc Selection Committee for their efforts in selecting the delegates.

John A. Blume
Delegation Leader

EXECUTIVE SUMMARY

From September 19, 1980, through October 6, 1980, a delegation of eleven U.S. earthquake engineering specialists, sponsored by the Earthquake Engineering Research Institute (EERI), toured the People's Republic of China (PRC) for the purpose of expanding cooperation between the two countries in the field of earthquake engineering.

The specific objective of the visit was to expedite implementation of the Agreement on Cooperation in Science and Technology between the U.S. and the PRC signed by President Jimmy Carter and Vice Premier Deng Xiaoping in January 1979 and more specifically to put into effect the Implementing Protocol in earthquake research signed by the U.S. and the PRC in January 1980. These objectives were to be achieved by familiarizing the delegation with earthquake-resistant design, construction practices, and research in the PRC; and by acquainting the U.S. earthquake experts with their counterparts in the PRC. In addition, each of the delegates lectured on his particular field of expertise to at least one Chinese audience.

The delegation included specialists representing most of the disciplines involved in earthquake engineering and was composed of private-sector representatives from both academic institutions and private practice. The members of the delegation were:

John A. Blume (Delegation Leader)
Chairman of the Board
URS/John A. Blume & Associates,
Engineers
San Francisco, California

Kalman Lee Benuska
Vice President
Kinemetrics, Inc.
Pasadena, California

Neville C. Donovan
Partner
Dames & Moore
San Francisco, California

Robert D. Hanson
Chairman
Department of Civil Engineering
University of Michigan
Ann Arbor, Michigan

Roy G. Johnston
Vice President
Brandow & Johnston Associates
Los Angeles, California

Willard O. Keightley
Professor
Department of Civil Engineering
and Engineering Mechanics
State University of Montana
Bozeman, Montana

Helmut Krawinkler
Associate Professor
Department of Civil Engineering
Stanford University
Stanford, California

Henry J. Lagorio
Associate Dean for Research
College of Environmental Design
University of California
Berkeley, California

Roger E. Scholl
Technical Director
Earthquake Engineering Research Institute
Berkeley, California

Anestis S. Veletsos
Brown & Root Professor
Department of Civil Engineering
Rice University
Houston, Texas

Leon Ru-Liang Wang
Professor
School of Civil Engineering and Environmental Science
University of Oklahoma
Norman, Oklahoma

The State Capital Construction Commission (SCCC) of the PRC sponsored and hosted the delegation. The SCCC is responsible for construction financing, the implementation of earthquake-resistant design, and a large part of earthquake-resistant design research in the PRC. The delegation visited six cities in the PRC: Beijing (Peking), Harbin, Tangshan, Tianjin (Tientsin), Shanghai, and Guangzhou (Canton). The tour included technical visits to model and large-scale earthquake test facilities, universities, construction sites, field (provincial) offices, damaged structures, strengthened structures, repaired structures, and ground-failure sites. The delegation also spent many hours in technical discussions with PRC earthquake engineers and researchers comparing research practices, design procedures, construction practices and procedures, codes and standards, and construction inspection practices.

During the tour the delegation was also given a wide variety of cultural and educational opportunities, including banquets, sight-seeing tours, shopping, live stage performances, visits to Chinese leisure spots, and tours of light and heavy industrial facilities and a power plant. These activities provided relaxation in a busy schedule, but they also made a significant contribution to the delegation's understanding of the Chinese people and their social customs.

The delegation's visit to the city of Tangshan was of particular significance. This city of one million inhabitants was essentially destroyed by the earthquake of 1976. A total of 242,000 fatalities was attributed to the earthquake

(148,000 in Tangshan alone), and all production in this industrial city was stopped by the earthquake. The delegation was given a description of the post-earthquake disaster relief measures, the process of constructing some 400,000 temporary housing units within four months of the earthquake, the master plan established for rebuilding the city, and finally the actual reconstruction. In addition, the delegation had the opportunity to visit some of the ruins that still reveal, as clearly as during the rescue work, the catastrophic result of nonearthquake-resistant structures subjected to strong ground shaking.

During the eighteen-day tour, the delegation was given an extensive view of earthquake engineering research and practice in the PRC and gained a broad awareness of the social and cultural milieu currently existing in the PRC. Individual delegates can speak knowledgeably about earthquake engineering research and practice in the PRC and can offer advice on how and where to best pursue specific cooperative activities.

In general, theoretical knowledge of earthquake-resistant design is quite advanced in the PRC and is virtually equal to current theory in the U.S. Actual design and construction practices are not on a par with those currently evident in the U.S., however. Practice often lags behind theory. The PRC has only recently decided to emphasize earthquake-resistant design. The current inadequacies in design and construction are the result of the extensive time required to get theory into practice. Certainly the U.S. could help minimize the lag time between advances in theory and their application in practice; in fact, many constructive suggestions were made during the tour.

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1. INTRODUCTION

The Earthquake Engineering Research Institute (EERI), the largest multidiscipline, private-sector organization of earthquake engineers and scientists in the United States, sent a delegation of U.S. earthquake engineering experts to tour the People's Republic of China (PRC) in September and October 1980. The purpose of the tour was to expedite implementation of the Agreement on Cooperation in Science and Technology between the U.S. and the PRC signed by President Jimmy Carter and Vice Premier Deng Xiaoping in January 1979 and to put into effect the Implementing Protocol in earthquake research signed by the U.S. and the PRC in January 1980.

The eleven-member EERI delegation, headed by Dr. John A. Blume, President of EERI, included persons representing the broad spectrum of disciplines involved in the field of earthquake engineering. A list of the delegates, including their positions and specialties, is given in Appendix A. Figure 1.1 is a photograph of the delegation.

BACKGROUND

Both the United States and PRC recognize the importance of earthquake research in reducing the destructive power of severe earthquakes. Although each country is engaged in independent earthquake research, the advantages of information exchange and of cooperative research are jointly acknowledged.

Bilateral exchanges between Chinese and U.S. earthquake scientists and engineers started about eight years ago and have increased rapidly over the last five years. Many of these exchange activities were supported by the Scholarly Exchange Program of the U.S. National Academy of Sciences (NAS). Under NAS sponsorship, two U.S. seismological teams and one earthquake engineering and hazard reduction team (Jennings, 1980) visited the PRC. Similar visits by Chinese earthquake engineering delegations to the United States were made at about the same time. Such exchanges and other visits to the PRC by individual U.S. scientists have considerably enhanced our understanding of common problems and deepened our knowledge of earthquake science and technology. These interactions have established a sound basis for engaging in mutually supportive research projects in this field.

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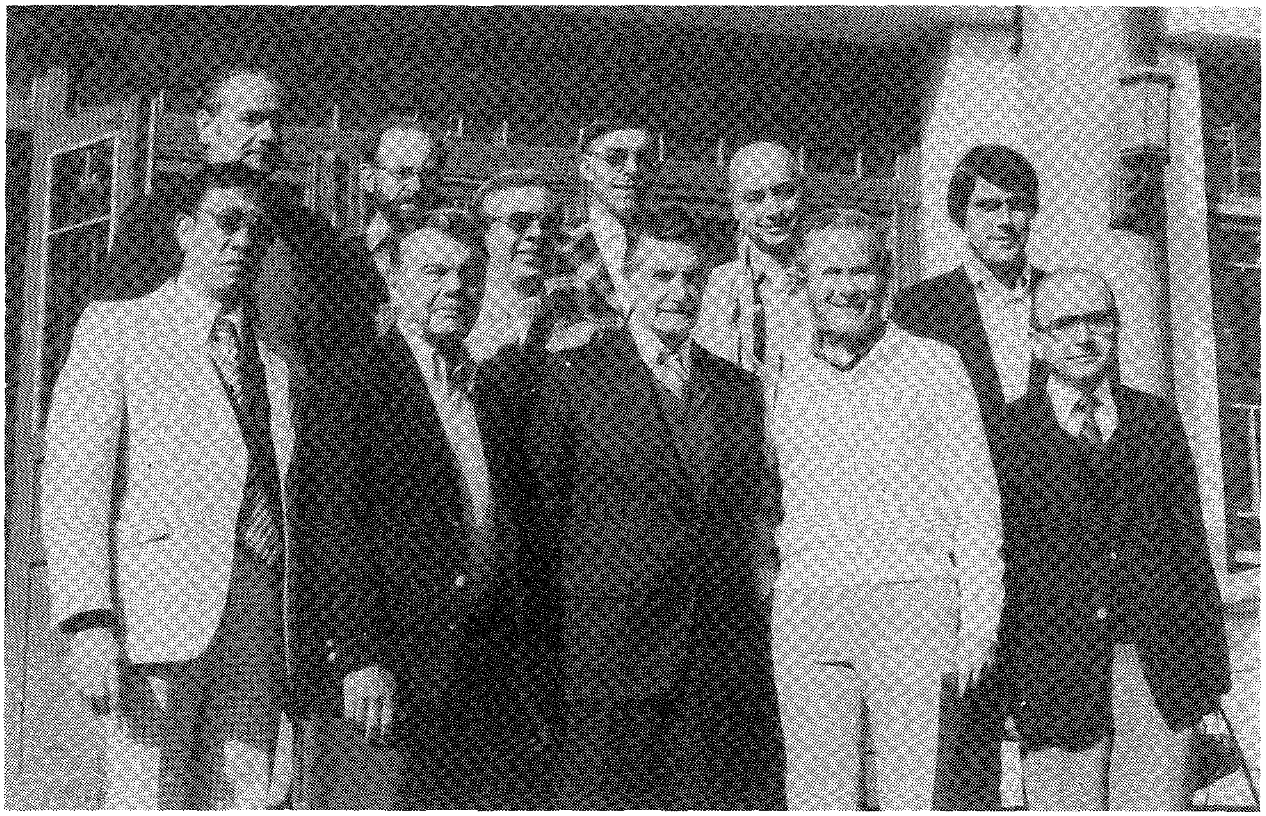

Figure 1.1 The Earthquake Engineering Research Institute delegation to the People's Republic of China. Back row, left to right: Henry J. Lagorio, Neville C. Donovan, Robert D. Hanson, Roger E. Scholl, Willard O. Keightley, and Kalman Lee Benuska. Front row, left to right: Leon Ru-Liang Wang, Roy G. Johnston, John A. Blume, Helmut Krawinkler, and Anestis S. Veletsos.

In July 1978, Dr. Richard C. Atkinson, Director of the National Science Foundation (NSF), and Dr. Frank Press, Director of the Office of Science and Technology Policy (OSTP), made an official visit to the PRC to discuss bilateral cooperative research. Consistent with the general opinion of scientists and government officials in both countries, earthquake research was selected as a promising area for joint research. While touring the United States, Dr. Chou Pei-Yuan, head of the delegation from the Chinese Education Mission, further confirmed PRC interest in conducting earthquake research jointly with the United States.

In Washington D.C. on January 31, 1979, President Jimmy Carter and Vice Premier Deng Xiaoping signed the U.S.-PRC Agreement on Cooperation in Science and Technology (the S&T Agreement). The S&T Agreement calls for the establishment of formal cooperative research programs in all areas of science and technology. Earth science is specifically identified as a fruitful area for cooperative research activities.

The U.S. executive agency in charge of administering the S&T Agreement, OSTP, approved a proposal by the U.S. Geological Survey (USGS) and NSF to establish a formal cooperative program in earthquake research between the U.S. and the PRC. This proposed program was formally established when representatives of USGS and NSF and a representative of the State Seismological Bureau (SSB) of the PRC signed an Implementing Protocol in January 1980. The protocol calls for the formation of a working group to coordinate earthquake research activities between the two countries. Although the U.S. working group is cochaired by representatives from USGS and NSF and draws many of its members from these and other government agencies, OSTP Director Frank Press has encouraged the inclusion of nongovernment members as well. A similar working group, headed by the SSB, was formed in the PRC.

PURPOSE AND SCOPE OF THE TOUR

The Implementing Protocol for earthquake research includes seven annexes that identify specific areas of cooperative research. Contact between scientists and engineers in the U.S. and those in the PRC is essential to the success of this venture and may help broaden the Protocol by generating new ideas for research. Toward this end, a delegation of ten earthquake engineers from the

PRC made a four-week scientific and technical tour of the United States during August and September 1979. The tour was coordinated by EERI and sponsored by NSF. The success of that tour prompted Li Jingzhou, Vice Minister of the State Capital Construction Commission (SCCC) and the head of the Chinese delegation, to invite EERI President John A. Blume to bring a group of U.S. earthquake engineers to the PRC for a reciprocal visit.

A thorough understanding of mutual research needs is essential to the successful implementation of the formal cooperative program in earthquake research. The PRC delegation that EERI hosted in 1979 made a significant contribution to knowledge of research needs in earthquake engineering in both the U.S. and the PRC (*The 1976 Tangshan, China, Earthquake*, 1980). Further expansion of this knowledge was the primary objective of the EERI delegation's tour of the PRC. To this end, the specific activities of the EERI delegation included:

- Exploring work in earthquake engineering in the PRC
- Renewing and expanding contacts with Chinese earthquake engineers
- Giving lectures on U.S. research, practice, and procedures in earthquake engineering

PURPOSE OF THIS REPORT

The primary objective of this report is to document the tour. Earthquake-related research and practice in the PRC has been previously documented by the American Seismology Delegation (1975), the Haicheng Earthquake Study Delegation (1977), and the Earthquake Engineering and Hazards Reduction Delegation (Jennings, 1980). To avoid unnecessary duplication, this report only discusses observations that go beyond those previously reported by other delegations.

2. TOUR ITINERARY

The tour began with a rendezvous in Tokyo, Japan, on September 17, 1980. It was not practical to assemble in the United States, since the tour followed the Seventh World Conference on Earthquake Engineering, which was held in Turkey. On September 18, we visited the new earthquake engineering research facilities at Tsukuba, Japan, and spent the evening in a briefing session.

At 8:35 a.m. on September 19, 1980, we departed Narita International Airport for Beijing. Our tour of the PRC included visits to six cities: Beijing, Harbin, Tangshan, Tianjin, Shanghai, and Guangzhou. In addition, a brief two-hour sight-seeing stop was made at Shanhaiguan. Figure 2.1 depicts the tour route. A general summary of activities in each of these cities follows, and a detailed itinerary is given in Appendix B.

BEIJING

Mr. Ye Yaoxian and Mrs. Nie Fenglan met us at the new Beijing airport. Both were known by many of us because they were members of the PRC delegation to the United States hosted by EERI in the fall of 1979. From the airport we took a bus for our one-hour trip to the SCCC Headquarters in Beijing. During our visit to Beijing, we stayed in a dormitory in the SCCC compound where everything was done to make us comfortable and keep us well nourished.

On the afternoon of the day we arrived, we were officially welcomed by our host, Mr. Li Jingzhou, Vice Minister of the SCCC. At that meeting, Vice Minister Li described the organization and operation of the SCCC for us. The SCCC is responsible for nearly all building construction and for the implementation of earthquake-resistant design in the PRC. In addition, Mr. Ye Yaoxian, Deputy Director of the Office of Earthquake Resistance (OER) of the SCCC, lectured on historical seismicity and earthquake losses experienced in the PRC, underscoring potential losses and the need for earthquake-resistant design.

The SCCC is actively encouraging the construction of improved earthquake-resistant structures in a multitude of ways. They have adopted a building

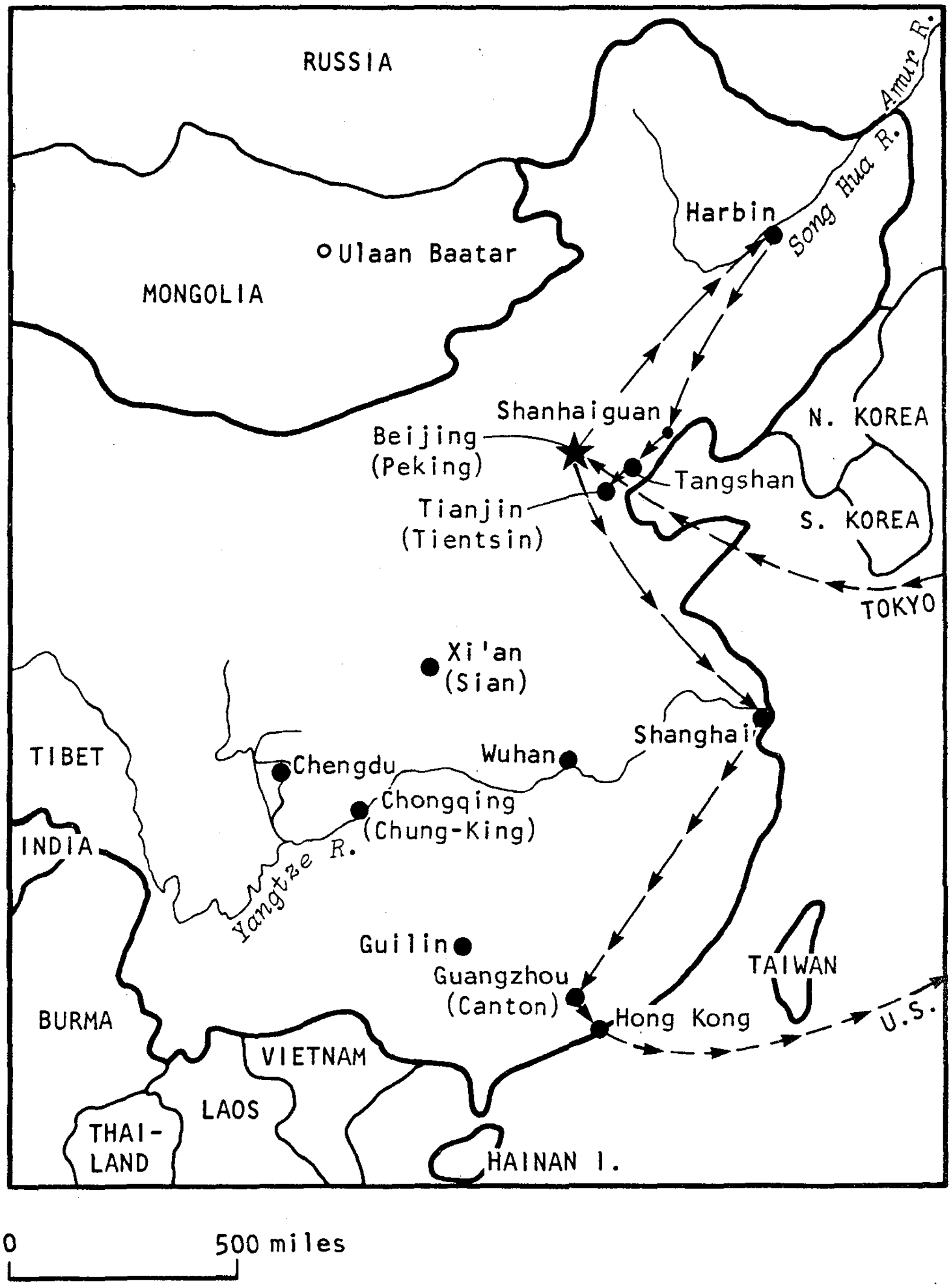

Figure 2.1 The tour route followed by the EERI delegation.

code and are supporting applied research at several academies throughout the PRC. In addition, the OER was created at SCCC Headquarters in Beijing and similar offices have been established at several of the provincial Capital Construction Commission Headquarters to ensure that earthquake-resistant procedures are developed and implemented.

The technical highlights of our six-day stay in Beijing included visits to Tsinghua University, the Chinese Academy of Building Research, the Institute of Hydraulics, and the SSB. Each of the delegates delivered a lecture in one of the office buildings at the SCCC complex.

HARBIN

The only technical exchange at Harbin was with the Institute of Engineering Mechanics (IEM). Mr. Liu Huxian, Director of IEM, met us at the airport and was our host during our stay there. The IEM has a long history of involvement (since about 1956) with earthquake engineering and has made a significant contribution to earthquake engineering in the PRC. The SCCC is currently emphasizing applied research activities in earthquake engineering, whereas the IEM emphasizes more basic and theoretical aspects of earthquake engineering research.

The technical highlights of our two-day stay in Harbin were an orientation to IEM activities by the IEM staff, a tour of the IEM laboratory facilities, and a visit to the construction site of a new hotel. Four of the delegates delivered talks here.

TANGSHAN

While the entire eighteen-day tour made significant impressions on each of the delegates, our visit to Tangshan was generally regarded as the singular highlight because of the devastating effect of the 1976 Tangshan earthquake and because so few have had the opportunity to visit the city since that time. Our delegation was the first large group to be invited to Tangshan since the 1976 earthquake.

The highlights of our visit to Tangshan included visits to earthquake ruins (in particular, the Institute of Mining and Metallurgy and the locomotive factory), reconstruction sites, new residential construction, and a reconstructed fossil-fueled power plant. Our Chinese hosts provided extensive descriptions of the effects of the earthquake, the post-earthquake disaster relief measures, reconstruction, and new city planning efforts and sponsored an exchange discussion of the construction procedures used in reconstruction. A detailed description of Tangshan is given in Chapter 3.

TIANJIN

Tianjin was also an important city to us because it sustained significant damage during the 1976 Tangshan earthquake. About 80% of the buildings in Tianjin were damaged. Tianjin is one of only three cities in the PRC to have provincial status. (The other two cities with provincial status are Beijing and Shanghai.) Accordingly, the city has a Capital Construction Commission and an Office of Earthquake Resistance within the Commission. The Office of Earthquake Resistance was our principal contact during our two-day stay in Tianjin.

The highlights of our visit to Tianjin included tours of pre-earthquake strengthened buildings, post-earthquake repaired and strengthened buildings, and buildings with unusual manifestations of earthquake damage (e.g., ground elongation that caused a building to tear apart).

SHANGHAI

At Shanghai we met with representatives from Tongji University. Tongji University specializes in civil engineering but also has a language department for those engineering students who choose to study a foreign language. The majority of the faculty at Tongji University speak German as their second language. German scientists have significantly influenced the university during the past several decades.

Our principal technical activities during our two-day visit to Shanghai included an orientation tour of Tongji University conducted by the staff, tours of the Tongji University Research Institute laboratory facilities (including their photoelasticity and large-scale model structural testing laboratories), and detailed discussions with University staff members on soil-structure interaction and engineering structures. For these discussions, which were conducted simultaneously, our delegation was divided into two groups according to expertise. Three of the delegates delivered lectures in Shanghai.

GUANGZHOU

The Guangzhou Capital Construction Commission was our host for our two-day stay in Guangzhou. Three of the delegates delivered lectures here, but we did not engage in any other technical activities.

DELEGATION LECTURES

We went to the PRC prepared to give talks on our special areas of expertise. At Beijing each of us gave his lecture. In Harbin, Blume, Benuska, Donovan, and Veletsos gave their lectures. Lectures were given by Hanson, Krawinkler, and Veletsos in Shanghai, and, in Guangzhou, Blume, Johnston, and Lagorio gave lectures. At our hosts' request, Blume, as team leader, gave lectures that were considerably longer than the other lectures, generally taking about 150 minutes with translation. Titles of the lectures are given below:

Name		Lecture
John A. Blume	Beijing:	Earthquake Engineering: Its History, Developments, and What It Needs Today
	Harbin:	On What We Have Learned from Earthquakes and from Research in Structural Dynamics and Risk Analysis
	Guangzhou:	Dynamic Properties and the Design of High-Rise Buildings
Kalman L. Benuska	Strong Motion and Ambient Vibration Instrumentation	
Neville C. Donovan	Seismic Risk, Ground Motion, and Code Forces	
Robert D. Hanson	Infilled Walls for Earthquake Strengthening	
Roy G. Johnston	Southern California Earthquake Design Laboratory	
Willard O. Keightley	Earthquake Resistance of Low-Cost Dwellings	
Helmut Krawinkler	Experimental Techniques in Earthquake Engineering Research	

Name	Lecture
Henry J. Lagorio	Urban Technology Options in Earthquake Hazard Reduction
Roger E. Scholl	Procedures and Data Bases for Assessing Seismic Risk in Urban Areas
Anestis S. Veletsos	Effects of Soil-Structure Interaction During Earthquakes and their Provisions in Design
Leon Ru-Liang Wang	Some Aspects of the Seismic-Resistant Design of Buried Pipelines

3. TANGSHAN, CHINA: A CITY DESTROYED BY EARTHQUAKE

> Unexpected, swift, and terrible was the blow that struck Tangshan in the predawn darkness of July 28, 1976. Persons who were sleeping peacefully at home with their families, with no premonition that the next day would be any different from the day before, suddenly found themselves confused, hurt, and bleeding in an unimaginable landscape of destruction, smothered in choking dust, the air rent by cries of terror, anguish, and pain. Frantically they called for loved ones and dug into the rubble with their hands, only too often to touch the unresponsive flesh of spouses, children, and parents crushed under the bricks, concrete slabs, and timbers that man piles up to make his places for living and working.

TANGSHAN PRIOR TO THE EARTHQUAKE

Tangshan is a major farming, industrial, and coal- and energy-producing center in Hopei Province. Industrial production in Tangshan includes steel, machinery, rolling stock, textiles, porcelain, and chemicals. Before the 1976 earthquake, Tangshan had a population of 1.06 million and was an urban center without any visible master plan. Its physical growth was uncontrolled, and new districts were randomly attached to the perimeters of the original urban center without even adjusting the street patterns. The transportation system was particularly complex, and it was extremely difficult to pass through and around the city. Few discernible routes existed for entering or leaving the city's major areas. Other services, including water, power, communications, gas, steam, and sewer systems, had been similarly constructed in an as-needed fashion. Prior to the 1976 earthquake, Tangshan existed as an urban center without the amenities of urban planning and design.

As is typical of many other Chinese cities, Tangshan was mainly a city of unreinforced masonry (brick) structures with heavy roofs. The engineered buildings that did exist were designed without seismic consideration. The maximum intensity expected in Tangshan was only 6 on the Chinese Intensity Scale (CIS),* and, for that intensity, the Chinese building code does not

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*The CIS consists of 12 degrees and corresponds approximately to the Modified Mercalli Intensity Scale. The CIS is used throughout for earthquake intensity unless otherwise stated.

require that seismic considerations be included in the design. Tangshan was the classic example of a disaster waiting to happen.

THE TANGSHAN EARTHQUAKE OF JULY 28, 1976

The Tangshan earthquake is one of the greatest disasters in history. The main shock occurred at 3:42 a.m. local time on July 28, 1976, almost beneath the city of Tangshan. The event was assigned a surface wave magnitude (M_S) of 7.8 (USGS, M 7.6). Figure 3.1 is a map showing the instrumental location of the main event with the aftershocks superimposed. The southwest to northeast trend of epicenters parallels the direction of a rupture band with an observed length of 10 km that extended northeast towards Tangshan, ending within the city itself. The observed surface movement was primarily horizontal in a right-lateral sense, with a maximum observed movement of 1.5 m. Detailed analyses by Chinese seismologists and geophysicists showed that the main shock was caused by a complicated fracture of an old fault, in an approximate northeasterly direction, with large right-lateral slip and some vertical movement (the southeastern side moved downward).

The main shock was followed by many aftershocks. Thirty aftershocks of magnitude greater than 4.0 occurred during the first three days. The largest of these aftershocks occurred at 6:45 p.m. on the same day as the main shock. This event, with a magnitude of 7.1, destroyed much of what had survived the main shock.

Man paid a high price that night for his ignorance of or lack of respect for the forces at work within the earth's crust. Out of a population of 1,060,000, Tangshan lost 148,000 -- one person out of seven. One person out of thirteen, 81,000, was seriously injured (1,700 of whom became paraplegics). Seven thousand families lost every member -- were completely wiped out. In the area of the locomotive works where shaking was especially intense, 25%, or 8,000, of the 32,000 members of the workers' families died. The factory manager, who showed us the ruins of the works, lost his wife, two children, and four other members of his immediate family. He was dug out of the ruins seven hours after the quake, one of only nine persons to survive out of the 43 who had lived in his apartment house. At the Institute of Mining and Metallurgy, almost half of the academic body of 2,000 students

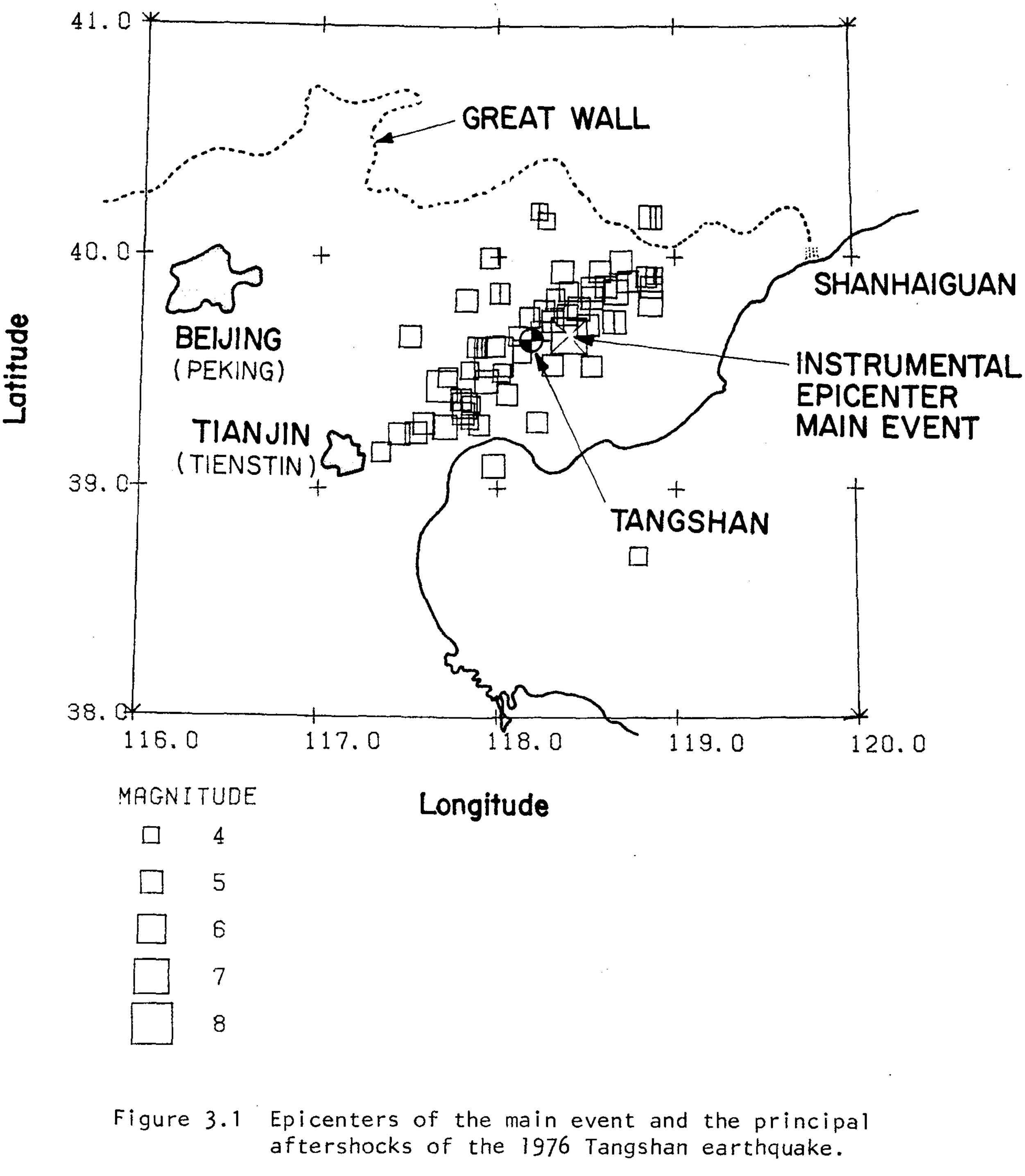


Figure 3.1 Epicenters of the main event and the principal aftershocks of the 1976 Tangshan earthquake.

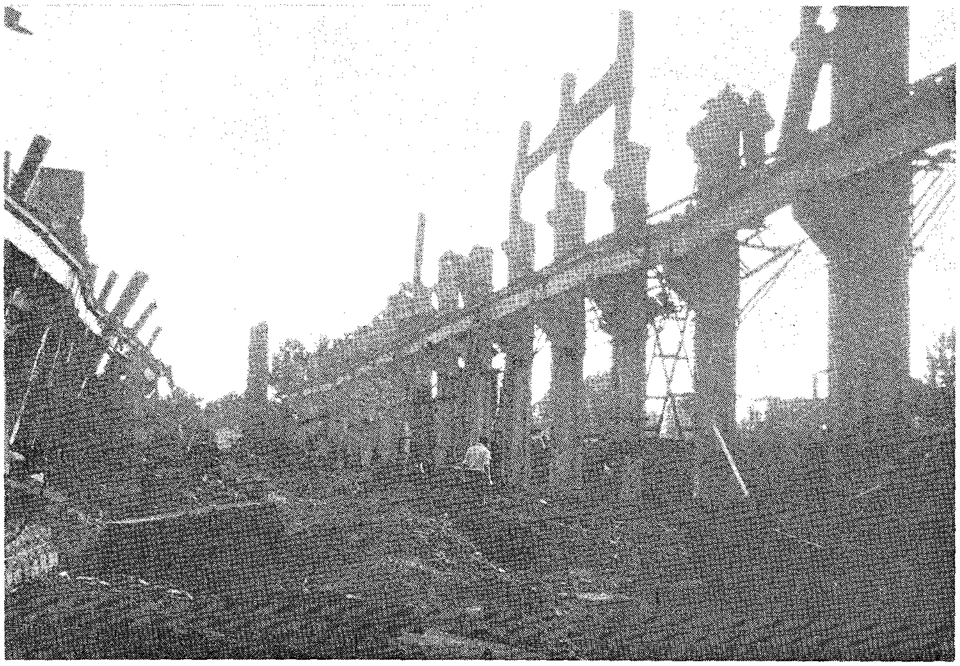
and 400 faculty were killed when almost all of the 30 buildings on the campus collapsed, destroying all laboratories and equipment, including the library, which caught on fire. Deaths in the entire area, including Tianjin 100 km away where over 1,000 died, totalled 242,000. This compares with 290,000 U.S. casualties in World War II. Figure 3.2 shows ruins of the locomotive works, the library at the Institute of Mining and Metallurgy, and a stadium, all of precast concrete frame construction. These ruins have been left standing as memorials of the catastrophe. Excellent photos and descriptions of the damage are given in Jennings (1980) and *The 1976 Tangshan, China, Earthquake* (1980).

More than 90% of the buildings in Tangshan were destroyed (98% of the residential structures), and most of the water and natural gas pipelines were ruptured; 60% of the highway bridges and 40% of the railway bridges were heavily damaged, most from being thrown from their piers or crushed by shifting abutments. Highways and rail lines were made impassable by shifting earth or falling debris. All electric power and telephone lines and switching equipment were put out of commission. Almost one million people were left without water, food, or housing, with 80,000 seriously injured among them and tens of thousands of bodies that needed burying. The major arteries into the area were impassable. It was a disaster comparable to that experienced by the civilian populations of large cities caught between warring armies. Fortunately, there was no war and the army could rush without restraint to aid the stricken city.

Because all lines of communication with the outside world were severed, there was no expeditious way to secure the badly needed assistance. A jeep was dispatched to the capital (Beijing) to apprise officials there of the catastrophe and to seek help. This was a long and arduous journey because many bridges in the surrounding area had collapsed. Finally, fourteen hours after the earthquake, the messenger arrived at the State Council headquarters with the news that Tangshan had been destroyed by an earthquake.

EMERGENCY RESPONSE TO THE EARTHQUAKE DISASTER

Under a strong communist government, the people of China can be mobilized on short notice for a group effort involving large numbers of people. Not only



a. Column and crane remains of a rolling stock factory -- a factory producing locomotives and railway cars. The destruction of this factory virtually wiped out China's rolling stock production capacity.

Figure 3.2 Ruins in Tangshan, China, that will be preserved as monuments to ensure that the potential destructiveness of earthquakes is not forgotten.

b. Remains of the library at the Institute of Mining and Metallurgy at Tangshan. More than 1,000 students and faculty members died on this campus. In addition to structural failures, the campus suffered substantial fire damage caused by the ignition of laboratory chemicals.

c. Remains of a stadium in Tangshan. Because the stadium was needed immediately, several construction companies participated in its construction, and it was completed in 8 days. It took about 8 sec for the earthquake to destroy the stadium.

Figure 3.2 (Continued)

are many army personnel spread throughout the land, particularly around Beijing, but almost everyone else is employed by the government, which also owns all machinery. (The private business sector is very small, consisting only of self-employed individuals or small groups of people working as partners.)

Sent quickly to the disaster area were 140,000 troops, 20,000 medical workers, and 40,000 cadres (workers other than laborers). The first tasks were rescue operations and care of the wounded. Although the airport buildings were damaged, the runways were still usable, so airlifts were established to evacuate the seriously injured to hospitals in nine other provinces. Sanitation measures were successful in preventing epidemics of any kind. Next came restoration of utilities. Some electricity was available on the second day after the earthquake, and water lines were repaired on the third day. To shelter the population, relief workers used tents and small wood panel units at first and then constructed 400,000 temporary houses from the rubble within a period of three months. Survivors housed in these emergency units were located as close as possible to their former dwellings to maintain recognizable ties with the city and to alleviate severe psychological stress. Figure 3.3 shows a typical example of the temporary housing. China handled these tasks by itself, refusing all offers of foreign disaster-relief assistance.

RECONSTRUCTION PLANNING

After life-preserving human needs were cared for, the task of rebuilding permanent residences and restoring industrial production had to be tackled. The destruction resulting from the earthquake was complete for all practical purposes, so Tangshan had the opportunity to approach reconstruction from a totally new perspective and to make plans to correct the deficiencies in the city's former urban environment. This disaster presented an opportunity to start fresh and to practically rebuild the city from scratch. Because the city of Tangshan did not have the required urban planning capabilities or design capacity after the earthquake, more than 100 planning and design professionals, including architects, urban planners, and engineers, were assembled from all parts of China to contribute to the development of a new urban plan. Professionals selected to participate in the team effort were mainly recruited from leading universities and design institutes throughout the country.

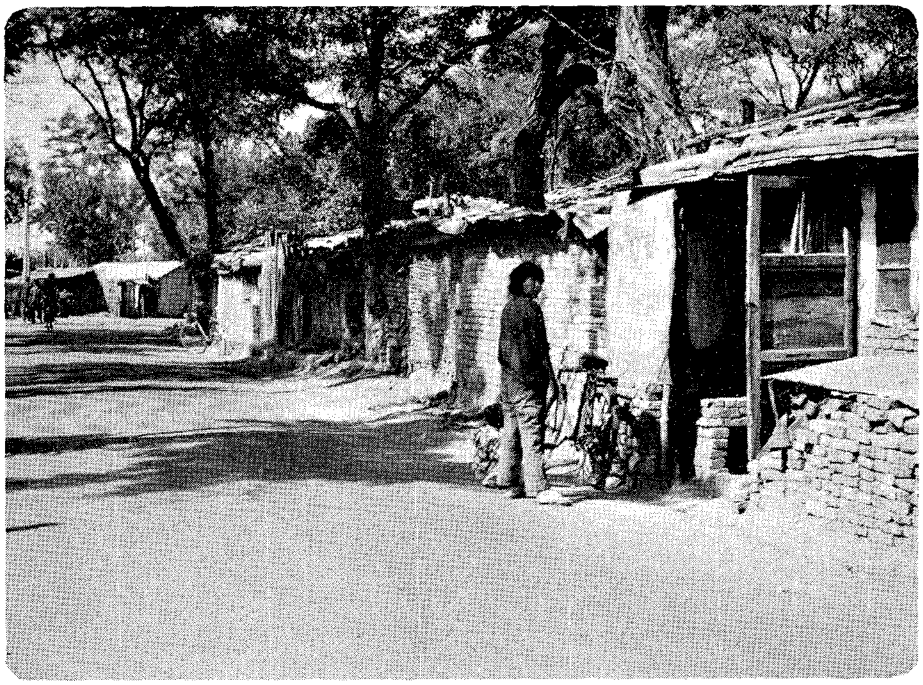


Figure 3.3 Temporary housing in Tangshan constructed of the rubble from collapsed buildings. The walls are braced with wood timbers, and the roofs are lightweight.

A city devastated by a major earthquake has three urban planning and design options (Figure 3.4):

- Completely rebuild on the same site
- Decentralize services and reduce high population density by developing satellite cities
- Abandon the old site and relocate to a completely new site

Tangshan chose the second option for its reconstruction efforts, and the new plan consists of three interdependent parts located approximately 35 to 40 km from each other: (a) the oldest part of the former city, called the Lunan District, which experienced the heaviest earthquake damage; (b) a new satellite city district identified as the main industrial area and developed around the existing coal mines to the east of the former city; and (c) Fengreen, a completely new satellite city district to the north of the former city, which is being developed with an emphasis on housing (Figure 3.5). The three city districts are further subdivided into four parts to include light industry, housing, community storage facilities (warehouses), and recreation and open space. Heavy industry is located in the eastern (coal mining) district.

The new plan will relieve the high population density of the old city through a decentralization process that includes open space and farm lands. The total population of the three separate urban centers of Tangshan is set at 1.25 million. Each of the three urban centers will have a population of between 300,000 and 500,000 when reconstruction is completed (Figure 3.6). The old city center and the two new satellite city centers will operate independently but will share all public services.

Before the earthquake, few exits existed from the city, and it was difficult to circulate through the narrow, tortuous, and complex streets that reflected the unplanned growth of Tangshan over the years. One of the fundamental objectives in planning the new city was to develop an organized transportation system to allow easy egress in all directions and unconstrained access to all parts of reconstructed Tangshan. Accordingly, two main arteries approximately 50 m wide are being developed as the principal means of circulation. Within the 50-m right-of-way, approximately 15 m will be developed for autos and buses,

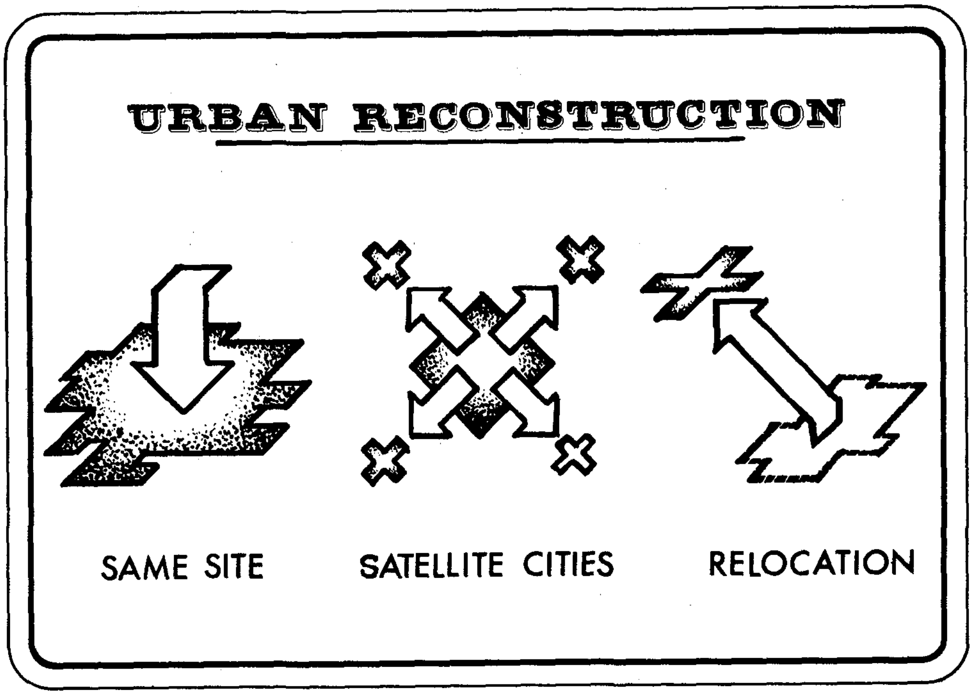


Figure 3.4 Planning and design options for urban reconstruction.

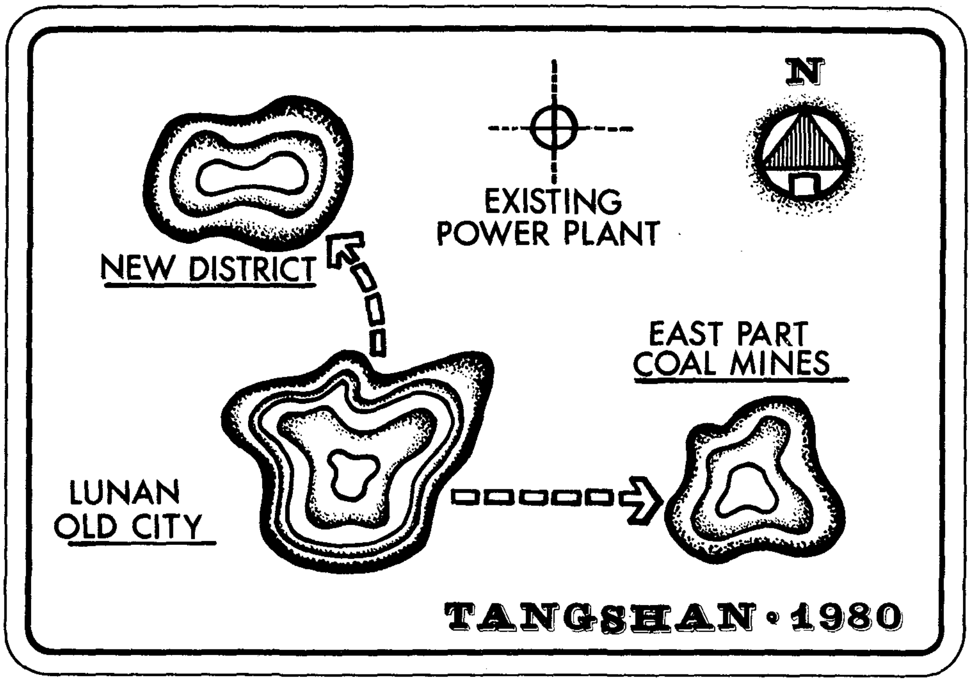


Figure 3.5 The reconstruction of Tangshan.

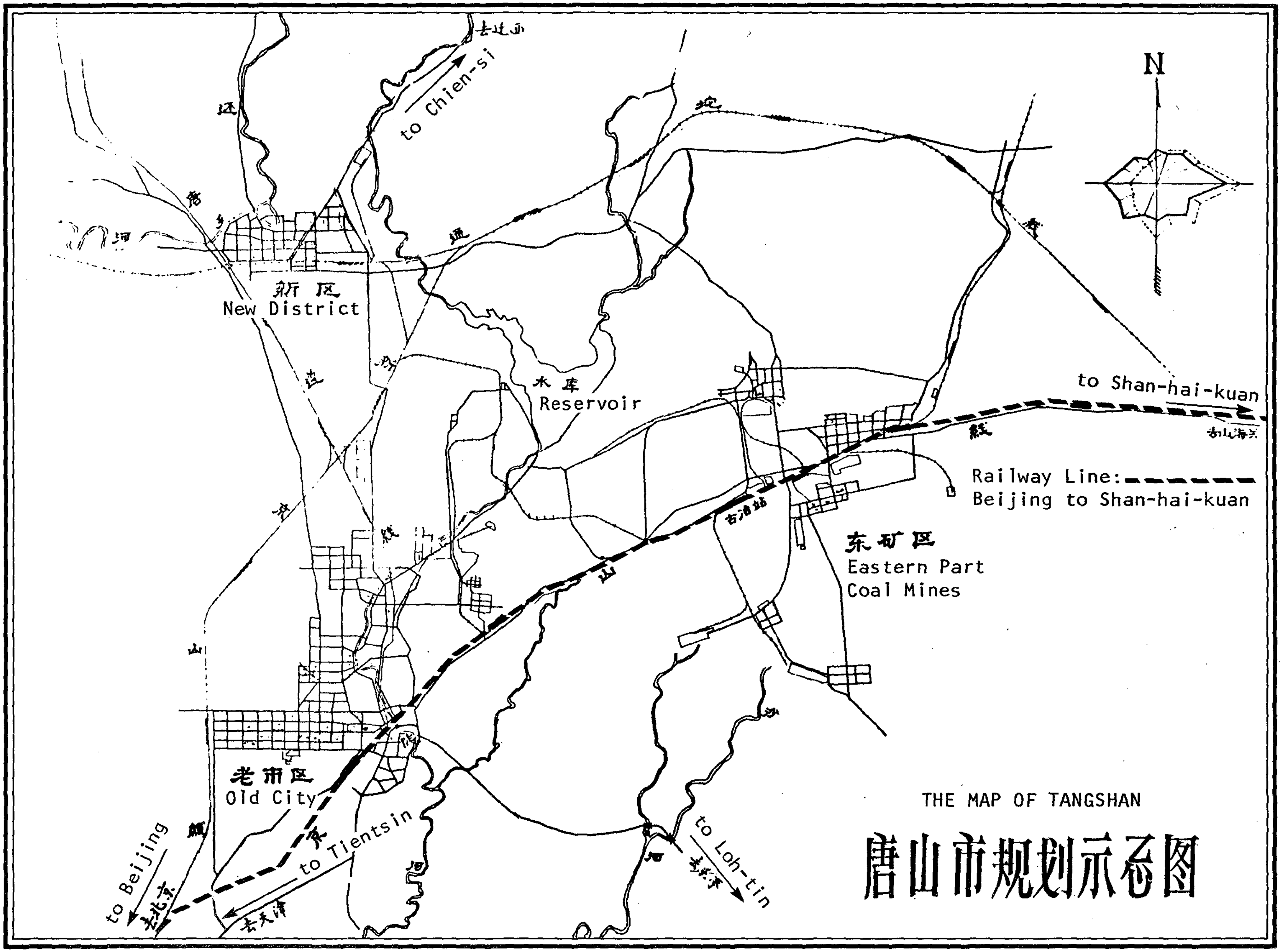


Figure 3.6 The new urban plan for the city of Tangshan.

15 m allocated to bicycles, 15 m allotted to pedestrians, and the remainder used for divider strips. All major buildings in the newly reconstructed city will be located along these two main arteries.

The central part of the former city of Tangshan, the Lunan District, is to be developed as a relatively open area and as the predominant commercial and cultural center. It will contain department stores, a sixteen-story tourist hotel (called the Friendship Hotel and designated the highest building in the city), shops, hospitals, a trade center, and a large formal park that will also include recreational facilities. A monument in the center of the park will be erected to commemorate the 1976 earthquake. Appropriate areas between buildings will be developed for use as permanent open spaces.

Geologic hazards and structurally poor soil, as well as major sites over existing coal mines, will be avoided. Major buildings cannot be located on type III soils, which are extremely unfavorable to earthquake resistance. In the *Aseismic Design Code* (1979), type III soils are defined as "saturated loose sand, silty sand (from soft plastic to flow-plastic), organic soft soil, hydraulic-fill soil and other soft and loose, manually back-filled soil." One- and two-story buildings can be constructed on such soil only if proper design precautions are followed. Contruction of completely unreinforced buildings will not be allowed. Before the 1976 disaster, earthquake-resistant structures were not required anywhere within the city limits.

The authorities have imposed other requirements to mitigate seismic hazards, including:

- Closed loops for all new utility lines to ensure a two-source supply
- Safety valves on all gas lines to prevent the spread of fires
- Adequate spacing between buildings to avoid one structure's banging against another

Most public utility lines (the designated lifelines) will be built underground during reconstruction. Seven types of utility transmission and distribution lines are to be located underground, which will make construction rather complex and difficult at major intersections. These seven are water supply lines, sewer and storm drain lines, steam and gas lines, and power and telephone lines. The diameters of these lines vary from 75 to 600 cm, and their lengths from 100 to 200 km. All new gas and power transmission and distribution lines and systems will be equipped with accessible shut-off valves to avoid the threat of fire following an earthquake. It is hoped that coal-burning equipment will eventually not be necessary and that air pollution in the residential areas can be avoided. Each housing complex is expected to have a central heating system, avoiding the need for independent heating units in each residence.

Provision of adequate housing is one of the main goals of the reconstruction process. The principal residential district of the new city, the Fengreen District, will be divided into 118 small living quarters, or residential complexes, each of which will accommodate a population of between 5,000 and 10,000. Primary and secondary schools, including a nursery; theaters; and shopping and commercial facilities will be provided in each residential quarter. Apartment buildings in the area, which are masonry load-bearing wall structures with reinforced concrete columns, slabs, and central spines to perform as shear walls, are limited to four to six stories in height. They are designed as walk-up buildings without elevators. The individual apartment units vary from one to three bedrooms in size and have a living area of 40 to 50 m^2 plus about 1 to 3 m^2 of outdoor space. Population density in the Fengreen district will be approximately 675 persons per acre, including parks.

While the new master plan for Tangshan was being developed, the OER in Beijing was conducting a continuous review and assessment of earthquake resistance. After final review by the SCCC, the new plan was forwarded to the State Council for final approval. The local Bureau of City Planning and Construction in Tangshan is overseeing the implementation of the master plan.

RECONSTRUCTION

The reconstruction of Tangshan is focusing on earthquake-resistant construction. In addition to the zoning described above, certain other precautionary measures have been undertaken to prevent a similar disaster from occurring a second time. One of the main factors that led to this catastrophe was that the earthquake intensity of the region had been assessed too low. As a result, most of the buildings were not required to be designed to resist earthquake ground motion, and very few buildings had sufficient resistance to prevent serious damage or collapse. Soil liquefaction, which was a prevalent problem in large areas in the Tangshan district, also contributed substantially to the disaster and is being carefully considered in reconstruction.

The building code was revised by the SCCC after the Tangshan earthquake. The present ordinance, called *Aseismic Design Code for Industrial and Civil Buildings*, TJ 11-78 (1979), was established as the national general design code for the PRC on August 1, 1979. (This code is on file at EERI.) The earthquake-design standard for the Tangshan area now requires that structures be designed to withstand a maximum intensity of 8 on the CIS. Previously, the maximum intensity expected in that region had been 6. The very few buildings that had been designed to withstand an intensity 8 earthquake remained undamaged or sustained minimal damage in the 1976 earthquake. For example, a five-story, reinforced concrete frame structure, the Tangshan First Flour Mill Building, was constructed according to design standards of intensity 8 and remained relatively undamaged, suggesting that structures designed to these standards would survive a similar earthquake.

Four types of construction practices are being used in rebuilding Tangshan:

- Interior cast-in-place walls, with exterior precast walls
- Interior cast-in-place walls, with exterior brick walls
- Interior and exterior walls of brick, with reinforced concrete columns at the junctions
- A cast-in-place, reinforced concrete frame, with precast panel walls

Most floors and roofs are made of precast concrete.

Reconstruction is proceeding at an extremely rapid pace. The construction capacity of the entire country was reoriented toward construction activities in Tangshan. Although 90% of the industrial structures were destroyed or severely damaged, by December 1979, overall production had exceeded the previous high. Construction of permanent housing is proceeding at an equally fast pace. We were told that 45,000 families were provided with safe housing by 1978. By the end of 1980 that number was scheduled to have grown to 80,000 families, or approximately 50% of the population. By the end of 1982, housing units for 700,000 persons are scheduled for completion.

Reconstruction of permanent industrial facilities, including the main locomotive works of China, are still under way. A comprehensive reconstruction effort is geared to replace all of the city's facilities within approximately ten years. During our visit, we toured the construction site of one of the new apartment complexes. Figure 3.7 is an example of one of the completed apartment complexes.

Severely damaged by the earthquake, the Duhe Power Plant was to be a modern coal-fired plant with a generating capacity of 750 MW located about 20 km from Tangshan. The plant was still under construction at the time of the earthquake but was partially operational. The turbine building is a long structure built to house the four Japanese-made Hitachi turbines and generators. The columns are constructed of reinforced concrete, and the roof system is composed of steel trusses. It appears that the only significant lateral-force resistance available in both the transverse and longitudinal directions was that provided by the base fixity of the very tall columns. Photographs of the turbine building, after repair, are shown in Figures 3.8 through 3.10.

The steel trusses had originally supported a roof system constructed of precast concrete panels. During the earthquake, nearly all the roof panels fell to the operating floor of the building. The columns experienced displacements of up to 30 cm at the top of the structure. The cause of the damage was the lack of continuity between the roof trusses and the columns, the minimal lateral-force capacity available, and the lack of provision for diaphragm action in a long structure such as this one. In spite of the severity of the structural damage, the only damage to the turbine generators was a casing that was struck by one of the concrete panels. No other damage or even misalignment of the turbine generator bearings resulted from the earthquake. The operating floor of the turbine building did not suffer any damage from the falling roof panels.

Figure 3.7 New apartment buildings in Tangshan.

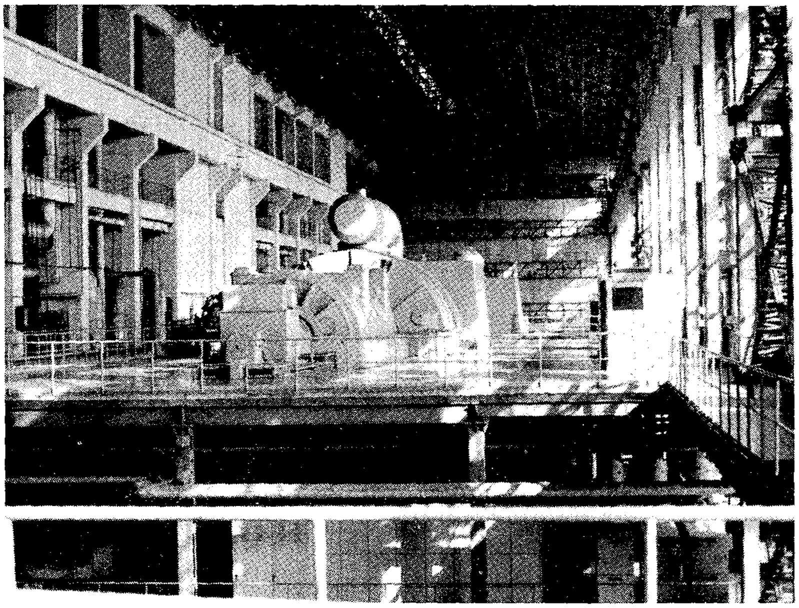


Figure 3.8
The turbine building of the Duhe Power Plant, showing the turbine layout.

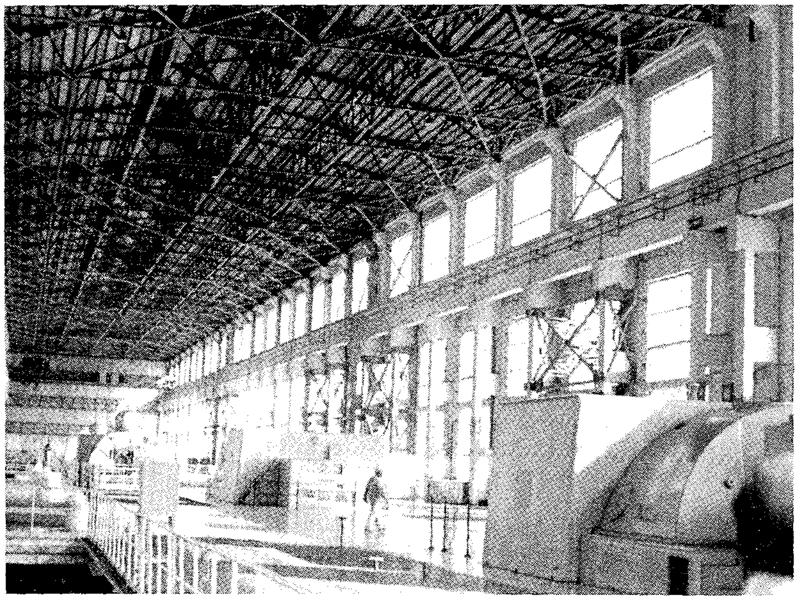


Figure 3.9
The turbine building of the Duhe Power Plant, showing the typical longitudinal and transverse framing.

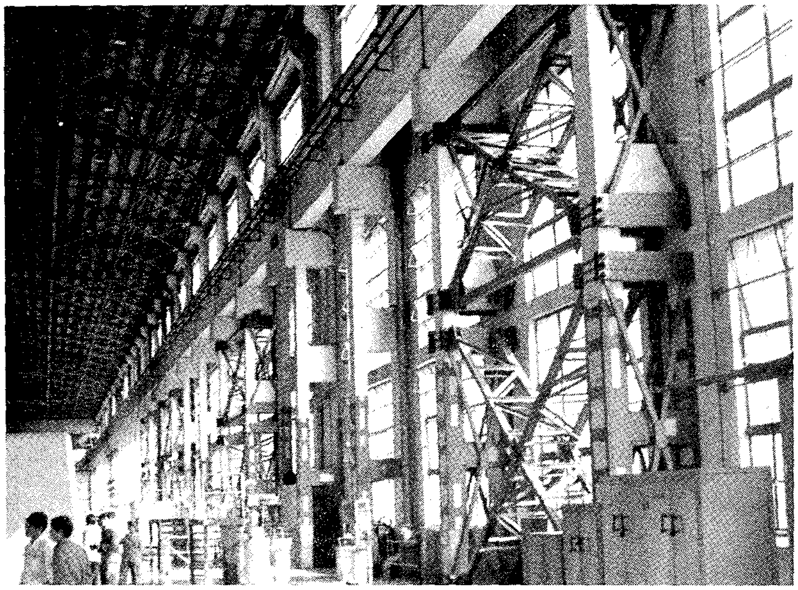


Figure 3.10
The turbine building of the Duhe Power Plant, showing the retrofit longitudinal bracing.

The steam generator building, a 30-m-high structure containing the boilers, suffered a total collapse. Additional damage included a 180-m reinforced concrete chimney, the top 50 m of which toppled to the ground. Several transformers outside the plant also fell over. Transmission lines, however, were not damaged. Of the 770 workers at the plant at the time of the earthquake, 222 died and 215 were badly injured.

Power output from the facility was restored in two weeks. The columns in the turbine building were strengthened through the use of steel plates and the addition of steel bracing between some of the columns in the longitudinal direction. The concrete roof panels were replaced with lighter wooden panels, but there is still no provision for diaphragm action or for possible transverse weakness. The steam generator building was completely rebuilt. Approximately 20 m were added to the top of the remaining 130 m of the damaged chimney. Anchorages for the damaged transformers were repaired. All reconstruction work was designed to withstand an earthquake of intensity 8.

4. EARTHQUAKE ENGINEERING IN CHINA

INTRODUCTION

This chapter describes various aspects of earthquake engineering education, research, and practice in the PRC. Our observations during the tour and the expertise of the individual delegation members were considered in selecting the topics.

EARTHQUAKE HAZARD MITIGATION IN THE PRC

In the report prepared by the American Earthquake Engineering and Hazards Reduction Delegation (Jennings, 1980), the SSB is mentioned as the leading organization in the PRC involved in earthquake research. In 1980, the EERI delegation observed that emphasis on the earthquake problem had been substantially increased and that the SCCC had become directly and actively involved in earthquake hazard mitigation. Observations from the 1975 Haicheng earthquake and, most importantly, from the 1976 Tangshan earthquake brought about this new focus on earthquake hazard reduction.

The Haicheng, Liaoning Province, earthquake of February 4, 1975, was a magnitude 7.3 event with a maximum intensity of 9. Some of the villages and towns in both Haicheng County and Yingkou County were severely damaged. The cities of Yingkou and Anshan were both affected. Five million square meters of city buildings were damaged, and 870,000 rooms of rural buildings were destroyed. The number of people injured totalled 4,300, and 1,328 persons were killed. Economic loss was established at 800 million yuan (approximately $560 million). Five years were needed for the reconstruction work.

The Tangshan, Hopei Province, earthquake of July 28, 1976, was a magnitude 7.8 event and had a maximum intensity of 11. The city of Tangshan was largely destroyed. The city of Tianjin was severely damaged, and the capital city of Beijing was affected. More than 60 million m^2 of urban buildings and 850,000 rooms of rural buildings were damaged, and many structures collapsed. The injured totalled 164,000, and 242,000 were killed. Economic losses were estimated at 8 billion yuan (approximately $5.6 billion).

The Haicheng earthquake was successfully predicted, and loss of life was substantially reduced by evacuating the urban areas. Economic losses were still severe because buildings and other facilities were not designed for seismic resistance. The Tangshan earthquake was not predicted, and both substantial loss of life and economic losses were sustained.

In the face of the Haicheng earthquake disaster and the even greater disaster of the Tangshan earthquake, the SCCC reevaluated its construction priorities and began an aggressive program to improve the seismic resistance of all structures for which it is responsible. (The SCCC is responsible for financing construction of all structures.)

Earthquake hazard mitigation in the PRC involves the following four activities:

- Short-Term and Medium-Term Prediction. Using seismic, animal, and other precursor anomalies, short-term earthquake predictions are analyzed in an attempt to minimize loss of life. The predictions of both the 1975 Haicheng earthquake and the 1976 Longling earthquake offer successful examples of this approach.
- Long-Term Regional Prediction. Long-term regional seismicity prediction is used to establish a seismic zoning map for the PRC.
- Earthquake-Resistant Design. Aseismic design codes, regulations, and manuals are being developed for use in designing structures for seismic resistance.
- Strengthening of Existing Structures. Using medium-term prediction data and the seismic zoning map, experts have designated 37 key cities as critical seismic areas. Past earthquake and seismic exposure performance are the criteria applied to select structures for systematic strengthening. Since 1976, 70 million m^2 of buildings, numerous bridges and chimneys, and some dams have been strengthened under this program.

The SSB has held and continues to hold the central position in the management and coordination of earthquake prediction (i.e., the first two tasks mentioned above). The OER, which was formed after the Tangshan earthquake and is under the auspices of the SCCC, is responsible for earthquake engineering (i.e., the latter two activities mentioned).

Such generalizations, however, never tell the whole story. The IEM at Harbin was still under the SSB in 1980 and was still performing earthquake engineering research at that time. We were told that the IEM conducts fundamental theoretical research, whereas the OER of the SCCC sponsors and conducts applied research.

UNIVERSITY INSTRUCTIONAL PROGRAMS

Introduction

The following account of civil engineering educational programs at universities in the PRC is based on information gathered during visits to Tsinghua University in Beijing and Tongji University in Shanghai. Although some of the observations made may be representative of conditions at other universities as well, it is important to keep the limited base of information in mind.

Several of the research establishments we visited, such as the Chinese Academy of Building Research in Beijing and the IEM in Harbin, are also involved in the educational process through their participation in university research programs. The contributions of the latter groups and some of the earthquake engineering research in progress at the universities visited are discussed in other parts of this report.

Recent Changes in University Programs

The universities in China prior to 1949 were typically comprehensive, offering courses of study in a wide range of disciplines, such as the arts, humanities, science, and engineering. Following the nationwide reorganization of colleges in 1952, however, university programs became highly specialized, patterned after the Soviet educational system. For example, Tsinghua University became essentially an engineering school, and Tongji University was transformed into a predominantly civil engineering educational center. Both universities had previously offered a broad range of programs.

There was no unanimity of opinion among the faculty members we met concerning the merits of the specialized educational system now in effect. While some appeared to favor it, others felt that a broader educational experience would be better for the students, and there were some suggestions to the effect that a broader-based system may well evolve in the future.

Higher education in China was severely disrupted during the Cultural Revolution (1966-1976). Many of the universities closed, and those that did remain open operated with a reduced faculty and student body, curtailed programs, and, in most instances, dismantled physical facilities. The quality of the student body during this period was generally low, because many students were admitted not for their academic qualifications but in furtherance of political objectives. The duration of university education in this period was shortened to three years, and a diploma rather than a degree was awarded upon satisfactory completion of a program of studies. The process of reconstruction, which is still in progress, was begun in 1977.

Since 1977, admission to the universities has been based on the results of unified, national college entrance examinations that are administered annually to middle school (the equivalent of our high school) graduates. Competition in these examinations is extremely keen, and only a small fraction of those taking them succeed in gaining admission. We were told that of the approximately 7,000,000 candidates taking the examination in 1980, only 270,000 were successful.

Candidates are asked to list in order of decreasing preference the universities they wish to attend and their intended fields of study. Although an effort is being made to satisfy a successful candidate's first or second preference, limited enrollments and quotas in individual areas may make this possible for only the top-ranking candidates.

Universities are organized into departments. There are no deans in the administrative structure; department heads or directors report directly to the president or vice-president of the university. Students are admitted to individual departments or areas of study. Transfers to other areas are in principle possible, but again, because of existing quotas, such changes are difficult to implement and are generally discouraged. From the experience gained in the period prior to the Cultural Revolution, it is expected that more than 90% of the students now admitted to universities will complete their studies and graduate.

Undergraduate engineering programs take four years and lead to a bachelor's degree, except at Tsinghua University, which has a five-year program of studies. Graduate programs include a master's degree program, which requires two years to complete, and a doctoral program, which requires four years beyond the bachelor's degree. While the practice of special lectures and seminars appeared to be in wide use, the universities we visited had no special extension courses for practicing engineers who may wish to update their knowledge.

Programs at Tsinghua University

Tsinghua University in Beijing is the successor to Tsinghua College, which was founded in 1911 as a preparatory school for students going to the United States. It acquired its university status in 1928 with the establishment of separate colleges of arts, science, engineering, law, and agriculture.

In the early 1950s, the university developed into a leading engineering educational center, and enrollment reached a peak of about 12,000 students prior to the Cultural Revolution. From 1966 to 1970, the university was closed, and operations were disrupted until about 1976. At the present time, the university is expanding both its educational and its research programs.

The university campus occupies about 300 acres with a building area of over 5 million ft^2. There are approximately 8,000 undergraduate and 1,000 graduate students enrolled. By 1982, it is projected that the enrollment will increase to the peak of 12,000 students reached prior to the Cultural Revolution. All students live on campus.

The university is organized into the following fifteen departments: applied mechanics, architectural engineering, chemical engineering, civil and environmental engineering, computer science and engineering, economic management, electric power engineering, electronics and radio engineering,

engineering mechanics, engineering physics, hydraulic engineering, mechanical engineering, precision instrumentation, thermal energy engineering, and a department of basic courses. Approximately 50 different specialties are offered. There are also several research institutes and laboratories, and additional research units are planned for the future. The department of hydraulic engineering, which also encompasses geotechnical engineering, is administratively independent of the civil and environmental engineering department.

The teaching staff at the university numbers more than 3,000, approximately 600 of whom have the rank of professor or associate professor; the remainder are assistants and lecturers. The rank of assistant professor does not exist in China. There is also a research staff of about 1,000. Unlike the United States where teaching and research assistants are generally part-time students, in China they are full-time employees.

The undergraduate program at Tsinghua University is the only five-year undergraduate engineering degree program in China; all others are four-year programs. Because the five-year program was instituted in 1978, there are no students at the fifth-year level at this time. English and Japanese are the principal foreign languages taught. At the graduate level, there are programs leading to the master's and the doctoral degrees.

About 600 students are enrolled in civil and environmental engineering, and about 350 of these are in structural engineering. These figures do not include those enrolled in the department of hydraulic engineering. From 15% to 20% of the students in the various branches of civil engineering are women.

There was no opportunity to examine in detail the scope of, and requirements for, the undergraduate and graduate degree programs in civil engineering. However, the following general information was provided:

> During the first three years of undergraduate study, the emphasis is on mathematics and other basic and engineering sciences. The fourth and fifth years are devoted to specialized topics in civil engineering. Some flexibility in the curriculum is provided

through electives in the fourth and fifth years of study.

- A fourth-year course on structural dynamics and a fifth-year course on earthquake-resistant building design is required of those taking the structural option. In addition, an introductory course on probability theory is required.
- As part of the requirements for the bachelor's degree, students are required to spend one term on a special project or a thesis.
- Both the master's and the doctoral programs require participation in research and the presentation and defense of a thesis.

Classes in civil engineering typically consist of about 30 students, but there may be as many as 200 or 300 students in some of the common core courses. The typical teaching load for faculty members is one to two courses per term. Faculty promotions are based on a consideration of both teaching and research.

The academic publications of the University are the *Journal of Tsinghua University* and *Science Reports of Tsinghua University*.

Programs at Tongji University

Founded in 1907, Tongji University had faculties in the natural sciences, engineering, medicine, and law until the early 1950s, when it was transformed into a civil engineering educational center. Its activities were later expanded to include mechanical and electrical engineering, but civil engineering has continued to be the dominant program of studies. Because of the disruption suffered during the period of the Cultural Revolution, the principal effort since 1978 has been directed toward rebuilding the facilities and strengthening the instructional and research programs.

The university campus covers an area of about 170 acres, and the floor area of its buildings is approximately 2.3 million ft^2. The undergraduate program takes four years, although students who elect German as a foreign language must devote an additional year to the study of that language. Graduate activity is now limited to a two-year master's degree program. A doctoral program will be instituted in 1981.

There are about 4,500 students enrolled at the university, including 220 graduate students. Approximately 50% of the students are from Shanghai; the remainder come from other provinces or from other Asian countries (about 40 students). About 16% of the students are women.

The faculty numbers about 1,500 and includes 220 with the rank of professor or associate professor. Teaching loads range from a minimum of 6 hours per week to a maximum of 12 hours per week, depending on an individual's other responsibilities.

In 1980, 140 professors or associate professors received promotions. Faculty promotion is based on considerations of teaching quality, the quality of and productivity in research, and administrative effectiveness. Each responsibility is considered equally important; a highly effective teacher who is inactive in other areas is as likely to be promoted as one whose primary contribution is to research or administration. Student evaluations of faculty members are not used in the PRC.

Upgrading the faculty was identified as the highest priority by the administration. Because the present faculty is considered too large for the size of the student body, an effort is being made to reassign some of the assistants and lecturers to other agencies of the government. In addition, the most promising members are provided the opportunity to pursue graduate studies abroad. About 40 faculty members are now attending foreign universities; 20 are studying in the United States. Tongji University has no formal exchange program with any foreign university at this time.

The university is organized into fourteen departments: mathematics and mechanics, physics, chemistry, architecture, building and offshore engineering, highway and bridge engineering, materials engineering, underground structures and engineering geology, marine geology, surveying, environmental and energy engineering, mechanical engineering, electrical engineering, and foreign languages. This organization is similar to that employed at Soviet universities, and closely follows the principal areas into which the Chinese ministries are subdivided.

Since 1978, several research institutes have been established, including the Institute of Structural Theory, which emphasizes earthquake engineering. The institutes are administratively independent of the departments, and while faculty members may have dual responsibilities in a department and a research institute, they are affiliated with only a single unit. Funding for research is provided from university sources or from other organizations interested in specific studies.

As might be inferred from the names of the departments listed, the civil engineering programs are structured along professional rather than disciplinary lines. Although they have a common two-year scientific core, all programs are highly specialized.

Table 4.1 gives the course requirements for the degree in building engineering. The technical content of the degree program in building engineering is quite high by U.S. standards and is due to the lack of requirements in the humanities and social sciences. Compared to representative civil engineering programs at U.S. universities, the program is also highly structured and specialized. Note that all of the civil engineering courses required in the third and fourth years of study relate to the design of buildings or industrial structures and that there are no required courses dealing with any other civil engineering specialties.

About 30 graduate students are affiliated with the Research Institute of Structural Theory. Organized in six divisions, this institute has a professional staff of about 150, including professors, lecturers, and technicians. The divisions cover the areas of engineering mechanics, structural engineering, soil dynamics and earthquake-resistant foundations, soil mechanics, experimental mechanics, and models and instrumentation. In addition to carrying out fundamental analytical studies on wave propagation and the characteristics of strong earthquake ground motions, the division of engineering mechanics has the responsibility for installing and maintaining the seismic network in eastern China.

RESEARCH AT UNIVERSITIES AND GOVERNMENT LABORATORIES

We had the opportunity to visit five organizations that are concerned with analytical and experimental research in earthquake engineering. Throughout

TABLE 4.1

PROGRAM OF BUILDING ENGINEERING AT TONGJI UNIVERSITY

Item	Course	Term (Number of Weeks per Term)								Total Number of Contact Hours
		1(18)	2(18)	3(18)	4(16.5)	5(17)	6(13)	7(18.5)	8(10)	
		Number of Contact Hours per Week								
1	Politics	2	2	2	2	2	2	2	2	201
2	Physical Education	2	2	2	2					141
3	Foreign Language	4	3	3	4					246
4	Physics		6	5						198
5	Advanced Math	6	4	5						270
6	Chemistry	4								72
7	Descriptive Geometry and Engineering Drawing	4	2							108
8	Surveying		3							54
9	Building Materials				4					66
10	Theory of Machines						5			65
11	Electronics					5				85
12	Theoretical Mechanics			3	3					103
13	Strength of Materials				4	3				117
14	Structural Theory					4	5			133
15	Theory of Elasticity								6	60
16	Algorithms			2						36
17	Structural Testing								4	40
18	Architecture and Building					4				68
19	Organization and Planning of Building Operations							4		74
20	Reinforced Concrete and Masonry Structures						5	4		139
21	Steel and Timber Structures							4		74
22	Soil Mechanics and Foundations							4		74
	Subtotal	22	22	22	19*	18	17*	16*	10*	2,424
23	Other†									180
	Total									2,604

Note: Information provided by Professor Zhu Zhende.

*Exclusive of courses listed under Item 23.

†This must include 7 weeks' work at a construction site during the fourth and sixth terms, 10 weeks of a design project during the eighth term, and four elective courses during the last three terms. The electives must be selected from the following topics: lift slabs, space frameworks, chimney structures, structural dynamics, earthquake-resistant structures, tower and mast structures, and water-reservoir structures.

these visits our Chinese hosts, as well as the administrative and technical personnel at the institutes, were exceedingly helpful in accommodating our wishes and providing complete information on all aspects of their research activities. Considering how little time we had at each place, we learned a great deal about the research efforts of our Chinese colleagues. Nevertheless, our impressions are based on relatively brief visits to only a few institutes and thus on only a small portion of the research activities in the PRC.

Owing to the nature of our short visits, we were exposed primarily to experimental research, rather than to analytical work, and saw only portions of the ongoing research activities. Thus, the emphasis in this section is on the laboratory work performed at five of the leading earthquake engineering institutes in the PRC. The following list gives examples of research activities at the institutes we visited.

National Academy of Building Research, Beijing

Institute of Building Structures

- Materials research
- Behavior of prestressed concrete components
- Behavior of reinforced concrete components
- Behavior of shear walls with boundary elements
- Behavior of column-slab connections
- Behavior of unbonded post-tensioned slab systems
- Model studies of brick walls
- Model study (1:6 scale) of twelve-story reinforced concrete building
- High-cycle fatigue studies

Institute of Soil and Foundation Engineering

- Dynamic triaxial testing of soil samples
- Shake-table studies of soil liquefaction
- Instrument development

Water Conservancy and Hydroelectric Power Scientific Research Institute, Beijing

- Model studies on arch dams
- Shake-table studies on model sections of concrete dams

- Field instrumentation of existing dams
- Field tests on dams with vibration generators and explosives
- Soil liquefaction studies
- Instrument development

Tsinghua University, Beijing

- Materials research
- Behavior of reinforced concrete elements under cyclic loading
- Behavior of single-story precast concrete building
- Behavior of multistory buildings (shear wall frame structures, tubular structures, column-slab systems, frame structures with exterior bearing walls)
- Model study of shear walls with openings
- Dynamic triaxial testing of soil samples
- Stress analysis of dam models using photoelasticity

Institute of Engineering Mechanics, Harbin

- Development of strong motion network
- Microzonation
- Earthquake resistance of brick structures
- Earthquake resistance of reinforced concrete structures
- Earthquake damage evaluation
- Earthquake resistance of chimneys and water towers
- Earthquake resistance of bridges
- Vibration tests on models of concrete gravity and arch dams
- Optimum seismic design
- System identification
- Soil liquefaction mechanisms
- Behavior of earth dams
- Wave propagation in soil layers
- Instrument development

Tongji University, Shanghai

- Earthquake resistance of brick and reinforced concrete structures
- Earthquake resistance of two-story cinder block houses
- Model study of steel roof trusses
- Photoelastic studies of pressure vessels and multistory buildings
- Ground motion studies
- Soil-structure interaction studies

As can be seen from this listing, considerable emphasis is placed on practice-oriented research that permits immediate application of research results to ground motion and structural response evaluations, engineering designs, and construction practices. It appears that the efforts are well coordinated so that little overlap exists, and priority is given to problems whose solution will lead to an immediate improvement of present-day practice.

In building research, emphasis is given to improving the design and construction of single-story and multistory brick and reinforced concrete buildings. Very little attention is paid to structural steel, since it is rarely available in the PRC. The emphasis in research is shifting away from clay brick towards reinforced concrete, because past production of clay bricks has depleted the fertile soil that is urgently needed for agricultural production. The poor performance of unreinforced brick structures in recent earthquakes may also have contributed to this shift.

The experimental research on brick masonry ranges from racking tests of individual walls to shake-table tests on 1:4 scale models of three-story brick buildings. The specimens for the latter tests (at the IEM in Harbin) consist of three boxes with openings, stacked on top of each other and loaded with lumped masses at the floor levels to simulate gravity and inertial forces (see Figure 4.1). The tests will be performed on a hydraulically driven shake table (3-K force capacity) that rests on oil-film bearings and is capable of reproducing motions in the frequency range from 0 to 24 Hz.

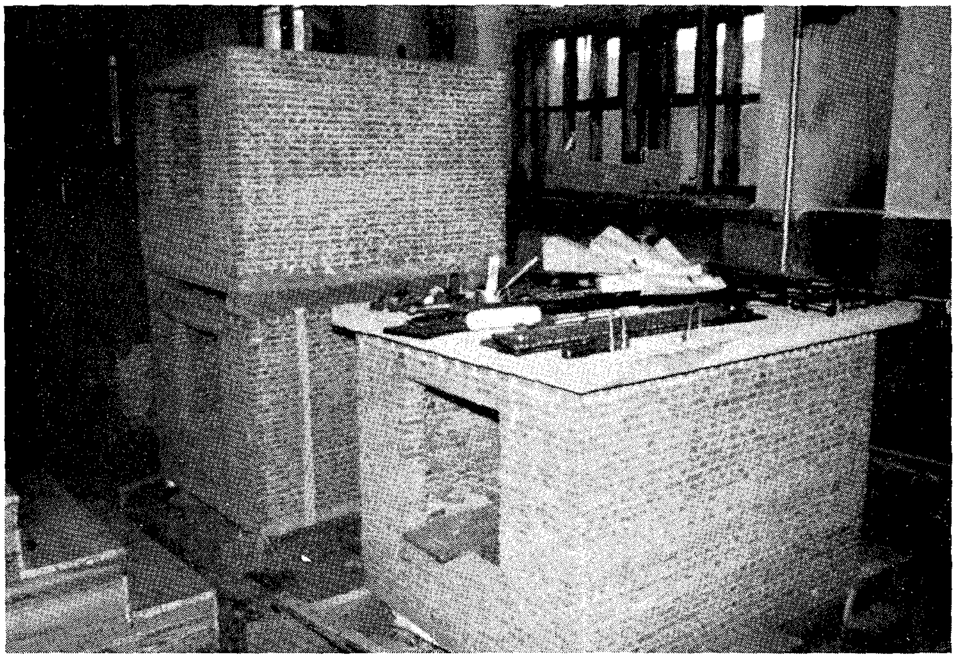


Figure 4.1 Model of brick building for shake-table study at IEM, Harbin.

The results of the experimental studies are used to develop empirical models of the load-deformation response of brick walls (including stiffness degradation) that are then used in nonlinear dynamic analyses to predict the seismic response of multistory brick masonry buildings. We also saw publications on the inelastic dynamic response of reinforced concrete frame structures with brick infill walls.

We did not see any work on concrete block masonry, which appears to be little used in the PRC. Of interest was a pseudo-static cyclic load test on two half-scale models of two-story cinder block houses at Tongji University in Shanghai (Figure 4.2). This experiment is intended to study the use of a by-product of coal production for building construction.

A large amount of research is conducted on the cyclic response characteristics of reinforced concrete elements and structures. This research is rather similar to that carried out in many of the leading laboratories in the United States. We observed some very interesting work on shear wall configurations, ranging from small-scale models of eight-story coupled shear walls (Figure 4.3) to large-scale models of four-story walls with slab segments (Figure 4.4).

An extensive parameter study on shear wall configurations is in progress at the National Academy of Building Research. All of these shear walls have boundary elements but are constructed both with and without beam elements at the floor levels (Figures 4.5a and 4.5b). In some cases the beams were prestressed, and vertical slots were provided between the boundary elements and the wall panels (Figure 4.5b). We were told that significant improvement in ductility was achieved with these configurations.

At the Structures Laboratory of the National Academy of Building Research a 1:6 scale model of a twelve-story reinforced concrete building is presently under construction (Figure 4.6). This model, which will be 20 ft wide and 23 ft high, will be tested on a large static test bed with the lateral loads applied through six synchronized hydraulic actuators attached to a vertical reaction wall.

Much emphasis is placed on research on precast, prestressed beam and slab elements and their connections to either precast or cast-in-place columns.

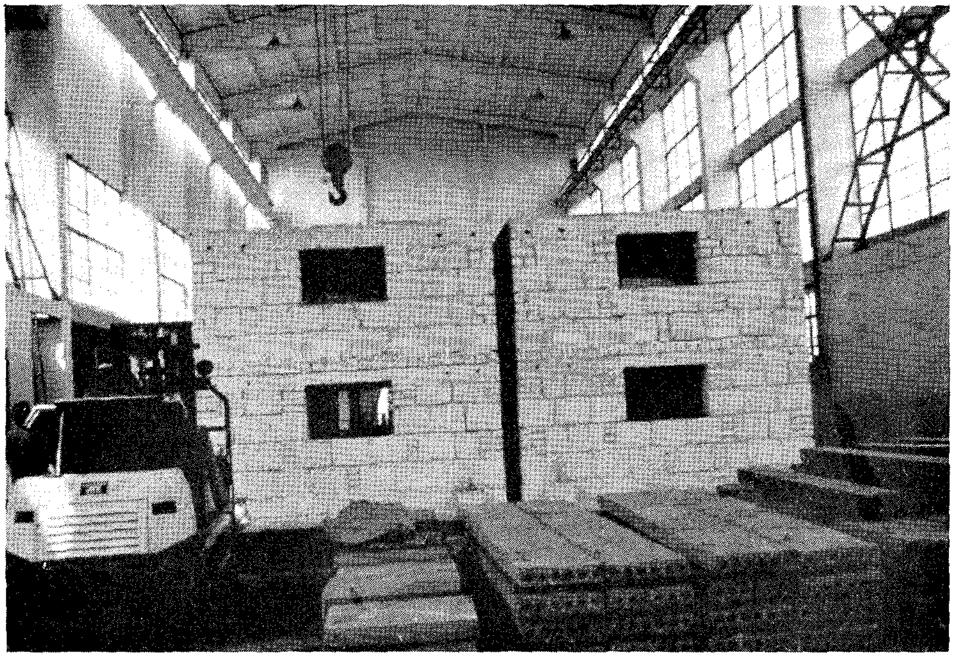


Figure 4.2 Two-story cinder block houses at Tongji University, Shanghai

Figure 4.3 Model of coupled shear wall at the Academy of Building Research, Beijing.

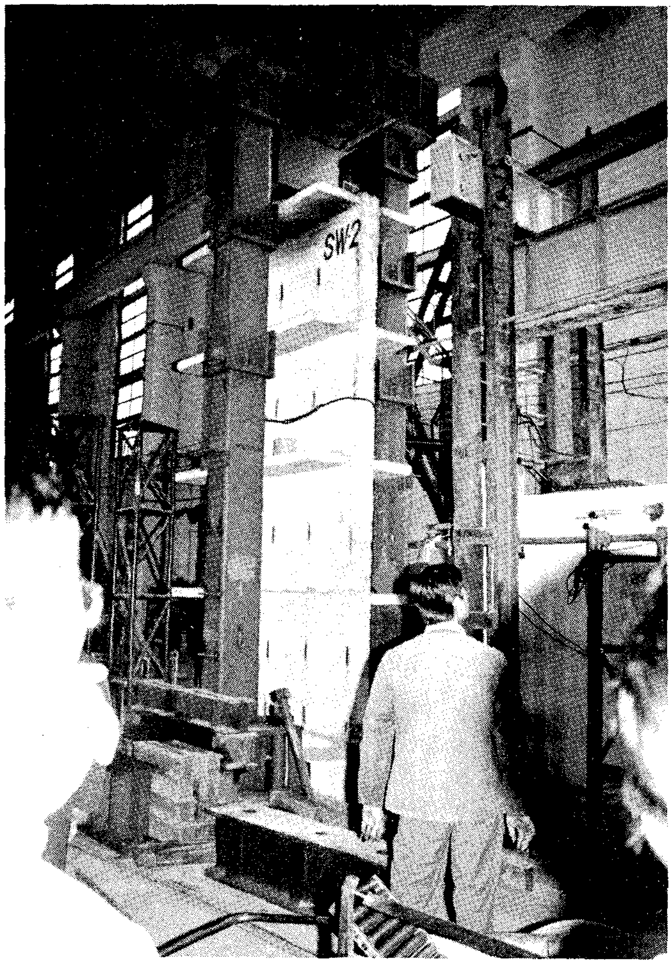


Figure 4.4 Four-story wall with slab elements at the Academy of Building Research, Beijing.

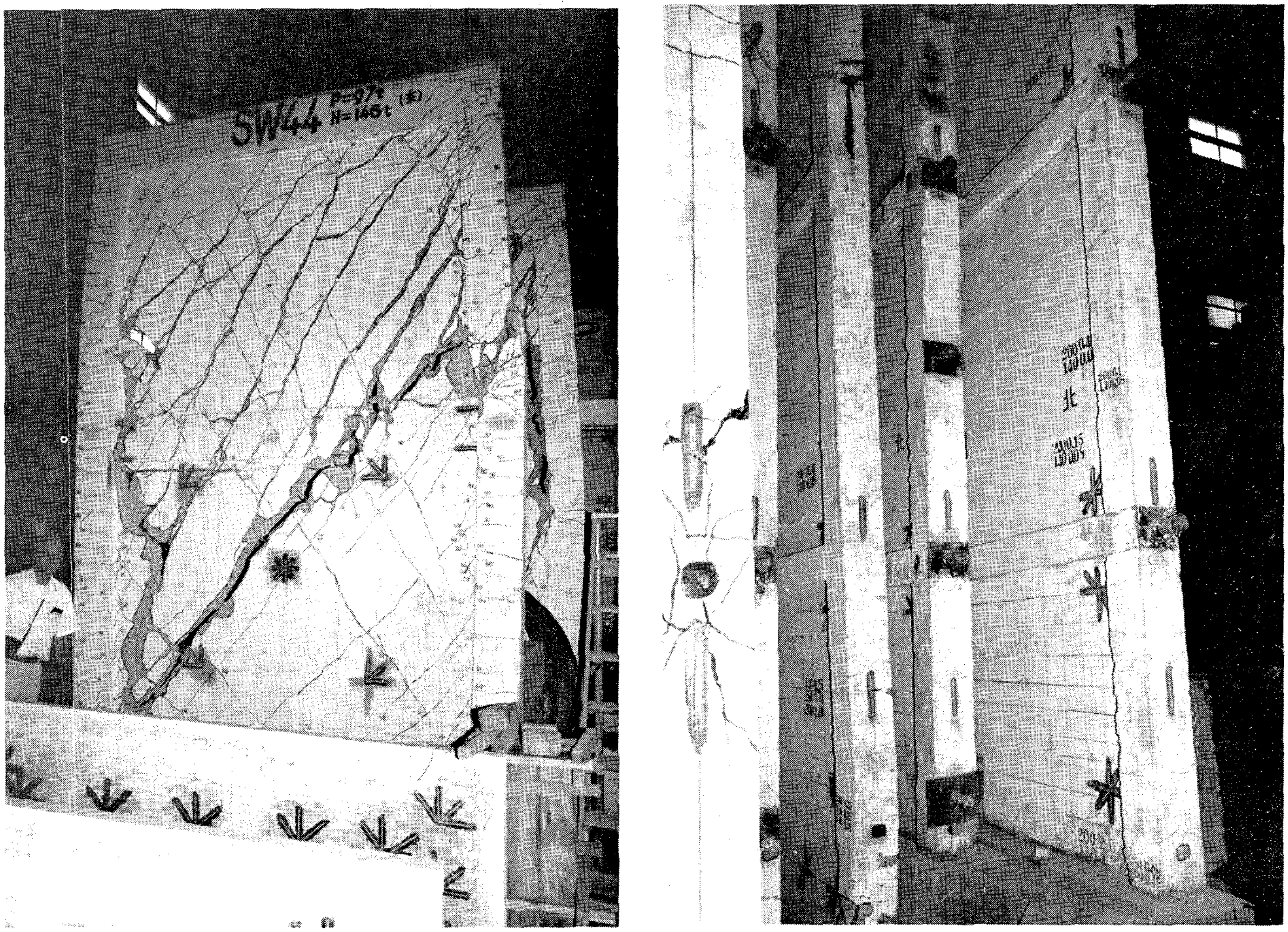


Figure 4.5 Shear wall specimens at the Academy of Building Research, Beijing.

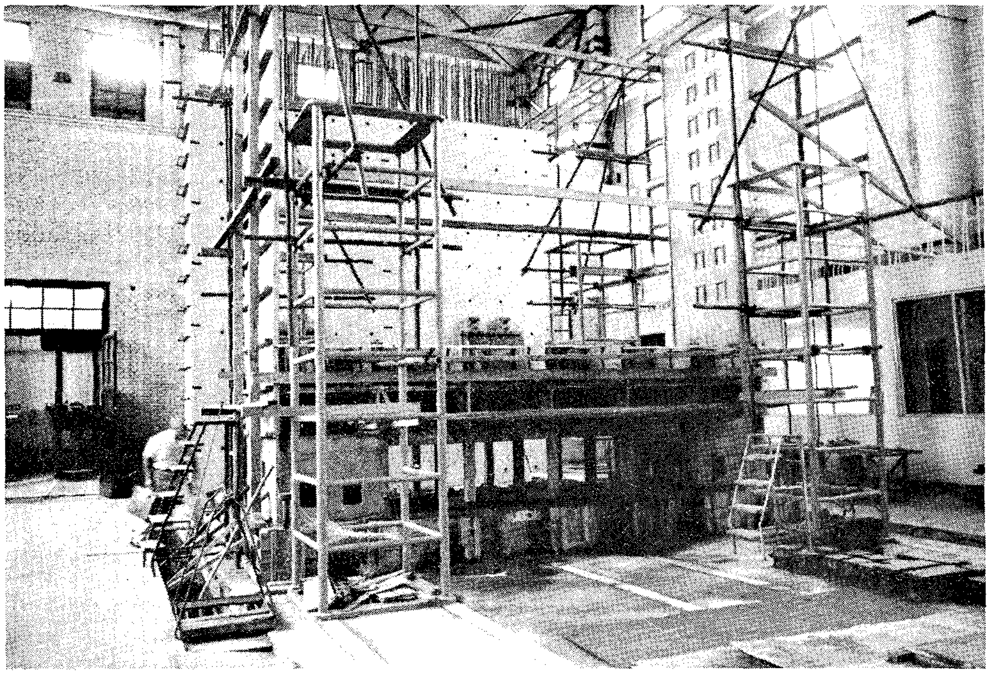


Figure 4.6 Scale model of twelve-story reinforced concrete building under construction at the Academy of Building Research, Beijing.

In one research project we saw experiments on column-slab connections where both elements were prefabricated and then connected in the field through post-tensioning. Another research project was concerned with the connections of precast, prestressed beams to cast-in-place columns.

In essence, much of the research on reinforced concrete is concerned with developing design details that may contribute to an improvement in ductility. This emphasis on ductility was reflected in our discussions, in the observed research, and in the Chinese building code provisions. The desired ductility values between 4 and 6 were mentioned several times by our Chinese colleagues, but these numbers appear to be as mysterious as the same numbers quoted so often in U.S. practice.

Significant differences between the PRC and the U.S. in their approach to experimental research are difficult to find. In general, the problems are similar and the process of solution follows the same avenue. Most of the work done in the PRC utilizes pseudo-static cyclic-load histories and involves individual elements, subassemblies, and complete structural configurations. Perhaps there is more reliance in the PRC on small- and medium-size models, particularly for multistory wall assemblies and complete structures. There appears to be an increased interest in dynamic testing, reflected in the plans to build or purchase several shake tables at least 10 ft x 10 ft in size.

Our exposure to research activities in fields other than building engineering was rather limited. Specific observations in the fields of ground motion and building response measurements, soil mechanics, soil-structure interaction, and earthquake prediction are discussed elsewhere in this report. A summary of the research efforts on dams is included here, since the institutes we visited perform a considerable amount of work in this field.

An extensive research program on the earthquake resistance of gravity and arch dams is in progress at the Water Conservancy and Hydroelectric Power Scientific Research Institute in Beijing. This institute has a department of aseismic engineering that does field and laboratory studies on concrete and earth dams. The institute has an instrument laboratory that develops and manufactures 9-channel strong-motion accelerographs that have already been installed at ten dam sites. At one of these dams (Hsinfengkiang Dam, 120 miles northeast of Canton), they recorded a reservoir-induced earthquake in 1962. Field experimentation at dam sites uses either four synchronized rotating-mass vibration generators or explosives as excitation sources.

The laboratory research is done on small-scale models, using hardened rubber, epoxy resin, or gypsum mortar with heavy additives as the modeling material. A test specimen of a section of a concrete gravity dam on a shake table is shown in Figure 4.7. The shake table is driven by an electromagnet and has a frequency reproduction range from 1 to 600 Hz, permitting the proper scaling of earthquake time-history records for very small-scale models. In the same laboratory, experimental research is performed on a small-scale model of a complete reservoir—arch dam system. The arch dam (made of epoxy resin) is excited with small, electrically driven, synchronized eccentric-mass vibrators, and vibration measurements are recorded on a 16-channel strip chart recorder or on magnetic tapes. The tests are performed for various water levels in the reservoir.

Model tests on gravity and arch dams are also conducted at the IEM in Harbin. At the university laboratories (Tsinghua and Tongji Universities), stress analyses of dam models are performed in well-equipped photoelasticity laboratories.

Experimental Facilities

The laboratories' size and equipment serve as a witness to the important role of experimental research in the PRC. For instance, the Structures Laboratory of the National Academy of Building Research measures 90 x 24 m, is serviced by a 20-ton crane, and contains several static test beds, reaction frames, compression test machines up to a capacity of 1,000 tons, and a 7-m-high reaction wall (see Figure 4.6) with a moment capacity of 1,000 tm at the base. A new Earthquake Engineering Laboratory is presently under construction. It will be 24 x 50 m in size and will house a 3 x 3 m shake table and a large reaction wall. Space is reserved in this laboratory for a larger shake table.

The loading equipment consists primarily of hydraulic actuators that are manually controlled in most cases. However, we have seen several servo-valve

Figure 4.7 Section of concrete gravity dam on shake table.

controlled actuators and also synchronized loading equipment. The plans for the Earthquake Engineering Laboratory of the National Academy of Building Research include a computer-controlled loading and data acquisition system comparable to that existing at the Building Research Institute in Tsukuba, Japan (on-line computer control for generating seismic deformation histories).

We saw small shake tables in most of the laboratories we visited. Very common is the 50 x 60 cm electrically driven table shown in Figure 4.8. Other tables range from this size to approximately 1 x 1.5 m. Signal generators that permit the input of white noise or prerecorded motions are available. The measured response is recorded on strip chart recorders or magnetic tapes. Most of the tables have been manufactured in the PRC. Our Chinese colleagues stressed the need for larger shake tables, and at least two 3 x 3 m tables will be installed in the near future.

The laboratories are generally well equipped with electric sensors and signal conditioners for the measurement of forces, displacements, pressures, and accelerations. Several of the institutes have instrument laboratories involved in developing measurement devices and recording instruments. Standard recording equipment, such as X-Y recorders, strip chart recorders, magnetic tape recorders, and oscilloscopes appear to be readily available. More advanced equipment, such as spectrum analyzers and data acquisition systems, is available only in smaller numbers and usually from a foreign source. We saw a Japanese-made 200-channel data acquisition system that produces a digital readout on paper tape at the rate of 10 readings per sec.

What we did not see in the laboratories are minicomputer systems adapted to test control, data acquisition, and data reduction. Experimental data are sometimes recorded on magnetic tapes, but in most cases either graphic or digital records are made. Digitization tables are available for the digitization of graphic records. We have no first-hand information on the ways in which experimental data are reduced, manipulated, and plotted in their final form. We believe that part of this work is done by transferring the digital or analog data to general-purpose computer facilities, which then manipulate the data in the time and frequency domains and generate the final plots.

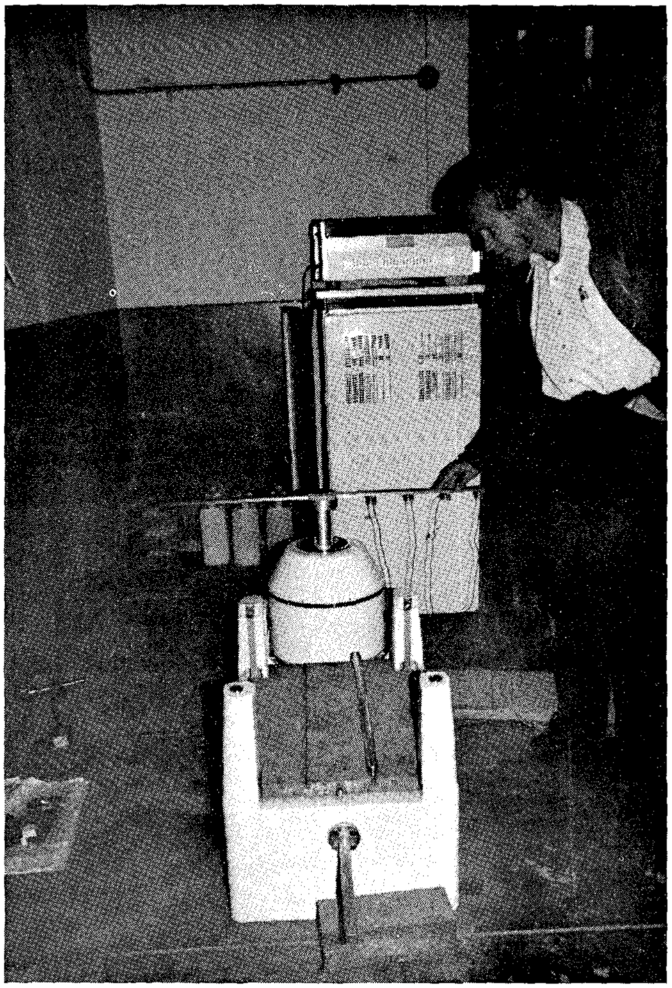


Figure 4.8 Small electromagnetic shake table at the Academy for Building Research, Beijing.

Dissemination of Research Results

Our Chinese colleagues report their research results mostly in individual papers published by their institutes or in national journals such as the journal of *Earthquake Engineering and Engineering Vibration*, which is written in Chinese but contains abstracts in English. More recently, information on Chinese research and code development can also be found in proceedings of international conferences, for example, the *Proceedings of the Seventh World Conference on Earthquake Engineering* held in Istanbul, Turkey, in September 1980. Papers presented by a Chinese delegation at the Second U.S. National Conference on Earthquake Engineering at Stanford University in August 1979 were published by EERI in March 1980 in a volume titled, *The 1976 Tangshan, China, Earthquake* (1980).

We were told that a direct line of communication exists between the research institutes and the SCCC, which sponsors much of the research and is responsible for implementing research results in codes of standard practice. The SCCC schedules annual meetings at which the research results are presented and future research efforts are discussed.

SEISMIC INSTRUMENTATION

The Chinese are increasing the number of strong-motion recording instruments installed throughout the active earthquake areas of China. Given the relatively high frequency with which destructive earthquakes occur in China, the increased instrumentation should provide many new records for their engineering use. In addition, through cooperative programs, strong-motion recording instruments in China may soon provide abundant data for engineers in the United States.

This section describes the information we gathered on strong-motion instruments: how they are deployed, their characteristics, new developments, and how visual records are digitized.

Network Administration

The SSB in Beijing provides the overall coordination and administration of seismological and strong-motion measurement stations and networks. In addition, the SSB administers professional organizations in Beijing and other cities, including the Seismological Research Institute in Wuhan and the IEM in Harbin. There are many seismological groups throughout China. Each province has a seismological bureau or brigade, and many have a seismological research organization.

The SSB Director, Zou Yu, said that their projects in earthquake engineering and seismic risk are conducted at the IEM in Harbin for historical reasons. As mentioned previously, IEM emphasizes the theoretical aspects of earthquake engineering, while the Chinese Academy of Building Research and the SCCC emphasize applied research.

The SSB Director expressed interest in taking more basic ground motion measurements. Time radio broadcasts are not available in China. In his opinion, time broadcasts are not needed for engineering studies but will be necessary for future seismological studies. The Director pointed out that computers are not widely used for earthquake analysis in China. A cooperative program with the United States will bring a PDP 11/44 computer to the SSB in Beijing.

At the IEM in Harbin, Guo Yuxue discussed his specialty, strong-motion measurement. His group is responsible for strong-motion instrumentation and record processing and focuses on three areas: network design and deployment, data processing, and use of strong-motion records. Their network goal is to increase the data base for large earthquakes. Deployment of modern Chinese strong-motion instruments began in 1966. Large earthquakes occurred so often that 40 strong-motion stations were in place by 1972. The Institute was involved in post-earthquake investigations during the Cultural Revolution (1966-1976), including Hsingtai (1966), Pohai Gulf (1969), Haicheng (1975), and Tangshan (1976). These investigations stimulated the desire for increased ground motion and building site instrumentation.

The Water Conservancy and Hydroelectric Power Scientific Research Institute in Beijing and the Research Institute for Earthquake Engineering under the Chinese Academy of Building Research both conduct studies of strong ground motion and the earthquake behavior of structures. Part of these studies involve installing and monitoring instruments at representative sites and on typically important structures. These agencies administer their own instrumentation but cooperate with the SSB.

The SCCC encourages and sponsors some instrumentation programs at research institutes connected with universities, for example, Tongji University in Shanghai.

Location of Instruments

In 1980 there were approximately 100 permanent stations in China. Almost one-half of the stations were in Hopei Province, which includes Beijing, Tangshan, and Tientsin. A group of stations are deployed in a north-south line along the eastern front of the Tibetan Plateau in the provinces of Kansu, Szechwan, and Yunnan. The provinces of Kwangtung in the south and Kiangsu in the east have some permanent strong-motion stations.

Of the 100 stations, approximately 60% of the recording channels measure structural response; the remaining 40% measure ground motion. Almost all ground motion measurements are part of a system installed on and around a structure. Programs presently under way will add free-field stations around Beijing and Tangshan.

Fifteen of the stations are on concrete and earth dams. These stations were installed by the Hydroelectric Power Research Institute.

IEM is directly responsible for maintaining 40 stations in northern China. The remainder of the stations are under the provincial care of institutes such as the Academy of Building Research in Beijing and the Water Conservancy and Hydroelectric Power Scientific Research Institute.

Types of Strong-Motion Instruments

Most stations consist of a small network of up to 12 motion transducers connected by cable to a central recorder that uses galvanometers and photosensitive paper. The transducers are "overdamped seismometers," a technique not widely used to measure strong earthquake motion in the rest of the world. A seismometer with damping less than but approaching the critical damping ratio of 1.0 (usually 0.7) will provide an electrical output proportional to the velocity for ground motion frequencies higher than the seismometer's natural frequency. The Chinese design incorporates a large amount of damping in the transducer, on the order of 10 times critical, thus providing an electrical output proportional to acceleration within a frequency band surrounding the undamped natural frequency of the sensor.

The Model RDZ1-12-66 accelerograph system is the most widely used. It was designed by IEM in 1966 and is manufactured in Beijing by SSB Factory No. 581. It has the following characteristics:

- Transducers
  - -- Natural frequencies: 4 Hz (horizontal), 4.5 Hz (vertical) ± 0.2 Hz
  - -- Damping: 9 to 12 times critical
- Trigger
  - -- Sensitive direction: horizontal
  - -- Natural frequency: 1-1/2 to 3 Hz
  - -- Damping: 10%
  - -- Sensitivity: 5 to 10 gal
- Recorder
  - -- Maximum of 12 channels
  - -- Photosensitive paper
  - -- Paper speeds: 2.1, 4.8, or 11.3 cm/sec
  - -- Galvanometers: 120 Hz
  - -- Time trace: 20 Hz ± 1%
- System
  - -- Sensitivity: 0.1 to 2.0 mm/cm/sec^2
  - -- Flat response: 0.5 to 35 Hz
  - -- Normal range: 5 to 100 gal

In 1976 the IEM designed Model RZS-II, a 9-channel accelerograph manufactured by the Beijing Geophysical Instrument Plant. It is somewhat more compact than the RDZ1-12-66 and has similar system characteristics.

The Water Conservancy and Hydroelectric Power Scientific Research Institute is using a Model DJ59-I, a 12-channel accelerograph, on five dams. It was developed about the same time as IEM's RDZ1-12-66. It uses accelerometers (damping ratio between 0.5 and 0.6) instead of overdamped seismometers. However, the recording galvanometers have a low natural frequency of 10 Hz and are damped at 20 times critical. When combined with the accelerometers, the galvanometers produce the same system sensitivity (0.1 to 2.0 mm/cm/sec^2) and range (5 to 100 gal) as the RDZ1-12-66. The frequency band is specified as flat over the range from 0.5 to 20 Hz.

The Water Conservancy and Hydroelectric Power Scientific Research Institute in Beijing has a portable displacement measuring system that is used for ambient vibrations. It uses CD-7 transducers (1-sec period), CJ1 amplifier/filters, and a 4-channel FM analog recorder. The system is manufactured by the Beijing Geophysical Instrument Plant.

New Instrument Developments

We were shown three accelerograph development projects at the IEM in Harbin and one at the Chinese Academy of Building Research in Beijing.

IEM has developed an improved Model RZS-II. The transducers (and trigger) have been significantly reduced in size and weight -- from 6 kg to 1 kg each. The natural frequency of the transducer is about 6 Hz and incorporates 7 times critical damping. The improved RZS-II has automatic sensitivity changes with three ranges, 500 gal, 130 gal, and 50 gal.

A prototype FM-analog accelerograph is under development at IEM. This development is concentrating on a small 4-track FM recorder using a reel-to-reel tape drive. The goals are a start-up time of less than 0.2 sec and a 50-dB dynamic range. The sample records viewed in Harbin showed a transient baseline of long duration beginning immediately after start-up, which is one of the major design challenges in applying FM-analog technology to strong-motion recording.

FM-analog records are attractive in China because of the availability of existing analog fourier analyzers in the laboratories and the relative ease with which the analog playback can be connected to A-to-D equipment incorporated in the foreign minicomputers that will be acquired over the next few years.

The RDZ1-12-66 accelerograph system is not efficient for recording simple free-field ground motion. IEM is manufacturing prototypes of a Model GQ-III 3-component accelerograph using 25-Hz accelerometers and recording on film. It is copied from the Kinemetrics' SMA-1 instrument. Film recording is important because data accuracy at lower frequencies (longer periods) is highly dependent upon the digitizing accuracy. Light-beam galvanometers recording on photosensitive paper cannot be focused as well as the film recordings presently available on U.S. accelerographs.

The Chinese Academy of Building Research has built a prototype accelerograph, the 3-component Model JJ-1. It uses overdamped transducers, galvanometers, and photosensitive paper and is designed for the frequency band from 1 to 30 Hz. An acceleration-sensitive vertical trigger is used in addition to the standard displacement-sensitive horizontal trigger.

Data Preparation

About 300 accelerograms of engineering interest have been produced by the strong-motion instruments throughout China. Most have been digitized at the IEM in Harbin using a semiautomatic digitizer produced by the Eto Denki Company of Tokyo. Its specifications are:

- Digitizer: Model ZT206
- Punch: Model CDZ-2
- Resolution: 0.1 mm
- Sensitivity:

Sensitivity:	Vertical	Horizontal
-- maximum	500 pt/cm	115 pt/cm
-- useful	400 pt/cm (0.025 mm)	100 pt/cm (0.10 mm)

- Length: 700 mm
- Height: 300 mm

The X,Y output goes to a printer and punched paper tape. Digitization includes a fixed centerline trace and the time trace at 20 Hz.

Guo Yuxue, who directs this work, said that standard processing of the records gave a bandwidth between 0.5 and 35 Hz. With corrections, the low-frequency range can be extended to 0.10 Hz.

The Water Conservancy and Hydroelectric Power Scientific Research Institute in Beijing uses a Model JTS 86 semiautomatic digitizer manufactured by the Chi Au Instrument Factory. Its specifications are:

- Resolution: 0.01 mm
- Accuracy: 0.10 mm
- Length: 800 mm
- Height: 600 mm

These digitizers are similar in performance to the Caltech Benson Lehner semiautomatic system used during the 1970s. The accuracy and bandwidth expectations of earthquake engineers in the United States are based largely on the performance of this system. The primary differences in present Chinese practice are the use of photosensitive paper instead of film and of overdamped intermediate frequency transducers instead of high frequency accelerometers.

Available Earthquake Data

The timing and format of our meetings did not permit a thorough review of available data. The IEM in Harbin seems to have the most complete catalog of accelerograms, and we did examine the following three documents.

- "Earthquakes Induced by Reservoir Impounding and their Effect on the Hsinfengkiang Dam," *Proceedings*, International Commission on Large Dams of the World Power Conference, Madrid, 1973. A report on earthquakes during the period from 1962 to 1973, including 121 accelerograms of M_S less than 5.4. These were aftershocks of the unrecorded main event in March 1962 with an M_S of 6.1.
- *Aftershocks of the Haicheng Earthquake of 1975*, publication of the State Seismological Bureau in Chinese. Aftershocks with M_S ranging from 1.1 to 4.5 following the unrecorded main event of M_S 7.3.
- Strong-motion records of the Tangshan earthquake from *Earthquake Engineering and Hazards Reduction in China*, P. C. Jennings, editor, CSCPRC Report No. 8, National Academy of Sciences, Washington, D.C., 1980. Chapter 4 discusses and catalogs accelerograms at distances greater than 80 km from the main event (M_S 7.8). The largest complete record registered 0.097g at 153 km. Aftershocks recorded near field showed M_S ranging from 4.2 to 6.0.

SOIL MECHANICS, SOIL DYNAMICS, LIQUEFACTION, AND SOIL-STRUCTURE INTERACTION

Soil Mechanics and Soil Dynamics

We did not give any special attention to the fields of soil mechanics and soil dynamics. However, during our visits to universities and laboratories, we made several interesting observations. As a practical means of putting the present observations in perspective, especially those regarding liquefaction and liquefaction testing, some of the already available Chinese publications in English should be mentioned. The Chinese liquefaction criteria that had been informally communicated were formally presented in 1979 by Xie Junfei. This work presented the basic Chinese code relationships regarding earthquakes and also extended the list of instrumented liquefaction case histories that was first published by Peacock and Seed (1968) and later extended by Christian and Swiger (1975).

The relationship between blow counts and intensity of ground shaking, which causes liquefaction, has been incorporated into the 1980 edition of the Chinese seismic design code, which is available in the publication of the International Association of Earthquake Engineering. Additional data from Chinese liquefaction analyses, including some valuable experiences with silty soils, have been published by Don Wang Wenshao in a report entitled *Some Findings in Soil Liquefaction* (August 1979).

Apparently, there is a growing interest throughout China in soil dynamics and liquefaction. Each laboratory and university we visited was either developing equipment for dynamic soil testing or had such equipment already operational. The following list includes some of the dynamic soil testing equipment we observed:

- Tsinghua University, Beijing: This dynamic triaxial testing machine (Figure 4.9) provides the dynamic excitation electromagnetically from the base of the apparatus. Loading is applied from the base of the sample via a loading ram equipped with a rolling rubber seal to reduce friction losses. The top of the sample is held stationary in the apparatus, and loads and deflections are all measured externally. This apparatus does not presently have back-pressuring capability.

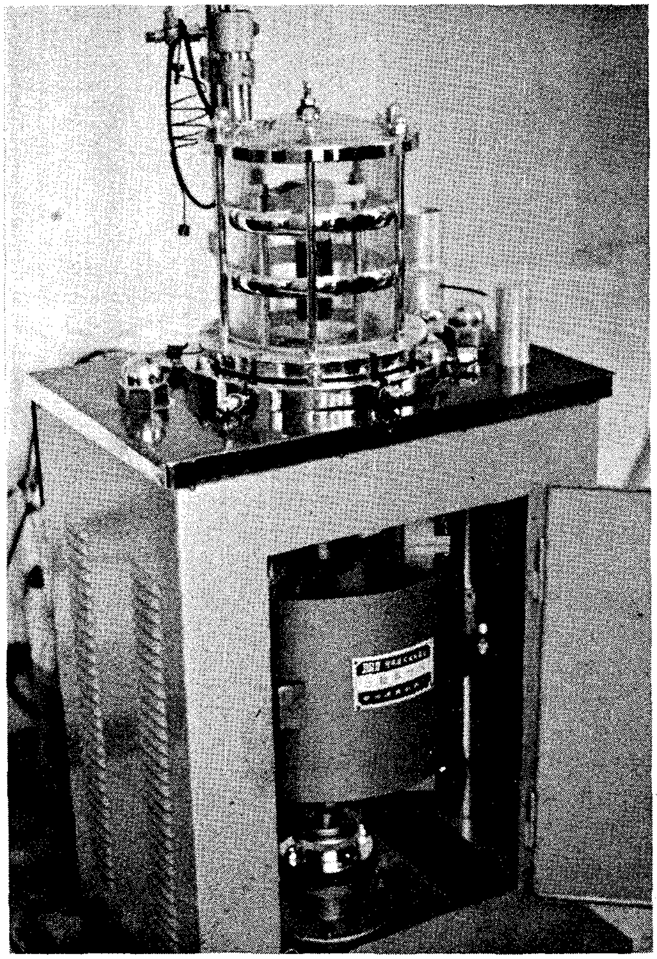


Figure 4.9 Dynamic triaxial apparatus at Tsinghua University, Beijing. Note the loading mechanism below the triaxial cell.

- Academy of Building Research, Beijing: This dynamic triaxial machine with back-pressuring capability has the ability to provide phase differences between σ_3 (confining pressure) and σ_v (vertical pressure) if desired. This capability requires a triaxial cell with no free air space; the loading is applied from above. The machine is used for routine testing at the rate of approximately one test per day. We observed a dynamic triaxial test on a soft marine clay that is believed to be subject to additional settlement after seismic activity. The Academy has also installed a shake table for correlating dynamic test results and field liquefaction behavior. At the Academy of Building Research, part of the test bay that contains the shake table has been left without a concrete foundation. Although no dynamic tests are currently planned, a static loading distribution study beneath a mat-founded model of a ten-story, eleven-bay frame is being prepared. Details of the modelling technique were not available, but the study was instigated after the currently available analytical methods of estimating pressure distribution were found to be inadequate.

- Water Conservancy and Hydroelectric Power Scientific Research Institute, Beijing: This institute has tested for liquefaction properties using a triaxial cell mounted on a vertical shaking machine and employing the inertial forces of a mass located on the top of the sample to provide the cyclic stresses. This machine was undergoing modification and was not available for inspection.

- Institute of Engineering Mechanics, Harbin: The primary development of dynamic testing equipment in China has occurred in Harbin. The cyclic triaxial testing machine being installed at Tsinghua University appeared to be a later model developed from a well-used prototype in Harbin.

- Tongji University, Shanghai: This university does not presently have dynamic soil testing equipment, but, under the direction of Professor D. T. Zheng, a direct shear apparatus for dynamic testing and a resonant column machine are being developed.

Liquefaction

Extensive liquefaction occurred during the 1976 Tangshan earthquake. The delegation was not taken to any of the areas outside the city of Tangshan where liquefaction occurred, and it is doubtful that any useful results would have come from a superficial examination. Some liquefaction did occur at the Tianjin Gear Factory, which was visited and is described in more detail elsewhere in this report. Liquefaction beneath structures was the main cause of building failure among factory buildings that had been strengthened following the 1967 Hajian earthquake. Examination of the area following the earthquake revealed a zone of loose silty sand with standard penetration blow counts between 4 and 10 to a depth of 12 m. Structures being built or reconstructed in this area are being placed on driven piles to ensure a penetration of at least 1.5 m into nonliquefiable material. Numerous sand-boils were observed at the factory site in 1976, but only a few were noticed following the 1967 event.

Soil-Structure Interaction

The dynamics of soil-structure interaction were of considerable interest to the institutions we visited, as evidenced by the fact that Veletsos's lecture (Effects of Soil-Structure Interaction During Earthquakes and their Provisions in Design) was presented at three different locations. This topic is of special interest to engineers in the Shanghai area because of the relatively soft soil conditions encountered there.

In China, the principal research on this topic appears to be related to the behavior of dams. During our visit to the SSB in Beijing, reference was made to earthquake ground motions measured in the vicinity of several dams. These measurements provide some insight into the relationship of free-field ground motions to ground motions close to, or beneath, the base of the dam. Instrumentation for the acquisition of such data is available in about ten different locations. Analyses of the records obtained to date have led to the conclusion that the foundation motion is generally less intense than the free-field motion since the peak base acceleration of the foundation is roughly two-thirds of that obtained under free-field conditions.

Several studies conducted at the IEM in Harbin are also relevant to this topic. These include studies of the effects of local topography and the depth of the soil layer on the intensity of ground shaking and analytical studies of soil-structure interaction using finite-element techniques.

The only studies of structures we were advised of were those carried out under the direction of Mr. Liu Xihui in Beijing. These involved testing an eleven-story reinforced shear-wall building for which the soil conditions were described as "soft." In addition to ambient vibration tests, forced vibration tests were conducted over a range of frequencies with the building excited by a harmonic force at the top floor level. The response quantities measured included the horizontal displacement and rotation of the foundation as well as the displacement of alternate floors. It was found that foundation rocking can contribute significantly to the deflection of the structure. Similar tests were conducted on a number of other buildings, but in these the rocking component of the foundation motion was not measured.

STRUCTURAL ENGINEERING DESIGN

Chinese Aseismic Design Code

The SCCC is responsible for the seismic design requirements for the PRC. These standards are incorporated in the *Aseismic Design Code for Industrial and Civil Buildings*, TJ 11-78. The effective date of the latest issue was August 1, 1979. Any modifications or interpretations are to be made by the Chinese Academy of Building Research.

The Code applies to all structures including chimneys, water towers, and other edifices located in areas where the maximum seismic intensity is 7, 8, and 9. Areas of seismic intensities less than 7 do not require earthquake-resistant design. Areas subject to seismic intensities greater than 9 require special investigation and design procedures. The basic regional intensity may be modified according to the importance or use of the structure.

The Code contains clear statements of the basic philosophy and design principles that govern the Chinese practice of earthquake-resistant design. The primary purpose is, "The safeguarding of human life and property, so that the damage to the buildings designed by this Code will not endanger human life and valuable production equipment, and the buildings themselves can still be serviceable without repair or with moderate repair after an earthquake." To achieve this goal, the Code outlines the following principles:

1. Select site and subsoil that are favorable to earthquake resistance.
2. Make a comprehensive plan to prevent a secondary disaster from occurring after the earthquake (e.g., fire and explosion).

3. Choose a technically advanced and economically reasonable earthquake-resistant design.
4. Make an effort to arrange the building configuration as simply as possible: to have symmetrical and uniformly distributed weights and rigidities and to avoid irregular shapes or any abrupt change in elevation and plan.
5. Ensure the integrity and ductility of the structures and their connections.
6. Avoid or minimize decorations, parapets, or cornices that are apt to collapse during an earthquake.
7. Reduce the weight of the building and lower its center of gravity.
8. Carefully specify requirements to guarantee construction quality in design documents.

Although the Code does not require earthquake-resistant design in areas subject to seismic intensity 6, it does require structures in those areas to adhere to principles 4, 6, and 8. These rules encourage simple configurations that are uniform and symmetrical; discourage the use of parapets, decorations, and cornices; and require proper design documents to guarantee the quality of construction.

In many ways, the Chinese Intensity Scale is similar to the Modified Mercalli Intensity Scale developed in the United States. Certainly the basic philosophy of earthquake-resistant design is much the same as that of the Structural Engineers Association of California. Although a direct comparison of the *Aseismic Design Code for Industrial and Civil Buildings* with the *Uniform Building Code* currently in use in the state of California is difficult because of the differences in terminology, they are similar in content, and the base shear is of the same order of magnitude.

The base shear is determined by the formula:

$$Q_o = C \cdot \alpha \cdot W$$

where

C = Structure-related coefficient to be taken from Table 4.2.

TABLE 4.2

VALUES OF THE STRUCTURE-RELATED COEFFICIENT, C

Structures	C
Frame structure	
Steel	0.25
Reinforced concrete	0.30
Reinforced concrete frame with shear wall or aseismic bracing	0.30 - 0.35
Reinforced concrete shear wall structure	0.35 - 0.40
Unreinforced masonry structure	0.45
Inner-framed multistory or framed first-story buildings	0.45
Hinged frame bent with:	
Steel columns	0.30
Reinforced concrete columns	0.35
Brick columns	0.40
Tall and slender structures, such as chimneys and water towers	
Steel	0.35
Reinforced concrete	0.40
Brick	0.50
Various wooden structures	0.25

α = A function of the fundamental period, T, of the structure, modified by the type of soil at the site as shown in Figure 4.10. For seismic intensities 7, 8, and 9, the maximum values of α are 0.23, 0.45, and 0.90, respectively.

W = Total building weight contributing to seismic load: dead load, snow load, live load on floor area, and crane load.

Q_o = Base shear of the structure (i.e., the total horizontal seismic load).

Tangshan Construction

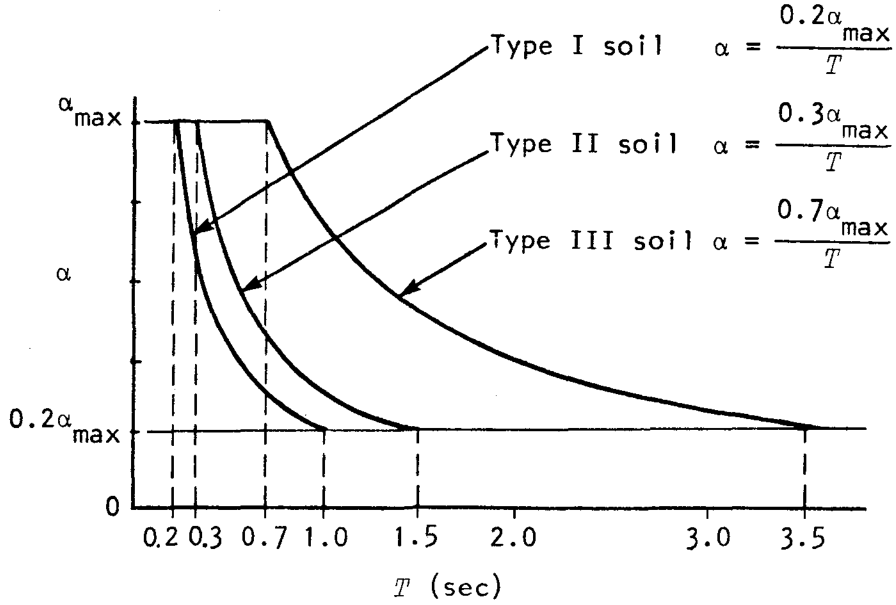
In Tangshan, we examined a five-story apartment building under construction that had been designed in accordance with the new seismic code (Figure 4.11). The structural frame consisted of brick masonry exterior walls and reinforced concrete interior walls. The main shear walls were cast-in-place concrete, and the room divider walls were precast units (Figure 4.11b). The floors were room-size, precast concrete units.

Of particular interest is the way reinforcing steel is utilized in the design. It is obvious that there is a shortage of steel. The bond beams at each floor are reinforced with four 12-mm bars and serve as ties, drag struts, and chord reinforcing for the floor diaphragms. At each corner of the building and at each intersection of the transverse shear walls and the exterior masonry walls, vertical reinforced pilasters are positioned within the brick walls. This reinforcing consists of four 16-mm deformed bars.

Figure 4.12 shows several views of the floor panels connected to their supports. The dowels projecting from the panels are to be embedded in the cast-in-place concrete wall, locking the various units into an integrated system. Figure 4.13 shows the connection of the various elements and the interlocking reinforcing steel.

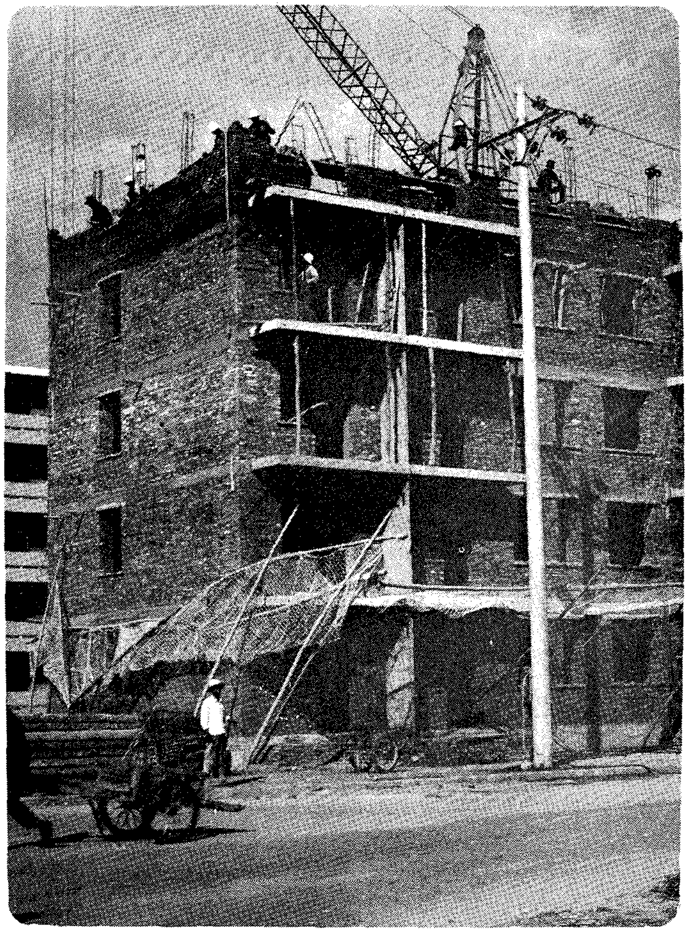
This type of construction was reported to cost 120 yuan per m^2, or approximately \$8.00 per ft^2.

The structural design of the building appeared to follow the principles of seismic design outlined in the Code. The quality of materials seemed to be consistent with the design concept. Only in the area of construction work

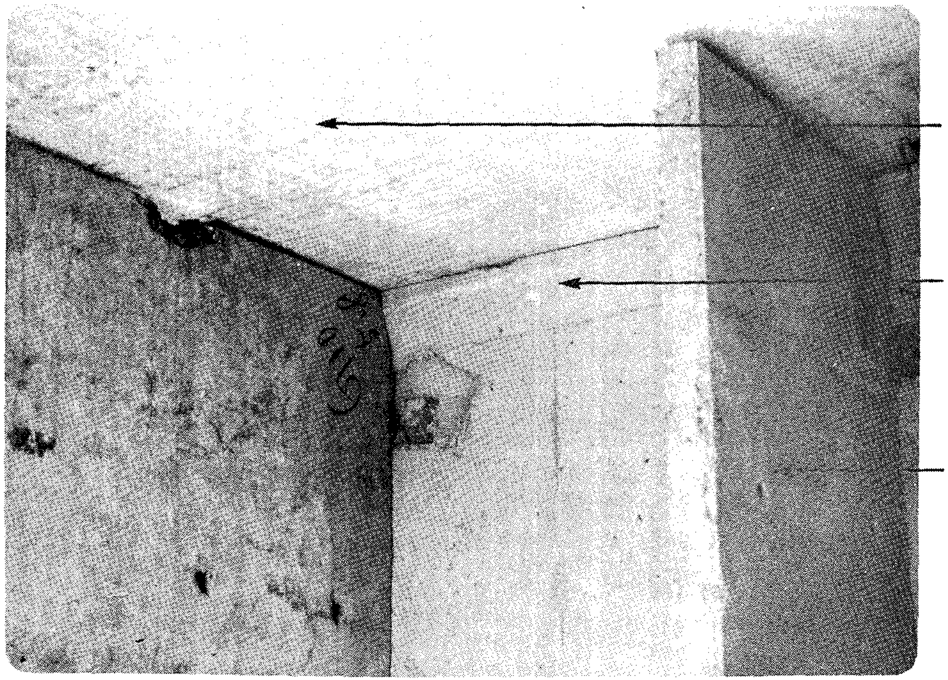


Type I soil:	Stable rock
Type II soil:	Ordinary stable soil (except Types I and III)
Type III soil:	Saturated loose sand, silty sand (from soft plastic to flow plastic), organic soft soil, hydraulically filled soil, and other soft and loose manually back-filled soil

Figure 4.10 Earthquake-related coefficient.

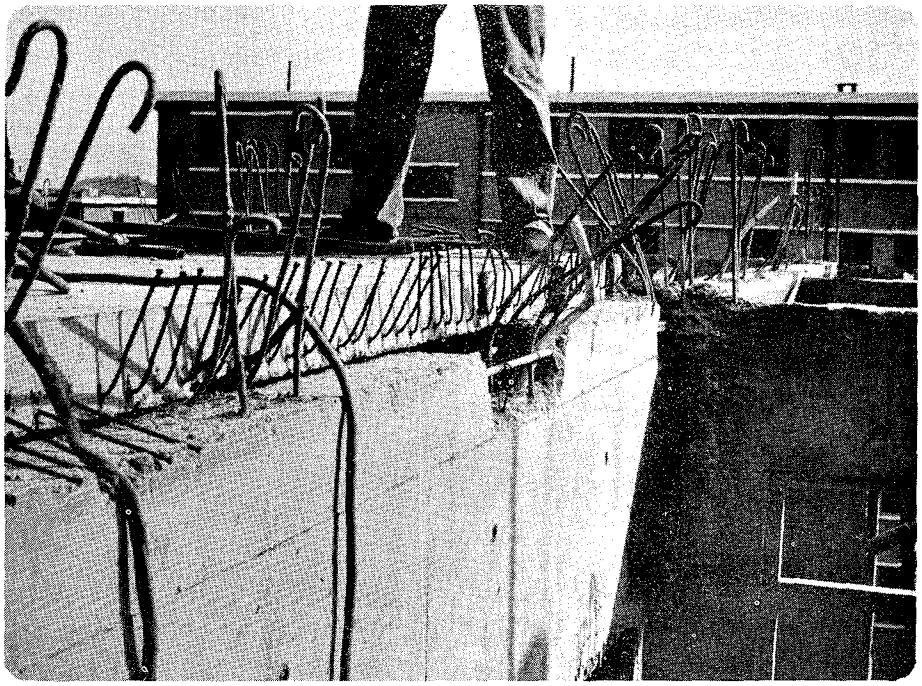


a. View of exterior masonry walls.

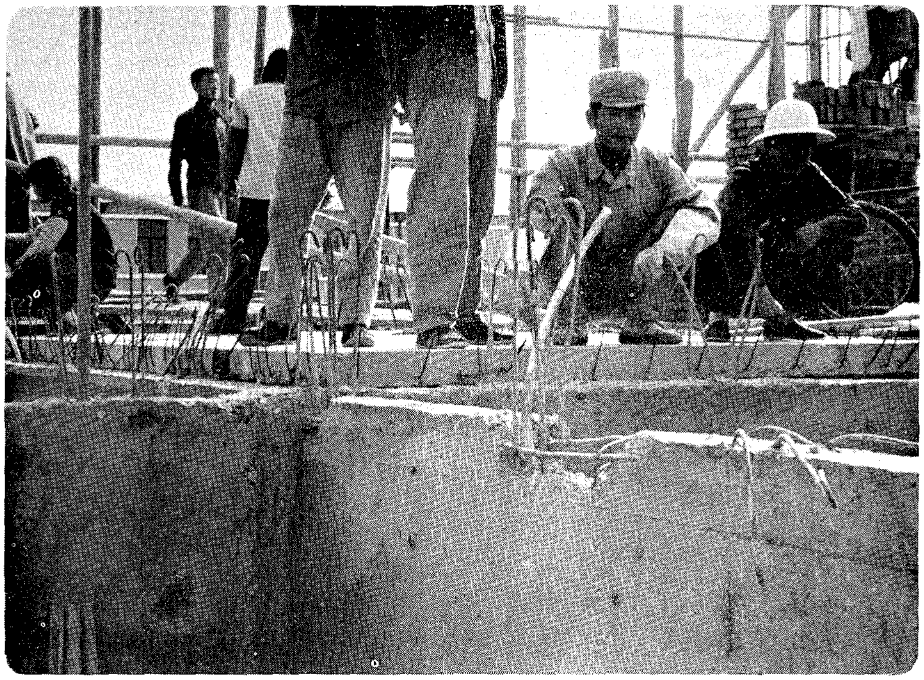


b. Typical interior concrete walls.

Figure 4.11 Five-story brick masonry apartment building under construction in Tangshan.

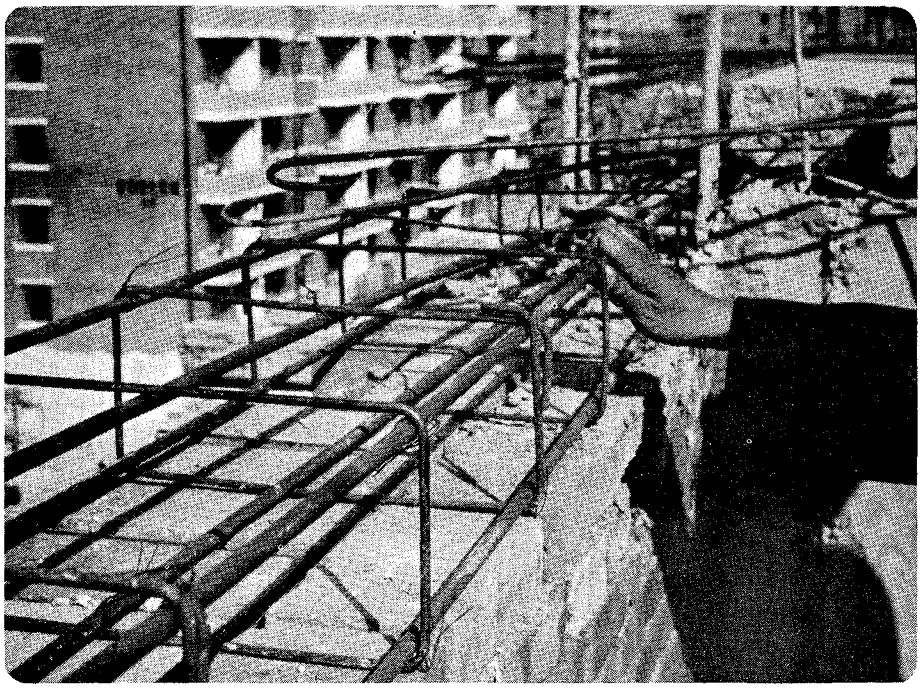


a. The concrete interior.

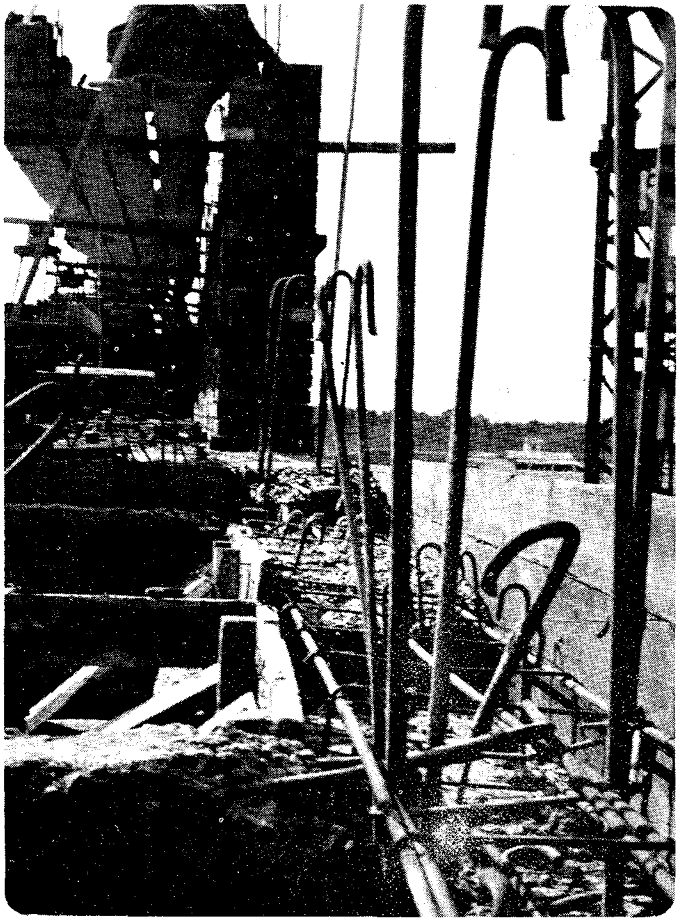


b. The connection of concrete elements.

Figure 4.12 Close-up view of the construction work on the five-story apartment building shown in Figure 4.11.



c. A bond beam with steel reinforcing.



d. View of construction practices.

Figure 4.12 (Continued)

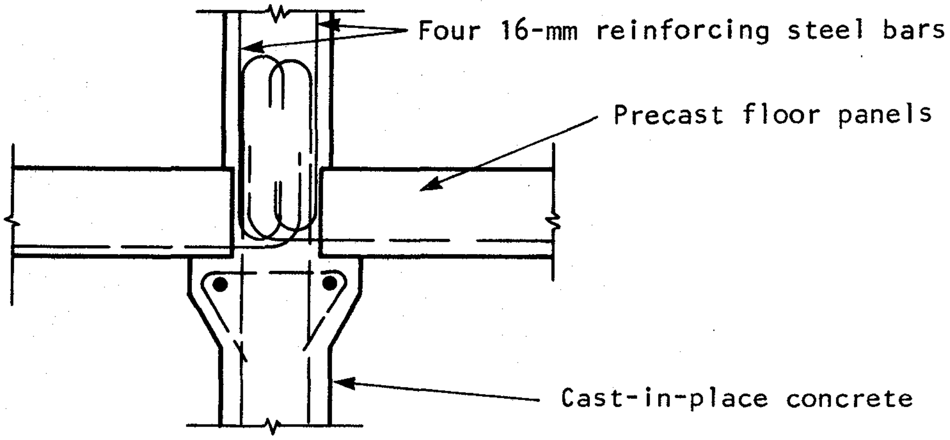


Figure 4.13 A detailed view of the connection between the reinforcing steel and the concrete.

did we note any variations in practice from that in the United States. Generally the bricks were not moistened immediately prior to laying, nor were the bricks being laid in the wall shoved into place. The head joints were not completely filled, and, consequently, the adhesion of the mortar to the brick was at least suspect and might be less than adequate.

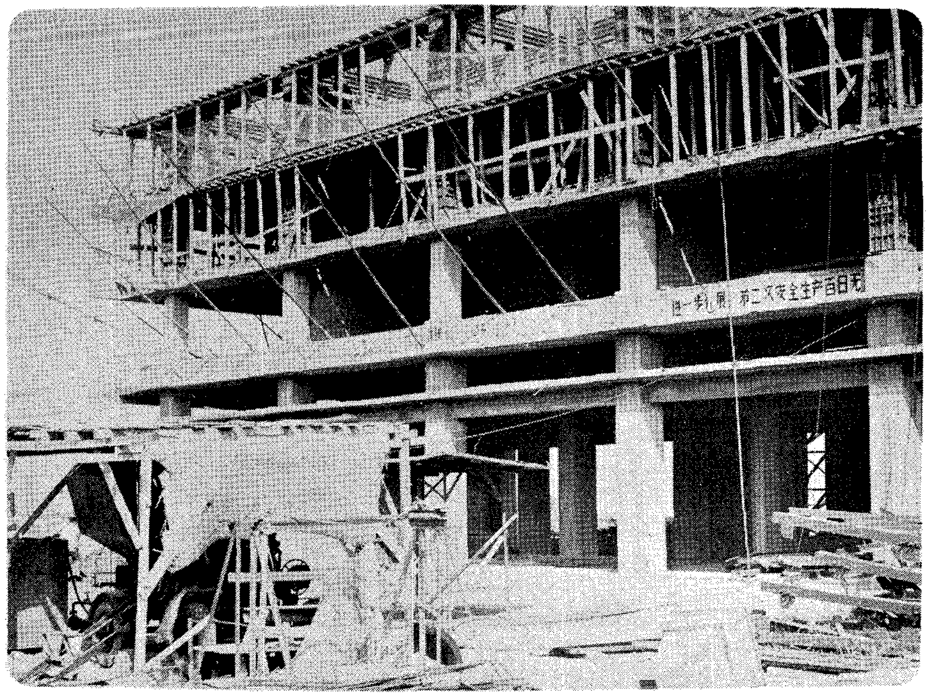
Brick construction with minimal reinforcement is a necessity if the Chinese are to house their vast numbers of people. Brick materials are in abundance and are manufactured in many small kilns throughout the countryside. There is an abundance of clay. At present, they are using the materials at hand. As was expressed on several occasions, however, their goal is to use more reinforced concrete construction.

Construction in Harbin

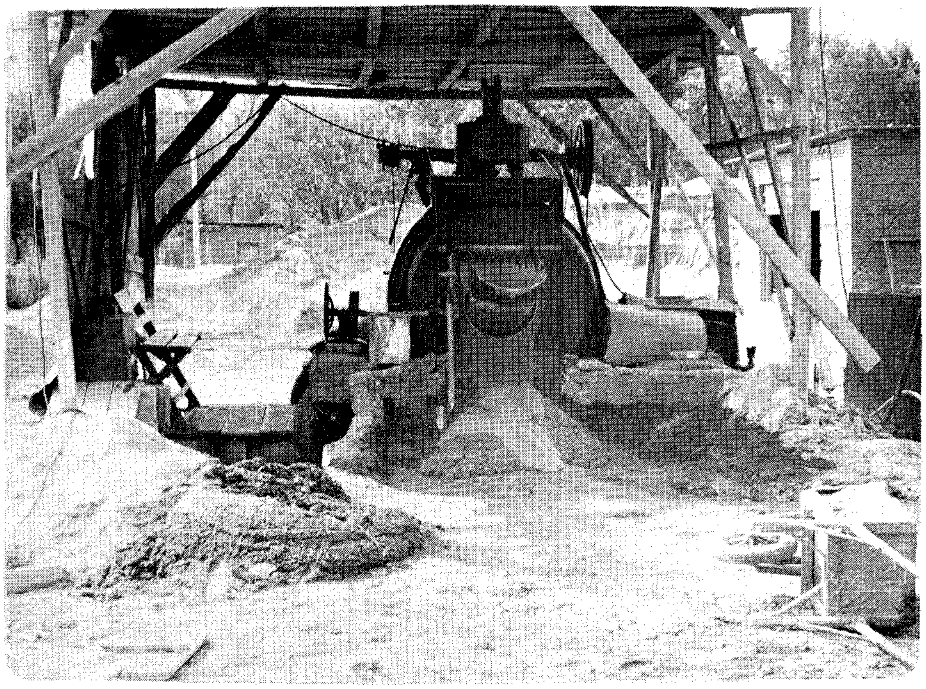
In Harbin, we observed a fifteen-story hotel building under construction. This was one of twenty-three hotels being built in several of the major cities of China. The structure was a reinforced concrete cast-in-place frame and floor system with concrete shear walls to resist the lateral forces (Figure 4.14a). The secondary floor beams were precast units. Most of northern China, including the city of Harbin, is in an area of minimum earthquake intensity. Consequently, the shear walls were functioning not as earthquake-resisting elements but as a wind-resisting system.

The building was being constructed with a minimum of equipment and an abundance of field labor. The concrete was mixed at the site in a batch mixer (Figure 4.14b) equivalent to a one-yard concrete mixer in the United States. The materials were handled with shovels and transported in wheelbarrows or carts. The platform-type hoisting equipment was large enough to carry one wheelbarrow or cart (Figure 4-14c). There were no man lifts. It appeared that the workers either walked up a ladder or on a ramp incorporated into the wooden scaffold. Most of the forms were made from wooden timber and boards, although a few of the more standard and repetitive units were made of sheet steel (Figure 4-14d).

The designs of various concrete members were similar to comparable designs used in the United States for members exposed to gravity loads. The position

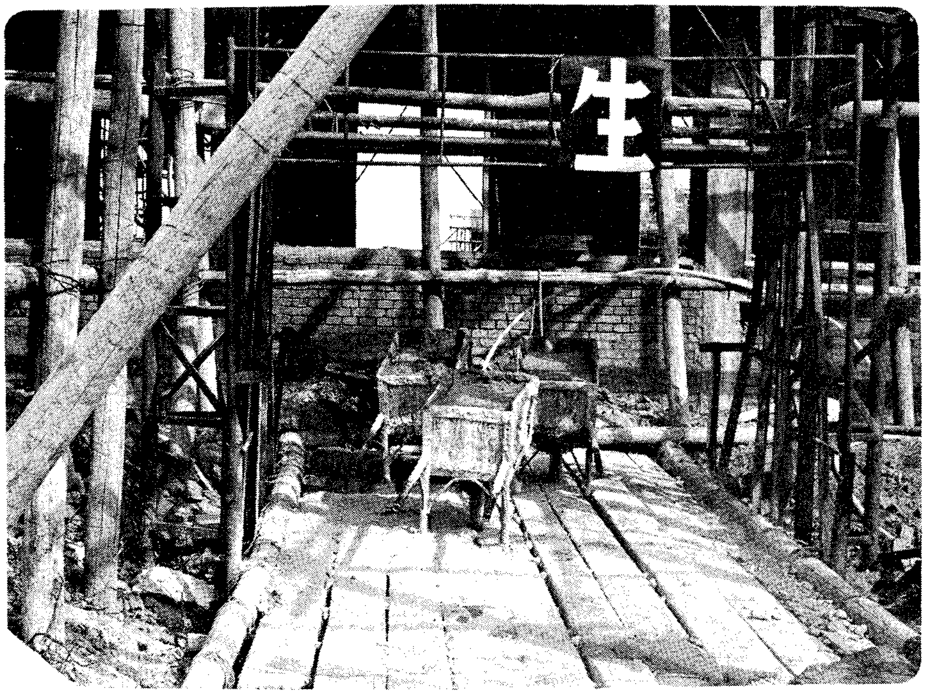


a. General view of the lower stories.

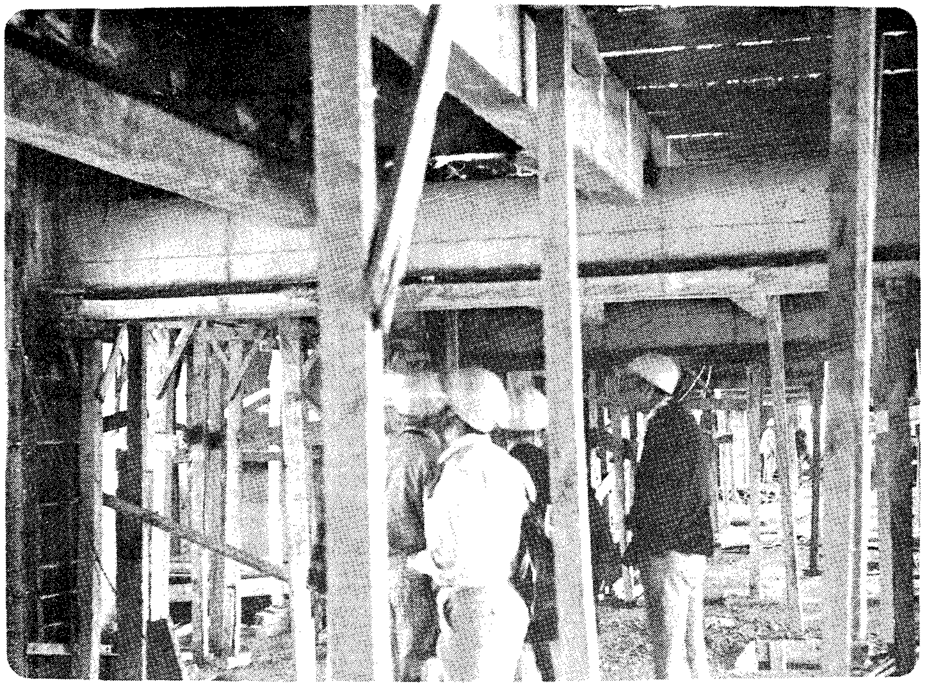


b. Batch plant concrete mixer.

Figure 4.14 Construction of a new fifteen-story hotel in Harbin.



c. Vertical hoist and concrete buggies.



d. View of frames, showing precast members and shoring.

Figure 4.14 (Continued)

of the reinforcing steel and the coverage and spacing of the bars compared favorably with the standards of the American Concrete Institute. We did observe that the members did not comply with any requirements for ductile framing. The reinforcing bars, particularly the ties, were not anchored in zones of compression, nor closely spaced in the columns. The longitudinal reinforcing steel in the beams terminated at the columns instead of extending through the column zone to splice points in the center portion of the beam span. The code-prescribed seismic intensity in Harbin is 6.

ARCHITECTURAL, MECHANICAL, AND ELECTRICAL COMPONENTS

Because of the increased vulnerability of cities with a high population density, input by architects, planners, and electrical and mechanical engineers is an important element in earthquake hazard reduction programs geared to the urban environment. Although a structure may not totally collapse in a severe earthquake, there is ample evidence from major earthquakes in the past that damage to nonstructural components and systems in a building can result in losses equivalent to between 60% and 75% of replacement costs and can cause significant casualties. Elevators in multistory buildings are particularly vulnerable to earthquake forces as data collected after the 1971 San Fernando earthquake have shown. During that earthquake, approximately 90% of the elevators in the Los Angeles metropolitan area were rendered inoperable. Subsequent research substantially improved the performance of elevators by recommending modifications in the design of counterweight and guide-rail systems.

In the PRC, the Institute of Architectural Design is responsible for raising the level of building design for the entire nation. As one of the institutes under the jurisdiction of the Academy of Building Research in Beijing, which also houses the Institute of Architectural History and the Institute of Architectural Physics, it provides technical information on the design of major large-scale buildings, such as the Peking Main Library. By coordinating its activities with the Institute of Earthquake Engineering during the design process, specific consideration is given to foundation design and seismic safety concerns.

Currently in China, the first priority in seismic safety research is given to mitigating structural damage and preventing structural collapse during an earthquake. Understandably, as was the case in the United States several years ago, there is no current evidence that architectural, electrical, or mechanical building components or systems are being tested in China, and no tests were observed by the team members during visits to universities and laboratories included in our tour. However, the research staff and the administrators of the Academy of Building Research indicated their awareness of the importance of this sector of earthquake engineering. And, in fact, uniform building configuration has already been included in the requirements of the *Aseismic Design Code.*

Since the 1976 earthquake in Tangshan, the Academy has been comprehensively collecting and documenting data on nonstructural damage for future testing and study. As research in structural systems and assemblies advances, it is clear that attention will eventually be directed toward the seismic performance of architectural and other nonstructural elements. This will be particularly true for elevator design as the construction of new multistory buildings with sophisticated structural systems increases in the major urban areas of China. With the advance of research in earthquake-resistant building construction, the exchange of technical and scientific information between the United States and the PRC will become increasingly valuable in avoiding a duplication of lessons learned from past earthquakes in both countries.

REPAIR AND STRENGTHENING OF EXISTING BUILDINGS IN CHINA AGAINST EARTHQUAKES

A national program for the repair and strengthening of existing buildings has been implemented in China under the jurisdiction of the OER of the SCCC, located in Beijing. The OER develops policy, design strategies, and codes and determines yearly target quotas for the number of buildings to be strengthened. During the five-year period from 1977 to 1981, about 92,000,000 m^3 of

The national program called the "Repair and Strengthening of Structures in China" has been very effective and successful. As we noted during a visit to a gear factory in Tianjin City, a large metropolitan area about 110 km southwest of Tangshan, those buildings that had the benefit of preventive measures, consisting of strengthening their beams and columns, performed better and experienced much less damage than those buildings without such strengthening.

Methods and processes used for the repair and strengthening of existing structures varied by building type and location. For brick walls and masonry buildings, cracks were first filled with cement mortar, then a fabric of reinforcing wire mesh was applied to both sides of the wall. Finally, heavy coats of a stucco-cement mortar were placed over the reinforcing mesh along the entire wall surface, exterior and interior. Steel tie rods were placed transversely through the building to tie the entire building together. Further efforts were made to reduce loads on bearing walls by such measures as reducing roof construction weights, adding additional column supports to distribute loads more evenly, and applying other measures to improve the performance of the building as a unit. This method was also used to repair and strengthen the Academy of Building Research in Beijing, which was substantially damaged during the 1976 Tangshan earthquake (see Figure 4.15).

Another method used in Beijing to strengthen existing brick masonry buildings consists of building reinforced concrete frames, or a series of concrete pilasters, on the outside of the structure as a literal three-dimensional cage around all sides of the building (see Figures 4.16 and 4.17). In this case, the pilasters were wrapped around the corners of the building as a means of obtaining continuity at the ends and corners, thus tying the building together to act as a unit. Again as in the previous example, steel tie rods were placed transversely through the building at floor and wall lines to tie the existing walls of the structure and the new concrete frames together.

With column-frame systems, column loads can be reduced by using lighter roof construction materials when an effective reduction of loads is shown to result in improved building performance. Additionally, weak or cracked columns were reinforced with steel angles at the top and bottom and along the edges of the column, where necessary. Special attention was given to strengthening the connections between roof trusses and columns.

Figure 4.15 The Academy of Building Research after repair and strengthening.

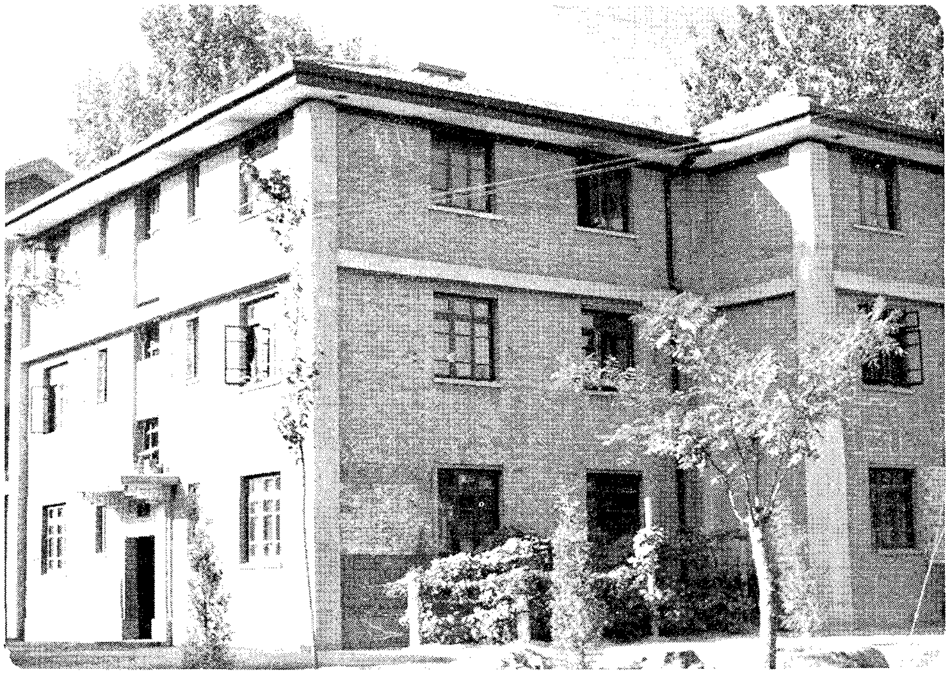


Figure 4.16 An apartment building in Beijing after strengthening.

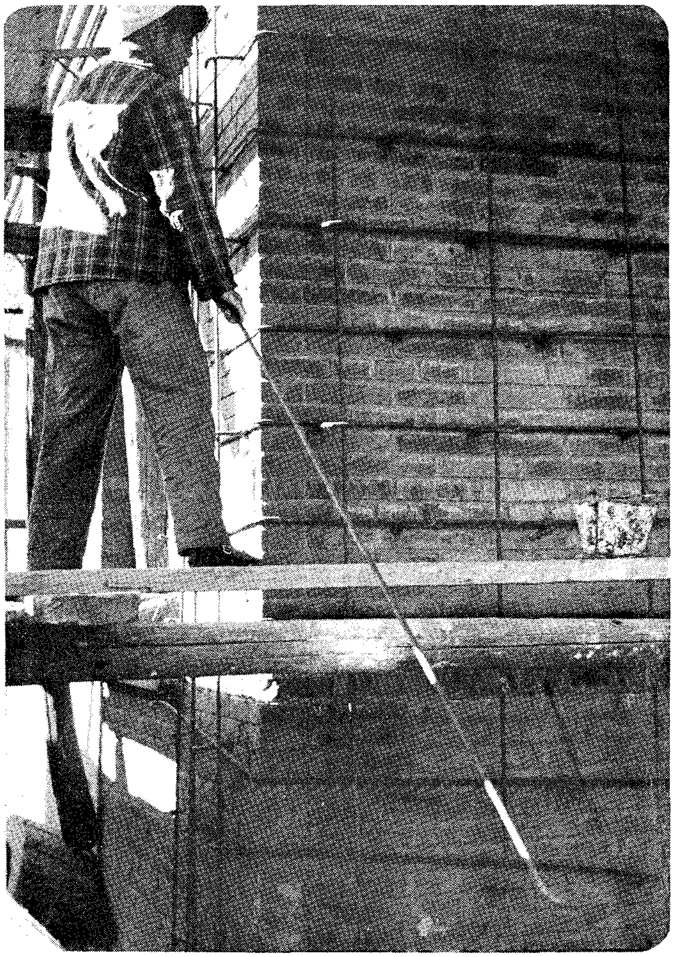


Figure 4.17 Close-up view of reinforcing steel bars.

At the gear factory in Tianjin, the methods used to strengthen reinforced concrete foundations consisted of reducing the loads as discussed before, increasing the bearing area, and driving new piles adjacent to existing foundations, then tying the pile caps to the foundation. Electric transformers and other critical nonstructural elements were anchored and tied to the ground.

The OER has also successfully implemented a national parapet ordinance during the past few years. All hazardous or poorly fastened parapets and cornices have been secured or removed to mitigate this hazard in areas of high seismic risk.

The final construction work was being completed on an electric power plant near Tangshan at the time of the 1976 earthquake, and the plant was in partial operation. Major damage occurred to all portions of the plant. As a result, the seismic design requirements for repair and reconstruction were increased. The reinforced concrete columns on the exterior wall were strengthened and stiffened with steel cross braces. The construction details were carefully executed to avoid column failure in the direction of the bracing. A number of similarly strengthened buildings and some new construction using this cross-bracing concept were observed in Tianjin.

LIFELINES

Damage to Lifeline Facilities Caused by the Tangshan Earthquake of July 28, 1976

The seismic damage discussed in this section was reported in the Chinese literature included in the References. The Tangshan earthquake severely damaged the lifeline systems in Tangshan and adjacent cities, but by the time we visited Tangshan, most of the damage had been repaired and most of the services had been restored. Some new facilities are under construction.

A great number of cracks produced by the Tangshan earthquake formed an earthquake rupture band about 10 km wide. Highways, roads, and rows of trees crossing this band were offset by as much as 1.5 m. The railroad tracks from Tanggu to Fengnan County bent at 106 locations as shown in Figure 4.18. About 60% of the highway bridges and 40% of the railway bridges suffered severe damage. Figure 4.19 shows a bridge that collapsed.

Figure 4.18 Bend in the railway tracks between Tanggu and Fengnan.

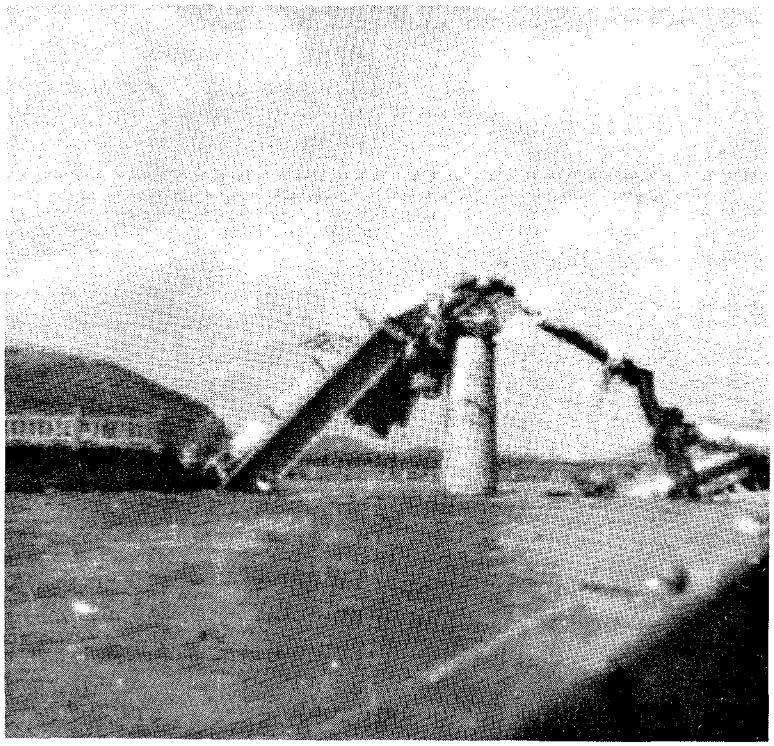


Figure 4.19 A collapsed bridge.

The main causes of well damage were soil liquefaction, sand blows, ground movement, and slippage. Damage to the wells ranged from 10% to 80%. Thirty-three percent of the masonry water tanks were damaged, as opposed to only 10% of the reinforced concrete water tanks.

The damage to buried water and sewer pipes included pipe-barrel ruptures (Figure 4.20), joint separation (Figure 4.21), longitudinal cracks, and burst fittings. Pipes situated on soft soil, loose sand, siltlike soil with a high water table, riverbanks, or excavated hollow zones suffered the heaviest damage. Pipe fitting connections such as tees and elbows are most apt to sustain damage.

Both gas holders and the gas-storage tanks were heavily damaged, but the damage to contained liquefied gas was slight. Damage to gas holders varied from 50% to 80%, depending on the type of construction. A cylindrical shell oil tank in Tangshan with a capacity of 1,000 m^3 displaced 7 cm and settled 50 m after the main shock, and another containing 900 tons of oil developed a bulge at the lowest segment of the wall.

Buried gas pipelines made of steel were only slightly damaged, but cast-iron pipes with cement mortar joints sustained heavy damage. The collapse of a highway bridge caused the oil pipelines to break, polluting the river.

Highway and railway bridges were severely damaged, which led to traffic interruption. In Tangshan, 62% of the bridges were damaged; in Tianjin, 21%. Bridge failure was a result of the collapse of the superstructures, subsidence of the embankments, and movement of the abutments toward the river because of landslides.

In Tangshan, power and communication services were completely interrupted during the main shock, owing to the collapse of a power plant and the failure of buildings, which caused damage to poles and lines.

Aseismic Measures for Lifelines

Site selection is very important for lifelines. Whenever possible, they should be far removed from fault lines, riverbanks, or steep hillsides.

Figure 4.20 A ruptured pipe barrel.

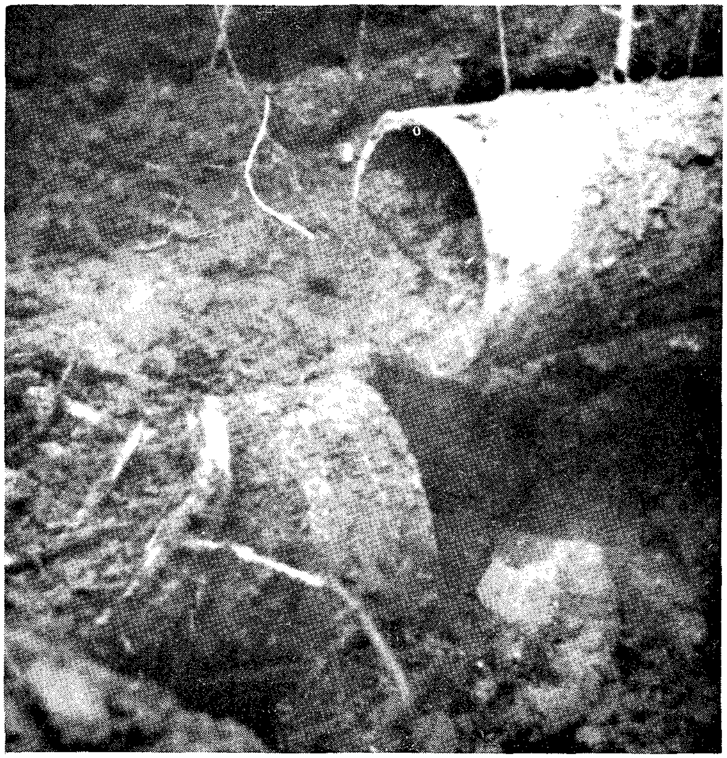


Figure 4.21 Joint separation of a water pipeline.

The foundation systems for lifelines or their components should be on firm soil; the surrounding soil materials must be compacted in order to prevent deformation during the main shock. The possibility of soil liquefaction should be minimized.

Continuous rigidity of the structural system should be provided, e.g., joints should be strengthened using the highest quality welds to help anchor the support systems. Cast iron, unreinforced masonry, and concrete are easily cracked and displaced; steel, reinforced concrete, and other ductile materials should be used instead. The best material is one that is both very strong and very ductile. Continuous pipelines should have welds that provide uniformity and continuity. To withstand seismic displacement, segmented pipelines should have flexible joints such as rubber rings. Other rigid structures in a lifeline system, such as bridges and tanks, should have strong joints and connections and the supports should be well anchored: this is very important to ensuring overall structural integrity and rigidity.

The Tangshan earthquake demonstrated that underground and semiunderground storage facilities experienced less damage than the aboveground facilities. Communication cables belong underground, too; the underground cables in Beijing remained intact during the Tangshan earthquake. (Shaking at Beijing was not severe, however.) System redundancy should, of course, be considered in plans to reduce seismic hazards.

Reconstruction of Lifelines in Tangshan City

All transportation (highway and railway) and power systems had been restored by the time we visited Tangshan. Reconstruction work will include two main arteries, 50 m wide, as the principal means of handling traffic during normal and emergency conditions.

Most public utility lines will be built underground. Figure 4.22 shows a trench and reinforced concrete pipes for a water supply line under construction in Tangshan City. There are seven kinds of underground utility transmission and distribution lines: water supply lines, sewer and storm lines, steam and gas lines, and power and telephone lines. The diameters of these lines vary from 75 cm to 600 cm and their lengths vary from 100 km to 200 km.

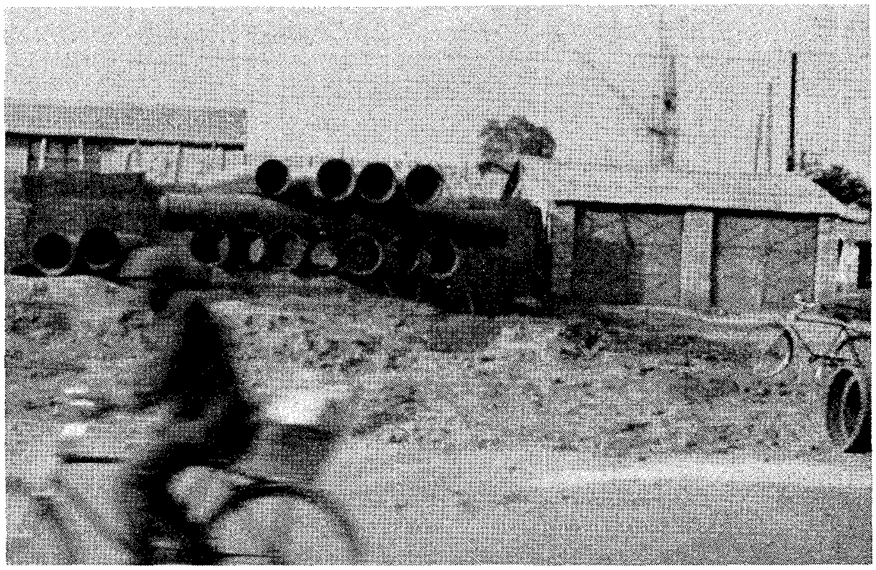


Figure 4.22 Reinforced concrete pipes to be used in reconstructing the Tangshan water supply lines.

All seven utility systems are to be built underground. Because some systems require specific gradients, such as storm and sewer lines, the construction of these buried lifelines is complex, particularly at junctions and intersections. Special attention was given to seismic considerations in the initial planning and design stage, as discussed in Chapter 2.

LOW-RISE RESIDENTIAL CONSTRUCTION

We saw only a miniscule part of the total area of China -- not even the entire eastern edge of the country and only large cities or their environs. Although the most evident new construction in large cities is five stories or more in height and of reinforced concrete, sometimes combined with brick, it seems safe to say that most people live in houses of three stories or less, with single-story houses predominating.

With the exception of a few mud-plaster houses near Harbin, all the other low-rise houses we saw were of brick or block masonry. The extent to which adobe, rammed earth, fieldstone, and other materials are used in China, particularly in the interior, is not known. That houses of earth are being built is suggested by the fact that articles 91 through 96 of the *Aseismic Design Code* pertain to adobe and rammed earth. These articles restrict earth houses to zones where the shaking intensity is 7 or less; restrict height to 6 m (two stories); require ring beams of reinforced concrete, reinforced brick, or wood; require reinforcement such as bamboo at intersections and corners of walls; and require buttressing of gables, lime mortar for laying adobe bricks, a minimum wall thickness of 25 cm, and a minimum compressive strength of rammed earth of 15 kg/cm^2 (213 psi).

Figure 4.23 shows a one-story village house typical of older rural houses in the region of Beijing and Tianjin. There was no opportunity to view the interior, but we were told that the roof is supported by a few main longitudinal beams placed to form a slight crown, and that these are overlaid with small transverse poles, culminating in 3 in. or more of cinder concrete. Although the front wall is mostly open, the rear and side walls contain only very small windows, or none at all. The arrangement of interior walls or columns to support the roof beams is not known.

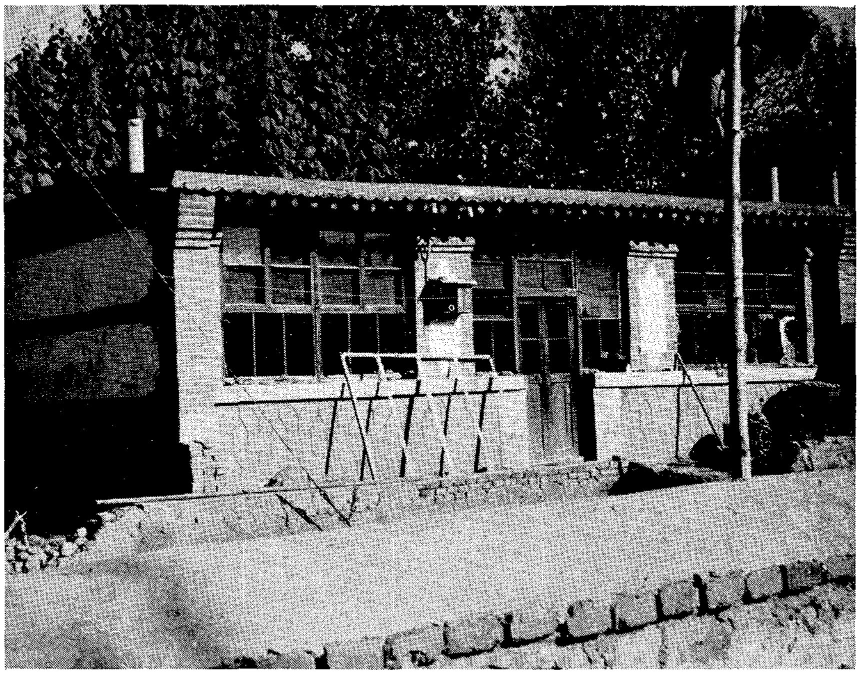


Figure 4.23 A typical older village house in northeast China.

The minimal stiffness and strength of the front wall and the great difference in stiffness between front and rear walls are the most obvious points of weakness. Other possible weaknesses, including lack of ties between front and rear walls and flexibility of the roof in diaphragm action, cannot be discerned from the photo. Laid up in lime mortar without reinforcement, this type of house is said to have caused many deaths in the Tangshan earthquake.

New rural housing somewhere between Harbin and Tangshan, shown in Figure 4.24, has wider piers and some depth of masonry above the piers so that they do not act as cantilevers in their plane. The main roof beams may span the short direction of this building, helping to tie together the tops of the longitudinal walls, or a reinforced ring beam may be present as required by the *Aseismic Design Code*. In the foreground, the group of small trees typifies plantings along roads and railroads throughout eastern China, possibly a future source of construction material in rural areas. We did not, however, see wood used in houses for any structural purpose other than for roofs. The excavation in the foreground was perhaps a source of clay for locally made bricks. One of our hosts expressed concern that so much agricultural land in China had been ruined by the removal of soil for brick making. He thought that the use of concrete, the ingredients for which usually come from non-agricultural land, should be encouraged to replace brick.

New houses in Tangshan (see Figure 4.25) appear well built and were said to be reinforced, but this style is a rare exception; most new houses in Tangshan are five or six stories tall. The *Aseismic Design Code* apparently requires that the provisions of Tables 4.3, 4.5, and 4.6, as well as other provisions for multistory brick buildings, be instituted for single-story brick houses. We did not learn of any research work planned or in progress that deals with single-story dwellings.

Figure 4.26 taken at Tongji University, Shanghai, shows one-half scale models of local two-story houses ready for testing using reciprocating loading, which will be applied through rods inserted through four holes at the top of each story. Large solid cinder concrete blocks are commonly used for walls in the Shanghai region. Floors and roofs are made of precast hollow-core concrete planks without keys or other means of developing horizontal diaphragm action

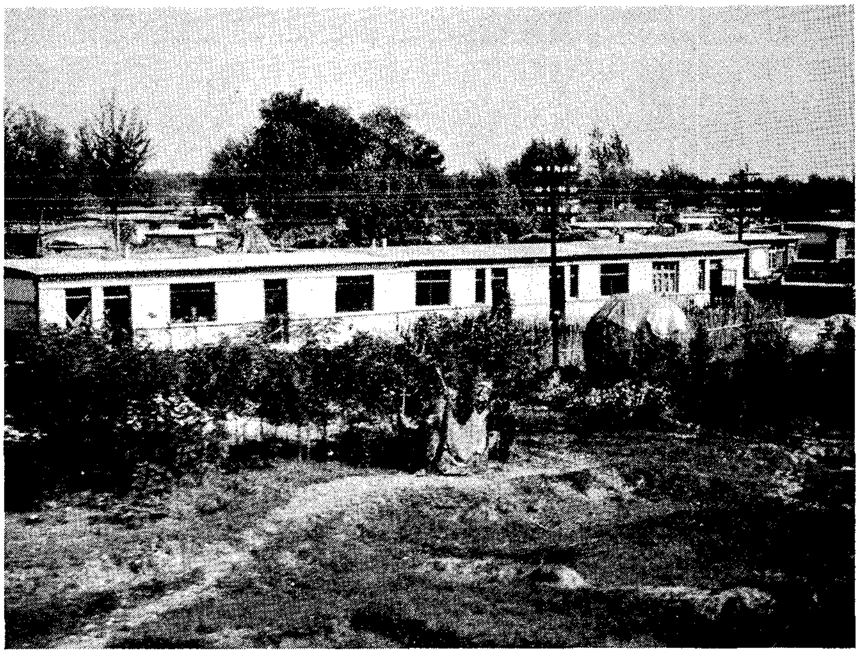


Figure 4.24 New rural housing in northeast China.

Figure 4.25 New houses in Tangshan, not typical of the area.

TABLE 4.3

MAXIMUM DISTANCE BETWEEN EARTHQUAKE-RESISTANT WALLS IN MULTISTORY BRICK BUILDINGS

(meters)

Type of Floor	Design Intensity (CIS)		
	7	8	9
Cast-in-place reinforced concrete	18	15	11
Precast reinforced concrete	15	11	7
Wood	11	7	4

TABLE 4.4

MAXIMUM HEIGHT OF MULTISTORY BRICK BUILDINGS

(meters)

Type of Walls	Design Intensity (CIS)		
	7	8	9
Solid walls, at least 24 cm thick	19	13	10
Walls 18 cm thick	12	9	--

TABLE 4.5

DIMENSIONS OF BRICK WALL ELEMENTS

(meters)

Type of Construction	Design Intensity (CIS)			Remarks
	7	8	9	
Minimum width of load-bearing piers between windows	1.00	1.20	1.50	
Minimum distance from the end of an exterior bearing wall to the edge of a door or window opening	1.00	2.00	3.00	The limit is waived when reinforced concrete columns are used at corners, in compliance with Article 30 of the *Aseismic Design Code.*
Maximum height of unanchored parapets	0.50	0.50	--	Parapets above entries and exits must be anchored.
Minimum distance from the quoin of an interior wall to the edge of a door or window opening	1.00	1.50	2.00	The limit is waived when reinforced concrete columns are used at the quoin.

Note: The distance from the end of a nonbearing exterior wall to the edge of a door or window opening shall not be less than 1 m.

TABLE 4.6

REQUIREMENTS FOR RING BEAMS

Location and Reinforcement	Design Intensity (CSI)		
	7	8	9
Location			
• Along exterior walls and interior longitudinal walls.	On roof and on every other floor level.	On roof and on each floor level.	
• Along interior transverse walls.	On roof and on every other floor level. Spacing on roof not to exceed 7 m and on floor levels not to exceed 15 m.	On roof and on each floor level. Spacing on roof not to exceed 7 m and on floor levels not to exceed 11 m.	On roof and on each floor level. Along all transverse walls on roof. Spacing on floor levels not to exceed 7 m.
Reinforcing Bars	4 round #8	4 round #10	4 round #12

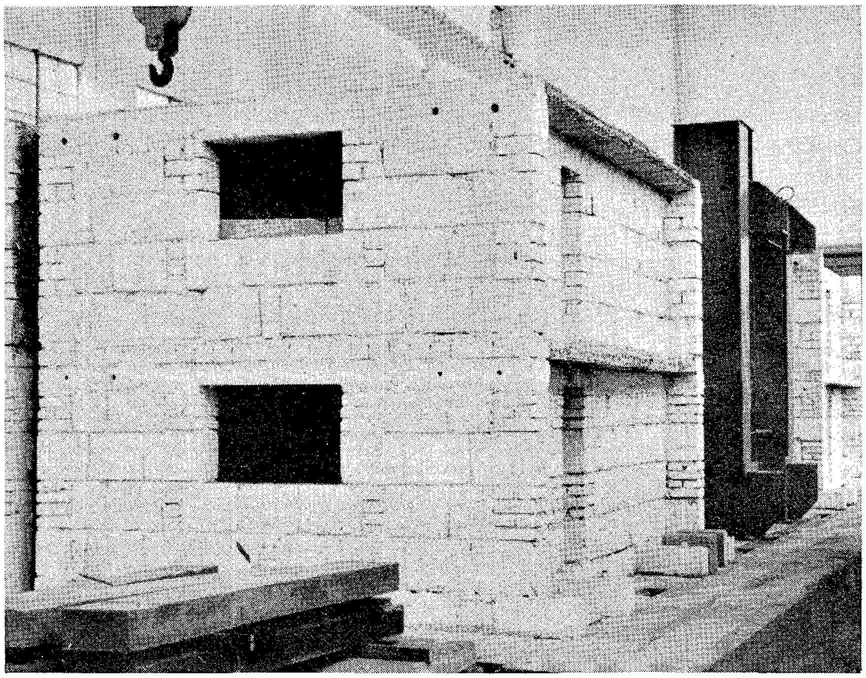


Figure 4.26 Half-scale unreinforced models ready for testing at Tongji University, Shanghai.

other than friction. Longitudinal reinforcing wires extending from the ends of these planks are said to be bent around anchorage bars where the slabs abut over supporting walls or contact reinforced concrete bond beams, which are used in buildings having more stories. In the Shanghai region, this type of building is usually six stories tall. (Being in zone 6, the buildings in Shanghai are not treated in the *Aseismic Design Code*.)

There are significant differences between Chinese and American techniques for building earthquake resistance into multistory brick buildings. In China, limitations dependent on the intensity of ground shaking are placed on the spacing of shear walls (Table 4.3), on the ratio of building height to wall thickness (Table 4.4), and on the widths of piers (Table 4.5). Buildings meeting these requirements may be unreinforced, except that steel ties (two bars, with a diameter of 6 mm, at 50-cm spacing) must be provided at corners and intersections of walls, and reinforced concrete ring beams (Table 4.6) must be built into walls if floors are not cast in place.

By contrast, the 1976 edition of the *Uniform Building Code* (*UBC*) requires minimum reinforcement throughout the walls of all brick buildings in zones 2, 3, and 4: the sum of the vertical and horizontal reinforcing steel areas is to be at least 0.002 x a cross-sectional area of the wall, a minimum of 0.0007 in any one direction, the maximum bar spacing is to be 4 ft, and bars are to be placed around openings in the walls. In addition, the *UBC* requires that walls be connected to floors and ceilings and to other walls at intersections with a connection capacity of at least 200 lb per ft. Pier width, wall spacing, and building height are not specified in the *UBC*, but these are governed by limitations on stresses in the walls and on the ratios of wall length and height to thickness (25:1 maximum). The *UBC* does not require ring beams.

Brick shear walls in China must be able to resist specified design forces at specified stresses or factors of safety. In the zone of highest seismic intensity, 9, the *Aseismic Design Code* specifies a base shear of 0.41 x (dead load plus actual live load), whereas the *UBC* specifies a base shear of 0.28 x (dead load) for brick shear walls in zone 4. Sufficient information is not available, however, to compare allowable stresses or the strengths assigned to the masonry.

Grouted masonry, in which grout is poured to fill reinforced cavities a few inches wide between parallel tiers of a brick wall, does not seem to be used in China, nor is the practice of building masonry walls with bars embedded inside used, except for brick chimneys. For buildings taller than the maximum specified in Table 4.4, the Chinese use a reinforcement practice that is different from anything done in the U.S. After the walls have been constructed, reinforced concrete "constructive columns" are cast against the exterior faces of the walls at the intersections of the interior and exterior walls and at the corners of walls, and also spaced along the walls at approximately 8 m apart when the building is 3 m taller than specified in Table 4.4 and approximately 4 m apart when the building is at least 6 m taller. These columns contain longitudinal bars with hoops and are tied to the brickwork (2 bars, with a diameter of 6 mm, at 50-cm spacing) and to ring beams. Figure 4.27 shows a three-story building of this construction located in Tianjin. We do not have data on tests or on the performance of this type of construction during strong ground motion (see *The 1976 Tangshan, China, Earthquake* [1980]).

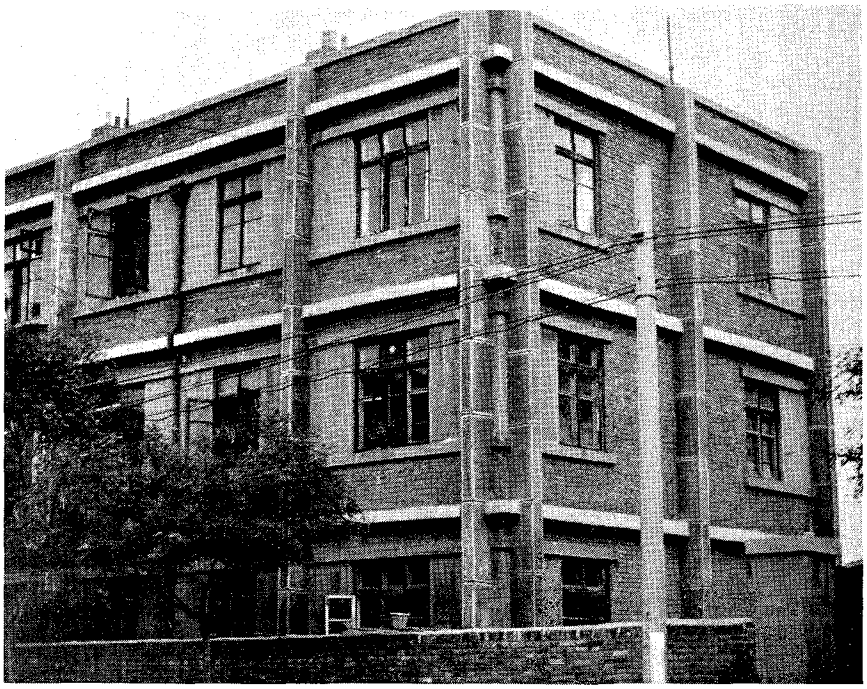


Figure 4.27 A Tianjin apartment building with "constructive columns."

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5. SUGGESTIONS MADE TO ENGINEERS AND OFFICIALS IN THE PRC

Among the benefits of visiting different countries are the fresh viewpoints and varied experiences that the visitors bring with them. The EERI delegation was formally asked, on several occasions, to comment on earthquake-resistant design and construction procedures and practices in the PRC. In response to their requests, members of our delegation offered a number of suggestions and recommendations to our Chinese hosts; we look forward to reciprocal comments from Chinese visitors to our country.

The PRC is engaged in a tremendous undertaking in rebuilding Tangshan and in retrofitting existing buildings in other cities for earthquake resistance. Either project alone constitutes a tremendous effort in design, materials procurement, logistics, and construction. The Chinese are to be commended for their great efforts to improve the level of earthquake resistance.

Especially noteworthy are the measures used to strengthen multistory masonry buildings. An exterior frame of concrete columns and beams is erected, and the whole structure is tied or post-stressed with steel rods that extend below floor level from one side of the building to the other at upper floor and ceiling levels. The buildings so treated are not only stronger and safer, but their appearance is surprisingly attractive. We would do well to consider such measures in the United States.

Many large industrial buildings were strengthened or repaired by banding columns with steel members to strengthen them and by adding bracing within the building walls and between certain interior columns. Because much of the damage in 1976 resulted from inadequate column-base fixity coupled with little or no horizontal anchorage at roof levels, we stressed the importance of strengthening joint connections as well as members. Special care should be taken to ensure adequate horizontal diaphragms or horizontal bracing systems at roof levels or else to fully develop fixity at the base of columns to enable them to act as vertical cantilevers.

Many new measures are being taken to provide earthquake-resistant residential structures in Tangshan. In general, construction consists of a combination

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of red brick masonry or block construction, precast floors, and interior concrete walls, both precast and cast-in-place. The masonry is reinforced not at closely spaced intervals, as in the United States, but at rather long intervals. Except for large bars, the reinforcing bars are not deformed. We observed both good and poor quality masonry work in the new construction. Our main suggestions for improvement included wetting the bricks and shoving them solidly into fully filled head joints to get a better bond with the mortar and using ductile steel and deformed instead of plain bars for reinforcement.

Strengthening existing masonry and reinforced concrete chimneys by surrounding them with a framework of steel members would be more effective if the steel members were anchored or bonded to the chimney at closely spaced intervals. This might be accomplished by explosively driving hardened steel pins through the steel members into the chimney. The same principle would apply to large columns that require strengthening.

Earthquake forces commonly exceed code design forces; accordingly it is important to obtain the full measure of value from all the materials used. Building configuration is also an important aspect of earthquake resistance. Typical new multistory residential buildings being constructed in the PRC have two or more interior transverse shear walls but only one interior longitudinal wall. In this connection, exterior masonry walls are very important, even when the interior concrete walls are relied upon to provide lateral-force resistance in buildings. We also stressed the value of using two interior longitudinal structural wall systems in lieu of one whenever possible.

The increased use of hollow concrete blocks from walls was suggested as a replacement for the rather large solid blocks observed in Shanghai. Hollow blocks, in addition to weighing less, provide cavities for grouting and anchoring reinforcing bars.

Although construction companies in China are state owned, their aim is to do a job for less than a prescribed budget and to make a profit. Naturally, as in all countries, this can lead to the neglect of details that are all-important for earthquake resistance and durability. If an inspector is used at all, he is usually an employee of the construction company. We recommended that either trained inspectors representing the design office or the future occupants be employed at the construction site as inspectors. These inspectors should have the authority to stop construction and order work to be torn down and rebuilt if improperly constructed.

Officials in the PRC are to be commended for their enormous efforts to improve the earthquake resistance of their buildings and factories. This diligence will pay off in years to come but, as in the United States, constant vigilance of design, construction, and inspection is necessary to minimize potential earthquake problems. The spirit as well as the letter of the seismic codes must be followed.

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6. CONCLUSIONS

This tour allowed us to obtain first-hand knowledge of the state of the art of earthquake engineering research and practice in the PRC. It enabled us to assess Chinese research needs and to determine those areas where the United States could benefit from PRC expertise and vice versa. Throughout the tour, we attempted to formulate the research needs we identified into possible research projects for the cooperative program.

Friendly communication between Chinese and U.S. earthquake engineers is as necessary to the identification of mutual research needs -- and the ultimate success of the cooperative research program -- as the exploration of PRC work in earthquake engineering. During their tour of the United States in 1979, the PRC delegation talked with various EERI members about the PRC's research needs. Our tour provided an opportunity to renew and expand contacts made with the Chinese earthquake engineers who visited the United States and to continue discussions of the research needs that they expressed. Moreover, many new contacts were made, and additional research needs were revealed. Through these contacts, subsequent plans for specific additional, mutually beneficial research projects will be developed.

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APPENDIX A

Members of the EERI Delegation

MEMBERS OF THE EERI DELEGATION

Name	Position	Specialty
BLUME, John A. (Delegation Leader)	Chairman, URS/John A. Blume & Associates, Engineers, 130 Jessie Street, San Francisco, CA 94105, (415) 397-2525	Structural Engineering/ Structural Dynamics/Risk Analysis
BENUSKA, Kalman Lee	Vice President, Kinemetrics, Inc., 222 Vista Avenue, Pasadena, CA 91107, (213) 795-2220	Structural Engineering/ Instrumentation
DONOVAN, Neville C.	Partner and Senior Engineer, Dames & Moore, 500 Sansome Street, San Francisco, CA 94111, (415) 433-0700	Geotechnical Engineering/Ground Response
HANSON, Robert D.	Chairman, Dept. of Civil Engineering, University of Michigan, Ann Arbor, MI 48109, (313) 764-8494	Structural Engineering/ Testing
JOHNSTON, Roy G.	Vice President, Brandow & Johnston Associates, 1660 West 3rd Street, Los Angeles, CA 90017, (213) 484-8950	Structural Engineering/ Design
KEIGHTLEY, Willard O.	Professor, Dept. of Civil Engineering and Engineering Mechanics, Montana State University, Bozeman, MT 59717, (406) 994-2111	Structural Engineering/ Testing
KRAWINKLER, Helmut	Associate Professor, Dept. of Civil Engineering, Stanford University, Stanford, CA 94305, (415) 497-4129	Structural Engineering/ Testing
LAGORIO, Henry J.	Associate Dean for Research, College of Environmental Design, Room 230, Wurster Hall, University of California, Berkeley, CA 94720, (415) 642-2896	Architecture/ Urban Planning

MEMBERS OF THE EERI DELEGATION (Continued)

Name	Position	Specialty
SCHOLL, Roger E.	Technical Director, Earthquake Engineering Research Institute, 2620 Telegraph Avenue, Berkeley, CA 94704, (415) 397-2525, ext. 331	Structural Engineering/ Damage Prediction
VELETSOS, Anestis S.	Brown & Root Professor, Dept. of Civil Engineering, Rice University, Houston, TX 77001, (713) 527-8101, ext. 2388	Structural Engineering/ Soil-Structure Interaction
WANG, Leon Ru-Liang	Professor, School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, OK 73019, (405) 325-5911	Structural Engineering/ Lifeline Engineering

APPENDIX B

Tour Itinerary

TOUR ITINERARY

Friday, September 19

Afternoon	Arrived in Beijing. Met with representatives from the State Capital Construction Commission (SCCC) for welcome and discussions.
Evening	Attended welcoming banquet hosted by the SCCC.

Saturday, September 20

Morning	Visited Tsinghua University.
Afternoon	Visited the Chinese Academy of Building Research.

Sunday, September 21

Morning	Visited the Great Wall.
Afternoon	Toured the Ming Tombs.

Monday, September 22

Morning	Blume and Donovan gave lectures to an audience of about 100 people.
Afternoon	Scholl, Hanson, and Krawinkler gave lectures. Other delegates were free to sightsee.
Evening	Attended magic show.

TOUR ITINERARY (Continued)

Tuesday, September 23

Morning	Visited the Water Conservancy and Hydroelectric Power Scientific Research Institute and the State Seismology Bureau.
Afternoon	Toured the Forbidden City, including the Palace.
Evening	Attended banquet at the Summer Palace hosted by the SCCC.

Wednesday, September 24

Morning	Benuska, Johnston, and Veletsos gave lectures to an audience of about 100 people. Other delegates were free to sightsee.
Afternoon	Wang, Lagorio, and Keightley gave lectures. Other delegates were free to sightsee.
Evening	EERI delegation hosted a banquet.

Thursday, September 25

Morning	Departed Beijing at 11:55 a.m. for flight to Harbin.
Afternoon	Arrived in Harbin at 2:00 p.m.
Evening	Attended banquet at the hotel hosted by the Institute of Engineering Mechanics (IEM).

Friday, September 26

Morning	Visited the research facilities at the IEM.

TOUR ITINERARY (Continued)

Afternoon	Donovan and Veletsos gave lectures to an audience of about 100 people at the IEM. Other delegates were free to sightsee.
Evening	Viewed movie.
Saturday, September 27	
Morning	Benuska and Blume gave lectures to an audience of about 100 people at the IEM. Other delegates visited the construction site of a new hotel in Harbin.
Afternoon	Took a boat trip on the Songhau River and visited the Children's Park in Harbin.
Evening	Departed Harbin by train at 7:26 p.m. for trip to Shanhaiguan.
Sunday, September 28	
Morning	Arrived in Shanhaiguan at 7:30 a.m. Began sight-seeing tour at the Great Wall. Departed Shanhaiguan by train at 9:25 a.m. for trip to Tangshan. Arrived in Tangshan at 11:30 a.m.
Afternoon	Toured Tangshan to see earthquake ruins, including Institute of Mining and Metallurgy.
Evening	Attended banquet hosted by Vice Mayor of Tangshan.
Monday, September 29	
Morning	Toured reconstruction work in Tangshan, including fossil-fueled power plant and porcelain factory.

TOUR ITINERARY (Continued)

Afternoon	Attended presentation by staff of Tangshan Construction Headquarters on reconstruction policies and procedures. Participated in discussion of reconstruction policies and procedures.
Evening	Departed Tangshan at 6:48 p.m. for train trip to Tianjin. Arrived in Tianjin at 8:33 p.m.

Tuesday, September 30

Morning	Toured strengthened buildings and a carpet factory in Tianjin.
Afternoon	Toured damaged buildings and visited Tianjin Water Park.

Wednesday, October 1

Morning	Departed Tianjin at 9:00 a.m. for bus trip to Beijing. Arrived at the Beijing airport at 11:30 a.m.
Lunch	Ate lunch at Beijing airport with hosts from the SCCC. Participated in discussions with SCCC staff concerning earthquake-resistant design and construction practices in the PRC.
Afternoon	Departed Beijing at 2:55 p.m. for flight to Shanghai. Arrived in Shanghai at 4:40 p.m.
Evening	Attended banquet hosted by Tongji University.

Thursday, October 2

Morning	Visited Yu-Fu Temple and Yu Garden Arcade.

TOUR ITINERARY (Continued)

Afternoon	Took a boat trip on the Huang-Pu River.
Evening	Attended acrobatic performance.

Friday, October 3

Morning	Visited Tongji University.
Afternoon	Hanson, Krawinkler, and Veletsos gave lectures to a group of about 75 people at Tongji University. Other delegates were free to sightsee.
Evening	Departed Shanghai at 7:05 p.m. for flight to Guangzhou. Arrived in Guangzhou at 9:05 p.m.

Saturday, October 4

Morning	Blume, Lagorio, and Johnston gave lectures to an audience of about 250 people at the Provincial Headquarters of the Guangzhou Capital Construction Commission.
Afternoon	Sightseeing
Evening	Ye Yaoxian delivered a lecture to the EERI Delegation on the PRC *Aseismic Design Code*.

Sunday, October 5

Morning	Visited White Cloud Mountain.
Afternoon	Toured Guangzhou

TOUR ITINERARY (Continued)

Evening	Attended banquet hosted by Guangzhou Capital Construction Commission.
Monday, October 6	
Morning	Departed Guangzhou at 10:15 a.m. for train trip to Hong Kong.
Afternoon	Arrived in Hong Kong at 1:30 p.m. Attended briefing session at 3:30 p.m.

APPENDIX C

Partial List of Persons Met in the PRC

PARTIAL LIST OF PERSONS MET IN THE PRC

State Capital Construction Commission (SCCC), Beijing

Li Jingzhou	Vice Minister
Ye Yaoxian	Vice Director Office of Earthquake Resistance
Shu Bin (Mrs.)	Vice Director Office of Earthquake Resistance
Gong Yiongsong	Engineer Office of Earthquake Resistance
Zhao Yundong	Chief Foreign Affairs Division
Hu Lingyu	Staff Member Foreign Affairs Division
Guo Tieliam	Staff Member Foreign Affairs Division
Ning Ho (Mrs.)	Interpreter Foreign Affairs Division
Lin Li	Interpreter Foreign Affairs Division

Tsinghua University, Beijing

Wang Guozhou	Director Department of Civil and Environmental Engineering
Shi Shisheng	Professor Department of Civil and Environmental Engineering
Wang Chuangzhi	Associate Professor Department of Civil and Environmental Engineering
Sheng Jumin	Associate Professor and Director Earthquake Engineering Research Division

Tsinghua University, Beijing (Continued)

Zhen Zhaoyang	Associate Professor and Director Hydraulic Structures Teaching Group of the Hydraulic Engineering Department
Fan Erhua	Lecturer Earthquake Engineering Research Division

Academy of Building Research, Beijing

Yuan Ginshen	President
He Guanqian	Vice President
Li Chenggang	Director Institute of Building Structures
Gao Wenzue	Deputy Director Institute of Geology Research
Gong Sili	Deputy Director Institute of Earthquake Engineering
Ji Zhicheng	Engineer
Xu Peifu	Engineer
Chen Huilin	Engineer
Wei Lian	Engineer
Xu Wei	Engineer
Xu Chengchang	Engineer
Zhon Xiyuan	Engineer
Nie Fenglan (Mrs.)	Interpreter

Water Conservancy and Hydroelectric Power Scientific Research Institute, Beijing

Qin Xiudian	Vice Director
Chen Houqun	Engineer

PARTIAL LIST OF PERSONS MET IN THE PRC (Continued)

State Seismology Bureau, Beijing

Zou Yu	Director
Xu Zhuhe	Engineer Division of Investigation and Measurement

Institute of Engineering Mechanics, Harbin

Liu Huixian	Director
Cui Jinping	Vice Director for Administration
Zhang Zaiyong	Vice Director for Technical Affairs
Guo Yuxue	Chairman Strong-motion Measurement Department
Chen Dasheng	Chairman Engineering Seismology Department
Yin Zhigian	Chairman Earthquake-resistant Structures Department
Wang Qianxin	Chairman Structural Mechanics Department
Xiong Jianquo	Chairman Shock and Vibration Department
Liu Ying	Chairman Soil Mechanics Department
Liu Zhengrong	Chairman Applied Mathematics Department
Lu Rongjian	Staff Member Information Services
Qi Xiaozhi	Staff Member Program Management
Wang Xinying (Ms.)	Interpreter

PARTIAL LIST OF PERSONS MET IN THE PRC (Continued)

Tangshan

Bi Xinwen	Vice Mayor
Li Baocang	Tangshan Foreign Affairs Office
Gu Xiangling	Interpreter
Wang Zhengzhang	Deputy Director Tangshan First Construction Company
Hwa Kaoming	Architect/Engineer Design Institute, Tangshan
Zhang Shuhwa	Architect/Engineer Design Institute, Tangshan
Xie Zhongfu	Deputy Chief Engineer and Vice Director Construction Headquarters, Tangshan
Tan Zuoji	Engineer Construction Headquarters, Tangshan
Jian Zhaohong	Engineer Construction Headquarters, Tangshan
Tang Gengyiang	Engineer Construction Headquarters, Tangshan
Hou Minzheng	Engineer Construction Headquarters, Tangshan
Li Wenhui	Lecturer Tangshan Institute of Mining and Metallurgy
Liu Chishang	Deputy Director Tangshan Second Construction Company

Tianjian Capital Construction Commission

Liu Yukun	Chairman Office of Earthquake Resistance
Jin Gaoliang	Engineer Office of Earthquake Resistance

PARTIAL LIST OF PERSONS MET IN THE PRC (Continued)

Tianjian Capital Construction Commission (Continued)

Wang Chonchun	Engineer Office of Earthquake Resistance

Tongji University, Shanghai

Li Guohao	President
Wang Dashi	Vice President
Zhu Bolong	Vice Chairman Tongji Research Institute of Structural Theory
Dong Jianhong	Deputy Chief Foreign Affairs Division
Zhu Zende	Professor
Mei Derong	Interpreter
Xing Baodi	University Staff Member
Wu Mingshun	Lecturer
Yu Andong	Lecturer
Lu Weimin	Lecturer
Jiang Zhixian	Lecturer
Chang Dadong	Lecturer
Yu Xaidow	Lecturer

Guangzhou Capital Construction Commission

Li Zhemin	Vice Director
Du Boqi	Deputy Chief Engineer
Li Yunsheng	Vice Head of the Office
Zhu Qiri	Staff
Wu Sanzhong	Staff

APPENDIX D

Photograph Source List

PHOTOGRAPH SOURCE LIST

Figure 1.1	Staff photographer at the Institute of Engineering Mechanics, Harbin
Figure 3.2	Roger E. Scholl
Figure 3.3	Roy G. Johnston
Figure 3.4 and 3.5	Henry J. Lagorio
Figure 3.6	State Capitol Construction Commission, Tangshan
Figure 3.7	Henry J. Lagorio
Figures 3.8—4.8	Robert D. Hanson
Figure 4.9	Neville C. Donovan
Figures 4.11—4.14	Roy G. Johnston
Figures 4.15—4.17	Henry J. Lagorio
Figures 4.18—4.21	Sun Shaoping, Earthquake Institute, Beijing
Figure 4.22	Leon Ru-Liang Wang
Figures 4.23—4.27	Willard O. Keightley