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Earthquake Engineering and Hazards Reduction in China

A Trip Report of the American Earthquake Engineering and Hazards Reduction Delegation

Edited by Paul C. Jennings

Submitted to the Committee on Scholarly Communication with the People's Republic of China

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1980

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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The Committee represents American scholars in the natural, medical, and social sciences, as well as in the humanities. It advises individuals and institutions on means of communicating with their Chinese colleagues, on China's international scholarly activities, and on the state of China's scientific and scholarly pursuits. Members of the Committee are scholars from a broad range of fields, including China studies.

Administrative offices of the Committee are located at the National Academy of Sciences, Washington, D.C.

The views expressed in this report are those of the members of the Earthquake Engineering and Hazards Reduction Delegation and are in no way the official views of the Committee on Scholarly Communication with the People's Republic of China or its sponsoring organizations--the American Council of Learned Societies, the National Academy of Sciences, and the Social Science Research Council.

The romanization of Chinese personal and place names in the text has not been adapted to the pinyin romanization system. However, a partial list of the people met by the delegation has been included as Appendix II. Please refer to this appendix for the correct spelling in pinyin and the Chinese characters for personal names.

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16. Abstract (Limit: 200 words)

The U.S. Earthquake and Hazards Reduction Delegation reports its 1978 visit to learn about earthquake engineering, prediction, mitigation and research in China. The delegation comprised mostly earthquake engineers plus two geoscientists and a China scholar. The itinerary covered visits to six major cities beginning with the State Seismological Bureau, Tsinghua University and three construction sites at Peking. At Harbin the team visited the Institute of Engineering Mechanics which has principal responsibility for earthquake engineering research in China. At Canton, Chinese engineers presented earthquake studies on the analysis of tall buildings. In turn, delegation members presented 24 technical lectures during the tour. Various features of earthquake engineering and practice in China and information learned about specific earthquakes; i.e., the disastrous earthquake at Tangshan and the 1976 Sungpan-Pingwu earthquakes, are reported. Photographs of earthquake resistant structures and scenes of earthquake damage in China are included.

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INTRODUCTION

The Earthquake Engineering and Hazards Reduction Delegation visited the People's Republic of China during July and August 1978. The visit was arranged jointly by the Committee on Scholarly Communication with the People's Republic of China (CSCPRC)--which is sponsored by the National Academy of Sciences, the Social Science Research Council, and the American Council of Learned Societies--and the Scientific and Technical Association of the People's Republic of China (STAPRC). Under the exchange program operated by these two organizations since 1972, two delegations of Chinese geoscientists and engineers have visited the United States. The first of these two teams (1974) was made up primarily of geologists and seismologists, and the second (1976) mainly of earthquake engineering research workers. The Chinese teams visited widely in the United States. Their sites included the various research centers of the U.S. Geological Survey as well as the University of California, Berkeley, the University of Illinois, the California and Massachusetts institutes of technology, and other universities.

The Earthquake Engineering and Hazards Reduction Delegation was the third earthquake research related group to visit China under the CSCPRC/STAPRC exchange program. The first two groups, the American Seismology Delegation and the Haicheng Earthquake Study Group, were composed of seismologists and geologists, although one engineer, R. W. Clough, was a member of the first group.

The Earthquake Engineering and Hazards Reduction Delegation was comprised mainly of earthquake engineers, but two geoscientists were also members. In accordance with CSCPRC policy, the delegation included a China scholar, G. C. Dean. Members of the delegation, their affiliations, and their areas of interest are given below:

George W. Housner (Chairman), California Institute of Technology
Earthquake engineering, engineering seismology, and hazard mitigation
Ray W. Clough, University of California, Berkeley
Finite element methods, earthquake response of structures
Henry J. Degenkolb, H. J. Degenkolb & Associates
Structural engineering, earthquake engineering practice
Genevieve C. Dean, Stanford University
Science and technology policy and planning in China

William J. Hall, University of Illinois, Urbana
Structural engineering and dynamics, earthquake engineering
Paul C. Jennings (Reporter), California Institute of Technology
Earthquake engineering, dynamic testing
S. C. Liu, National Science Foundation
Earthquake engineering research administration, earthquake risk analysis
R. B. Matthiesen, Seismic Engineering Branch, U.S. Geological Survey
Earthquake engineering, strong-motion instrumentation and data processing
Joseph Penzien, *Vice-Chairman*, University of California, Berkeley
Structural dynamics, statistical methods in earthquake engineering
Teng Ta-liang, University of Southern California
Earthquake prediction, theoretical and observational seismology
Robert E. Wallace, Office of Earthquake Studies, U.S. Geological Survey
Tectonics, active faulting, earthquake hazard evaluation
Robert V. Whitman, Massachusetts Institute of Technology
Geotechnical aspects of earthquake engineering, seismic design criteria

The primary purpose of the delegation was to learn about earthquake engineering research and practice in China. We were also interested in earthquake prediction and other efforts to mitigate earthquake hazards, and in the effects of the disastrous Tangshan earthquake of July 1976.

After a preliminary meeting in Washington, D.C., on May 9, 1978, and a preflight meeting in Tokyo, the delegation flew to Peking on July 24, beginning a very interesting, informative, and sometimes exhausting tour that encompassed 21 days in China with visits to six major cities.

The itinerary of the delegation is shown in Figure 1.1 and described in detail in Appendix I to this report. In summary, we began in Peking with visits to the State Seismological Bureau, Tsinghua University, and three construction sites selected by the State Capital Construction Commission. These technical activities were interspersed with sightseeing trips to the Forbidden City and the Summer Palace. We then traveled by railroad to Harbin, site of the Institute of Engineering Mechanics (IEM), which has the principal responsibility for earthquake engineering research in China. This was the technical highlight of the trip, and five full days were spent in Harbin, where reports on earthquake engineering research and practice were interchanged with our Chinese hosts (Figure 1.2). Of particular interest were detailed presentations on the Tangshan earthquake. Also, panel discussions and informal conversations took place here. From Harbin we returned by train to Peking for another two days of technical activities and tourist visits, including the Great Wall and the Ming Tombs. We were joined in Peking by Robert Wallace and Teng Ta-liang, who had left Harbin early for a geological side trip to Sian. The entire delegation then flew to Chengtu, the capital of Szechuan Province in western China, where we were hosted by the Szechuan Provincial Seismological Bureau. Our technical activities included presentations on the Sungpan-Pingwu earthquakes of 1976. We also toured the large Tuchiangyen irrigation project that dates from 256 B.C. From Chengtu we flew to Kweilin where our primary activity was visiting the tourist attractions of this scenic

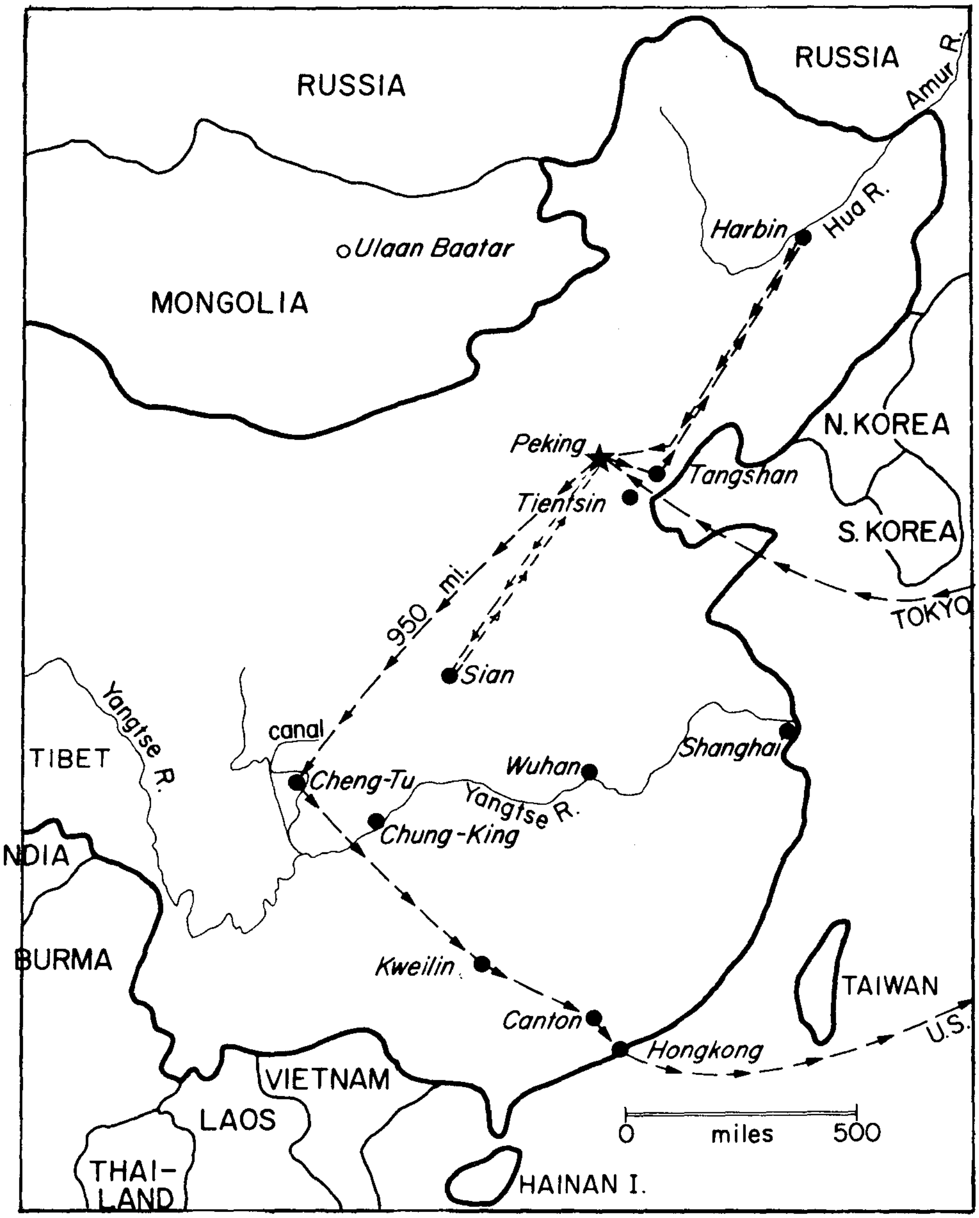

FIGURE 1.1 Itinerary of the Earthquake Engineering and Hazards Reduction Delegation. The delegation arrived in Tokyo July 29, 1978, and departed from Canton on August 13.

FIGURE 1.2 The Earthquake Engineering and Hazards Reduction Delegation and Chinese hosts at the Institute of Engineering Mechanics (IEM), Harbin. From left to right: T. L. Teng, R. W. Clough, Chinese host, M. B. Bullock, G. C. Dean, W. J. Hall, Chinese host, Hu Yu-hsien (IEM), R. B. Matthiesen, G. W. Housner, P. C. Jennings, Liu Hui-hsien (Director of IEM), R. E. Wallace, S. C. Liu, H. J. Degenkolb, Kao Wen-hsueh, Chinese host, Liu Peng-hsin (Chinese Information Officer), R. V. Whitman, and Chinese host.

region. From there we flew to Canton, where the engineers and scientists of the Provincial Seismological Bureau presented the results of some of their studies, including reports on the earthquake analyses of two tall (33 and 24 stories) reinforced concrete buildings and studies of Hsinfengkiang Dam, which had been damaged by an earthquake. We also visited a spa near Canton, stopping en route at a standard seismic station with a radon monitoring laboratory that was part of the earthquake prediction studies program of the Provincial Seismological Bureau. Delegation members gave a total of 24 technical lectures in Peking, Harbin, and Chentu, and these seemed to be much appreciated by the audiences.

Throughout our visit we were accompanied by Dr. Kao Wen-hsueh, Deputy Director of the Institute of Geology, State Seismological Bureau, who had administrative responsibility for our visit, and by Liu Peng-hsin, Information Officer for the State Seismological Bureau, who made all travel and hotel arrangements for the group, served as an interpreter, and generally performed the functions of a host and guide. At Harbin and for the rest of the trip, we were also accompanied by Dr. Hu Yu-hsien, who had received his Ph.D. at the University of Michigan. Dr. Hu speaks excellent English and, along with our own Dr. Liu, acted as technical interpreter. It was a great asset to have two bilingual hosts traveling with us, as well as three bilingual delegation members. Our delegation was treated with a uniformly high level of genuine courtesy and hospitality; the Chinese hosts at the various cities and institutes we visited and the organizers of our trip worked hard to make us as comfortable as possible. In addition to our technical program, we were treated to many Chinese banquets and other entertainments, including ballets and a circus. The entire delegation enjoyed the trip thoroughly, in both a professional and a personal sense.

Chinese earthquake engineers, especially in Harbin, are well informed of developments in earthquake engineering research in other countries. The IEM library in Harbin was large, well stocked and well organized, and contained copies of late issues of all the major journals relevant to earthquake engineering. Although most of the research workers have some competency in reading English, there were at least three interpreters associated with the library whose job it was to prepare translations of selected documents. Each member of the delegation was presented, for example, with a copy of the book, *Earthquake Engineering* (R. Wiegel, Editor), in Chinese. It is also clear, however, that the Chinese are seriously deficient in modern laboratory equipment and computing facilities, in comparison to the West and Japan. They are aware of this problem, of course, and now that the political climate is more favorable, are making vigorous efforts to catch up. A similar problem exists with facilities for technical communication at meetings; good audio-visual equipment is rare in China, and in some cases, rooms could not be sufficiently darkened to show slides with the available equipment. Although photocopying capabilities are limited, there was no indication of any problems with printing and internal dissemination of technical papers and reports. The deficiency in laboratory equipment and computing facilities was particularly obvious at Tsinghua University, where political disruptions had taken a heavy toll. The staff and students of the institutes we visited were clearly very able, and it appears likely that the Chinese will quickly come up to international standards of earthquake engineering research, given adequate funding and a continuingly favorable political climate.

Progress in earthquake engineering construction practice in China is more difficult to assess. There is a great need for public housing, and one gets the impression that construction is proceeding as fast as possible using all available means and materials. It is clearly within the capability of the Chinese to build special structures to international standards, but the need for housing, the limited availability of steel and cement, and the traditional use of masonry and brickwork indicate that it will be many years before the Chinese depart from their heavy reliance on unreinforced or partially reinforced masonry in a major fraction of their construction. Nor did we get the impression that the Chinese will soon adopt standards of reinforcing and detailing similar to those practiced in Japan, New Zealand, and the more seismic areas of the United States.

The programs in hazard reduction were hard for us to evaluate because of time limitations. It is clear that evacuation of selected portions of the populace is a routine part of the final stages of earthquake prediction. Also, the Chinese are very active in the development of seismic zoning maps, in microzonation studies of some cities, and in the study of ways to improve the seismic provisions of the building code.

There have been a number of delegations to China in recent years that have reported in detail on the general aspects of science and technology in China. For this reason, we have concentrated on our technical subjects in this report. The report is organized as follows. The following chapter explains the organization of earthquake engineering in China. The third chapter is a collection of reports on various features of earthquake engineering research and practice in China and is as comprehensive as permitted by our limited time in the country. The fourth and fifth chapters are devoted to reporting what we learned about specific earthquakes. The fourth chapter reports some of the Chinese studies of the disastrous Tangshan earthquake. This earthquake practically destroyed the city and may have killed as many as 650,000 people, making it one of the most disastrous of all earthquakes. The fifth chapter reports on the Sungpan-Pingwu earthquakes that occurred in Szechuan Province in August 1976. This earthquake series is notable because the main shock and two main aftershocks were predicted by Chinese seismologists, who presented us with a detailed account of the evolution of the predictions. The final section of the report contains appendixes, which include a listing of the earthquake engineers and scientists we met in China and a bibliography of the papers and reports we received.

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ORGANIZATION OF EARTHQUAKE ENGINEERING IN CHINA

INTRODUCTION

The Earthquake Engineering and Hazards Reduction Delegation visited China at a time of change in Chinese science policy. The organization and administration of institutions engaged in earthquake-related research and engineering now differs in significant ways from that reported by the American Seismology Delegation (1975)* in 1974 and the Haicheng Earthquake Study Delegation (1977) in 1976. Changes are still going on, and what is described here therefore should be viewed as a transitory stage in the organization of earthquake research in China.

The changes now underway reverse the science policies and institutional experiments of the past dozen years in China. This new trend began soon after the so-called "Gang of Four" was unseated from positions in the top ranks of the Chinese government and Communist Party a month after the death of Mao Tse-tung in September 1976. Inspired by Mao's wife, Chiang Ch'ing, and her three associates, radicals in academic and scientific institutions throughout the country had sought to preserve such practices as "open-door" running of schools and research institutes, and administration of such institutions by "revolutionary committees." These and other reforms associated with the Cultural Revolution had been introduced, it was said, to make research institutes more responsive to immediate, practical problems and to tighten control over "bourgeois" scientists by the Communist Party Committee in each institute. However, by carrying these measures to extremes, for example, by making scientists and engineers one of nine categories of "counterrevolutionaries," the "Gang" and their followers nearly destroyed basic research and higher education in China and isolated Chinese scientists from new developments in their fields. Not surprisingly, the scientists soon rallied to Mao's successor as Party Chairman, Hua Kuo-feng, when he moved to restore the status quo ante in science and education. The first task of the new leadership was to rehabilitate the scientists politically. Equally urgent, conditions for research had to be restored, starting with the guarantee that only one sixth of the scientists' time would be used for political education and other nonprofessional activities.

*References are included at the end of each chapter.

This process accelerated in September 1977, when the newly elected Central Committee of the Chinese Communist Party announced that a national science conference would be convened in the spring of 1978 and listed specific reforms to be made prior to the conference. The circular directed that leadership of research institutes revert to professional scientists, with the Party secretary in a supporting role; it acknowledged basic research to be both legitimate and necessary, in contrast to the "Gang's" virtually exclusive emphasis on applied work; and it not only permitted but also encouraged the normal activities of a scientific community, from publication of journals to direct contact with scientists in other countries. In the following months these reforms went into effect on an institute-by-institute basis, depending on the local political situation and conditions within each research organization.

Simultaneously, preparations were underway for the national science conference, the exact date of which depended on the progress of these reforms. Planning of long-range scientific development began in October 1977 when delegates from the Academy of Sciences, institutions of higher education, and government scientific and technical departments met in Peking and drafted an "outline national program for developing the basic sciences." Soon afterward, a conference sponsored by the Ministry of Education considered arrangements for the applied sciences and engineering. Fang Yi, the minister in charge of the newly re-established State Scientific and Technological Commission, announced in December that the appropriations to science and technology had been increased (though he did not specify amounts). The national science conference finally met in Peking from March 18 to 31, 1978, when it endorsed a draft "Outline National Plan for the Development of Science and Technology, 1978-85."

Most striking of the changes in China's science policy since 1976 has been the rapid expansion of international scientific and technical contacts. Shortly before our delegation's trip, President Carter's science advisor led a high-level American science policy delegation to China. The atmosphere in discussions with our hosts therefore was one of expectation that scientific and academic relations with the United States were about to increase, and mention was frequently made of the desirability of sending students to the United States to study science and engineering and to have exchange visits by research workers.

ORGANIZATION OF EARTHQUAKE RESEARCH

The diagram in Figure 2.1 represents our understanding of the current organization of earthquake-related research in China. In addition to the organization shown in Figure 2.1, some government ministries have research bureaus. Figure 2.2 identifies the provinces referred to in Figure 2.1 and in the following text.

Two major changes have occurred since the 1974 and 1976 visits of previous U.S. earthquake delegations. The State Seismological Bureau (SSB), which both delegations reported within the Chinese Academy of Sciences, is now independent of the Academy; that is, it is now directly

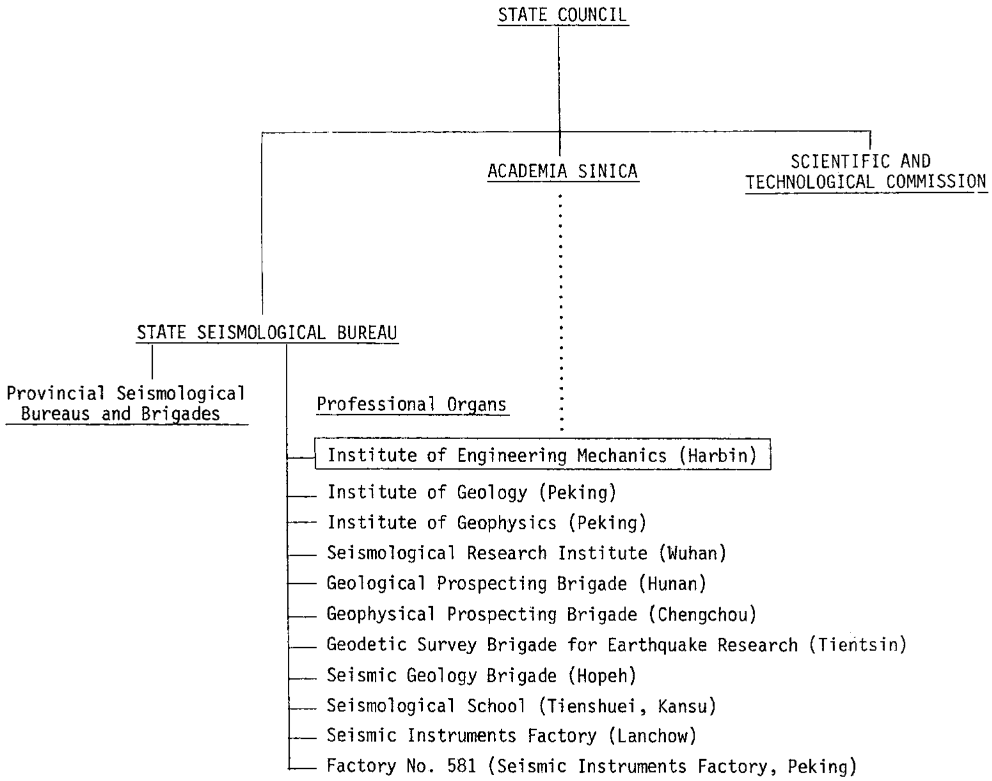

FIGURE 2.1 Current organization of earthquake-related research in China.

responsible to the State Council, though it is slightly lower in rank than and may be advised by the Academy and the Scientific and Technological Commission. A second recent change, apparently effected in the spring or summer of 1978, is the division of the Institutes of Geology and Geophysics between the Academy and the SSB. As the American Seismology Delegation noted in 1974, geophysics in China had been highly theoretical until the mid-1960's, when a national program of research on earthquake prediction began. The SSB was set up in 1971 to coordinate this research, and the Institutes of Geology and Geophysics in the Academy of Sciences were placed under the SSB (at that time, still within the Academy). Their new role strongly biased the work of these institutes toward applied research related to earthquake prediction. With SSB now independent of the Academy, separate Institutes of Geology and Geophysics have been set up in each body. An American geophysicist visiting China in June-July 1978 reports being told that this arrangement had been made specifically to strengthen basic research (J. T. Kuo, unpublished manuscript).

According to the American Seismology Delegation, in 1974 the State Seismological Bureau was responsible for earthquake studies carried

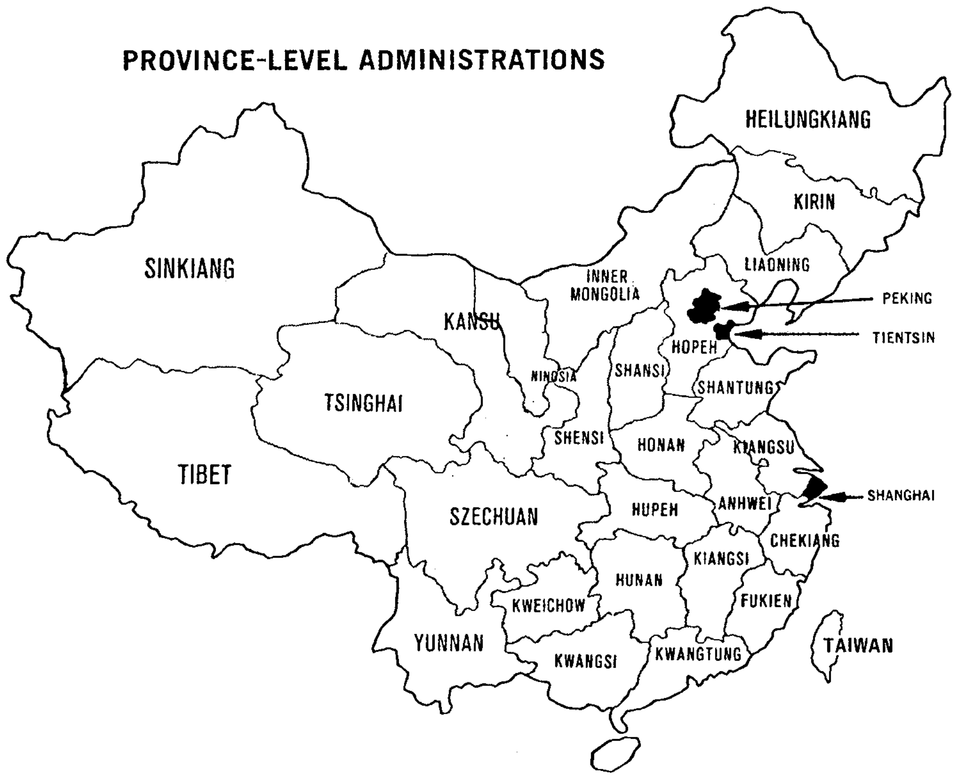

FIGURE 2.2 Province-level administration in the People's Republic of China. The three large cities noted are administered as provinces.

out by the provincial seismological units and, in this capacity, reviewed and funded annual program proposals submitted by them. Within each province the function of these units was described as gathering basic data for advanced research, organizing popular participation in this effort, and disseminating information about earthquakes to the public. The SSB did not exercise official leadership of the provincial seismological bureaus and brigades. Instead, local governments, i.e., Communist Party committees and Revolutionary committees, at the corresponding provincial or county level were the overseers of the programs. Also, the 1974 delegation found that provincial seismological bureaus and brigades drew up their own research programs for submission directly to central authorities for ratification and funding, that is, presumably bypassing the Academy of Sciences, to which SSB was at that time subordinate.

In 1976 the Haicheng Earthquake Study Delegation observed that brigades were being upgraded to the status of provincial seismological bureaus (PSB's). The largest PSB currently is that in Kansu Province; the bureaus of Hopeh, Liaoning, Szechuan, Yunnan, and Shantung are considered to be "large." A "medium-sized" PSB, such as that in

Kwangtung Province, has a staff of about 400; bureaus of about the same size are located in Shensi, Shansi, Ninghsia, Sinkiang, Fukien, Anhwei, Honan, and Kwangsi. Not all provinces have PSB's, however, and two province-ranked large cities, Peking and Tientsin, have their own large-sized seismological bureaus. Typically, those provinces which do not have a seismology bureau have a seismological brigade or office (a lower-ranking administrative unit), which is primarily responsible for dissemination of information. It was stated that approximately 10,000 persons are presently employed in this seismological effort nationwide, of which about one half have at least some technical education.

In general, PSB's are staffed by both professionals and nonprofessionals. Professional seismologists are responsible for instrument maintenance; they staff the provincial networks of seismological stations and analyze data for premonitory evidence of earthquakes. Earthquake engineers have recently been added to the staffs of some provinces. Nonprofessional personnel operate "mass" observation posts at the levels of special seismic district (up to 10 within a province), *hsien*, or county (perhaps a dozen per special district), commune, and production brigade: for a total on the order of 10,000 mass observation posts for those provinces with a large PSB. In each post at the production brigade level a few individuals with some scientific training measure and record water levels, animal behavior, weather, radon content of water, and other phenomena considered to be possible precursors of earthquakes. These are part-time responsibilities that the amateur seismologist fulfills in addition to his regular duties.

In 1974 the American Seismology Delegation found SSB's main task to be program management, with research a secondary function. In 1978, earthquake research programs in provincial academies of science were being transferred to the provincial seismological bureaus. Illustrating this development, Kwangtung's new PSB, formerly an institute in its Provincial Academy of Science, still shares quarters with the Academy while waiting for construction of its own building. Thus the trend is toward strengthening SSB's research role.

The second major organization in Figure 2.1 is Academia Sinica, or the Chinese Academy of Sciences, which is China's highest-ranking research organization. A high-level government body reporting directly to the State Council, or cabinet, the Academy currently has 72 research institutes. Prior to the Cultural Revolution, the Academy's institutes numbered some 120, organized into five departments: mathematics, physics, and chemistry; earth sciences; biological sciences; philosophy and social sciences; and technical sciences. During the Cultural Revolution the Academy of Sciences was decentralized; many institutes were transferred to the jurisdiction of provincial governments. In 1975 the number of Academy institutes was down to 36, half of which were jointly administered by the Academy and the local governments where the institutes were situated.

INSTITUTE OF ENGINEERING MECHANICS

Earthquake engineering research in China is carried out principally at e Institute of Engineering Mechanics (IEM) in Harbin, although research is now starting at some universities. The IEM was formerly the Institute of Civil Engineering and Architecture, founded in 1954. In the early 1960's it was given responsibility for earthquake engineering research, and the name was changed to the Institute of Engineering Mechanics. At this time, the architecture program was transferred to the Ministry of Construction, and the work in soil and rock mechanics to a newly established institute in Wuhan. A national conference on earthquake engineering research met in Harbin at the end of 1962. Earthquake engineering research was strengthened at IEM after the destructive Hsingtai earthquake of 1966, when the government initiated a large-scale national program in earthquake-related research. The Institute has continued to divest itself of nonrelated divisions as the trend toward concentration on earthquake engineering studies has developed. A recent example is its Concrete Materials Division, which has been transferred to the Ministry of Industries.

In 1974 the American Seismology Delegation found IEM organized into three laboratories: strong earthquake motion, earthquake-resistant construction, and vibration test equipment. IEM currently has expanded into seven divisions: strong ground motion, microzonation, earthquake-resistant structures, dynamic loading of foundations, induced-earthquake studies, soil dynamics, and instrumentation. IEM also has a division of data collection and information. At present, IEM includes some 200 professional engineers and mathematicians plus some 300 workers. After the political disruption of its program in recent years, IEM is reorganizing, and further changes are anticipated within the year. The number of staff professionals is expected to increase rapidly, at the rate of several tens per year.

IEM, already an Academy institute, was placed under the SSB when the Seismological Bureau was set up within the Academy of Sciences. With the SSB now separate from the Academy, IEM remains an Academy institute, though its research plan and budget are derived solely from the SSB. Planning is underway for IEM's formal transfer to the SSB.*

The SSB's Research Planning Office, which is staffed by scientists, prepares a draft annual plan for its institutes, including IEM, in line with objectives set in the national plans for scientific and economic development. The SSB's draft plan may specify research goals, contents of research projects, technical procedures, duration of projects, personnel assigned to projects, equipment allocated to projects, and investment, or total expenditure, for projects. The SSB sends this draft to its institutes in July. The institutes may accept the SSB draft in whole or in part and may propose revisions and negotiate adjustments in their respective assignments. Each institute is informed of the SSB's overall research plan, including the draft plans being proposed to the Bureau's other institutes, at this time. On conclusion of this process, the SSB grants funds and equipment to the institutes for the research projects they have accepted. (Such equipment becomes the property of the institute and is retained by it after the project concludes.)

Proposals put forward by research staffs of the institutes in the

*A recent list of Academy Institutes (November 1978) did not include IEM course of negotiations over the SSB draft may become part of the final plan. Any member of the IEM research staff, for example, may submit a proposal through the Institute's Scientific Research Planning and Management Office, which, with the approval of the Director, may be sent to the SSB. Proposals put forward by professors are virtually certain to be approved by the SSB, it was said, since the main constraint on research programs at present is the shortage of trained research workers rather than funds. (The Director of IEM has professorial rank; he was a professor at Tsinghua University in Peking before moving to Harbin to organize the new Institute of Engineering and Architecture.)

Annual research plans are coordinated with the general goals for scientific development outlined in medium- (to 1980) and long-term (to 1985) plans. There is sufficient flexibility in the planning system to add projects to the annual and medium-term plans after these have been completed and, if necessary, to postpone projects (other than specified "key" projects).

When the final plan has been negotiated with the SSB, the Research Planning and Management Office of IEM assigns projects to the Institute's various divisions. The division chiefs, all professional engineers and scientists, are responsible for completing the projects assigned to them. The Research Planning and Management Office administers the research budget and has some latitude to shift funds among projects to cover cost overruns. Research results are reviewed at the Institute level and, in the case of major projects, may be reviewed by scientists in other interested agencies before being approved by the SSB. It is believed that this review process is similar to that performed in the United States by mission-oriented government agencies, such as the Department of Energy or the Bureau of Reclamation.

In addition to projects submitted to the SSB, approved by it, and formally included in the plan, institutes may perform research that is not part of the plan. The IEM was said to have many such projects every year. Typically, such research originates with a request from "industry."* IEM may undertake relatively small projects for local enterprises, such as those at the municipal or county level, without approval from the SSB, merely informing the Bureau of such work. In the case of large projects the enterprise may request assistance through the SSB. Enterprises do not pay for such research (though they would pay educational institutions for research undertaken on their behalf). The costs of research that are not part of the SSB plan are borne by the Institute and monitored by the Institute's Research Planning and Management Office.

OTHER EARTHQUAKE ENGINEERING RESEARCH

In addition to the work of IEM, earthquake engineering research of various types is being performed by several other organizations and

*All industrial enterprises are state owned in China (except certain small-scale enterprises that are collectively owned). Planning and administration of state enterprises is carried out by the national, provincial, municipal, and county governments.

agencies. The Earthquake Engineering and Hazards Reduction Delegation met with or was told about the research activities of several such groups, as follows:

1. Tsinghua University is becoming increasingly active in earthquake engineering, both in teaching and research; experiments were being done to evaluate the earthquake resistance of reinforced concrete slab column connections during our visit. Rather sophisticated model studies of the static strength of a particular concrete arch dam also were underway; this work was funded by a ministry concerned with the design of dams but not concerned with seismic resistance.

2. The Institute of Structural Research of the Academy of Building Research, headed by Dr. K'ung Szu-li, conducts research on the earthquake resistance of masonry buildings and components, including tests of four-story building models (one-quarter scale) subjected to static and dynamic loads. This institute also is responsible for recommending changes to be made in the seismic provisions of the building code. Further details of the work of this institute are presented in chapter 3.

3. The Ministry of Water Conservation and Hydroelectric Power maintains a research institute in Peking that conducts studies of special problems of dams, including earthquake behavior. Research projects include installation of seismic transducers for field measurement of earthquake response, dynamic laboratory tests of dam models, and analytical investigations by finite element methods.

4. Provincial seismological bureaus also have active earthquake engineering research sections, at least in some instances. For example, the Kwangtung Seismological Bureau supported both experimental and analytical studies on the dynamic properties of two tall buildings in Canton, and was also involved in development of instruments for recording dynamic building response.

HARBIN POLYTECHNIC INSTITUTE

Although the Harbin Polytechnic Institute is not engaged in earthquake engineering research, it was included in our itinerary and therefore will be mentioned here. The visit by the American Earthquake Engineering and Hazards Reduction Delegation to the Harbin Polytechnic Institute took place on the afternoon of July 30, at a time when part of the delegation was scheduled to present technical lectures at the Institute of Engineering Mechanics; therefore only about half of the delegation participated in this tour.

The Institute was established by the Soviet Union in 1920 with the original purpose of training engineers for the Soviet railroad line from Moscow. At that time the Institute was divided into three departments and had only a few hundred students. In 1935, when the railway was sold by the Soviets to Japan, the Institute became Japanese. After the end of World War II in 1945, operation of the Institute was taken over jointly by the Soviet Union and China, and after the People's Republic of China took over administration of the province in 1949, the Institute became completely Chinese for the first time.

The Institute grew steadily from then until the Cultural Revolution in 1966, when the student population was about 7,000. Political disruption closed the Institute from 1966 until it resumed operation in 1973. The present student enrollment is about 2,700, including 200 graduate students, with a staff of 1,200, including 81 full professors. By 1982 the enrollment is planned to exceed the number reached in 1966 and may approach 10,000.

The students now are taking a 4-year curriculum, provided by seven departments, as follows: precision instruments, machine dynamics, computers and automatic controls, radio engineering, electrical machinery, mechanical engineering, and production processes. Before the Cultural Revolution, there also was a Department of Structural Engineering, but that group has now become an independent institution with the name Harbin Civil Engineering College.

After this briefing, the delegation was taken on a tour of several classrooms and laboratories. For example, one of the laboratories visited was set up to teach the students the mechanics of watches and clocks.

TSINGHUA UNIVERSITY

The delegation's first visit to Tsinghua University took place on the morning of July 26, 1978, during the summer vacation period. We initially met with a group of about eight individuals, including Chang Kuang-tou, the Chairman of the Hydraulic Engineering Department and Vice-Chairman of the Academic Association; Tu Ch'ing-hua, Dean of Engineering Mechanics; and Sung Jung-chen, Administrative Office of the University.

A summary of the history of the University, as given by Mr. Sung, is as follows. Tsinghua University was founded in 1911, with the help of Boxer indemnity funds returned by the United States, as a preparatory school for students going to the United States. The University is essentially an engineering school. It was closed from 1966 to 1970 as a result of the Cultural Revolution. The politically inspired disruption suffered by the University from 1966 to 1976 was severe, particularly to the laboratories, some of which were virtually dismantled. Rebuilding is now under way, and in 8 years it is planned to bring the University back up to national and international standards. The University consists of 11 departments and 50 sections within the departments. The 11 departments are architectural engineering, hydraulic engineering, radio engineering, electronics, automation, engineering mechanics, structural engineering, engineering physics, chemical engineering, mechanical engineering, and precision instrumentation.

The school has a technical staff of 2,800, of which 180 are professors and associate professors. It is currently upgrading its staff and hopes to have this aspect of the rebuilding program finished by the end of 1979. Cooperative relationships are being developed with other institutes. For example, plans are being formulated for cooperative earthquake engineering research with the IEM at Harbin.

We were informed that at present there are about 6,000 students at the University and it is planned to have 10,000 students in 1980. In the fall of 1978 it is anticipated that 800 new students will enroll between the ages of 17 and 25 years, with the average age being 20. Of these new students, 60 percent will come from the ranks of workers and soldiers, and 40 percent from the middle schools admission program; admission from each group is on the basis of examinations. The central government decides who is admitted. Whereas before the Cultural Revolution, the engineering program took 6 years, in general, it now takes $4\frac{1}{2}$ years to graduate. All students take the same foundation program (mathematics, physics, chemistry) for the first 2 years.

In 1978 Tsinghua University enrolled 300 graduate students. The graduate program is a 2-year program (mainly thesis research), at the end of which time the student receives a diploma. The best students are encouraged to go on for 2 more years of work. It is planned to include a significant program of earthquake engineering in the curriculum soon. In the past, structural dynamics was taught in the Engineering Mechanics Department, and some material was given on design for earthquake loads, but this field will now be given greater emphasis.

At present, no major laboratories appear to be in full-scale operation, and it was indicated that they are in the process of bringing the laboratories back up to the capability required for research and teaching; this upgrading includes the purchase of foreign equipment. It is expected that 30 percent of the university staff will work in research in the future.

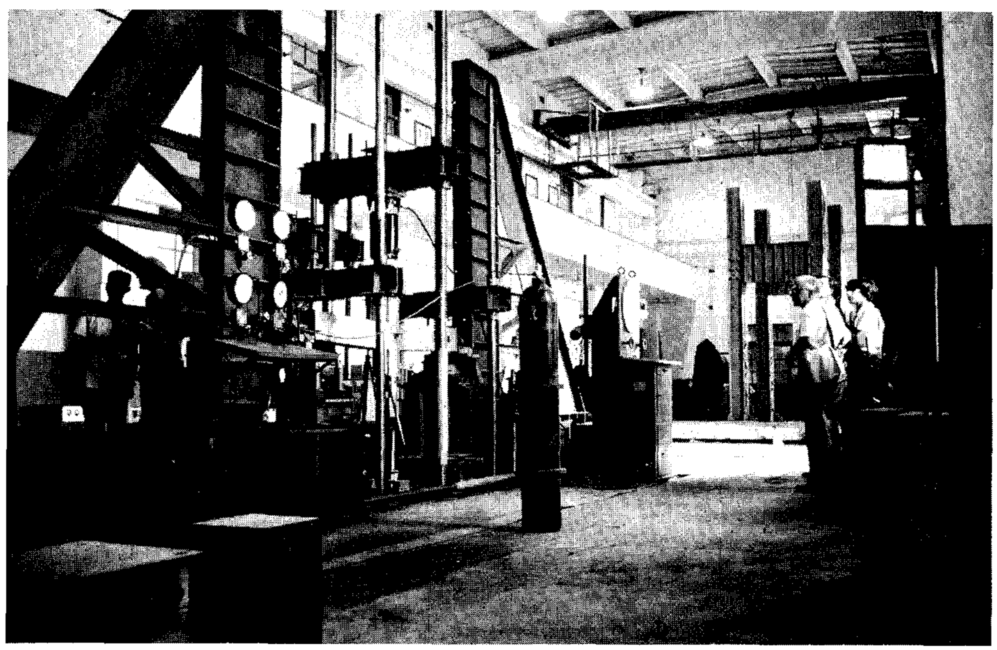

FIGURE 2.3 Structural engineering laboratory, Tsinghua University. A beam-column connection is being tested in the large testing frame in the left-hand center of the figure.

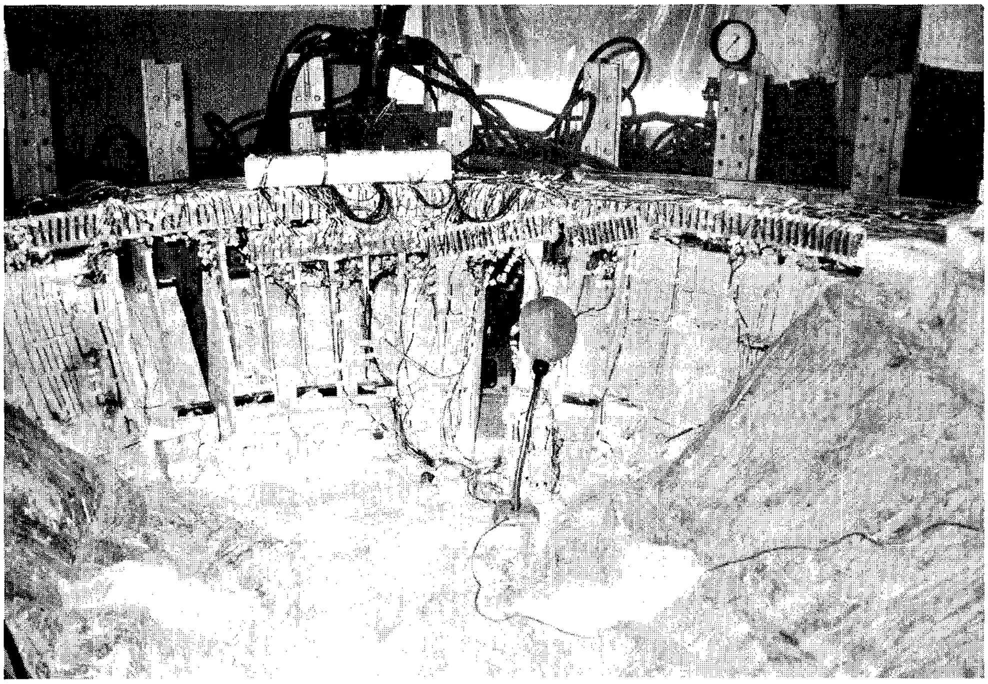

FIGURE 2.4 Hydraulic structures laboratory, Tsinghua University. The 1-m-high plaster model of an arch dam had been tested both in the elastic range and to failure.

Several laboratories were visited, including the structural engineering laboratory and the hydraulic structures laboratory. In the structural engineering laboratory (Figure 2.3), specimens were mounted for the testing of high-strength concrete beams of a type used in building construction. A reinforced concrete slab was under construction to be used principally to test the connection between two slabs. The slabs were to be subjected to stub column loads with unequal end slab loadings to exert a bending moment on the connection. The slabs were approximately 6 × 6 m in plan, and about 20 cm in thickness.

In the hydraulic structures laboratory we were shown some of the photoelastic studies that were made of the stress distribution in two-dimensional sections of a concrete dam to verify the accuracy of analyses by finite element modeling. Photoelastic studies also were being made of the influence of Poisson's ratio on stresses in three-dimensional models, and in two-dimensional multiply connected models.

In addition, we were shown a plaster model of an arch dam (approximately 1 m high) that had been tested (see Figure 2.4). Point loads were applied by jacks, and the resulting strains were measured by means of bonded wire strain gages. Strains were measured at approximately 25 points, and displacements were also measured at a number of points.

After the small displacement tests, the loading was increased to failure to help identify potential failure modes of the prototype. This project was being carried out for a government engineering agency and was for a particular site whose topographical characteristics were included in the model. This project, with its associated equipment, was at a technical level that might be found at a U.S. university or government laboratory engaged in a similar effort.

It is possible to gain some appreciation for the changes that have taken place at Tsinghua University in the past 4 years by referring to the discussion by the American Seismology Delegation (1975), which visited the University in 1974.

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EARTHQUAKE ENGINEERING RESEARCH AND PRACTICE

INTRODUCTION

This portion of the report is a compilation of various aspects of the state of the art of earthquake engineering in the People's Republic of China. The subjects range widely and include such diverse topics as microzonation, soil dynamics, building construction practices, building codes, and the popular literature available on earthquakes. In reading this section, it should be kept in mind that the delegation visited only a limited number of cities, and at each city much more work was in progress than could be presented and discussed in the available time. Therefore although the delegation tried to determine a balanced, comprehensive view of earthquake engineering research and practice in China, the presentation here is necessarily somewhat limited.

THE CHINESE INTENSITY SCALE (HSIEH, 1957)

The seismic intensity scale used in the People's Republic of China consists of 12 deg (degrees), corresponding approximately to the modified Mercalli intensity scale and other 12-deg scales. The zones in the Seismic Design Code for Industrial and Civil Construction are based on estimates of the maximum intensity that is likely to be experienced in each region.

The scale makes use of the following classification of buildings.

- Class I — Adobe houses, mud houses, rural structures, and houses built with stone.
- Class II — Old wood frame buildings and buildings with small wooden columns but without a well-built wooden frame.
- Class III — One story or multistory modern brick buildings, well-built wooden structures, reinforced concrete buildings, and mill (industrial) buildings.

The scale describes the intensity of the earthquake in terms of observations of the effect on class I, II, and III buildings, other structures, ground surface phenomena (including changes of surface and subsurface water conditions), and other phenomena. The brick buildings that were built in large numbers in China after 1949 are similar, at least in their general features, to those in European countries and may be used as a guide to correlating the Chinese and Western intensity scales. The scale is included as Appendix IV to this report.

SEISMIC ZONING

In the Chinese building code (see later in this chapter and Appendix V), design requirements including lateral forces are keyed to a "basic intensity" in the Chinese intensity scale. The responsibility for establishing this basic intensity throughout the country rests with the State Seismological Bureau in Peking. Locally, this basic intensity may be modified to reflect local soil conditions, as discussed later in this chapter.

Basic intensities have already been established for many and perhaps all parts of the country. For example, we were told that the basic intensity for Peking is VIII. Before 1976, the basic intensity for Tangshan was VI; now it has been revised to VIII. We did not see any existing zoning map for the country, but we were shown at the State Seismological Bureau a proposed new map in an advanced stage of development. This map is at a scale of 1:3,000,000. The main feature that catches the eye is the detailed and rapid variation of intensity with distance, with rather small and often irregularly shaped zones. We were told that the map gives "the intensity to be expected during the next 100 years," but the Chinese would not say just what probability was implied by this statement. The map was essentially complete and was expected to be published soon for discussion and adoption. Teng Chi-tung of the State Seismological Bureau in Peking described to us the general methods used in preparation of the map.

There have been four general steps in the development of the seismic zoning map. The first step divided the country into a number of regions and subregions, on the basis of seismic history, tectonics, and geology. The map at this step contained perhaps one to two dozen regions, some quite large and others rather small. The second step involved establishing for each region the magnitude of earthquake "expected during the next 100 years," and the third step determined where in each region these magnitudes were expected to occur. The result at this point was a map giving the geographical variation of "expected magnitude." The final step mapped the intensities resulting from the expected magnitudes. Most of the presentation dealt with the second and third steps.

Various methods have been used to estimate the expected magnitude, the choice apparently being dictated by the anticipated periodicity in earthquake occurrence. In northern China, four types of periodicity are recognized, having intervals of about 300, 100, 50, and 30 years. It is also recognized that in some regions there may be seismic gaps along fault zones which may have even longer intervals between major earthquakes.

Where the period is near 300 years, the Chinese believe that there is a standard time sequence of events. In the earliest stage of each cycle, earthquakes less than $M = 6$ can occur. In the next stage there can be earthquakes around $M = 6.8$. The main stage may see earthquakes up to $M = 8.5$, or several somewhat smaller shocks near $M = 7$. Finally, earthquakes with events in the $M = 6.5$-7 range can occur in the fourth stage. Choice of the expected magnitude then depends upon the stage deemed appropriate for the next 100 years.

When the cycle is relatively short, the Gutenberg-Richter relation,

$$\log_{10} N = a - bM$$

is used to predict for the next 100 years. In this equation, M is the magnitude, a and b are constants, and N is the number of earthquakes greater than or equal to M per year per unit area. From the census of historic earthquakes, the a and b values in this relation for various regions are analyzed to give an estimate of the average recurrence of earthquakes of various magnitudes.

In cases where a seismic gap along a fault zone is suspected, various gap-filling theories are used. We were shown a diagram of how certain gaps were filled by major earthquakes. A correlation was developed between length of gap L and the possible magnitude M:

$$M = 3.16 \log L - 0.31$$

(L in kilometers) based upon past earthquakes which were judged to have filled gaps.

Still other methods for selecting the expected magnitude were mentioned but not described to us in detail.

Once the time pattern of earthquake occurrence in a province has been established from historic seismicity, geologic and tectonic evidence is employed to determine the locations of the expected earthquakes. Fault activity is analyzed, the shapes of basins are considered, and ground deformation and crustal thickness provide further criteria. Several kinds of basins are considered most indicative, including grabens, asymmetric basins bordered on one side by faults, and young (Neogene) basins. Areas in which the gradient of ground deformation is steepest are considered likely sites. The margins of major crustal blocks as defined by crustal thickness are also prime targets.

To translate from expected magnitude to epicentral intensity (I_0), a relation was developed based upon statistical analysis of 150 earthquakes:

$$M = 0.66 I_0 + 0.98$$

This is essentially the relation used in the United States. Various studies of attenuation of intensity with distance were mentioned during our brief visit to the SSB but were not described.

MICROZONATION

The current earthquake resistant design standards for the People's Republic of China describes four classes of soil:

Category I	Slightly or intermediately eroded rocky ground.
Category II	Firm ground other than that falling under categories I and III.
Category III	Sandy mud or muddy ground, deposits of silt, organic soils.
Category IV	Soil that may liquefy.

Indices for classifying soils into these categories are available in a foundation design standard. The design lateral force specified by the building code increases (except at very small periods) in going from category I to category II to category III, and certain design requirements also become more demanding. We were told that it is the responsibility of the designer of a building to classify the soil at the site.

During our visit, several research studies were described. It was suggested that these studies might eventually be the basis for preparing microzoning maps.

Liu Tseng-wu of the Institute of Engineering Mechanics described a method for microzonation based upon an observed correlation between damage and the weighted shear modulus of the underlying soil (Liu et al., 1978). This correlation was first developed from studies of the earthquake at Tunghai in 1970 and, subsequently, was checked by observations during the Haicheng earthquake, 1975, and at Tangshan and Chinhuangtao during the Tangshan earthquake of 1976. An attempt was made to introduce corrections for topography, tectonics, and epicentral distance. A weighted shear modulus was used as the variable after it was found that damage did not correlate well with either the compressional or shear wave velocity of just the upper stratum.

The shear wave velocity, and hence the shear modulus, was measured in several ways. At Tunghai, underground explosions were used, whereas at Haicheng, hammering techniques were used. The weighted average of shear moduli, or average shear modulus G, is represented by the formula

$$G = \frac{\sum h_i G_i}{H} = \frac{1}{H} \sum h_i \rho_i V_{si}^2$$

where

h_i = depth of ith layer.

G_i = dynamic shear modulus of ith layer.

ρ_i = density of ith layer.

V_{si} = velocity of shear waves in ith layer.

H = depth of total layers.

The averaging typically is carried out over a depth of 20 m.

A so-called damage index i is represented by the formula

$$i = \frac{\sum d_i N}{N_T}$$

where

d_i = degree of damage to buildings expressed in five categories.

N_T = total number of buildings.

N = number of buildings damaged.

An index of zero means that no buildings were damaged, and an index of one means that all buildings collapsed. In calculating i, $d_i = 0.2$ corresponds to fine cracks, $d_i = 0.4$ means cracks that might be open ¼ in., etc., up to collapse.

The relation between damage index and average shear modulus in the 1975 Haicheng earthquake and in the 1970 Tunghai earthquake is shown in Figure 3.1. Figure 3.2 shows a comparison among three categories of damage and three ranges of average shear modulus for Chinhuangtao during the Tangshan earthquake. Typical values of weighted average of shear modulus that relate to different degrees of damage are as follows: severe damage, $G = 7.0\text{-}8.8 \times 10^4$; moderate damage, $G = 10.3\text{-}11.7 \times 10^4$; slight damage, $G = 18\text{-}26 \times 10^4$ (units are tons/m^2). A comparison between weighted modulus and damage index was also made for Tangshan.

As a practical example of the use of this approach, in the reconstruction planning for Tangshan, average shear modulus is considered valuable and is used as a criterion in those cases where no damage

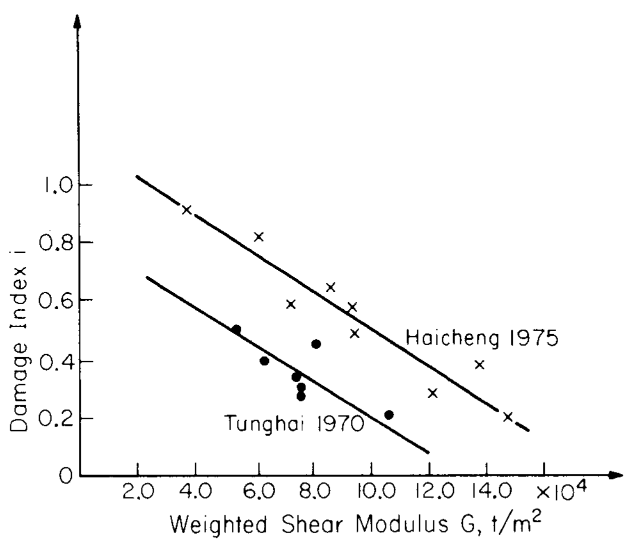


FIGURE 3.1 Correlation between weighted shear modulus and damage index.

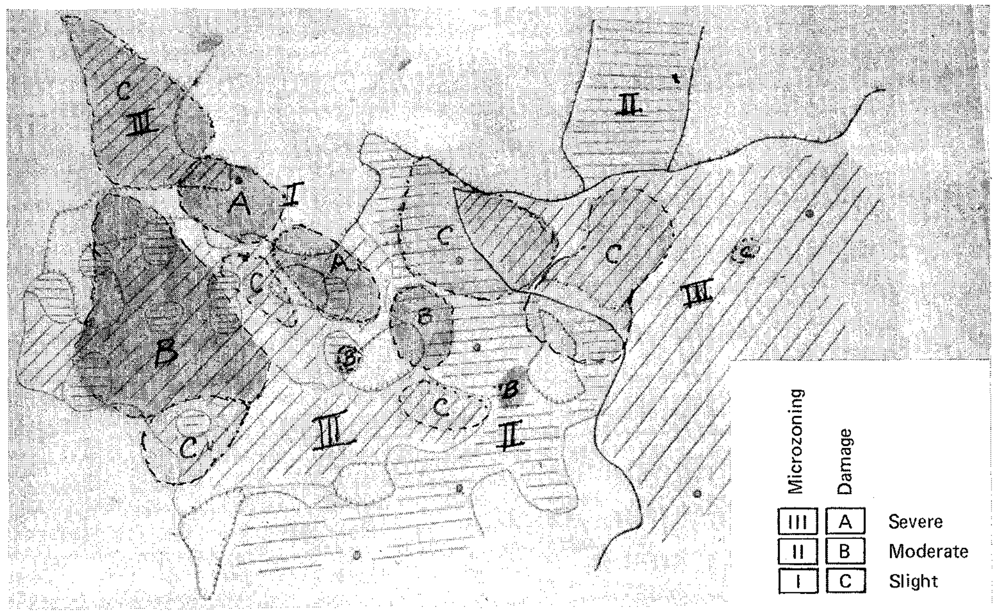


FIGURE 3.2 Correlation between microzoning and observed damage at Chin-huangtao during the Tangshan earthquake.

data are available. If data on damage are available, then they provide the principal basis for planning reconstruction. At Tangshan, data from test borings were combined with damage index and average shear modulus to create a microzoning plan for reconstruction of the city. Further work is planned on correlating penetration tests and tests of natural frequency of vibration of soils as factors in microzoning.

In another study at the Institute of Engineering Mechanics, Hsieh Chun-fei has described analyses of a damage anomaly in Tientsin. Here the Quarternary deposits extend to a depth of 300 m, underlain by mudstone and then competent rock at 1,000 m. In one area of the city (area A), 12 percent of the old brick buildings collapsed during the Tangshan earthquake, while in another part (area B), only 6 percent collapsed. This same pattern had been noted in previous earthquakes at other locations. We were told that studies had excluded differences in type of structure and foundation failures as a cause of this anomaly. Theoretical site amplification studies were made in an attempt to explain the difference. Deep borings established the soil profiles to a depth of 50 m. An aftershock record taken elsewhere in the city was deconvoluted through the soil profile at that site and, after normalization to 0.053g, was used as input. Computed surface accelerations were several times larger for area A than for area B, although the computed fundamental periods were greater at area B. The differences in computed response were the results of a soft stratum within the soil profile for area B, between depths of 11.5 and 16 m. No strong-motion records were available to confirm these conclusions, although instruments apparently have now been installed by the Tientsin Seismological Brigade.

The engineers at the Institute of Engineering Mechanics did not have a complete explanation as to why soft layers are beneficial in some cases but harmful in others.

In Peking, Chou Shih-yuan of the Peking Seismological Brigade described comprehensive site amplication studies for the city. Here the soils are sands, clays, and gravels deposited primarily by slope outwash. The depth of alluvium ranges from 15 to nearly 200 m. Shear wave velocities (measured in situ by the downhold method) range from 150 m/s near the surface to 200-400 m/s at 30-m depth. Dynamic triaxial tests were made upon undisturbed samples to evaluate modulus and damping as a function of strain. A lumped-mass representation was made for the soil with iterations to establish a strain-compatible modulus, and weighted modal damping was employed. Soil profiles were established at each of about 50 boreholes, and amplification analyses were made for each site. Several earthquake motions, including a Tangshan aftershock, were normalized to 0.1g as input. Computed fundamental period and surface accelerations were then mapped over the city. The eventual application of these results was not discussed.

LIQUEFACTION

During their visit to the United States in 1976, the Earthquake Engineering Delegation from the People's Republic of China presented a correlation between standard penetration resistance and field observations of liquefaction or nonliquefaction during earthquakes. This equation is

$$N_{crit} = \overline{N}\{1 + 0.125(d_s - 3) + 0.05(d_w - 2)\}$$

where

d_s depth to sand layer under consideration, m.

d_w depth of water table below ground surface, m.

$\overline{N}$ function of the shaking intensity, as follows:

Intensity	$\overline{N}$ (blows/30 cm)
VII	6
VIII	10
IX	16

Our visit provided an opportunity to inquire into the background of this equation. The main source of information was Liu Ying, Chief of the Division of Soil Mechanics at the Institute of Engineering Mechanics.

The original Chinese investigation apparently was made following the earthquake of 1970, although it was not published until recently, owing to the disruption caused by the Cultural Revolution. Data from eight earthquakes, with magnitudes ranging from 4.4 to 7.8, were utilized. Figure 3.3 shows the results, where open circles indicate liquefaction and crosses denote nonliquefaction.

In these investigations the penetration test differed from the standard penetration test. A mass of 10 kg falling 50 cm was used in place of 63.5 kg and 76 cm. In general, however, the Chinese apparently use the standard test. Figure 3.4 shows a correlation between the blow count n in the actual tests and the standard resistance N. Since liquefaction typically occurred at a depth of 3 m during the eight earthquakes, the ratio of n to N at this depth was used to convert the original blow count to the standard blow count. Figure 3.3 is the origin of the relation between $\overline{N}$ and intensity, as tabulated above. This relation is strictly empirical and was obtained for conditions where $d_s \simeq 3$ m and $d_w = 2$ m. The corrections for d_s and d_w in the above equation were deduced on theoretical grounds and were influenced by the work of H. B. Seed in the United States.

The validity of the equation for N_{crit} was further verified during the Haicheng earthquake. At the same time there were instances where liquefaction, although it occurred, did not cause foundation failures because of the strength of the overlying stratum of clay. The experience in Tangshan apparently was that the equation was, in many cases, too conservative; however, the soil shaken during the Tangshan event was often a loam with a considerable content of fines, to which the equation perhaps does not apply.

The equation for N_{crit} has been used in the Chinese building code since 1974. It is regarded as a screening test to identify sites

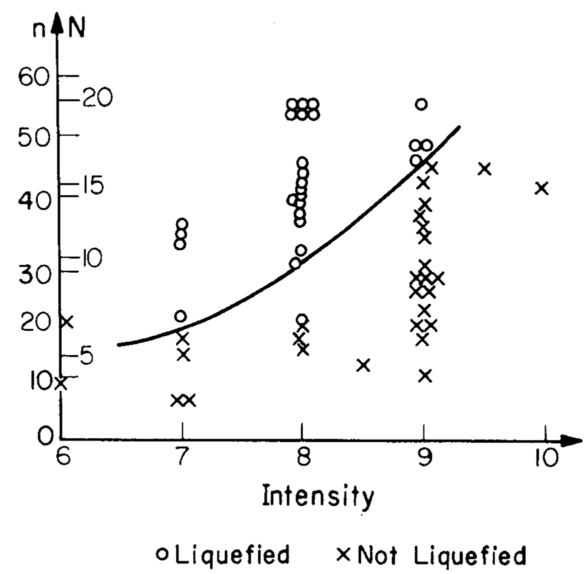


FIGURE 3.3 Relation between intensity of ground shaking, penetration n and N, and the occurrence of liquefaction. Open circles represent liquefaction, and crosses nonliquefaction.

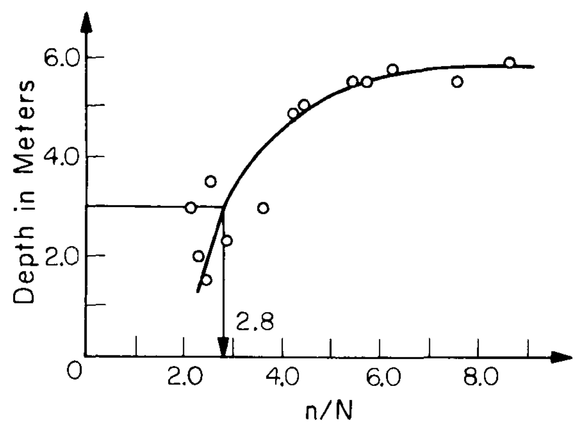


FIGURE 3.4 Correlation between blow count *n* used in liquefaction studies and standard penetration resistance *N*, as a function of depth.

requiring more detailed investigation. The limits of its validity are uncertain, especially where significant amounts of fines are present in the soil. It was determined that the soil layer where sand boils occurred typically has a plasticity index less than 10 and a clay content less than 10 percent.

The proposed revision to the code will say that the equation must be used when the mean grain size D_{50} exceeds 0.05 mm and the content of granular soils is more than 40 percent. However, the need for more research is recognized, and the influence of the composition of the soil upon its liquefaction resistance is being studied both at the Institute of Engineering Mechanics and at the Geologic Hazards Division of the State Seismological Bureau in Peking.

At the Institute of Engineering Mechanics we were shown a chart giving threshold conditions for the occurrence of liquefaction (Table 3.1).

TABLE 3.1 Thresholds for Liquefaction

Condition	Threshold
Maximum epicentral distance (km)	$\log D_{max} = 0.87M - 4.5$
Minimum intensity (Chinese scale)	6
Mean grain size (mm)	$0.02 < D50 < 1.0$
Clay particle content (percent)	<10
Uniformity coefficient	<10
Relative density (percent)	<75
Void ratio	> 0.8
Plasticity index I_p	<10
Depth to water table (m)	< 5
Depth of sand layer (m)	<20

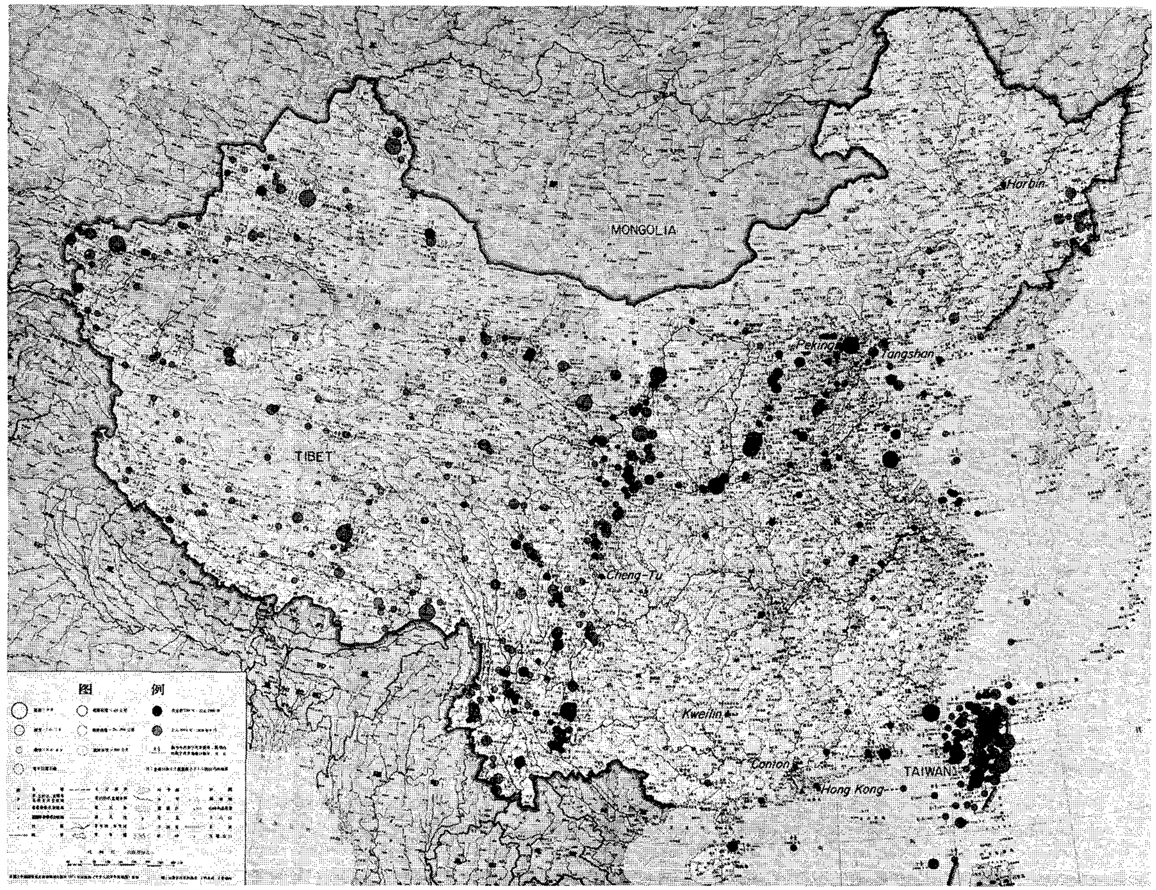


FIGURE 3.5 This large epicentral map (approximately 100 × 70 cm) of the People's Republic of China was purchased in a bookstore. The names in English, which include the cities visited by the delegation, have been added.

OTHER FEATURES OF RESEARCH IN SOIL DYNAMICS

At the IEM in Harbin, we were shown three devices for cyclic triaxial tests, one of which was just completed and had special capabilities. Both the axial load and the chamber pressure could be cycled with frequencies between 0.01 and 20 Hz, and the phase angle between these stresses could be adjusted. Sinusoidal, triangular, and rectangular wave patterns could be selected. Soil specimens may be either 40 mm in diameter by 80 mm long, or 62 × 124 mm. Horizontal consolidation stresses up to 5 kg/cm^2, and axial consolidation stresses up to 10 kg/cm^2, are possible. Axial and horizontal dynamic stresses can be up to 5 and 3 kg/cm^2, respectively. The device is intended both for studies of liquefaction and for evaluation of modulus and damping.

Several research topics in soil dynamics were described to us during our visit to the IEM. One of them was an analysis of strong-motion records at Huang-Bi-Zhang Dam in Hopeh Province. This is an earth-fill dam with a height of 19 m. Twenty-eight records have been obtained, with a maximum acceleration of 44 cm/s^2. Peng Kuan-chung of IEM is analyzing the influence of magnitude, epicentral distance, focal mechanism, and direction of epicenter upon the frequency characteristics at the base and the crest of the dam. Additional studies underway at IEM include a theoretical analysis of the effects of topography upon earthquake motions, a theoretical study of wave propagation in porous, fluid-saturated media, and a study of the stress concentrations induced by propagation of waves around underground tubular structures, such as might be found in underground power plants.

While in Peking we met with Dr. Chen Tsung-chi,* who had been an active participant in international soil mechanics meetings in the 1950's and early 1960's. He has just recently become the Director of the Institute of Geophysics at the Academy of Sciences, having previously been the Director of the Institute for Soil Mechanics and Rock Mechanics in Wuhan. Dr. Chen's major current interest is the rheology of rock, partly as related to earthquake faulting. He said that soil dynamics research as related to foundation vibrations and wave propagation was underway in several ministries and that some soil dynamics studies relative to earthquake engineering might be starting at a university in Shanghai.

STRONG-MOTION INSTRUMENTS AND RECORDS

About 70 permanent strong-motion stations are currently installed in the People's Republic of China. Thirty-nine are in Hopeh Province, including the installations in Peking and Tientsin. Another group is in the provinces of Kansu, Szechwan, and Yunnan along the active region that extends in a north-south direction along the eastern front of the Tibetan Plateau (see Figure 3.5). The remainder of the permanent stations are located in Kuangtung, Kiangsu, and Hopeh provinces in the south, east, and central areas. None were reported to be in far western China.

*Also transliterated as Tan Tjong-kie in the soil mechanics literature.

The overall operation of the strong-motion program is under the direction of the State Seismological Bureau in Peking. The initial planning and installation of the instruments in permanent stations was conducted by the Institute of Engineering Mechanics at Harbin. The emphasis in planning for strong-motion studies has been on the use of a combination of permanently installed stations in the more active regions, and mobile instrumentation that may be brought into an area either if there is a prediction of an earthquake or to study the aftershocks of a major earthquake. At the present time, IEM maintains a network of 28 instruments in the northeast region. Permanent stations are also being maintained by the Peking and Tientsin Seismological Brigades and by the provincial seismological bureaus and brigades in each of the provinces indicated above. Although each local organization operates somewhat independently and keeps its own records, copies of the records are sent to IEM for analysis.

The principal strong-motion instrument used is the RDZ-1-12-66. This is a 12-channel instrument designed and developed at IEM for use in studies of the response of structures. The instrument is shown in Figure 3.6. The system normally has eight horizontal and four vertical transducers distributed throughout the structure. Two uniaxial mechanical triggers are used, and the system is powered by a 24-V battery. The instruments are manufactured by the State Seismological Bureau in Peking (factory 581) and have the following characteristics:

Trigger:
- natural frequency, 1½-3 Hz
- damping, 10 percent
- sensitivity, 5-10 gals

Transducers:
- natural frequency, horizontal, 4 Hz
  vertical, 4.5 Hz

System characteristics:
- flat response from 0.5-35 Hz
- normal range, 5-100 gals
- paper speeds, 2.1, 4.8, or 11.3 cm/s
- time trace, 20-Hz signal ±1 percent

Field operation since 1967 is reported to bear out the satisfactory operation and reliability of the instrument. The drawbacks of the instrument are primarily its size and weight, and clearly, it is not an efficient instrument for recording ground motions. Improvements that are desired by the Chinese are automatic gain ranging and improved recording of long-period components.

Although most of the instruments currently in operation are the 12-channel RDZ instrument used on structures, some are an earlier six-channel model, and some of the instruments located at the seismograph stations are three-component instruments, designated the QZY-IV, reportedly based on the Japanese SMAC design. In addition, IEM had purchased one Kinemetrics SMA-1 accelerograph and had constructed a copy of this instrument, which is shown in Figure 3.7.

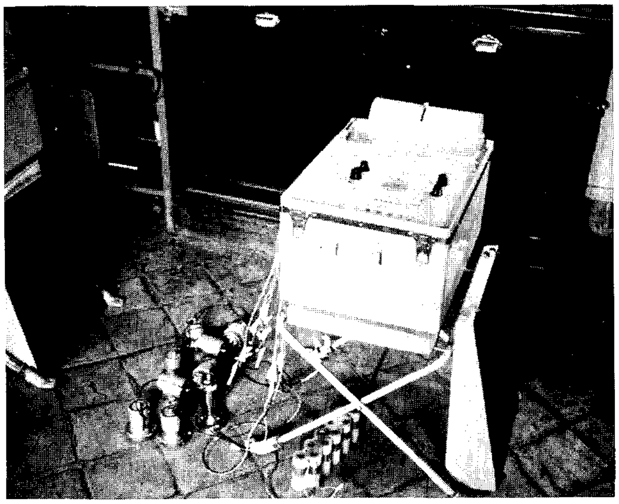


FIGURE 3.6 RDZ-1-12-66 accelerograph. The instrument has 12 channels and records on paper.

To date, approximately 300 strong-motion accelerograms have been obtained. These are mainly recordings of moderately strong ground shaking; the maximum recorded ground motion is about 0.2g. Records which are considered significant are digitized at IEM by means of a Japanese semi-automatic digitizer (Figure 3.8). Typical processing includes baseline correction, integration to obtain velocity and displacement, and calculation of response and Fourier spectra, similar to the standard processing being done by other organizations throughout the world.

Although the peak accelerations recorded to date are relatively low, the accelerograms have been used in earthquake engineering research.

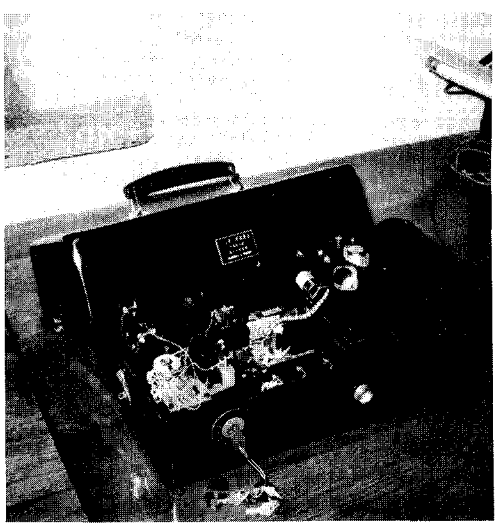
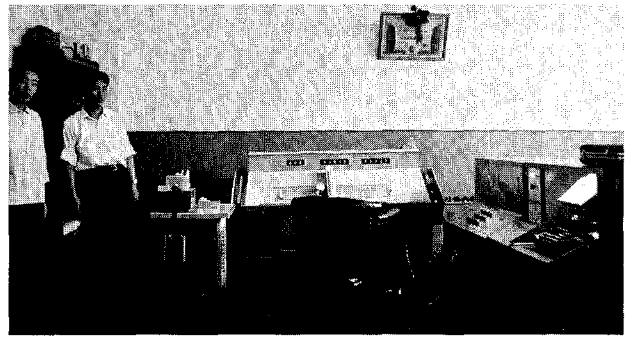


FIGURE 3.7 Prototype of film recording accelerograph copied from a Kinemetrics SMA-1 instrument.

FIGURE 3.8 Digitizer at the IEM in Harbin. The digitizer is of Japanese manufacture.



A collection of 68 Chinese accelerogram traces with some additional records from foreign sources have been used to compute 5 percent damped response spectra for use in design. From their studies of ground motion spectra, they have observed changes in the shape of the spectra with increases in the magnitude of the event. The data have been analyzed statistically with respect to three classes of soil, and the results are reflected in the Chinese building code. Most of the studies have been directed toward measurements in structures, and the Chinese have obtained many useful records of the response of buildings, dams, and bridges. In some cases, several events have been recorded on the same structure. Fourier spectra have been used to evaluate the frequency characteristics of the motion, and finite element analyses have been used to compare computed and measured time histories of response.

Further discussion of strong-motion results is included in the presentation on the Tangshan earthquake, chapter 4.

STRENGTHENING OF HSINFENGKIANG DAM

During our visit to Canton, L. Huang made two presentations concerning the Hsinfengkiang Dam, which had been damaged by an earthquake in 1962. The reservoir region had been subjected to increasing seismic activity since 1959, the first shock being experienced only a month after the reservoir began to fill. Both because this dam provides one of the most convincing examples of reservoir-induced seismicity and also because of the extensive efforts that were made to strengthen and repair the structure, it has been the object of continuing studies by the Kwangtung Provincial Seismological Bureau, both in engineering and seismology (Shen et al., 1974).

Hsinfengkiang Dam was built during 1958-1960, originally in the form of a diamondhead buttress dam. Its height is 105 m above the base, and the crest length is 400 m. Because the dam originally was designed only for seismic intensity VI (acceleration of 0.025g), concern was felt for its safety when seismic activity began with the reservoir filling. In 1961 the dam was strengthened for earthquake forces by tying the buttresses together with a concrete slab at the downstream face, and by filling the lower part of the space between buttresses with concrete.

In March 1962, a magnitude 6.1 earthquake with a focal depth of 5 km occurred at a horizontal distance from the dam of 1 km. This intensity VIII shaking damaged the strengthened structure, causing cracks on both faces across much of the length of the dam and extending entirely through the thickness for a portion of that length. The water level in the reservoir was 14 m below the dam crest at the time of the earthquake; the cracks formed about 2 m below the water surface and leaking was observed, so the reservoir was lowered 3 m to stop the leaking. The dam was then strengthened additionally by filling in more of the space between the buttresses, so that the structure now is essentially a gravity dam. It is interesting to note that this phase II strengthening was designed for static stability but that calculated dynamic stress levels from expected future earthquakes are not reduced by the modification.

After the dam was strengthened, two 12-channel RDZ-1-12-66 strong-motion seismograph units were installed at the dam. The seismic pickups are located at many points within the dam but at only one crest location. More than 100 earthquakes have now been recorded by this seismographic system, but the largest magnitude has been only 4.5. The data seem to indicate that the response is essentially two-dimensional locally but that relative deformations do occur along the transverse axis.

This strong motion installation was not planned so as to be able to identify spacial variations in the ground motions (wave propagation effects). However, the records are being used to study foundation-dam interaction. One pickup is located at the dam base, a second is 100 m downstream. The relative values of recorded peak accelerations at these two locations suggest that for $M < 4.5$ the free-field motion is 50 percent greater than the motion of the dam base. Extensive two-dimensional finite element studies are being carried out in an effort to understand this effect.

MASONRY BUILDING RESEARCH AT HARBIN

The most extensive and ambitious structural engineering research program being carried out at IEM is concerned with seismic resistance of masonry buildings. This is by far the most common type of construction in China, and most earthquake casualties result from damage or total collapse of such structures. It was stated that over 75 percent of the multistory buildings in Tangshan either collapsed or experienced severe damage in 1976.

The need for developing improved masonry construction was recognized by IEM long before the Tangshan earthquake, and a major experimental study on a group of four full-scale test structures already was under way at the Institute when the American Seismology Delegation (1975) made its visit in 1974. M. K. Cheng made a comprehensive report on this research program during the present visit to Harbin. The principal objectives of the investigation were to measure shear strength as a function of vertical compressive stress and to identify the major damage mechanisms in typical masonry buildings.

The test buildings, illustrated in Figures 3.9 and 3.10, were of two-story box configuration, 4 m square in plan with story heights of 2.6 and 2.5 m. The four buildings were arranged in a square pattern with a space of about 1 m in each direction between the individual units. Thus it was possible to apply lateral loads by jacking between pairs of the buildings; loads could be introduced on either axis by appropriate choice of the building pairs. The buildings were constructed on a 1.2-m deep layer of compacted rubble and had brick wall footings. One test structure (structure 4, on the left in Figure 3.9 and on the right in Figure 3.10) was reinforced with bars placed at equal intervals over the height of the four second-story walls; similarly, two bars were placed within the mortar joints at three levels of the first-story walls of this unit. Each test structure had a window opening in opposite wall panels of each story, while the perpendicular wall panels had no openings. The walls were of typical brick masonry construction, 24 cm thick, with mortar strength nominally 24 kg/cm^2 as measured in a standard 10-cm cube test. Floors and roof were cast-in-place reinforced concrete slabs, 18 cm thick.

Instrumentation consisted of (1) dial gages arranged to measure lateral displacement of floors and roof, (2) a total of ten 20-cm long strain gages cemented to the masonry surface, located along the diagonal of selected wall panels and oriented to measure strain in the opposite diagonal direction; and (3) clinometers at the floor and roof levels to measure rotation of the wall panels. Loads were applied by the jacking system in one sense only, either increasing monotonically to failure or as long-duration half-sine wave pulses of successively increased amplitude. The typical failure mechanism in unreinforced buildings (buildings 1 and 2) was a diagonal crack extending across the full width of each wall panel. In general, jacking applied at the top story produced cracking in that level only, and the bottom story was cracked by jacking at the bottom level. Cracking patterns in the reinforced walls were generally different: only in one panel did the diagonal crack extend across the reinforcing bars; in the other three panels the crack extended diagonally from the bottom corner only to the level of the first reinforcing bars at the opposite edge.

Principal results reported by Mr. Cheng included the failure stresses and ductility ratios observed in the panels. The ductility ratio was defined as the ratio of the failure displacement to the yield displacement; typical values observed in panels without window openings ranged from less than 2 to over 6, with the highest values indicated by the reinforced walls. Also reported were the variation of wall panel strains with monotonically increasing loading and the change in the period of free vibration with successive stages of damage. Although the type of construction and materials considered in these tests is not representative of U.S. conditions, it is believed that the results of this work would be of great value to those doing masonry research in this country. It is hoped that an English language version of this report will become available.

In addition to the full-scale experimental study which was being performed outside of the laboratory buildings, we were shown two programs of research on masonry structures being done within the laboratory. One

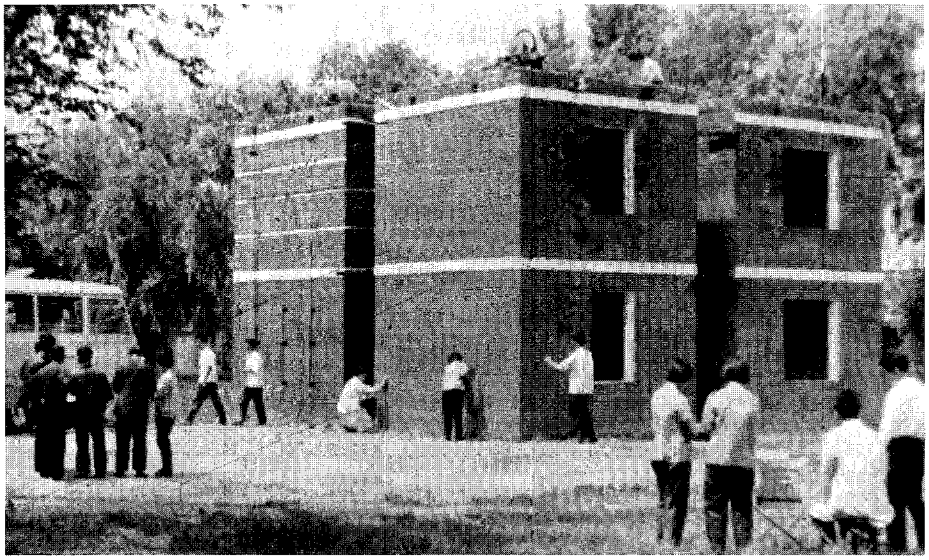


FIGURE 3.9 Masonry test structures at the Institute of Engineering Mechanics, Harbin.

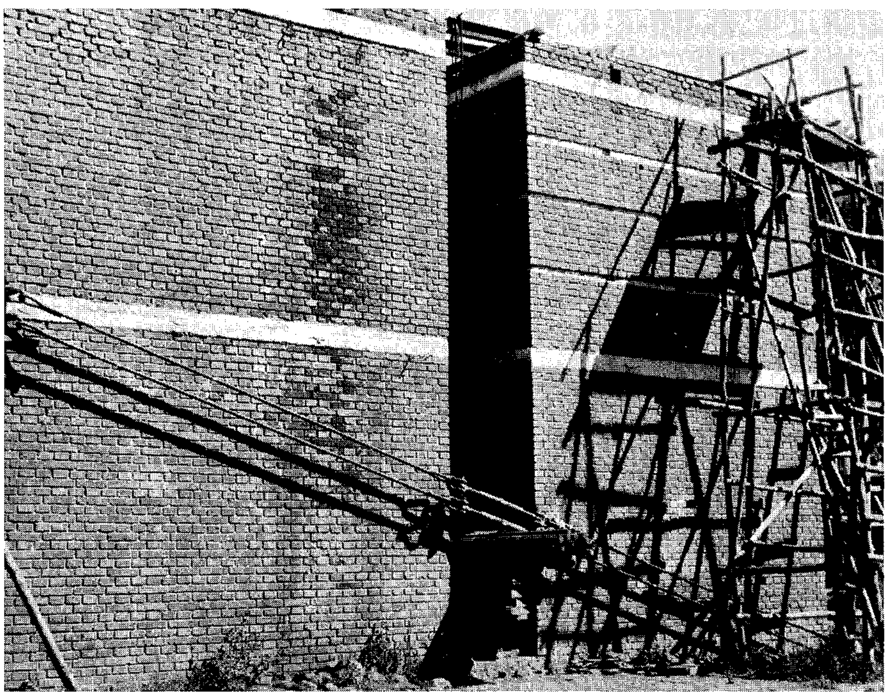


FIGURE 3.10 Close-up of the four buildings shown in the previous figure. The buildings are jacked apart to produce lateral loads.

of these was a typical component test involving a portion of a brick wall panel, as shown in Figure 3.11. The test specimen was about 2 m high by 3 m long; it included one wide panel (1.25 m) and one narrow window opening (0.24 m) and was of standard 25-cm thick unreinforced wall construction. The specimen was being tested in a fixture which applied a static vertical load together with cyclical horizontal load in the plane of the panel. Stress due to the vertical simulated gravity load was in the range 3-6 kg/cm^2 (appropriate to a four- or five-story building). The cyclic shear load was applied at 4-Hz frequency and was increased in steps from 3 tons up to 50 tons amplitude. The dynamic load acted only in one direction (sense) and was statically biased so that the minimum in each cycle remained at 0.5 tons. Standard compressive tests of 0.3-m by 1-m high prisms were performed to evaluate the strength of the masonry, which was reported to be in the range 75-100 kg/cm^2. Plans also had been made for diagonal compression tests of 1-m square specimens to obtain a nominal measure of the shear strength, but no measurements of this type had yet been made.

The other laboratory study of the earthquake resistance of masonry construction was a shaking table test of an approximately 1/10 scale model of a three-story brick building. This test is illustrated in Figures 3.12 and 3.13. The 1.2-m square, single horizontal component shaking table had only recently been completed, incorporating a hydraulic

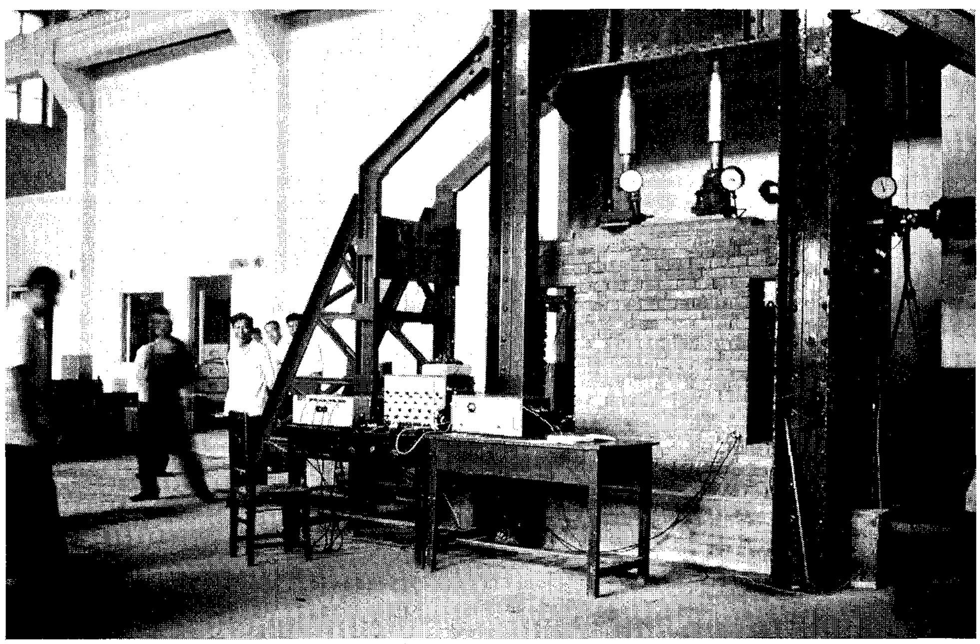


FIGURE 3.11 Component test of a brick wall panel at IEM, Harbin. The unreinforced panel is subjected to constant vertical load and cyclic horizontal load.

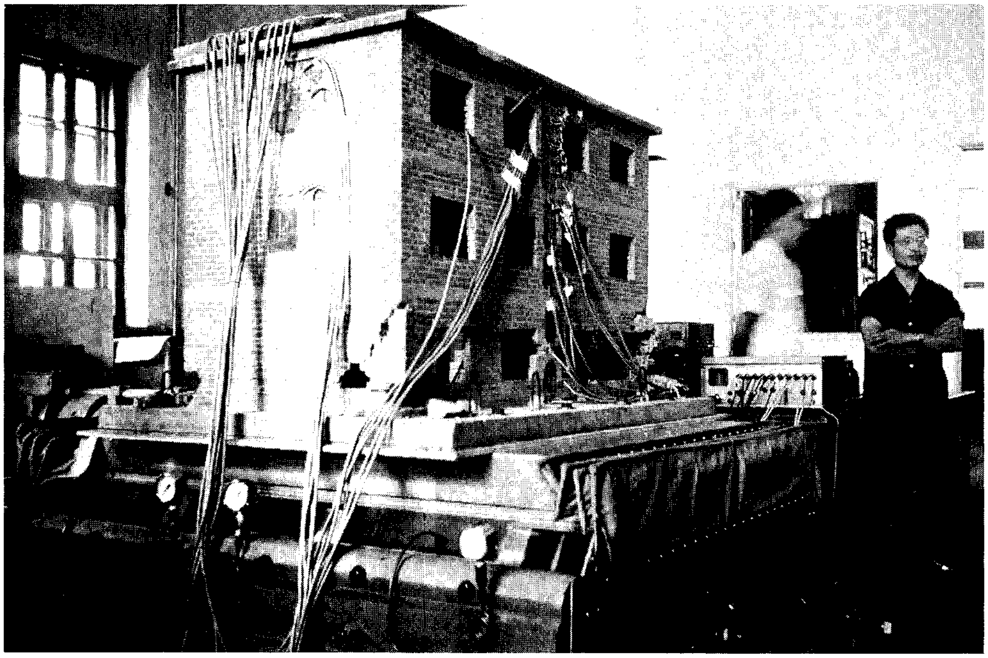


FIGURE 3.12 Model masonry structure subjected to shaking table tests at IEM, Harbin. One of the purposes of the test was to examine the failure mechanism of such structures.

actuator and control system purchased from Japan. In these preliminary tests, only harmonic excitation was applied, but it is understood that the system will be extended to permit simulation of actual earthquake motions. Testing of the model had been completed before our visit, but the damaged structure was still in position on the shaking table. Shaking intensity had been increased sufficiently to induce shear failure of one first-story end wall (Figure 3.13), with simultaneous collapse of the adjacent out-of-plane window wall. This test was the first major use of the shaking table and was intended mainly to evaluate the potential for this type of model testing; no studies had yet been made on similitude requirements for full-scale quantitative interpretation of such test results.

TALL BUILDING RESEARCH IN CANTON

Although Canton is considered to be in a relatively low seismic zone (intensity VII), earthquake engineer members of the Kwangtung Provincial Seismological Bureau have undertaken extensive studies of the dynamic properties and behavior of two tall buildings in Canton, which are the tallest in China. The taller of these is the 33-story White Cloud Hotel,

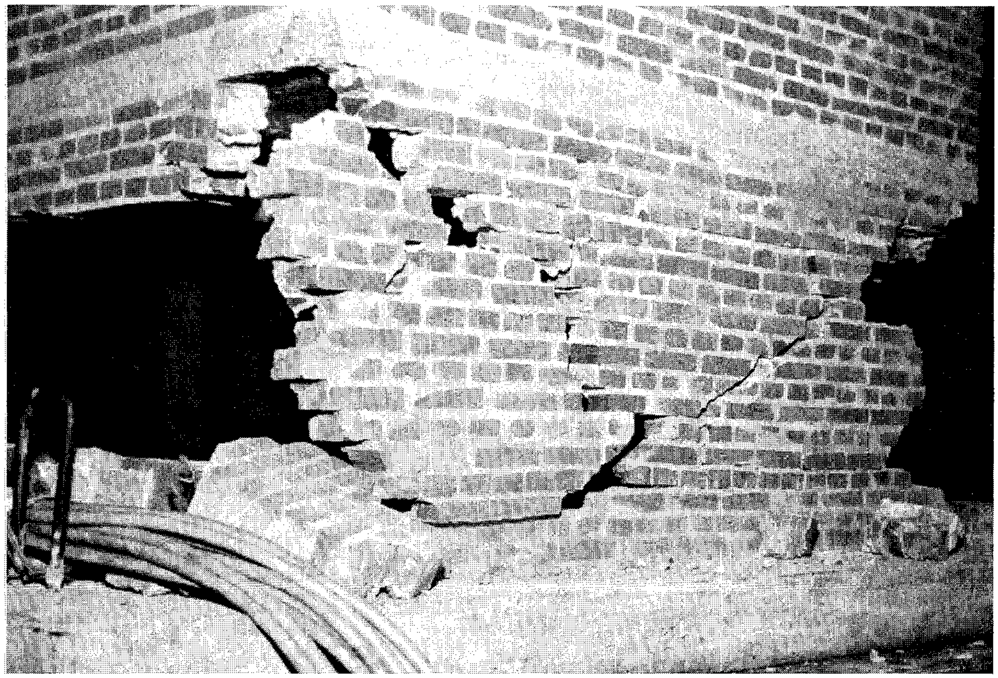


FIGURE 3.13 Close-up view of the lower floor of the end wall of the model shown in the previous figure. The end wall has failed in shear, with fracture occurring mainly through the bricks, rather than the grout.

which was completed in 1976. A 12-channel RDZ-1-12-66 strong-motion seismograph has been installed in this building, with three components of accelerometers located at the foundation level and one each at the eighth, twentieth, and thirtieth floors.

No strong-motion records have been obtained since this instrumentation was installed, but microtremor measurements have been made using a long-period vibrometer. The same vibrometer system also was used to measure the dynamic response of the second tall (24-story) building during a typhoon which passed close to Canton. The wind velocity was reported to be 24 m/s at the roof level; it was stated that the fundamental natural period of the building was evident in the dynamic response record, as well as the 20- to 30-s period of wind gusts.

Analytical studies were made of the vibrational behavior of these buildings for correlation with the measured results. It was stated that a dynamic response spectrum analysis is required by the building code in the design of such buildings. Mathematical modeling used in calculating the building's vibrational properties was described in this presentation; it appeared to follow standard concepts of modeling and analysis.

DESIGN AND CONSTRUCTION PRACTICES IN CHINA

A special interest of the delegation was to observe how the research and knowledge in earthquake engineering were translated into actual construction. Consequently, we requested, and were given, the opportunity to visit various construction sites and to inquire about materials, procedures, and details. Everywhere we went in China there was much construction activity, and we were able to assure ourselves that the projects we examined in detail were representative.

We had the impression that all available building material was being used. Generally, construction was for housing, with many structures in the 5- to 12-story range. The two most common types of construction for multistory buildings were (1) a combination of precast and poured concrete for walls, frames, and floor slabs and (2) unreinforced brick walls with precast concrete floor slabs. Some projects combined precast concrete, cast in situ concrete, and unreinforced brick.

Peking

Buildings in Peking are designed by the Peking Institute of Architectural Design for an earthquake of intensity VIII on the Chinese scale. The State Capital Construction Commission has responsibility for construction, and this organization arranged for us to visit three sites in Peking. The first and third projects were similar 12-story apartment buildings at different stages of construction. They seemed to typify new apartment construction in Peking. An exterior view of the first building visited is shown in Figure 3.14. The buildings normally contain two stairways, two elevators, and a basement for machinery. The

FIGURE 3.14 Exterior view of typical apartment building in Peking. The building has precast exterior walls, precast floors with topping, cast-in-place concrete shear walls, and brick partitions.

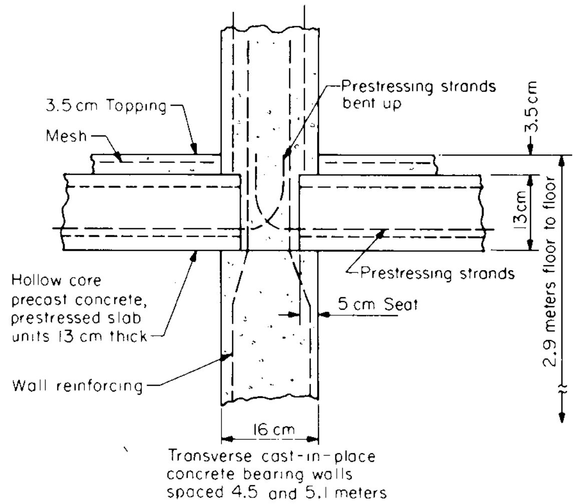


FIGURE 3.15 Details of a typical wall-floor connection in the building shown in Figure 3.14.

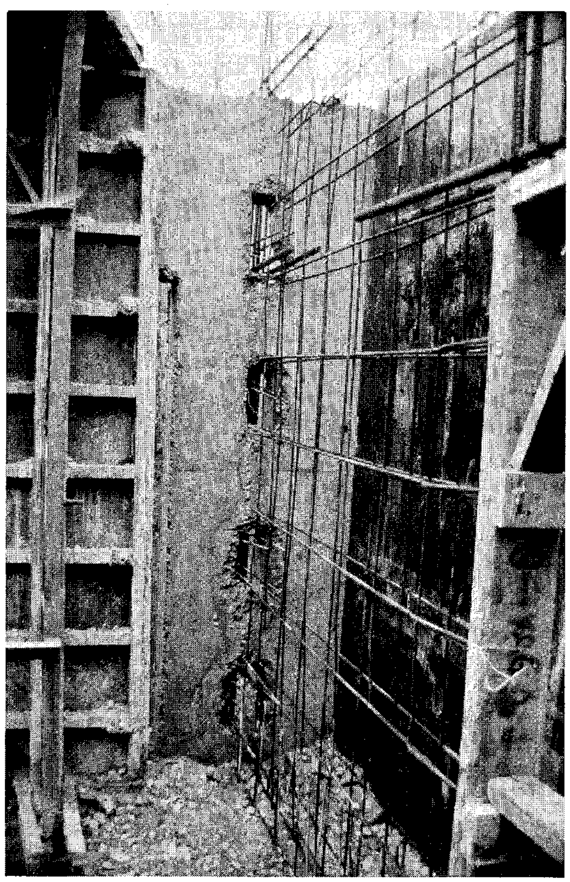


FIGURE 3.16 Preparations for cast-in-place shear walls in an apartment building in Peking. The transverse walls are cast first with blockouts. Forming and reinforcing shown for longitudinal wall are to be cast next. Note the steel wall forms.

individual living units have central heat, water, gas, and electricity.

The total floor area of the first project visited is 10,000 m^2, 12 floors, with 13 apartment units per floor (about 55 m^2 per family unit average). The exterior walls are precast concrete. Floors are 13-cm deep, hollow core precast units with a 3½-cm topping. The main interior walls are cast-in-place concrete, with one longitudinal wall running the full length of the building, and with cross walls at alternating 5.1- and 4.5-m spacings. The cross walls are bearing walls; there are no beams or columns in the structure.

The concrete walls are 16 cm thick, with the precast floor slabs bearing on 5 cm of the wall on each side. Prestressing tenons of the floor slab project into the wall to tie the floor to the wall, as shown in Figure 3.15. The interior subdivisions of apartments are nonstructural brick walls.

The construction procedure is somewhat different that one might expect. A floor is completed structurally on a 4-day cycle (with two 8-hour shifts). First the cross walls are poured, leaving blockouts for the longitudinal wall reinforcing. Then the reinforcing is placed for the longitudinal wall, and the steel wall forms are placed in position. This stage is shown in Figure 3.16. The precast exterior wall units are placed in position and supported from the cross walls (Figure 3.17). Then the precast floor units are placed for the floor above and

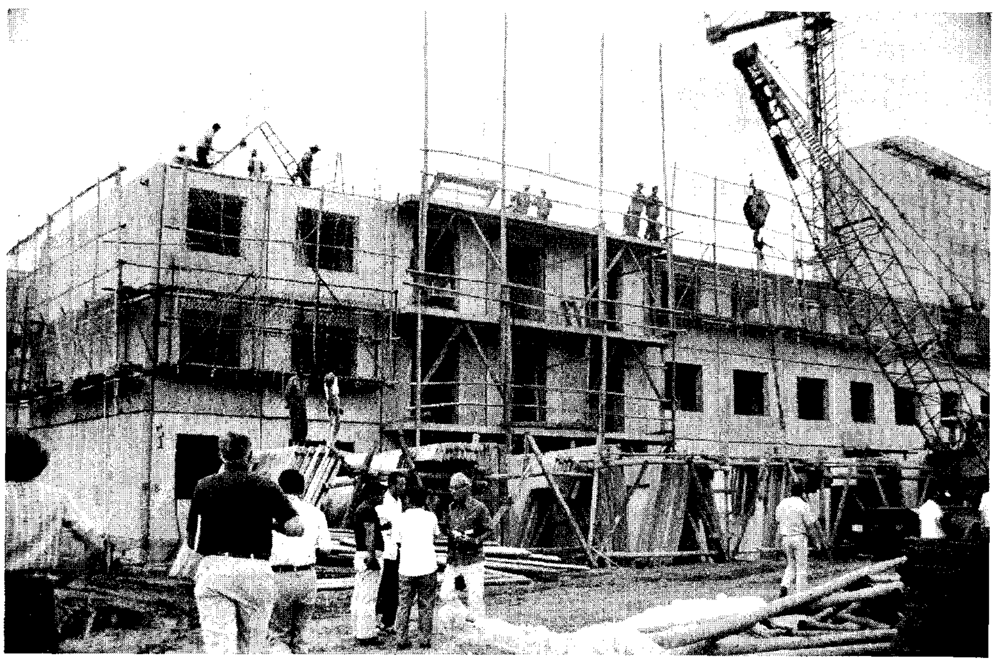


FIGURE 3.17 Exterior view of apartment building in Peking in an early stage of construction. The exterior walls are precast, while interior walls are cast-in-place.

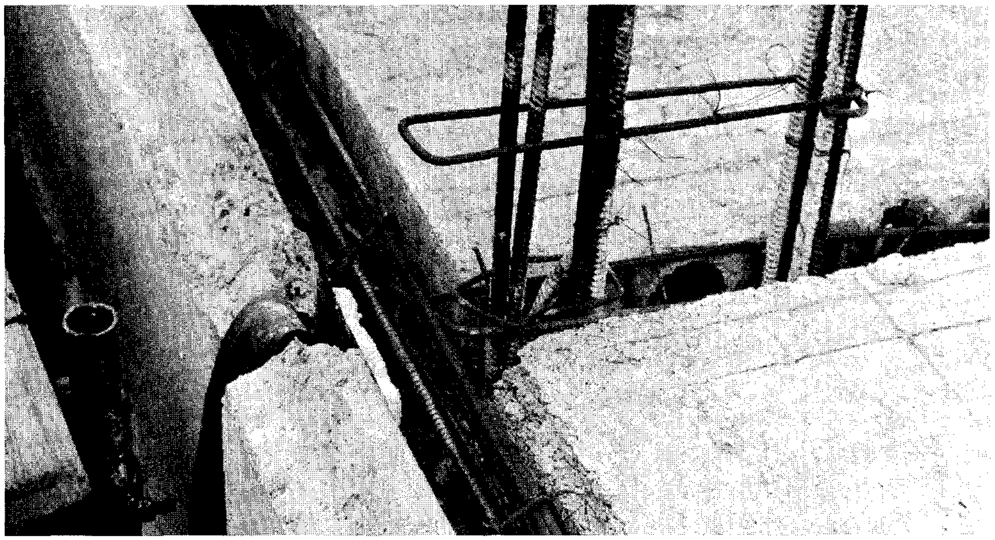


FIGURE 3.18 Precast floor slabs supported on transverse shear walls. Precast exterior wall panels at left. Connections and joints to be cast in place with reinforcing shown. Steel at left behind precast panels is for a cast-in-place beam backing up the precast panels. Building is that shown in Figure 3.17.

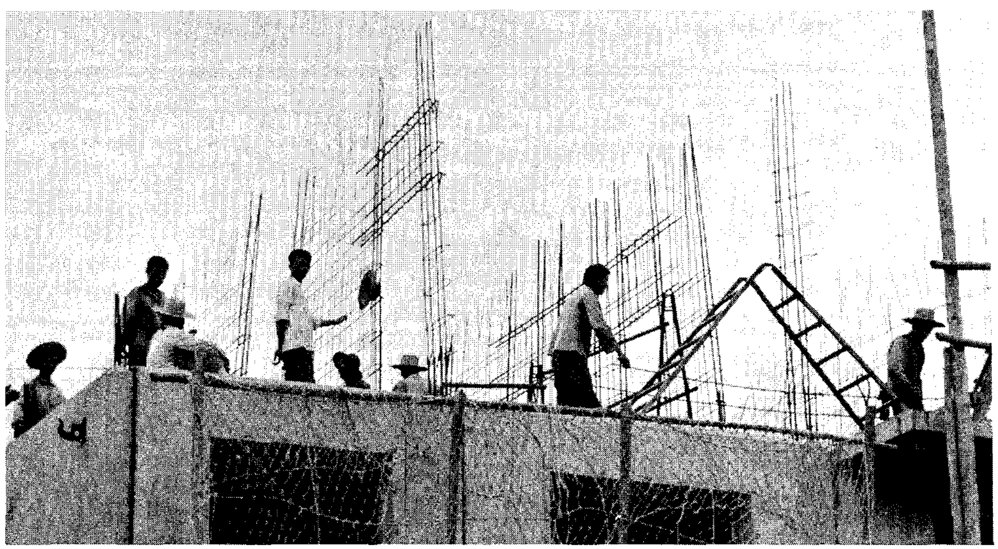


FIGURE 3.19 With one cycle completed, reinforcing for transverse shear walls is placed. Building is that shown in Figure 3.17.

the longitudinal wall and the connections of the exterior wall units poured, and the cycle repeats (Figures 3.18 and 3.19). The topping slab and the precast balconies are added about a floor or two later and are not a part of the basic cycle. With this procedure it takes approximately 2 months to finish the concrete construction and about 6 months for total building completion.

Regarding other details, we were told that the reinforcing steel has a yield point of 2,900 kg/cm^2 and that the concrete strength to the fourth floor is 250 kg/cm^2 and above that, 200 kg/cm^2. The foundation under these apartments is clayey sand, and a mat foundation 50 cm thick was used.

The second project visited was quite different. The seven-story future home of the famous Peking Duck Restaurant is shown in Figure 3.20. We were given a detailed and enthusiastic tour of the building by the engineer in charge of the project, who responded to all our questions including a request to examine the structural drawings. The building has a precast concrete frame, designed to take all lateral loads. The concrete details are nonductile in the U.S. sense. The building drawings showed rather complicated joints using flat bar inserts and welding. Since all lateral loads are calculated to be resisted by the frame, the walls are considered to be nonstructural. The exterior walls are brick

FIGURE 3.20 Exterior view of seven-story future home of Peking Duck Restaurant. Restaurants occupy lower five stories, with living quarters for the staff on the upper two floors.

cavity walls as shown in Figure 3.21 with one wythe of brick on the exterior and a lightweight concrete block on the inside; the exterior will be plastered. The interior nonstructural walls are of brick of low quality. For example, Figure 3.22 shows the walls around the elevator enclosure. Note the "leaning soldiers" under the concrete floor beam; this detail was seen often in construction throughout China.

Harbin

The next building projects examined in some detail were in Harbin, where a portion of the delegation again visited three buildings. The Harbin area is not considered to be highly seismic in comparison to other major cities such as Peking and Tientsin.

The first building visited was a six-story brick bearing wall structure shown in Figure 3.23, which will be an electronics factory when finished. Because of the large windows of the top story of the front (street) facade, this portion of the wall has a concrete frame. Aside from this location, there were no columns in this building except at

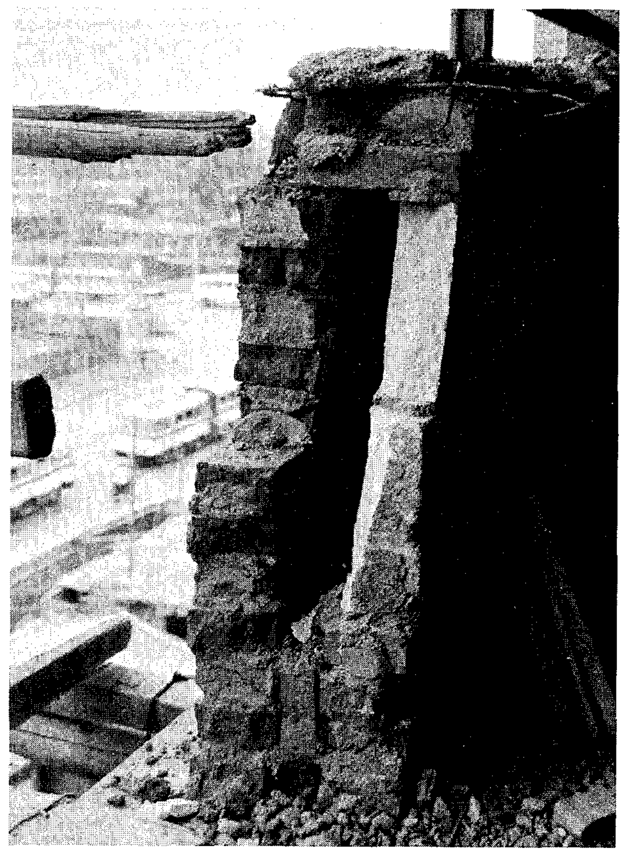


FIGURE 3.21 Section of exterior wall of Peking Duck Restaurant. There are no connections or spreaders between the outer brick course and the interior lightweight block.

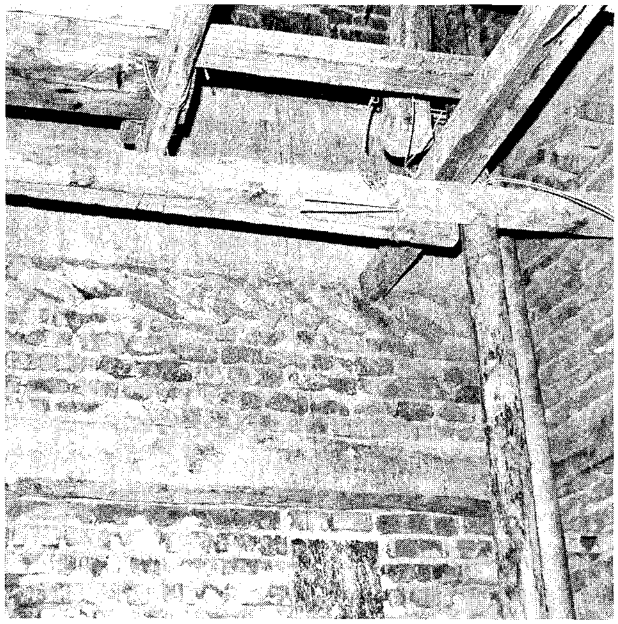


FIGURE 3.22 Interior of elevator shaft of Peking Duck Restaurant showing brick filler walls. Note "leaning soldier" bricks at top, a method of filling space, not a module of brick dimensions.

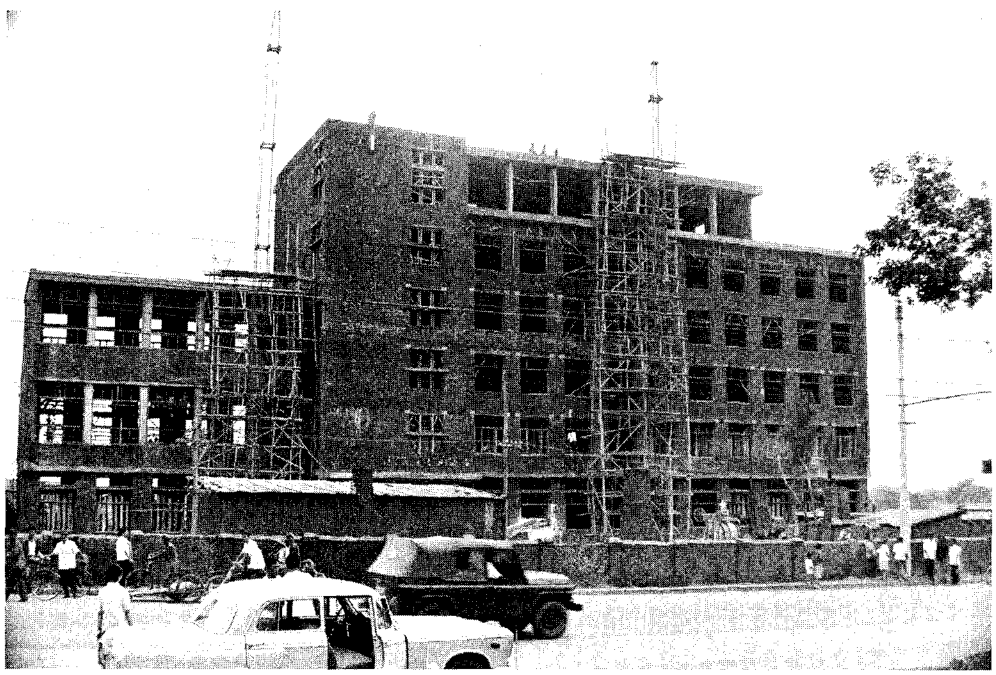


FIGURE 3.23 Exterior view of six-story brick walled building in Harbin. The structure will house an electronics factory when completed.

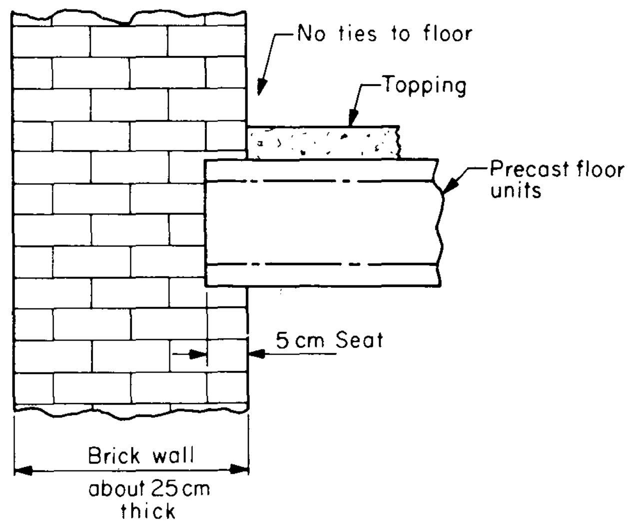


FIGURE 3.24 Typical detail of floor-wall connection in Harbin electronics factory.

the entry hall. Reinforcing steel in the columns was smooth with ties at about 20-25 cm, center-to-center.

The floors were precast concrete; there were apparently no ties between wall and floor construction. The typical detail of the floor-wall connection is shown in Figure 3.24. The roof is made of precast channel members supported on steel trusses shown in Figure 3.25.

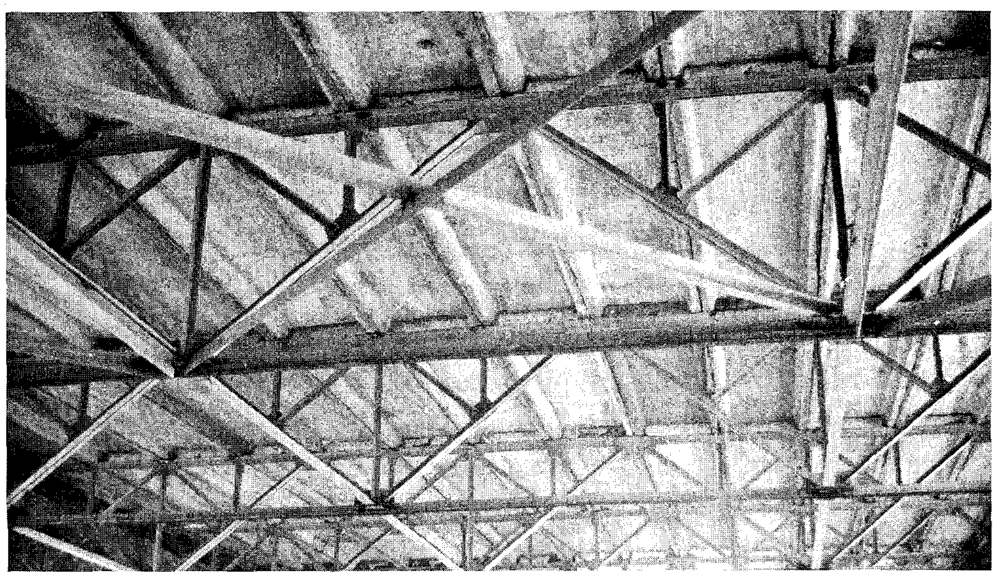


FIGURE 3.25 Harbin electronics factory. The roof over the small auditorium has steel trusses supporting precast concrete channel sections.

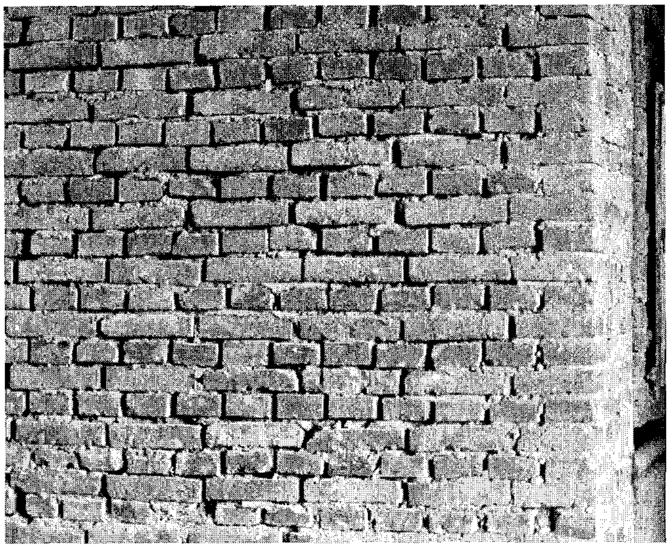


FIGURE 3.26 Typical brick wall construction, Harbin electronics factory. Note that head joints are typically not filled.

The quality of the brickwork in the building was quite poor by U.S. standards, as shown in Figure 3.26. This appears typical of masonry construction seen in China. The brick is often soft and the mortar very weak; normally, it can be broken with one's fingers. Head joints are rarely filled, and even the bed joints often have large gaps. An interesting practice also seen throughout our visit is shown in Figure 3.27; temporary fences are made of brick to be used later in the building.

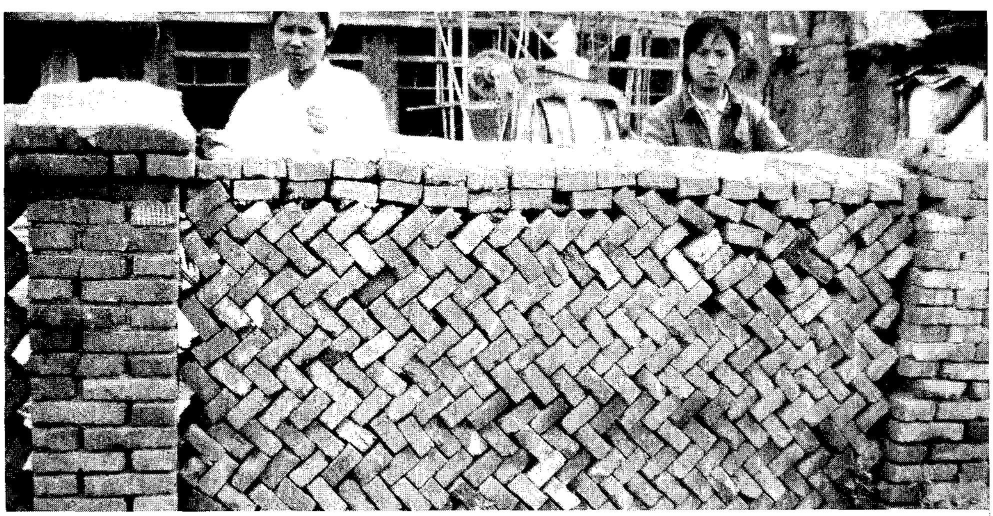


FIGURE 3.27 Harbin electronics factory. Temporary storage of brick on the site forms a construction fence.

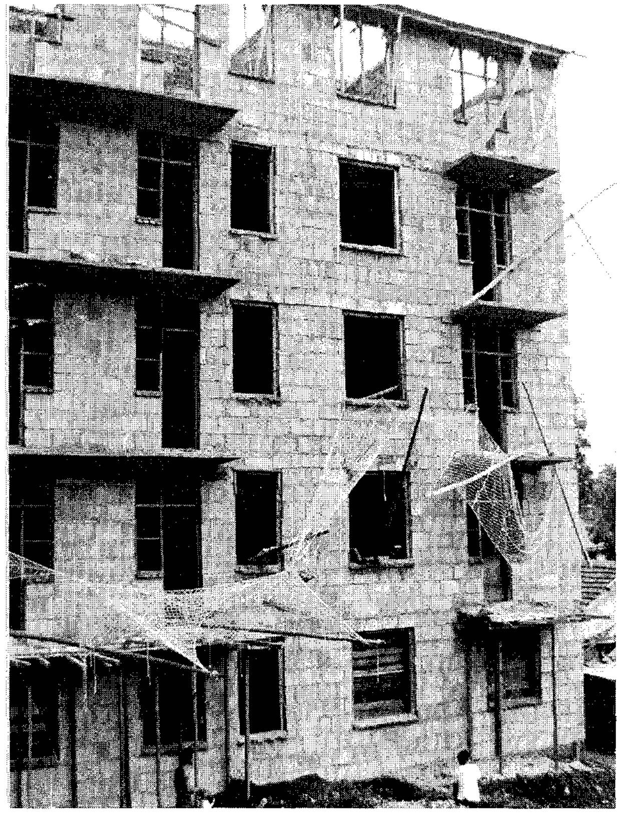


FIGURE 3.28 Exterior view of six-story apartment building in Harbin. Masonry blocks are cast of fly ash concrete.

The second project in Harbin was a six-story apartment house shown in Figure 3.28. This is also a masonry bearing wall structure, but in this case the exterior walls are made of 12-in. thick lightweight concrete block using a fly ash aggregate. This provides added insulation for the cold winters (Harbin has the same latitude as Billings, Montana). Interior bearing walls are of brick. In some cases the walls just butt against each other without ties, while at other walls some effort was made to tie the walls together as shown in Figure 3.29. The floor-to-wall detail is similar to that shown in Figure 3.24. An interesting detail was noted at the stair; one riser and one tread were precast as a unit with about 1½-in. thick concrete. In assembly, the units are connected neither to the landing nor the floor slab; each unit cantilevers out of the 8-in. thick unreinforced brick wall (Figure 3.30).

The third project was an almost complete six-story apartment house shown in Figure 3.31. It was a part of a large complex of about a dozen similar buildings. The construction was similar to that discussed above, namely, unreinforced brick bearing walls, precast floor units, precast stairs, etc. A portion of one of the walls is shown in Figure 3.32, illustrating the variability of workmanship in the construction of the wall.

FIGURE 3.29 Harbin apartment building of Figure 3.28. Some of the interior brick walls are meshed with exterior block walls.

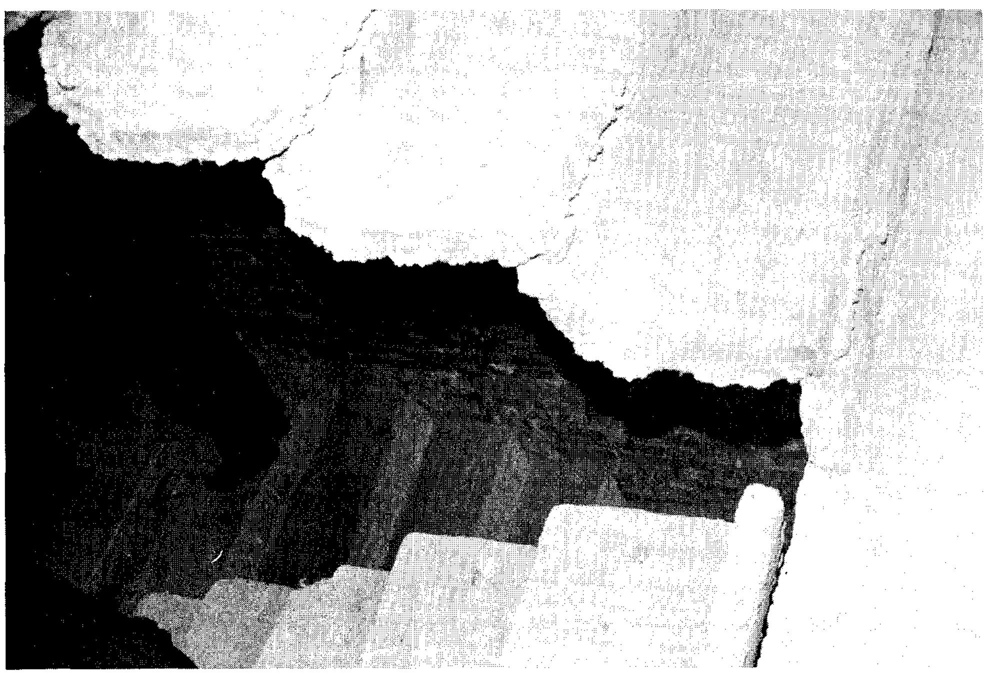


FIGURE 3.30 Harbin apartment building of Figure 3.28. The precast stair units, consisting of one step and one riser, are cantilevered from the unreinforced brick wall.

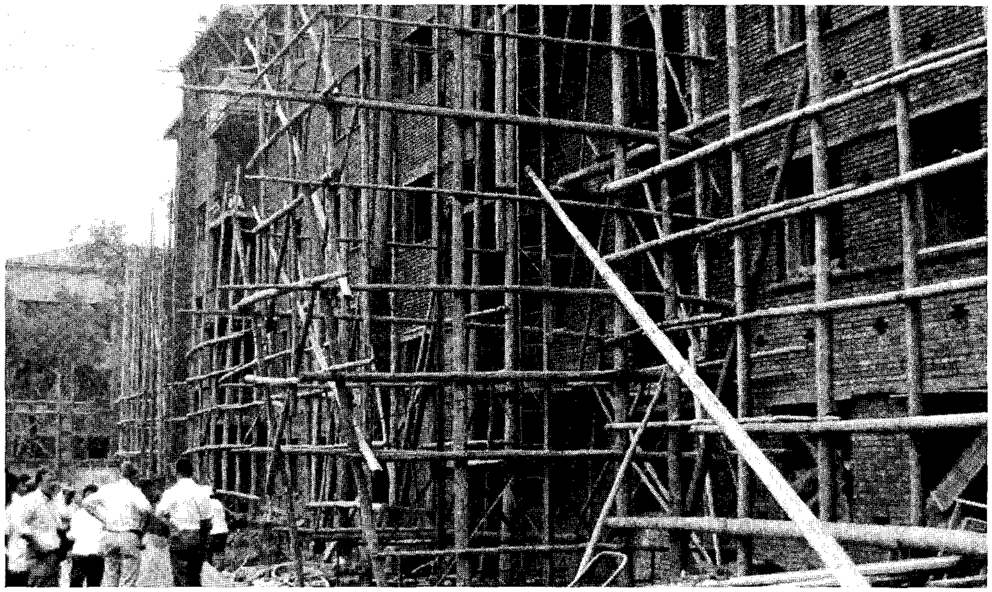


FIGURE 3.31 Exterior view of nearly completed six-story brick apartment building in Harbin.

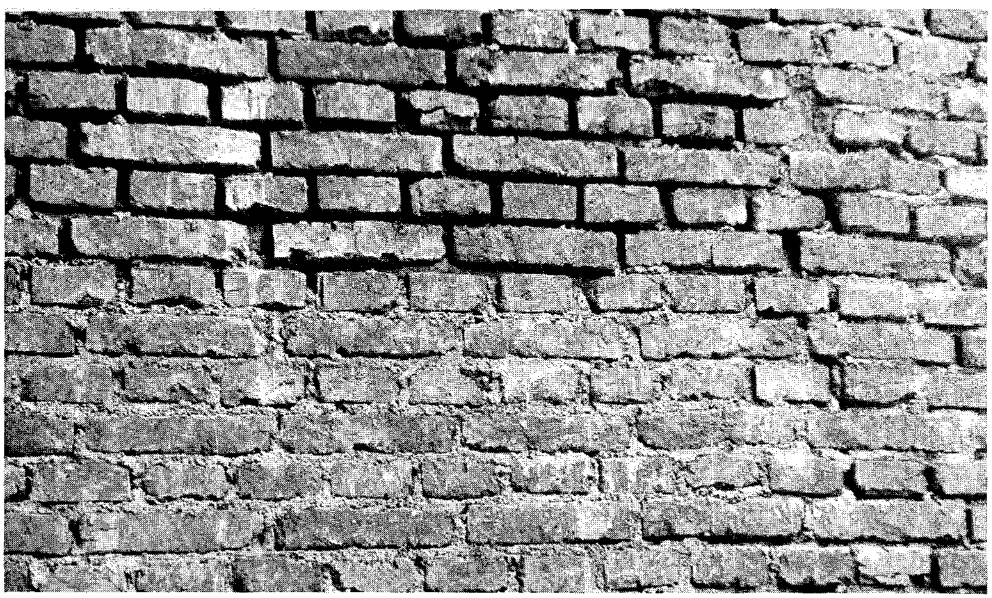


FIGURE 3.32 Apartment building shown in Figure 3.31. At lower left, joints are filled. In upper portion, head joints are open, and bed joints only partially filled.

Chengtu

The next construction examined was in Chengtu, the capital of Szechuan Province, which is a city with a population of .75 million people. The design intensity is VII. The first project viewed was a completed 2-year old split-level parking garage, the only one in the province. It has a cast-in-place concrete frame and floor slab, with infilled brick walls at the ends. The column spacing is 30 ft.

The second project was a nearly completed seven-story apartment house shown in Figure 3.33. It had brick bearing walls and un-prestressed precast concrete slabs. Near this project we saw a fence under construction (Figure 3.34), using brick with holes in it. Also at this location, a small building with timber trusses and brick columns was

FIGURE 3.33 Nearly completed seven-story apartment building in Chengtu. The building has brick bearing walls and precast concrete floor slabs.

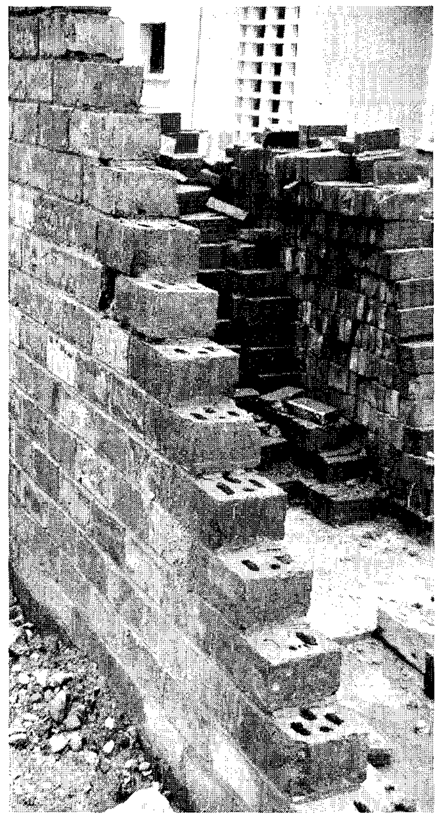


FIGURE 3.34 Brick fence in Chengtu made with bricks containing holes. Similar bricks were used in the shear walls shown in Figure 3.45.

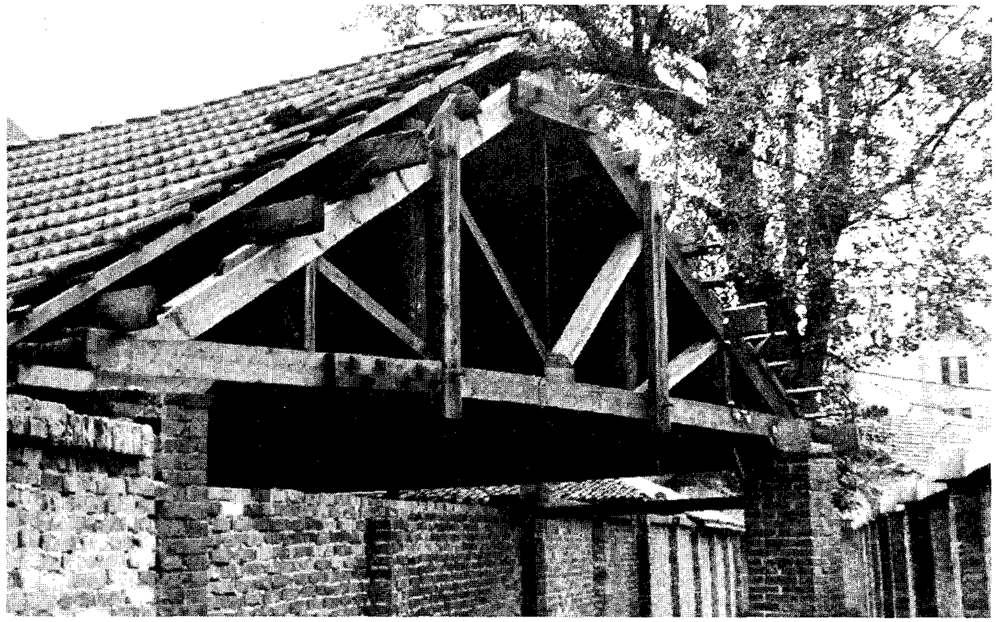


FIGURE 3.35 Timber truss on small building in Chengtu near apartment building of Figure 3.33. Note unreinforced brick columns, which are used extensively in China.

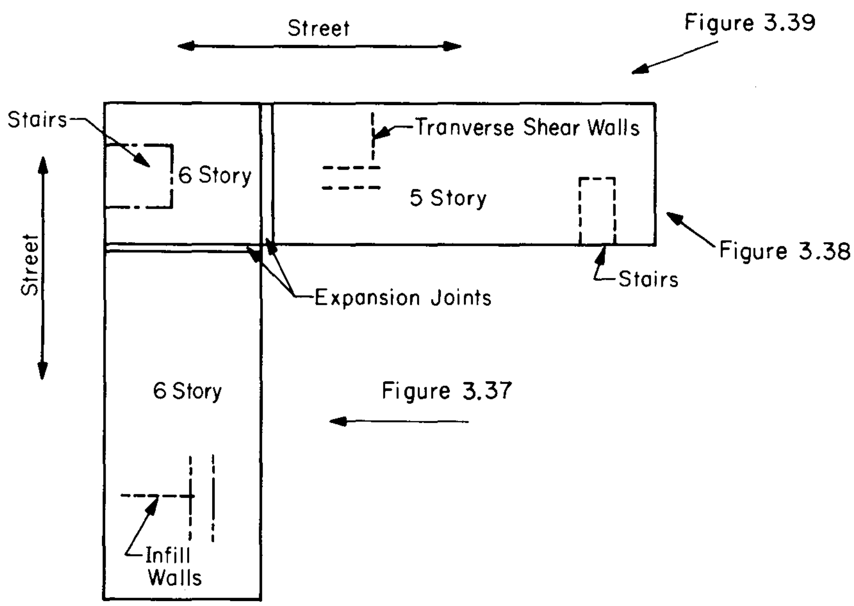


FIGURE 3.36 Plan view of five- and six-story office and storage building in Chengtu.

noted (Figure 3.35). Brick columns are common in China; also in rural areas we saw adobe columns supporting timber roofs.

The third project was a five- and six-story office and storage building. It was an L-shaped building (Figure 3.36) with expansion or seismic joints at the junctions. This is a concrete frame building with three lightly reinforced brick shear walls.

Figures 3.37, 3.38, and 3.39 show views of the building. The concrete frame is cast in place from the third floor up, whereas the first-floor columns and some second-story columns and beams are precast; an example of the connections is shown in Figure 3.40. Floors are precast hollow concrete planks with a topping. When the topping is placed, stirrups (Figure 3.41) from the cast-in-place beam will tie the slab to the beam where the slabs are parallel to the beam, but the tie to the beam that supports the slab appears minimal, as can be seen in Figure 3.42.

Figures 3.43 and 3.44 show a cast-in-place column and beam and the forms for the cast-in-place spandrel beam that will be poured next. This sequence results in construction joints through the structural joint itself. There is no provision for shear in the joint, and the detailing provides for little ductility.

The brick shear walls in this structure are made of bricks that have holes, and some light vertical wire reinforcing is inserted. In this

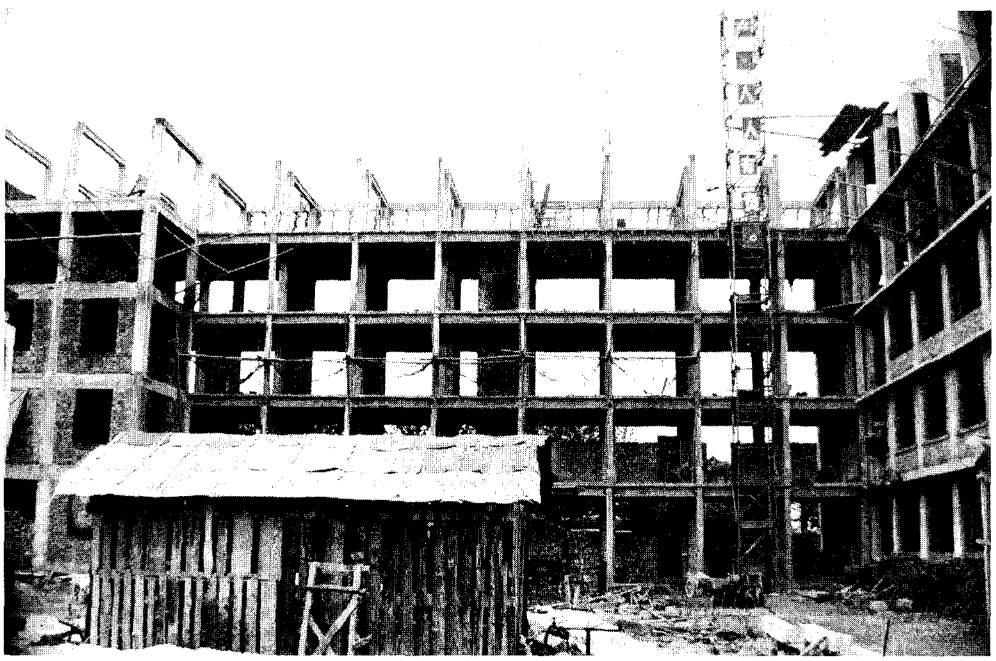


FIGURE 3.37 Six-story wing of an office and storage building under construction in Chengtu. The building is L-shaped in plan, as shown in Figure 3.36.

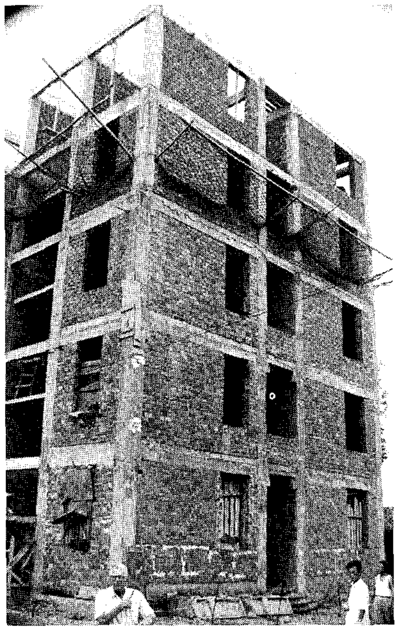


FIGURE 3.38 End wall of five-story wing of the Chengtu office and storage building. The brick walls are lightly reinforced shear walls.

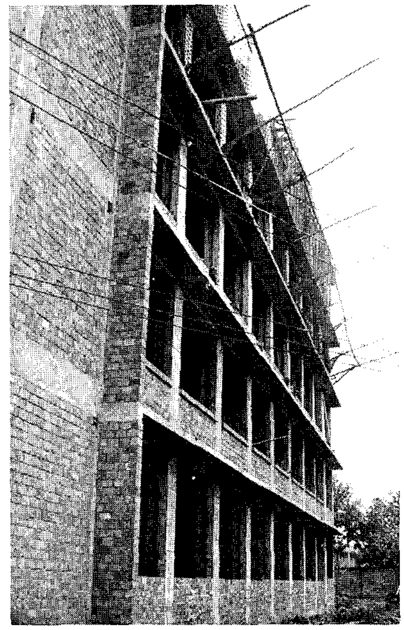


FIGURE 3.39 Street facade of the five-story portion of the Chengtu office and storage building.

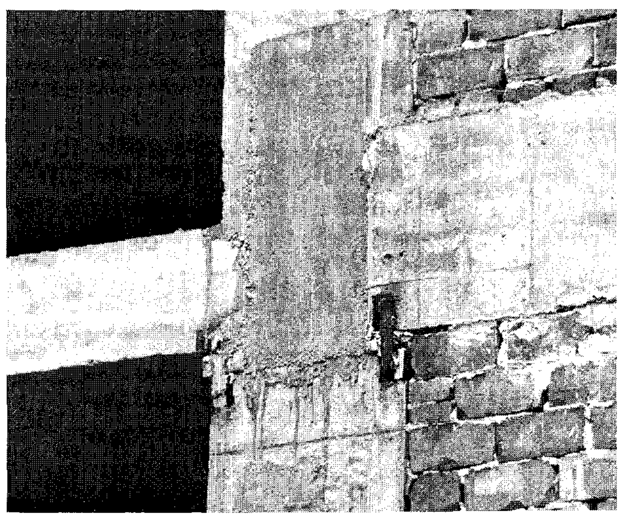


FIGURE 3.40 Chengtu office and storage building. The detail shown is a connection between precast columns and precast second-floor beams.

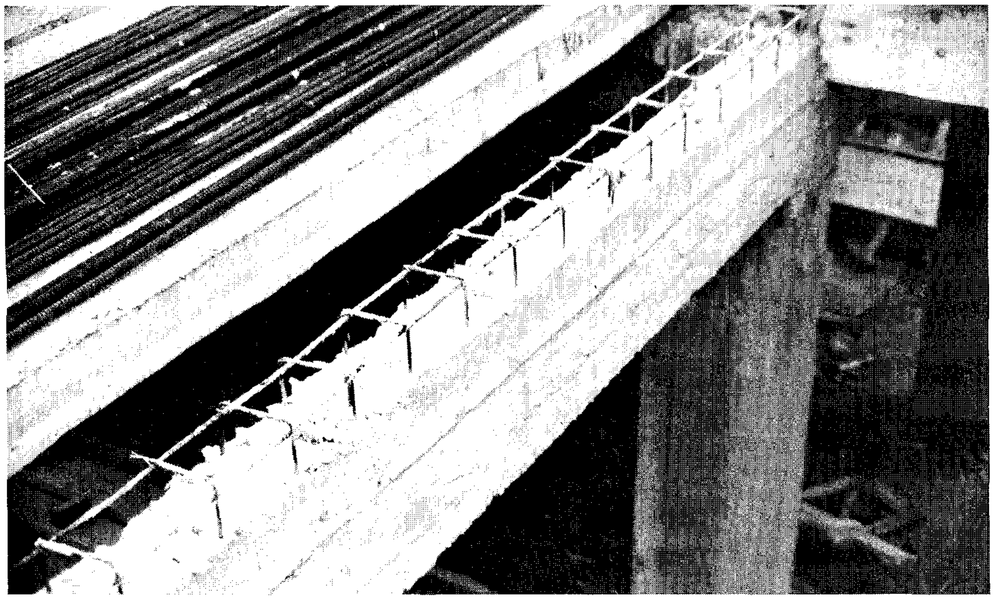


FIGURE 3.41 Chengtu office and storage building. In upper stories, columns and beams are cast in place. Later, precast floor units are placed on the beams. Note ties from beam where beam is parallel to slabs.

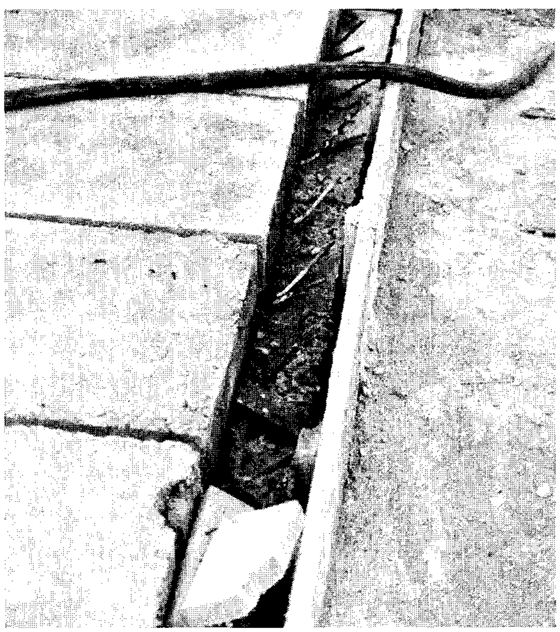


FIGURE 3.42 Chengtu office and storage building. The view is near that of Figure 3.41. Ties from the beam are minimal where beam supports slabs.

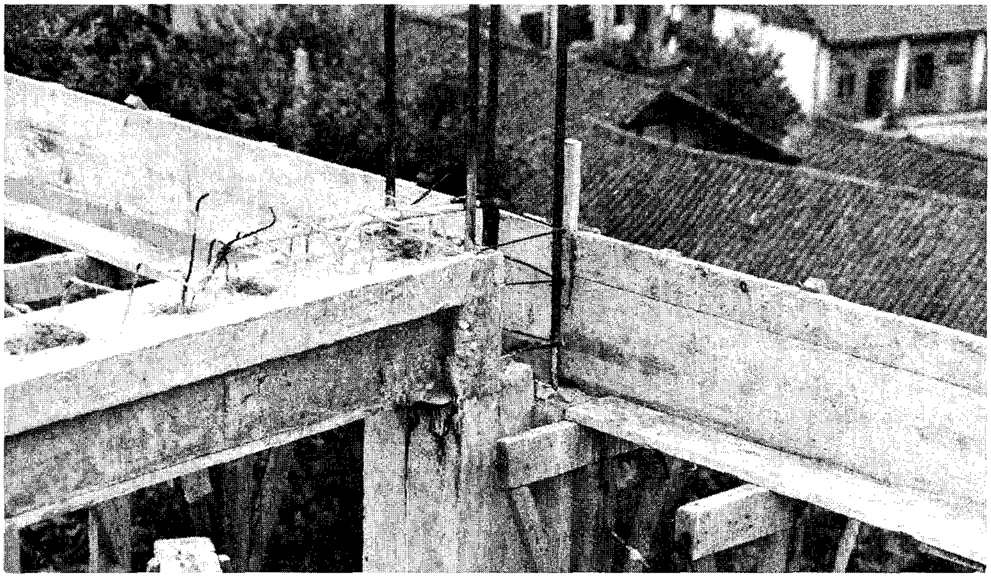


FIGURE 3.43 The columns and transverse beams have been cast in place in this detail of an upper floor. Forms are in place for the cast-in-place spandrel beam. The joint is integral but a construction joint goes through the center.

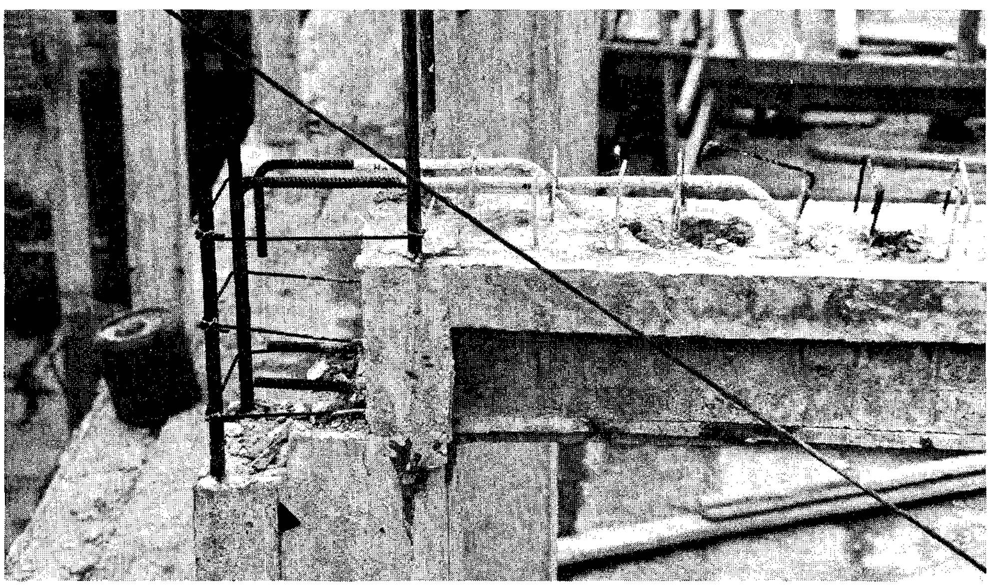


FIGURE 3.44 Upper floor detail of the Chengtu office and storage building. This is the same joint shown in Figure 3.43.

case there are dowels to column but no keys. The construction is illustrated in Figures 3.45 and 3.46. In response to a question about the amount of inspection that is customary, we were told that on this particular project they took samples of the concrete and mortar at each floor and that the job superintendent has special personnel to check the placement of the reinforcing steel. In addition, the design office has three men on the job at all times to inspect the work.

In the same vicinity there were a number of four-story apartments similar to that shown in Figure 3.47. Note the four-story high brick columns.

We next looked at a multistory industrial building under construction (Figure 3.48), but we were unable to ascertain the function or ultimate height of the structure. The columns, girders, and the beams on the column lines were cast-in-place concrete frame construction, while the intermediate beams and intermediate girts between columns were precast and welded together. This building has a high one-story wing. The frame in this one-story portion was entirely precast, using channels

FIGURE 3.45 Transverse brick shear wall made with bricks similar to those shown in Figure 3.34, Chengtu office and storage building.

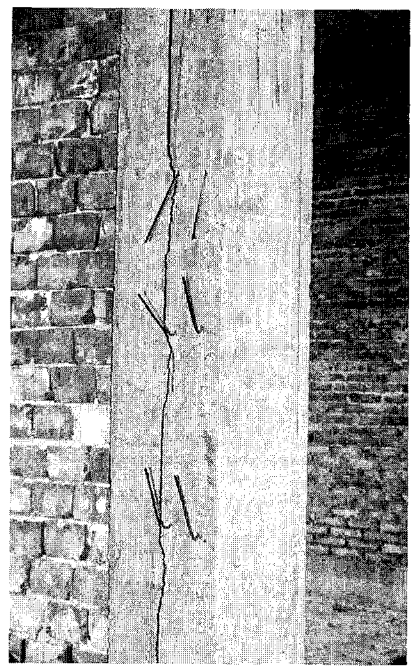


FIGURE 3.46 Brick shear walls in the Chengtu office and storage building had dowels protruding from adjacent columns, but shear keys were not provided.

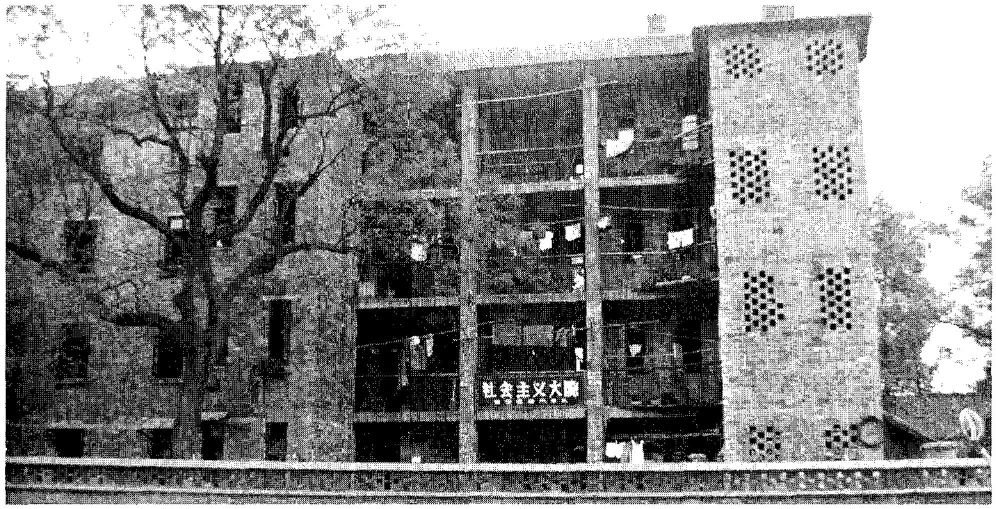


FIGURE 3.47 Occupied brick apartment house in Chengtu. Note the brick columns.

FIGURE 3.48 Multistory industrial building in Chengtu. The main frame is cast-in-place concrete, whereas intermediate girts and floor beams were precast.

for the roof and precast columns with corbels to support the precast girders (Figure 3.49). The girder had steel plates inset into the bottom in places, evidently to support a monorail. Figure 3.50 shows a column splice on an exterior column of this part of the building.

Canton

In Canton we looked at several buildings in general but only one in some detail. This was the nine-story Provincial Seismological Bureau building, which was scheduled for completion in about a month. This building is all cast in place including frame and floors. The walls are of infilled brick of above-average quality, although the mortar seemed weak. In conversations with the engineer of the building from the Provincial Construction Commission he estimated that in that region, 70 percent of the floor slabs are cast in place with the other 30 percent constructed of precast hollow slabs. Before the Tangshan earthquake, Canton was in zone VI; now it is in zone VII.

Seminars

Several members of the delegation held discussion meetings with groups of engineers in Harbin, Peking, and Canton. In these meetings we learned more about their design and detailing practices, and some of their experiences. Some observations resulting from these discussions follow:

1. The practice of detailing concrete for ductile performance has not been adopted in China. We saw no such evidence of detailing in the field, and discussions with engineers indicated a lack of general recognition of the need for such detailing. At the Peking meeting, discussions on masonry and the detailing of concrete confirmed that concrete reinforcing is detailed on the basis of strength alone.
2. The observed quality of masonry construction lead to questions about quality control and inspection. Some engineers were aware of the problem, but there were no clearly explained measures to improve the situation. In discussing inspection with one responsible engineer we were informed that for the 10 years under the influence of the "gang of four," manual labor was exalted and respected while intellectual concepts were demeaned. In construction practice this meant that the worker had increased authority and stature with respect to the engineer or inspector. If the inspector tried to disqualify work or refuse to accept poor materials or workmanship, the worker could criticize him. Such a situation could easily lead to a decline in standards of accepted workmanship.
3. At the Canton meeting with the local engineers, we discussed concrete reinforcing details. They use much more cast-in-place concrete there than in other places visited in China. Unlike other places, the trim bars around openings had longer anchorage lengths, there were more stirrups, and panel zone stresses were better accommodated. The design

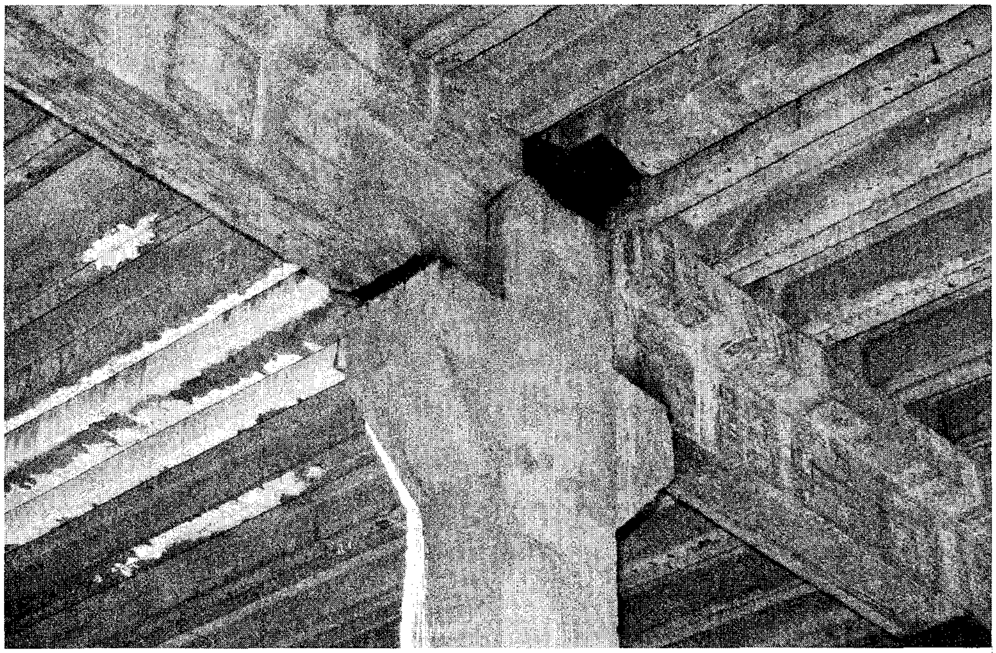


FIGURE 3.49 High one-story portion of Chengtu industrial building was of precast concrete construction. Roof slab is composed of precast concrete channel sections.

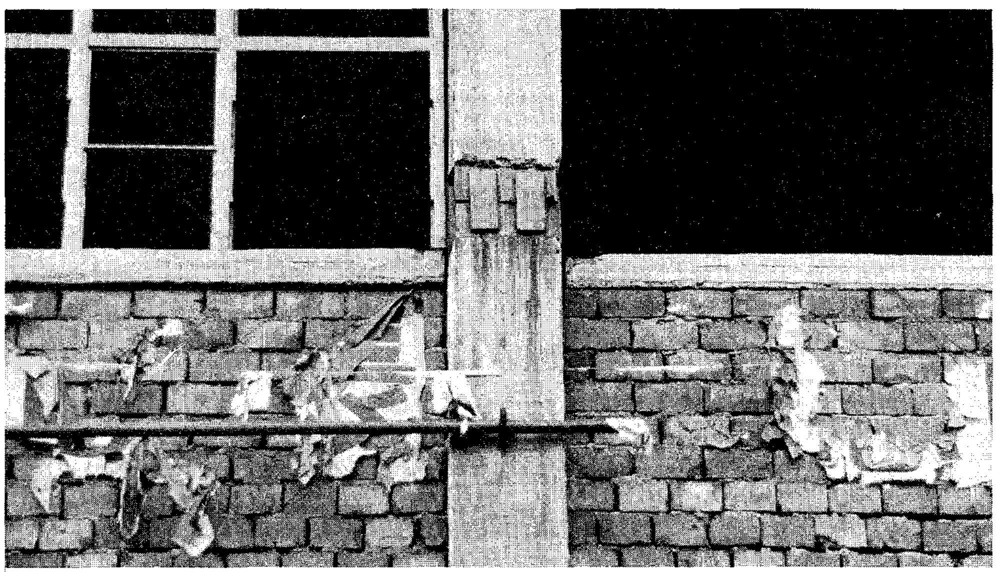


FIGURE 3.50 Precast column connection in one-story portion of Chengtu industrial building.

practices resemble California practice prior to the adoption of current American Concrete Institute and Structural Engineers Association recommendations.

CODE CHANGES RESULTING FROM TANGSHAN EARTHQUAKE

After returning from Harbin, the delegation attended several discussions at Tsinghua University. At the first of these, K'ung Szu-li, Director of Building Research for the State Capital Construction Commission, described the proposed changes to the Chinese Earthquake Code. Mr. K'ung was a member of the delegation that visited the United States in 1976. It had been 3 years since the 1974 Code had been adopted, and in the intervening period, the Haicheng and Tangshan earthquakes had occurred, each causing great structural damage. As a result of those experiences, revisions of the Code (see Appendix V) seemed necessary, and engineers have been working on various proposals. In the summer of 1978 the proposed changes had been assembled and were out for review by agencies in various parts of the country, and so are tentative. Because of the tentative nature, we could not obtain a copy but did receive a copy of Mr. K'ung's paper which presents the changes in general terms.

Aside from the various technical lessons that were learned from the observation of the damage, the experiences of recent earthquakes indicated that the reliance on prediction of "basic intensities" cannot be complete, so the structures must be designed for higher intensities; that "lifelines," e.g., transportation, communications, utilities, etc., are necessary after a disaster and need more protection; that loss of industrial capability is not acceptable, so these facilities need more protection; and that the economic impact of the loss of "nonstructural" elements is too great to accept.

There are six general areas of proposed changes, as follows:

Design Intensities The design intensities have been changed and increased. In many cities the basic intensity has been increased, and six intensity zones will be recognized in place of the three now used. The present Code recognizes four classes of buildings as follows:

1. Very important buildings where the design intensity is one greater than the basic intensity.
2. Important structures and critical facilities where the design intensity is the same as the basic intensity.
3. Ordinary structures where the design intensity is one less than the basic intensity.
4. Temporary structures where no earthquake design is required.

The proposed new Code has been revised as follows:

1. Very important structures now include transportation, utilities, communications, and medical facilities which were previously in class 2.
2. Important structures now includes all buildings except one- and two-story buildings of low occupancy. Most of these were previously in class 3.

3. One- and two-story buildings of low occupancy are the only structures remaining in class 3.
4. Temporary buildings.

Foundation Sections The foundation sections of the Code have been changed to require more checking for liquefaction, and the criteria for liquefaction have been made more stringent. Lifelines must be checked for liquefaction and soil stability. In the specific criteria it was stated that saturated light loam also liquefies, but this could be an error in translation or a different definition of terms than we are accustomed to.

Structural Characteristics There are proposed changes in the requirements concerning structural characteristics. A lower structural influence or "C" factor (see Code definitions in Appendix V) will be allowed previously for the more ductile materials or for systems that have a redundant method for resisting lateral loads, i.e., a "second line of defense," while higher "C" values will be required for materials that are less ductile and systems that are less redundant. For example, it is proposed that steel and timber structures will have a "C" value 20 percent lower than in the 1974 Code. Simple reinforced concrete structures will remain the same; reinforced concrete shear wall structures will have a "C" value 20-30 percent higher, and moment resisting frames of reinforced concrete will also be 20-30 percent higher. Single-story industrial buildings will be 20 percent higher, and unreinforced masonry structures 30 percent higher.

Vertical Accelerations Vertical accelerations are to be considered in areas with design intensities of VIII and higher. For a design intensity of VIII, a 10 percent g vertical acceleration must be included, and for design intensities of IX and above, the vertical acceleration is to be 20 percent g.

Construction Requirements In addition to the earthquake force changes noted above, the proposed construction requirements are more conservative. Examples that were presented included the following:

1. For brick buildings there will be a lower height limit. Above a certain height there must be reinforced columns embedded in the brick. Bracing cross walls must be closer together, there must be more bond beams, and the precast concrete floor units must be tied. There are also many changes in details to increase the quality of the connection and to tie the building together better.
2. Industrial buildings will have stronger posts and connections above the crane rails, better bracing for trusses and gable walls. Much more attention will be given to details.
3. Precast reinforced concrete construction must use cast-in-place reinforced concrete shear walls in place of brick walls, better tieing to increase the integrity of floors and roofs, and improved details to increase the strength and ductility of roof frames and columns.
4. Buildings must be simpler and more nearly symmetrical and have less ornamentation.

5. Proposals are made to reduce expensive and hazardous nonstructural damage. More attention must be given to detailing. When good finishes are involved, shear wall and frame construction are to be used, not just frame construction alone.

Reinforcement of Existing Structures A new code is presented for the reinforcing and strengthening of existing structures. This code will use the following formulae for relating the shear in existing brick walls to the required strength:

$$KQ = \frac{R_t A}{E}$$

where

K = required factor of safety.

Q = earthquake loading shear force on the wall.

R_t = ultimate unit shear strength of brick wall.

E = shear distribution coefficient for wall or section, equal to 1.2 for a rectangular section.

A = cross-sectional area of the wall.

R_t is related to the unit shear strength of the wall and to the compressive unit load on the wall due to dead loads, in the following manner:

$$R_t = R_j \left(1 + \frac{\sigma_0}{R_j}\right)^{\frac{1}{2}}$$

where R_j is the ultimate unit shear strength of the wall with no compressive load and σ_0 is the unit compressive stress on wall at the time that Q is acting. Rj for good brick walls is taken as 2 kg/cm^2 (28 lbs/in.^{2}). It should be noted that the Chinese Code specifies mortar strengths of 10 kg/cm^2 (140 lbs/in.^{2}) and 25 kg/in.^{2} (350 lbs/in.^{2}). In certain lintel or bond beams a mortar strength of 50 kg/cm^2 (700 lbs/in.^{2}) is required. By comparison with typical U.S. standards, these are very low required mortar strengths. For example, the Uniform Code specifies mortar strengths of 350 lbs/in.^{2} minimum to 2,500 lbs/in.^{2}. The allowable design shear on walls with 2,500 lbs/in.^{2} mortar is 20 lbs/in.^{2} with special inspection and 10 lbs/in.^{2} without.

POPULAR LITERATURE ON EARTHQUAKES

In 1974 the American Seismological Delegation found in China an earthquake research program of impressive size and scope: "a large-scale, well-supported program in earthquake prediction" which "encompasses every prediction method that has ever been suggested in any part of the world" (American Seismology Delegation, 1975). After visiting China 2 years later, the U.S. Haicheng Earthquake Prediction Delegation described "an impressively large amateur observation network" collecting vast quantities of data. China's avowed policy, according to that delegation, was to involve the general public in both the prediction program and in earthquake "precaution work" (Haicheng Earthquake Study Delegation, 1977).

To secure public cooperation in these efforts, national and local authorities in China have mounted a campaign of public education about earthquakes. An outgrowth of this campaign is a substantial body of popular literature on the subject: why they occur, how they may be predicted, and what precautions can minimize the damage they cause. Widely available (even to vacationers browsing in the bookstore at the Summer Palace resort!),* this literature sustains a high level of public consciousness of earthquake dangers. It is not merely alarmist, however. By presenting scientific explanations for earthquakes and the phenomena accompanying them, these books establish confidence in the effectiveness of earthquake resistance programs, and in the political authorities sponsoring them.

Examples of this literature on sale in various cities in China at the time of the Earthquake Engineering Delegation's visit in 1978 are listed in the bibliography at the end of this chapter. Most branches of the Hsinhua Bookstore were selling a map of the epicenters of "strong" earthquakes in China between 780 B.C. and August 1976 (thus including the Tangshan earthquake). A set of eight posters on earthquakes, earthquake prediction, and earthquake resistance, published in 1975 by the Kuangtung Provincial Revolutionary Committee's Seismology Office and the Kuangchou (Canton) Seismology Brigade under the State Seismology Bureau, was still available at Canton's Science and Technology Bookstore. In addition, popular science and technology magazines regularly carry articles on earthquakes and earthquake-resistant construction. A new periodical specializing in such articles, *Earthquake Front Line* (*Ti-chen Chan-hsien*), began publication in 1978.

Such popularized, elementary texts are not unique to earthquake studies in China but cover virtually all fields of science and technology. Since the 1950's, publications of this type have been used to disseminate basic scientific concepts, theories, and knowledge. Popularization of science is now explicitly the responsibility of the newly reconstituted Chinese Scientific and Technical Association, the umbrella organization for all professional societies in China (and the counterpart of the National Academy of Science's Committee on Scholarly Communications with the People's Republic of China in matters concerning scientific and technical exchange between the United States and China).

Some of the earthquake books follow the question and answer format characteristic of Chinese popular literature on science and technology. *Questions and Answers About Earthquakes* (see bibliography) poses 173 questions, each of which is answered in three or four paragraphs. The

*Translations of U.S. and Japanese technical publications on earthquake engineering were also on sale in the Peking branch of Hsinhua Bookstore.

questions are grouped under the headings "Earthquakes Are Natural Phenomena," "Earthquake Observation and Prediction," and "Earthquake Damage and Precautions." The first group provides basic geological explanations for earthquakes, including the interior structure of the earth, plate tectonics, faults, and the relationship between earthquakes and volcanoes, weather, the planets, and human action. This last deals with shocks caused by release of water from dams, oil well drilling, explosions, and passing autos and trains, conspicuously omitting traditional interpretations of earthquakes as supernatural punishment for human misbehavior. (A later chapter explicitly refutes common superstitions about the causes of earthquakes.)

Questions 64-128 deal with phenomena which are possible precursors of earthquakes and how these are observed and measured. A discussion of the value of historical records for earthquake studies is the occasion for recalling China's early scientific and technical accomplishments, among them invention of the world's first seismograph, attributed to Chang Heng, who lived between 78 and 139 A.D.

The third section of *Questions and Answers About Earthquakes*, on earthquake damage, begins with a dozen topics related to earthquake zoning. The next pages cover how earthquakes damage buildings and the kinds of buildings and building materials most resistant to earthquake damage. Strengthening existing buildings and the problems posed by particular features, e.g., foundations, chimneys, load-bearing walls, are then discussed. Apart from buildings, the only other structures covered in this section are dams. One question deals with the appropriate layout for cities in seismic areas (wide streets with open spaces at intersections), and a separate question asks why earthquake resistance measures are especially important in large cities and in big factories and mines. The final dozen questions urge public support for earthquake resistance programs: "What is the key in carrying out earthquake prevention and resistance measures well?" (be alert and prepared at all times; cooperate with the Communist Party in putting the necessary measures into effect); "Why must we emphasize 'mass' work in earthquake prediction?" (because professional seismologists are too few to collect the quantity of data needed to identify relevant anomalies); "Why should we emphasize popularization of earthquake knowledge?" (because "experience shows" that where people are informed about the danger of earthquakes, they take effective action to prevent structural damage and resulting casualties).

Questions and Answers About Earthquakes is the most detailed of the popular texts on earthquakes, though some of the shorter volumes follow a similar format and, in general, cover the same material. *Earthquakes*, for example, one in a series of "small books" on natural science, presents the geological explanation for earthquakes, earthquake measurement, prediction, and the earthquake resistance of buildings in less than one fifth the length of *Questions and Answers About Earthquakes*. *Earthquake Resistance Information* summarizes earthquake causes and prediction briefly, then devotes a higher proportion of its pages to earthquake-resistant construction: "Preventing Secondary Damage Caused by Earthquakes," "How Earthquakes Damage Buildings," "Earthquake Resistance of Some Building Structures," "How to Assess the Degree of Damage to Buildings After an Earthquake," "Strengthening and Repair of Civil Buildings," "How to Inspect and Strengthen Old-Style Buildings," and "Earthquake Resistance Measures for New Buildings in Rural Villages."

The publishers of *Earthquakes and Earthquake Resistance* describe its contents as

> divided into twelve chapters. The first six chapters focus on introducing general knowledge about earthquakes, and the latter six discuss earthquake-caused damage to structures, the influence of foundation conditions on the strength of the earthquake and zoning for earthquake hazards, earthquake resistance measures in buildings and experience with them, measures for reducing earthquake damage, etc.

The technical content of these materials clearly indicates that professional engineers and seismologists have had a part in their preparation, but they are definitely written for the nonexpert. The foreword to the second edition of *Questions and Answers About Earthquakes* declares that it has been revised and enlarged to "meet the needs of the worker-peasant-soldier masses" in response to their comments on the first edition. *Earthquakes and Earthquake Resistance* addresses "worker, peasant, soldier, cadre (i.e., Party or government officials), and young student readers."

Simple, nontechnical language and the use of illustrations, charts, and diagrams make these texts understandable to the lay reader. Two of the books, *Earthquake Information Picture Book* and *Common Sense About Earthquakes*, and the set of earthquake posters have limited and still more simplified texts, conveying their information largely through pictures. The technical content, however, is still high enough to indicate that they are not meant for children but for adults with limited formal education.

These examples of China's literature on earthquakes are handbooks for amateur seismologists, elementary texts for those who report their observations and measurements to local seismological offices. They are also manuals of specifications for earthquake-resistant design and construction. The utility of such manuals becomes apparent when it is learned that, after the 1975 Yingkou-Haicheng earthquake, reconstruction in the cities was supervised by engineers, but in rural areas, the only technical guidance for earthquake-resistant construction was that in the popular literature (Rosenblueth, 1976). Even in the cities, the Earthquake Engineering Delegation learned, a significant amount of local construction escapes State regulation and inspection but often poses some of the worst potential dangers in seismic zones. Because State building codes cannot cover all construction, the earthquake resistance of many structures depends on builders to adopt the necessary measures voluntarily. These books disseminate simple information on how to strengthen small, low-cost buildings.

Basic Information About the Earthquake Resistance of Buildings is somewhat different from the general texts. Edited by the construction research institute of a provincial engineering bureau but issued for national circulation, this book addresses "responsible personnel of construction units and members of rural people's communes, and may also be used for reference by teachers and students of local construction schools." It deals with the earthquake resistance of traditional building materials and techniques: earth walls, wood framing, and brickwork.

In contrast to "popular" earthquake books in the United States, this literature is part of a total effort to mobilize grass roots action. Each volume concludes with the message that preparedness is a political and ideological duty: not merely a matter of self-interest, but the individual's obligation to the community. These books and posters--as well as the films, public lectures, and broadcasts that make up the total public education program--aim to create the understanding that will lead to a broad consensus on the necessity and importance of earthquake prediction and earthquake engineering.

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4

REPORT ON THE TANGSHAN EARTHQUAKE*

INTRODUCTION

An earthquake of magnitude $M_S = 7.8$ originated under the city of Tangshan, Hopeh Province, at 3:43 a.m. on July 28, 1976. The epicenter was located in the southern part of the city, and the fault slip progressed through town in a N40°E direction and also extended in a S40°W direction to a lesser extent. There was evidence of surface faulting within the city of Tangshan over a distance of approximately 10 km. The aftershock zone indicated, however, subsurface faulting over a distance of approximately 140 km.

In the past there have been strong earthquakes in the general Tangshan region. As shown in Figure 4.1, since 1966 there have been four earthquakes of magnitude greater than 7.0: Hsingtai, March 22, 1966, $M = 7.2$; Pohai, July 13, 1969, $M = 7.4$; Haicheng, February 4, 1975, $M = 7.3$; and Tangshan, July 28, 1976, $M = 7.8$. These earthquakes occurred in an area approximately equal to that of California, so the earthquake hazard is relatively high in this region.

The highest intensity assigned to the Tangshan earthquake was XI on the new Chinese intensity scale (essentially, the Modified Mercalli scale). As shown in Figure 4.2, intensity XI covers Tangshan City. The isoseismal contours of intensities greater than IX showed pronounced northeast elongation, reflecting the northeast strike of the causative fault. The areas covered by different intensities (equal to or greater than) were as follows: XI, 27 km^2; X, 367 km^2; IX, 1,800 km^2; VIII, 7,270 km^2; VII, 33,300 km^2. The earthquake was perceptible to the north as far as Harbin and to the south as far as the north bank of the Yellow River in Honan Province; the radius of perceptibility was approximately 1,100 km and the corresponding area was 3.8×10^6 km^2.

Tangshan was mainly a city of unreinforced brick buildings. There were 916 multistory buildings (two to eight stories) in the city. Over 85 percent either collapsed or were severely damaged. These were mainly

*The information on the Tangshan earthquake contained in this chapter came mostly from seminars given at IEM and from copies of technical papers that were presented to the delegation.

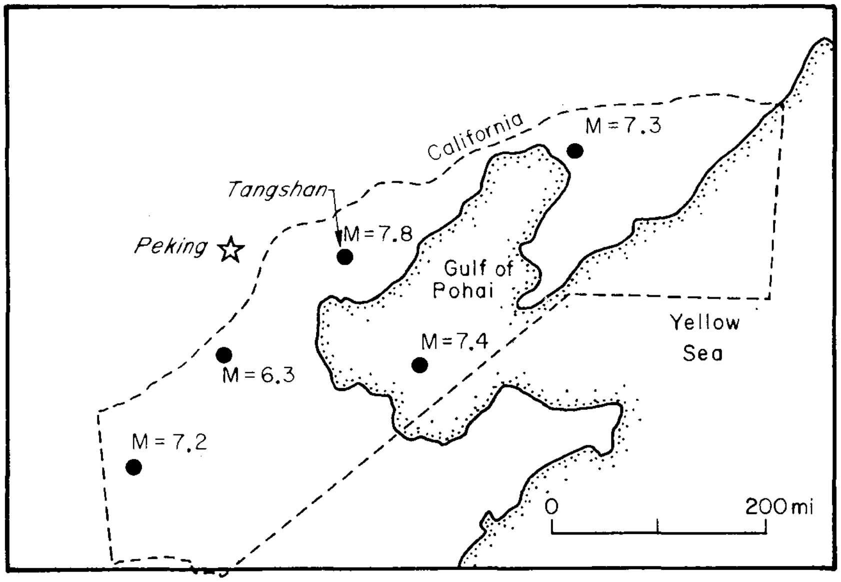


FIGURE 4.1 Epicenters of recent major earthquakes in the Pohai region: Tangshan, July 28, 1976, M = 7.8; Haicheng, February 4, 1975, M = 7.3; Pohai, July 18, 1969, M = 7.4; Hojian, March 27, 1967, M = 6.3; Hsingtai, March 22, 1966, M = 7.2. The outline of the state of California is shown dotted, so it can be seen that within 15 years there were four earthquakes of magnitude greater than 7 in a region of approximately the same area as California.

industrial structures and most of the population was housed in smaller, single-story buildings. Subsequent to our visit we were told by Chinese engineers that 90 percent of the residential dwellings in Tangshan either collapsed or were seriously damaged. In addition, a significant number of buildings in the major city of Tientsin collapsed or were seriously damaged. Dwellings in the cities and the countryside were mainly one-story buildings with very little earthquake resistance, and the collapse of these structures was, no doubt, the cause of the large loss of life which has been estimated as approximately 650,000.*

*The Chinese government has not made an official announcement about the number of casualties. Estimates ranging from 650,000 to 800,000 have appeared in newspaper reports, but the true number is not known. Hongkong's *South China Morning Post* in its January 5, 1977, issue stated that a "top secret" Chinese document said that 655,237 persons were killed and another 779,000 were injured. Of the injured, 79,000 were reported to have been seriously hurt. The title of the document was given as "Material (Part II) for the Study of the Conference on Resisting Earthquakes and Relieving Disasters Among Third Echelon Cadres."

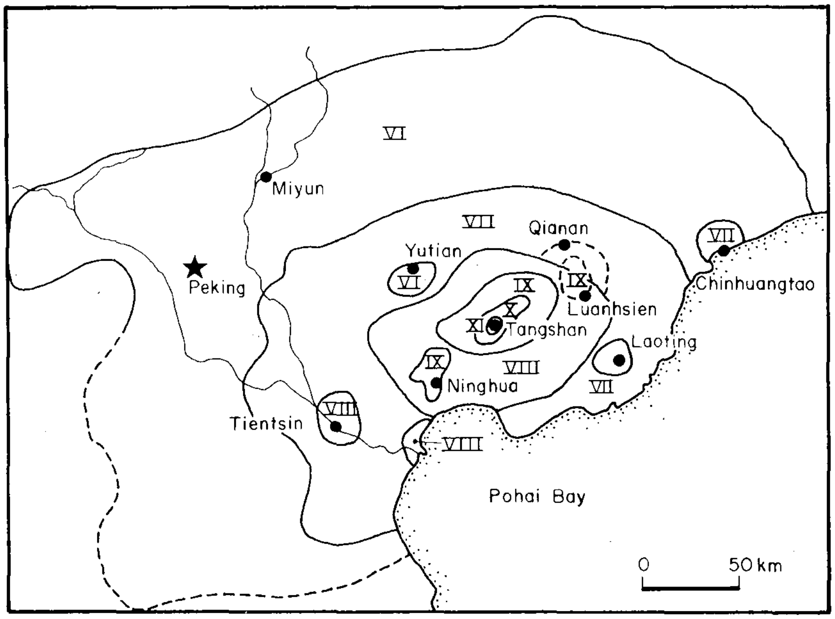


FIGURE 4.2 Intensity map of the 1976 Tangshan earthquake. The dotted lines represent a large aftershock. The Chinese intensity scale is similar to the Modified Mercalli intensity scale, but construction in China is quite different from construction in the United States, so that direct comparisons cannot be made.

Table 4.1 gives a summary of damage to facilities other than buildings. The extensive damage listed in this table indicates the magnitude of the disaster. Some 500 km of railway lines suffered various degrees of damage; in some cases deformation of the ground caused the rail lines to buckle as shown in Figure 4.3, and in other cases, settlement of the ground damaged the rail line as shown in Figure 4.4. Some 228 km of highways suffered various degrees of damage; in some cases the damage was severe, as shown in Figure 4.5, and there were numerous failures of underground pipelines; one example is shown in Figure 4.6.

Public utilities suffered severe damage during the Tangshan earthquake. Approximately 70,000 water supply wells were damaged, which amounted to 64 percent of the wells in the strongly shaken area; and 70 percent of the pumping units were damaged. Soil liquefaction and sand blows were observed in an area of 24,000 km^2. In the region of severe soil liquefaction (3,000 km^2), so many sandblows were produced that cultivated fields were damaged by the large quantities of sand, and the harvest was adversely affected. The sand silted up irrigation canals and water wells. Forty earth dams were damaged to a greater or lesser degree. Twenty-eight trains were operating in the area of strong shaking, and seven of these were derailed.

TABLE 4.1 Preliminary Statistics of Damage

Items	Items Suffering Various Degrees of Damage	Percentage of Items Suffering Damage in Tangshan Region	Number Collapsed or Seriously Damaged
Highway bridges			
Total damaged	231		20
Length	9.7 km	60	2 km
Highway pavement	228 km	20	
Railway	500 km		180 km
Derailments	7	25	
Liquefaction area	24,000 km^2		3,000 km^2
Pumping units		70	
Waterlocks	180		
Irrigation pumping stations (discharge >10 cu m/s)	40		
Water supply wells	70,000	64	
Earth dam of reservoirs (storage capacity >1 million m^3)	40		
River embankments	800 km		
Pipelines	1-3 (no. of fractures per km)		

Damage to the main underground water supply lines was worse in soft ground than in firm ground, as shown in Table 4.2. These water mains and supply trunk lines were either concrete pipe or cast iron pipe, with diameters up to 300 mm. The water supply system of Tangshan was totally disrupted, and several months were required to restore service; the water supply lines of Tientsin were also disrupted, presumably because of very soft soils. A visitor to Tientsin 2 years after the earthquake reported that fire hose was still being used for water mains in some parts of the city.

Some of the Kailuan coal mines in the Tangshan region were flooded as a consequence of the earthquake. The rate of inflow of water into mine galleries was increased by factors between 1.7 and 5. There were

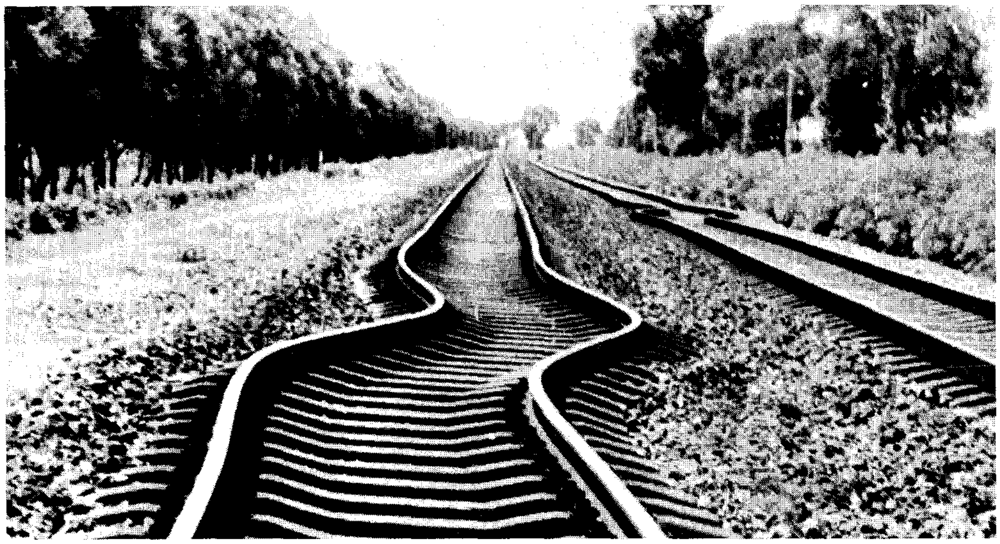


FIGURE 4.3 Buckling of rail lines due to ground deformations. The general Tangshan region had many soft soils that behaved poorly during the earthquake.

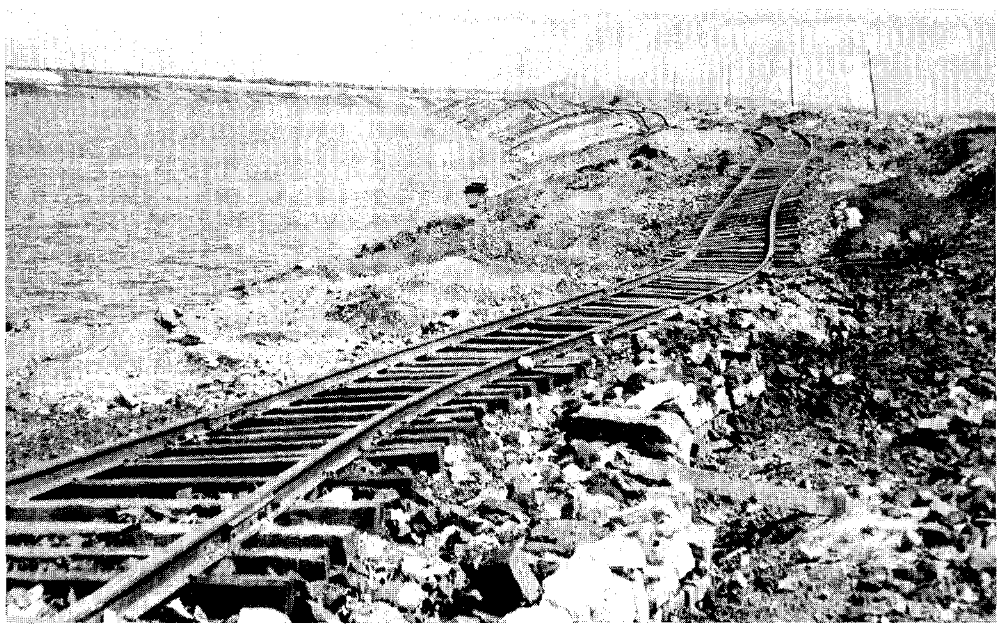


FIGURE 4.4 Failure of ground under railway line. Extensive damage was done to the rail system in the Tangshan region.

FIGURE 4.5 Damage to road near Loting Hsien. Slumping, lurching, and settlement of soft soils caused extensive damage to highways in the Tangshan region.

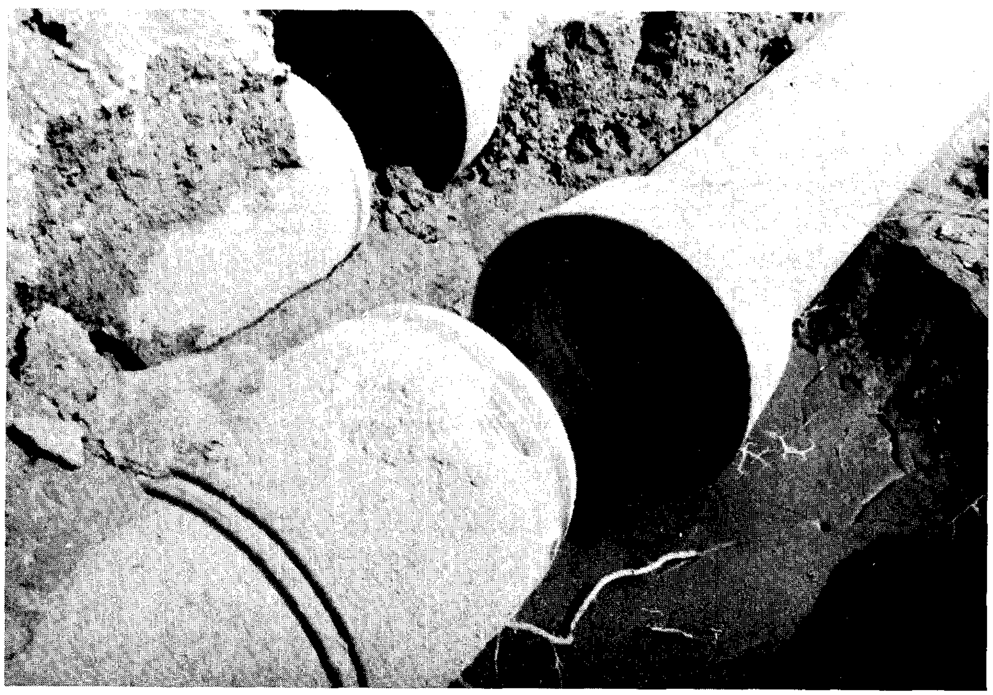


FIGURE 4.6 Underground pipes separated by extensional ground deformation.

several tens of shafts in the Kailuan coal mine system, with maximum depth greater than 700 m, and 75 percent of these shafts suffered various degrees of damage, mainly ring fractures around the cylindrical walls in the upper 20 m. Because of the increased inflow of water, many of these mines and their equipment were submerged. In Zaoge-zhuang mine branch the water level rose 280 m in the first 9 days after the earthquake. Electrical power disruption stopped the pumping, ventilation, and elevator systems in the mines.

An unusual feature of the Tangshan earthquake was the formation of craters in the countryside. An example of a crater of moderate size is shown in Figure 4.7. A partial view of a very large crater is shown in Figure 4.8. These craters were not associated with the extensive underground excavation for coal mining, but they have not yet been studied thoroughly and the reason for these ground collapses has not been established; one suggestion was that limestone karsts may have been responsible.

According to the Chinese engineers, this earthquake was such a great disaster mainly because the seismic risk in the Tangshan region had not been adequately estimated. Almost all buildings and structures had been designed without earthquake-resistant measures, except for a few of the more important structures. In addition, the poor behavior of soft soils contributed greatly to the damage. Low mortar strength in masonry, and inadequate continuity of connections between precast reinforced concrete elements also intensified the damage. Many structures suffered further damage from the aftershocks. The main shock occurred at 3:43 a.m. and was followed by a magnitude 6.5 aftershock at 7:17, and a magnitude 7.1 aftershock occurred at 18:45 on the same day. These aftershocks hit the eastern part of the epicentral area, and the cumulative damage effect of the successive aftershocks was very pronounced.

Chinese engineers outlined the valuable engineering lessons provided by the Tangshan earthquake:

TABLE 4.2 The Effect of Site Conditions on the Average Damage of Underground Water Supply Trunk Pipelines

District	Intensity	Soil Classification[a]	Average Damage (No. of Fractures/km)
Tangshan city	X-XI	II	2
Tientsin city			
Municipal district	VII-VIII	III	0.18
Tangku district	VIII	III[b]	4.18
Hanku district	IX	III[b]	10.8

[a] Soil classifications I, II, III represent hard, firm, and soft soils.

[b] Poorer than municipal district.

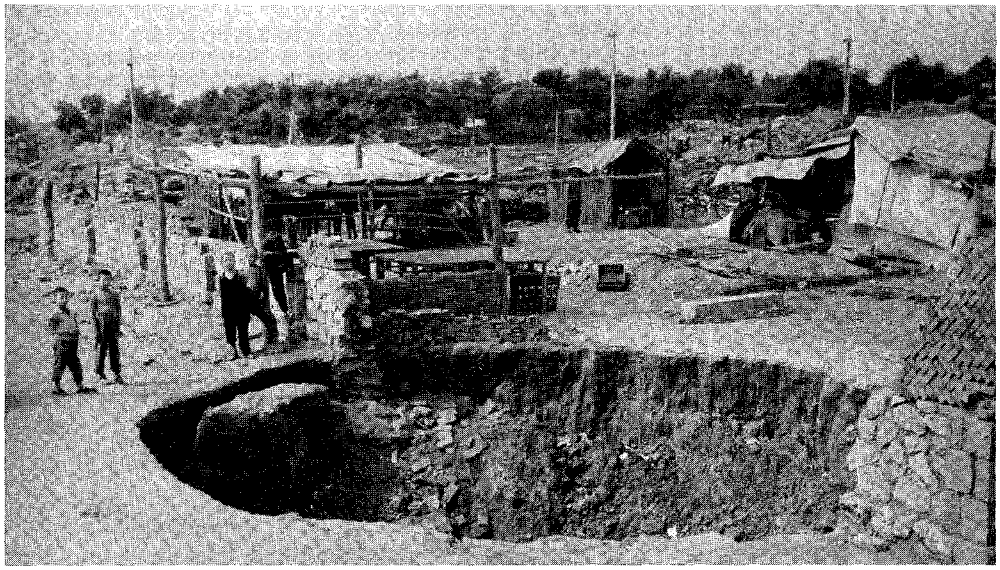
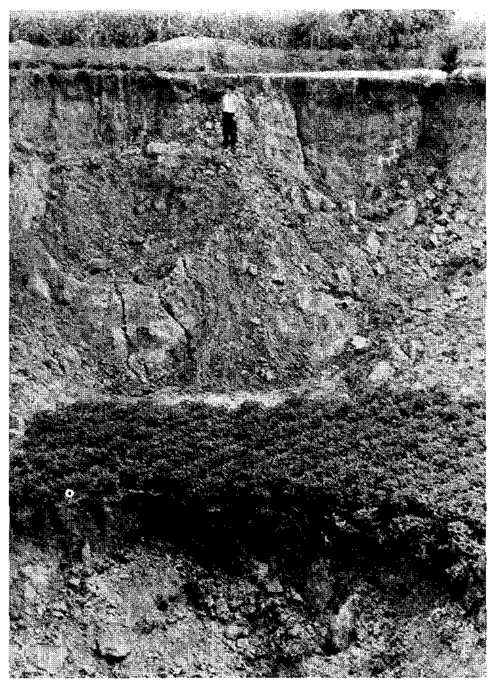


FIGURE 4.7 Ground collapse near Tachuangtuo Commune, Kuyeh Hsien. The Tangshan earthquake triggered the formation of a number of such craters. Geological investigations had not yet determined the underlying cause of these craters.

FIGURE 4.8 View of the interior of a very large crater formed near Hsiaotun, Chengchaungtze Commune, north of Tangshan.



1. Seismic zoning should be carefully and properly done, in particular, the "basic intensity" should be reliably assessed. (The basic intensity is defined as the maximum intensity to be expected for a certain period of years (100 years) with a certain probability.) Prior to the Tangshan earthquake, the basic intensity of the Tangshan region was rated as low as grade VI and therefore the city had little protection against earthquakes. (The building code specifies the level of earthquake-resistant design by means of intensity numbers such as VI, ..., XI, and this in turn determines the seismic coefficient; some Chinese engineers criticized this two-step procedure. Apparently, the seismic zoning is done by seismologists with no input from the engineers.)

2. A correct philosophy of earthquake-resistant design should be established. Important structures should be designed so that they can withstand a probable earthquake with only slight damage and will not collapse under the action of an unexpected very large earthquake. In earthquake design, auxiliary structures should not be overlooked, because their failure may paralyze factory production and may also have a severe effect on the public.

3. Open-air facilities, when practical, have the important advantage of avoiding damage from the collapse of buildings.

4. Damage to reinforced concrete buildings was less than that to brick buildings, and damage was mainly in the structural connections. The earthquake resistance of such buildings could be much improved at small additional cost. Brick chimneys, brick water tower supports, brick columns in mill buildings, and in general, brick masonry of poor quality suffered severely during the earthquake, and such structures should not be built in highly seismic regions.

5. The functioning of the principal "lifeline" systems should be maintained following an earthquake. The Tangshan earthquake severely damaged bridges on railways and highways so that traffic was blocked and this caused great difficulties in carrying out the relief work. Interruption of water supply and electrical power also caused great difficulty in the relief work and in the restoration of production after the earthquake. For example, the interruption of the water supply and the electric power supply resulted in molten iron freezing in four blast furnaces, so that the furnaces had to be demolished by explosives. Another example is that during the Tangshan earthquake the power system of the Kailuan coal mines failed and the underground ventilation stopped functioning, and thousands of miners were threatened with suffocation and gas explosion.

6. Buildings with basements and underground structures such as tunnels and shelters were more earthquake resistant. In Tangshan, many buildings with basements suffered only slight damage. Mine galleries came through the earthquake almost intact.

TANGSHAN CITY

Tangshan, the city at the epicenter of the earthquake of July 28, 1976, is a major industrial center strategically located on the railway line between Peking (approximately 120 miles west of Tangshan), Tientsin (45 miles to the southwest), and the coast (Figures 4.9, 4.10, 4.11). The

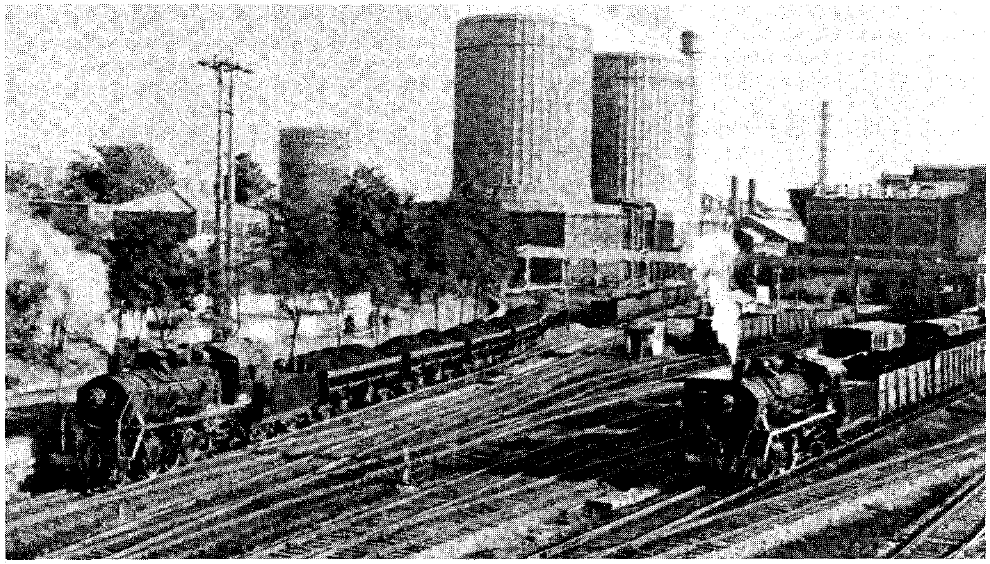
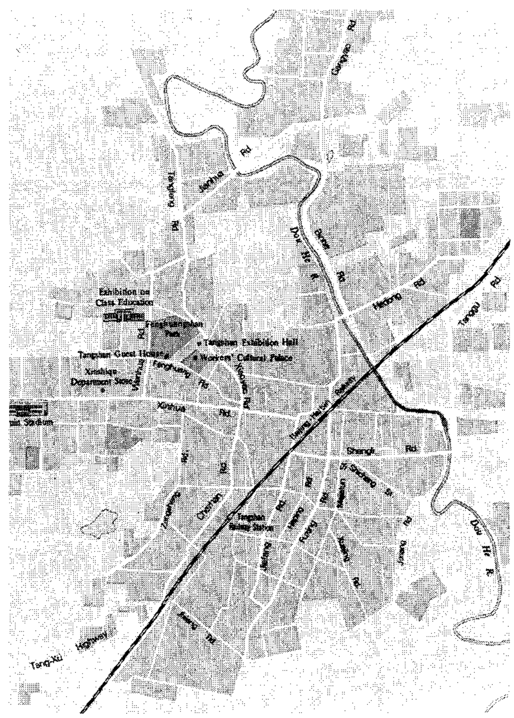


FIGURE 4.9 View of Kailuan coal mines in Tangshan before the earthquake. Coal mining was a major industry in this city of over 1,000,000 population.

FIGURE 4.10 Schematic map of Tangshan reproduced from a tourist manual.



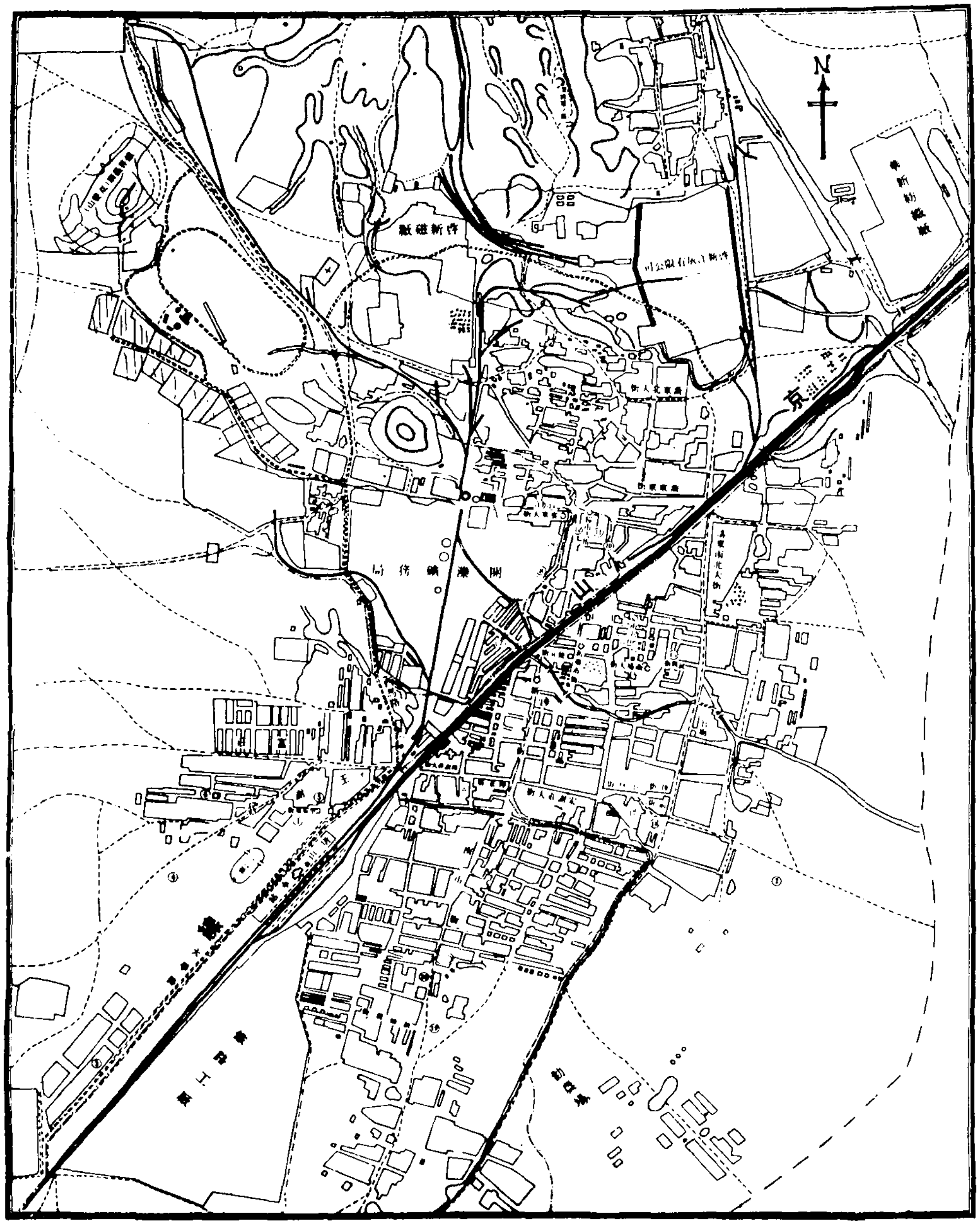


FIGURE 4.11 Map of Tangshan City, reproduced from a technical paper.

devastation of this city of over 1,000,000 inhabitants was thus a major loss to China's national economy, quite apart from the financial costs of relief and reconstruction.

Tangshan's industry is based on the Kailuan (Kailan) coal mines. The city's development began with the opening of its first modern colliery--the first in China--in the 1870's. This was followed in the 1880's by extension of the railway to Peking and Tientsin and to the seaports of Tangku and Chinhuangtao, which became outlets for the export of Tangshan coal. Other industries developed in Tangshan in the 1890's, either in connection with mining and the railway or to take advantage of other resources in the region. The latter included a cement industry based on the limestone found north and northeast of Tangshan and a ceramics industry that made use of kaolin deposits in the area. As its population increased along with industrial development, Tangshan also became a major agricultural marketing center.

Tangshan's coal mining industry continued to expand after the turn of the century. Nearby sources of bauxite also supplied a local aluminum and refractory brick industry. A modern textile mill and a railway locomotive factory had been added to the region's industrial base by World War II. After 1935, Tangshan was occupied by the Japanese, who built an electric power plant and established the Tangshan steel mill to refine iron ore mined in the vicinity. By 1959, steel had become Tangshan's second most important industry, after coal mining. The city's current importance in China's energy economy is underscored by the fact that its coal has accounted for some 10 percent of the country's total production of energy resources in recent years, and by its proximity to the pipeline from the big Taching oil field, which crosses the Luan River some 30 miles from Tangshan. In short, Tangshan is not only a regional center but has played a strategic part in China's economic development and modernization.

One of the six principal Kailuan mine pitheads is located in Tangshan City proper; all are sited within the larger administrative unit, Tangshan Municipality. Most of Tangshan's industry is situated in the eastern part of the city on the banks of the Tou River. Workers' housing is close to this industrial zone. Since the city's major industry, mining, occupies comparatively little surface area, one- and two-story residences made up a relatively high proportion of Tangshan's buildings at the time of the earthquake. The majority of industrial buildings were two to four stories high, the tallest being eight stories; these were predominantly brick buildings, though there were some reinforced concrete structures.

An area of 20 mi^2 in the heart of the city was devastated by the earthquake. The scene was described by a Reuters correspondent who traveled through Tangshan some months after the earthquake:

> One minute the train is speeding past waving fields of wheat, the next it is crawling through a desert of rubble stretching as far as the eye can see... Factories reduced to a maze of girders twisted into fantastic shapes flank the line... Normally level fields were shaken into mounds and craters. One can also see how surface earth caved into the Kailuan coal

> mines north of Tangshan. Three pit heads now appear to be working, but nearby coal trucks and twisted rails are scattered down a hillside like toys.

The Chinese government has never published official figures on the loss of life and property at Tangshan, though at the end of 1976, Chairman Hua Kuo-feng described the devastation as "rarely seen in history." The Chinese seismologists and engineers did not report casualties to us, but reports from elsewhere estimate as many as 650,000 deaths. Figures cited by a group of Hongkong journalists who had visited Tangshan in 1978 reveal the implications of this loss of human life for Tangshan's economy. They reported 10,486 deaths among employees of the Tangshan locomotive plant and their families, 1,892 dead at the Tangshan iron and steel company, and 1,280 at the Tangshan porcelain company.

The earthquake was not predicted; it has been stated that there were no perceptible foreshocks prior to the Tangshan earthquake and that other indicators had been ambiguous.

Rather than publishing details of the city's destruction, the government-run Chinese press has written about heroic actions that saved lives and salvaged or quickly restored production facilities and services in the city. Thus it is claimed that the 10,000 miners on the night shift who were underground when the earthquake occurred were all rescued, most within hours, though the last were not brought to the surface until 2 weeks later. The official accounts credit prompt action by local and provincial authorities, who organized rescue and relief operations and maintained public order and discipline, with keeping the losses from being even greater. Two years after the earthquake the Chinese press was still referring only indirectly to fatalities at Tangshan. The June 1978 issue of *China Pictorial*, for example, featured a story about a boarding school for orphans whose parents had died in the disaster without revealing the number of children involved.

Immediately after the earthquake, Hua Kuo-feng, then Premier and later Chairman of the Chinese Communist Party following Mao Tse-tung's death in September 1976, ordered the People's Liberation Army to mount a disaster relief operation. Under Hua's direction, the State Council and the Central Committee of the Chinese Communist Party coordinated assistance offered from all parts of the country for Tangshan's rehabilitation. In view of Tangshan's importance to China's economy, restoration of the city's industry was an urgent national concern. However, this program allegedly became involved in the political struggle then underway in the top ranks of the government and Party to settle the succession to Mao Tse-tung. Nonetheless, the Chinese claim that overall production at Tangshan 2 years after the earthquake had reached 90 percent of previous levels, which is very high in view of the extensive damage to industrial facilities.

Preliminary planning for rebuilding Tangshan was to be completed in 1978, and the new Tangshan is to be completely reconstructed by 1982. The national government is now underwriting the cost of building materials for the city's reconstruction (and one spin-off of this effort is the growth of a local building materials industry), while labor is being supplied locally. Blueprints for Tangshan's reconstruction call for several cities of 100,000-300,000 persons to be built in a wide area around Tangshan, which itself would be limited to 500,000. Each satellite town is to consist of a complex of industry, agriculture, and residential amenities. With a green belt preserved for recreation in the area south of the railway, and with a centralized system for handling industrial wastes that will minimize pollution, the new Tangshan, it is claimed, will be the product of modern techniques of city planning.

To completely plan and rebuild a city of over 1,000,000 inhabitants is a remarkable project of great interest to engineers, architects, and government officials in all countries. In view of this, our delegation requested permission to visit Tangshan and to be briefed on the reconstruction effort. However, permission was not granted, and the Delegation was given no information about casualties, relief operations, or rebuilding.

GEOLOGIC SETTING OF THE TANGSHAN EARTHQUAKE

The Tangshan earthquake occurred near the northeastern end of a seismic belt of large shallow earthquakes that extend from the Himalayas northeast across central China (Figure 4.12).

The northeastern part of this belt passes through the North China tectonic province (Figure 4.12) in which Tangshan is located. Extensive

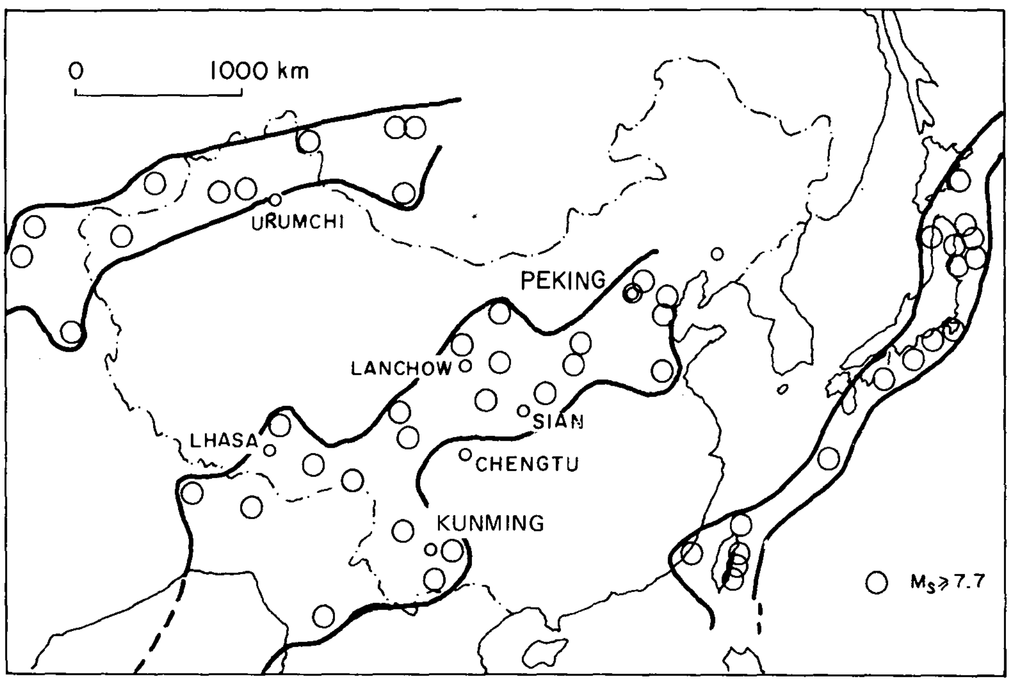


FIGURE 4.12 Three generalized seismic belts in China region.

geological studies have been carried out in this region (Chinese Academy of Sciences, 1974); and seismotectonics, as well as seismogenic models, were discussed following the Tangshan earthquake (Guo et al., 1977; Qiu et al., 1976). Wang (1974) has given an interesting summary of the Tangshan earthquake and some precursory data. The North China tectonic province constitutes the oldest continental crust in China, with rocks dating back to Pre-Cambrian. In the province there are two operative tectonic systems which influence seismicity. A Paleozoic system, composed of the Yenshan-Yinshan E-W tectonic belt and the Tapeishan-Chinling E-W tectonic belt, forms zones of folding and faulting along the northern and the southern borders of the province (Figure 4.13). The other system consists of a series of NNE-trending tectonic zones of Mesozoic-Cenozoic age (Figure 4.13). From east to west, they include the Tancheng-Luchiang fracture zone, a row of en echelon folds and faults called the Hopeh Plain fracture zone, the Taihang Piedmont fracture zone, and the Shansi Graben fracture zone. A system of WNW-trending faults intersects these fracture zones. Along the Tancheng-Luchiang fracture zone, an earthquake of magnitude 8.5 occurred in 1668, near Tancheng; a magnitude 7.4 event in the Pohai Gulf in 1969, and a more recent magnitude 7.3 event near Haicheng in 1975. Along the Shansi Graben fracture zone, $M > 8$ events occurred in Huahsien (1556) and in Linfen (1303, 1695), together with at least five $M > 7$ events. On the Hopeh Plain fracture zone, notable events include the $M = 8$ earthquakes near Peking (1679) and an $M = 7.2$ event in 1966 at Xingtai. The latter event inflicted

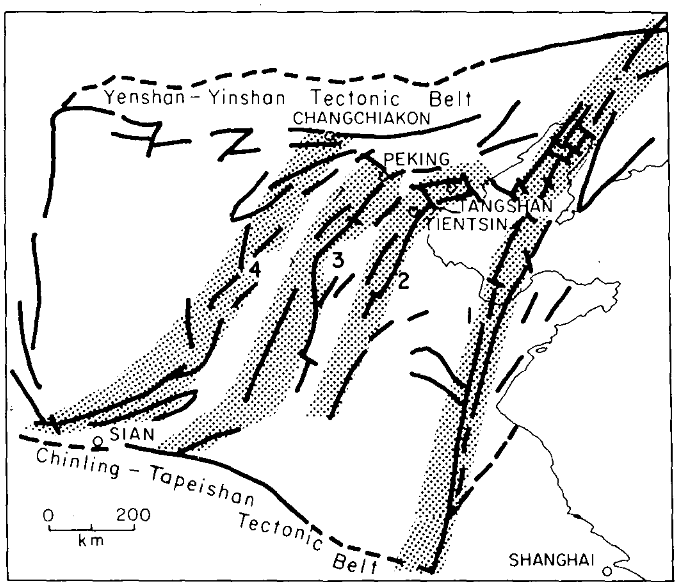


FIGURE 4.13 The North China tectonic province containing the following four fracture zones: (1) Tancheng-Luchiang fracture zone, (2) Hopeh Plain fracture zone, (3) Taihang Piedmont fracture zone, and (4) Shansi Graben fracture zone.

heavy losses and prompted the Chinese government to launch a major effort in earthquake prediction research. The Tangshan earthquake occurred on the northern extension of the Hopeh Plain fracture zone, near the location where the fracture zone intersects the Yenshan-Yinshan E-W tectonic belt (which lies a few tens of kilometers north of Tangshan). Limited by the older E-W trending Yenshan-Yinshan tectonic belt to the north, this fracture zone gradually turns to the NE and finally becomes nearly E-W in the Pohai Gulf. The Tangshan epicenter was located at this turning juncture on a fault that had not been identified before the earthquake. The causative fault of the Tangshan earthquake is, however, part of the system of NNE-striking fractures, and the branch passing through Tangshan to Kuyeh may have marked the surface projection of the rupture that caused substantial surface breaks in the city of Tangshan.

In the Hopeh Plain, Mesozoic and older rocks have been warped downward, and the basin near Tangshan is filled with sediments of Tertiary and Quaternary age ranging from 0-2 km thick. Downwarping or downfaulting has been uneven, so that Tangshan now is situated above a prominent northeast-trending ridge 200 km long in the surface of basement rocks. At the crest of the ridge the surface is as much as 3 km higher than it is to the northwest and southeast.

Although the causative fault had not been identified before the earthquake, many deep and large faults were known in the Tangshan area. Some of the faults at depths of 30-40 km have been revealed by seismic refraction and gravity studies. Many of the faults were active in late Tertiary time, and beds of late Tertiary age are displaced by as much as 500 m. On geologic and tectonic evidence, the area clearly was to be considered an active tectonic region even before the great earthquake.

SOILS AND NEAR-SURFACE GEOLOGY

Shallow geologic profiles through the region surrounding Tangshan indicate an erratic pattern of sandy gravels, sands, and clayey soils. These alluvial materials typically have considerable thickness, with depth to the underlying rock reaching as much as 800 m within 15 km of Tangshan. At least three processes have contributed to the formation of these deposits: slope wash from the uplands to the north, the emergence of the plain from the sea in recent times, and the action of the several rivers which cross this plain. Four thousand years ago the coastline was just a few kilometers south of Tangshan, as shown in Figure 4.14, and since has gradually advanced seaward to its present position about 50 km south of Tangshan. The rivers have apparently changed their courses several times, as numerous old river channels have been identified. Along the present river channels and near the coast the water table is generally within a few meters of the surface. The result of these surficial processes has been the deposition of many weak soils (class IV) that are susceptible to failure during an earthquake.

Tangshan itself is sited over a buried ridge of rock that extends from outcrop areas to the north. Low limestone hills outcrop in the northern part of the city. In parts of the city the thickness of the

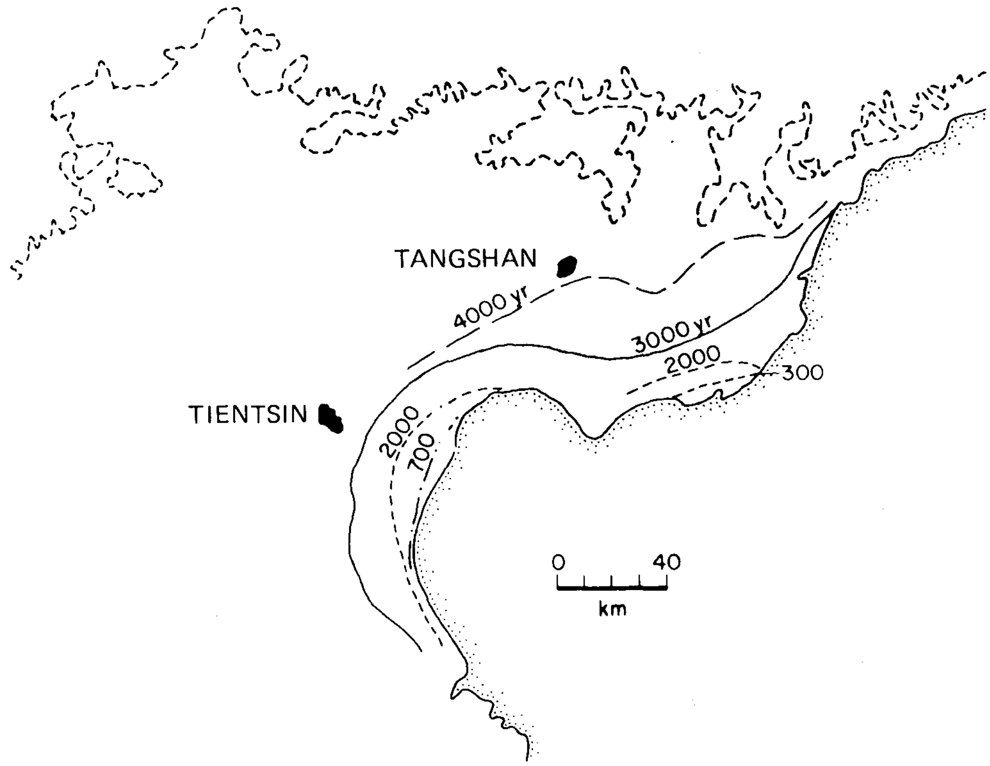


FIGURE 4.14 Map showing how the shoreline has advanced over the past 4,000 years. The shoreline 4,000 years ago passed just south of Tangshan City site; the map shows where the shoreline was 3,000 years ago, 2,000 years ago, 700 years ago, 300 years ago, and the present location. This makes clear why there were so many soft soils south of Tangshan.

alluvium is only 20 m, while under the outskirts of the city, thicknesses of 100-200 m occur. Chinese engineers described the predominant surficial soil as loesslike silty clay, not necessarily of windblown origin, with lenses of gravel and sand. It was rated as a class II soil. We were shown some typical boring logs but no data concerning blow counts. Shear wave velocities had been measured by modern downhole methods, and typical values ranged from 200-300 m/s. The typical depth to the water table was 4-5 m.

Weaker soils were said to exist along the Tou River, which flows through the eastern part of the city. Here, over a limited area, there was said to be a silt layer with a shear wave velocity of only 80-90 m/s.

HISTORICAL SEISMICITY

Seismic records in the North China tectonic province date back to 780 B.C., but early records are rather incomplete. Since 1000 A.D., however,

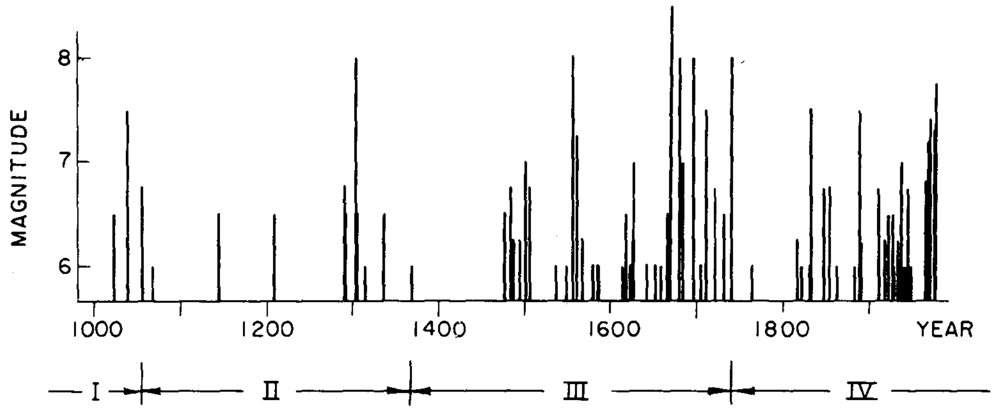


FIGURE 4.15 Four cycles of earthquake occurrence in the North China tectonic province. The data prior to 1500 are incomplete, but it is felt by the Chinese that the data are relatively complete since about 1500 A.D.

there have been one M = 8.5, five M = 8, twelve M = 7-7.9, and more than sixty M = 6-6.9 earthquakes in this tectonic province. A plot of the times of occurrence of these large events is shown in Figure 4.15. Chinese seismologists have identified (as seen in Figure 4.15) four cycles of earthquake occurrence in North China, which raises the interesting question as to whether similar cycles exist, for example, in California seismicity. Each cycle spans roughly 300 years and consists of a relatively quiet stage and a markedly active stage. The records for the first and second cycles are incomplete, but from the third cycle on, historical records are relatively complete. An enlarged plot of the third and fourth cycles together with the strain release curve are shown in Figure 4.16. The third cycle is considered to have begun in 1369 and

TABLE 4.3 Historical Large Earthquakes in the North China Tectonic Province

Activity Period	Activity Stage	Number			
		M = 8.5	M = 8	M = 7-7.9	M = 6-6.9
Third (1369-1739)	Quiescent	0	0	0	0
	Active	1	4	5	25
Fourth (1740-?)	Quiescent	0	0	0	0
	Active	(0)	(0)	(8)	(23)

ended in 1739, spanning a period of 370 years. During the first 100 years or so (1369-1476) in this cycle, possibly no $M > 6$ event occurred, and the North China tectonic province is considered to have accumulated strain energy during this time. After 1477, seismic activity began to pick up. Between 1477 and 1667 there were one $M = 8$, three $M = 7\text{-}7.5$, and twenty-two $M = 6\text{-}6.9$ earthquakes, with a gradual increase in the frequency of strong earthquakes. From 1662 to 1739 an outburst of great earthquakes occurred, including the $M = 8.5$ Tancheng-Luhsien earthquake, Shantung Province, in 1668; the $M = 8$ Sanho-Pingku earthquake, in Hopeh Province, in 1679; the $M = 8$ Linfen earthquake, in Shansi Province, in 1695; and one $M = 8$ and two $M = 7$ earthquakes, at Yinchuan, Ninghsia Province, in 1739 (Table 4.3).

The fourth cycle is considered to have begun in 1740 and lasted at least to the present, for a duration of 236 years. A stage of low seismic activity is found between 1740 and 1814. A steady increase in magnitude and frequency of occurrence of large earthquakes is seen during the years from 1815 until the $M = 7.8$ Tangshan event of 1976. During the last 160 years the North China tectonic province has been the site

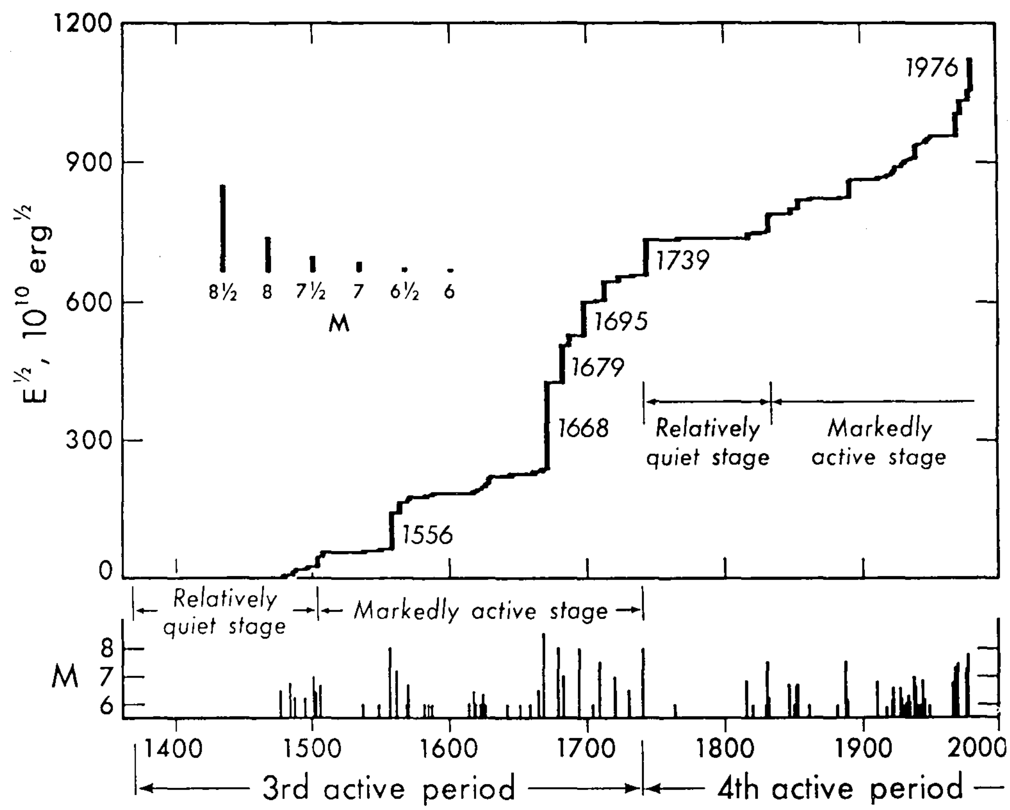


FIGURE 4.16 The third and fourth cycles of earthquake occurrence together with the accompanying strain release (from Wang, 1974).

of six M = 7-7.5 and more than twenty M = 6-6.9 events. Starting with the Hsingtai M = 7.2 earthquake of 1966, there have been a succession of large events in North China: in 1967 (M = 6.7, Hochien of Hopeh Province), in 1969 (M = 7.4, Pohai Gulf), in 1975 (M = 7.3, Haicheng of Liaoning Province), and in 1976 (M = 6.3, Inner Mongolia). The frequency of large events has been high and the losses have been heavy. One of the major questions currently under intensive study by the State Seismological Bureau staff is whether the Tangshan earthquake has marked the "peak" and thus would be considered to be the conclusion of the main seismic energy release of the fourth cycle. Many Chinese scientists take a conservative view toward this question by remarking that the Tangshan event, while the largest so far during the fourth cycle, was merely an M = 7.8. If the third cycle were to provide any clue, larger seismic energy release would probably be yet to come.

SEISMOLOGICAL DESCRIPTION OF THE TANGSHAN EARTHQUAKE

The earthquake of M_S = 7.8 that centered under the city of Tangshan, Hopeh Province, occurred at 1942:53.8 UT on July 27, 1976 (July 28 local time, 3:43 a.m.). The coordinates of the epicenter were 118.2°E, 39.4°N. The depth of the hypocenter was determined to be between 12 and 16 km.

The aftershock distribution defines an elliptical area 50 km wide and 140 km long, with the long axis striking N50°E (see Figure 4.2). Based on recorded P wave first motions of the main shock, two nodal planes were derived (Qiu, 1976): One strikes N41°E and dips 85° southeast; the other strikes N51°W and dips 70° northeast. The principal compressive axis has a strike of N86.5°E and a plunge of 18°. The principal tensile axis strikes N13.5°W and plunges 10°, and the intermediate stress axis strikes N78°E and plunges 60°. The northeast-striking nodal plane is consistent with the aftershock distribution and the surface break orientation; therefore it is chosen as the fault plane. The dislocation is a right-lateral strike-slip with a minor dip-slip component. From the time progression of aftershock occurrences, it is concluded that the rupture was an asymmetrical bilateral dislocation with the northeast as the principal propagation direction. The largest aftershock was an M = 7.1 event (this was sometimes described as an M = 6.9 event) that occurred 3 hours after the main shock near Luanhsien, a town some 70 km northeast of Tangshan. This aftershock was apparently generated by one of the NNW-striking conjugate faults with left-lateral strike-slip displacement, as was indicated by first-motion studies and the actual pattern of ground breaks observed north of Luanhsien (Wang, 1974).

Butler et al. (1979) give the following summary description of the complex faulting that accompanied the main event:

> . . . Detailed analyses of the teleseismic surface waves and body waves are made for the Tangshan event. The major conclusions are: (1) The Tangshan earthquake sequence is a complex one, including strike-slip, thrust, and normal-fault events.

(2) The main shock, as determined from surface waves, occurred on a near vertical right-lateral strike-slip fault, striking N40°E. (3) A seismic moment of 1.8×20^{27} dyne-cm is obtained. From the extent of the aftershock zone and relative location of the main shock eipcenter, symmetric (1:1) bilateral faulting with a total length of 140 km may be inferred. If a fault width of 15 km is assumed, the average offset is estimated to be 2.7 meters with an average stress drop of about 30 bars. (4) The main shock was initiated by an event with a relatively slow onset and a seismic moment of 4×10^{26} dyne-cm. The preferred fault plane solution, determined from *P*-wave first motion data, indicates a strike N160°W, dip 83°, and rake +175°. (5) Two thrust events follow the strike-slip event by 11 and 19 s, respectively. They are located to the south of the initial event and have a total moment of 8×10^{25} dyne-cm. This sequence is followed by several more events. (6) The principal aftershock was a normal-fault double event with the fault planes unconstrained by the *P*-wave first motions. Surface waves provide additional constraints to the mechanism to yield an oblique slip solution with strike N120°E, dip 45°SW, and rake -30°. A total moment of 8×10^{26} is obtained. (7) The triggering of lesser thrust and normal faults by a large strike-slip event in the Tangshan sequence has important consequences in the assessment of earthquake hazard in other complex strike-slip systems like the San Andreas.

Surface faulting occurred within the city of Tangshan over a length of between 8 and 10 km. Maximum displacement reached 3 m in a right-lateral strike-slip sense. The northwest side was usually raised, and extension of the ground surface over a width of 300 m was as much as 0.5 m. Buildings on the faults were damaged by the slip, whereas farther out, damage was lighter. Damage also was lighter at the ends of the fault segments. The surface faulting developed in five en echelon segments as shown in Figure 4.17. The individual surface breaks had an approximate strike of N40°E, and the overall zone of surface breaks trended roughly N30°E. This zone followed essentially the southwestern section of the Tangshan-Kuyeh fault, and surface breaks were developed in the loose Quaternary sediments. Roads and rows of trees were offset (Figures 4.17, 4.18, 4.19, 4.20), and compressional ridges were seen that were consistent with the ENE compressive axis and the NNW tensional axis.

Spectral analyses of the seismic records by Chinese seismologists have been interpreted to indicate that the causative main rupture was 120 km long and that rupture was asymmetrically bilateral, beginning approximately 70 km from the northeast end. This interpretation is in general agreement with that of Butler and others of bilateral rupture beginning near the center of a 140 km break. Secondary faulting was also reported underground in coal mines. In one example where the coal bed had been displaced earlier by five pre-Pleistocene faults, all five faults were reactivated in a dip-slip sense during the earthquake, with

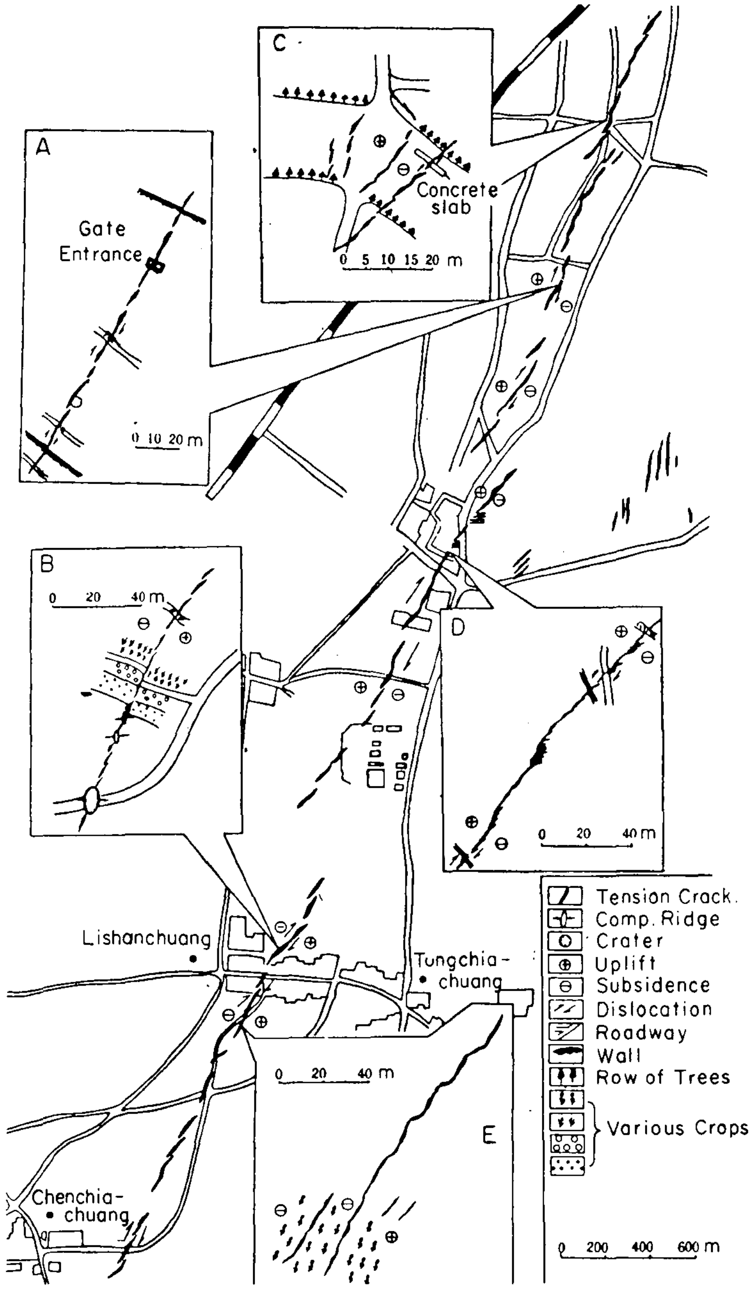


FIGURE 4.17 Surface faulting observed in the city of Tangshan. (A) Tangshan 10 high school; (B) North Lishanchuang; (C) Intersection of Yunhung Road and Hoping Street; (D) Tangshan native product warehouse; (E) South Lishanchuang.

FIGURE 4.18 Surface breaks and compressed pavement over drainage trench in Tangshan.

FIGURE 4.19 Offset in row of young trees by surface break near Laoting Hsien (direction N40°W, maximum displacement, 0.8 m).

maximum displacement of 1 m. A rather complete cross section, about 3,000 m long, of the coal formations at a depth of 600 and 700 m was shown to us; two of the reactivated faults were near one end of the cross section and three were near the other end.

Mine shafts at the coal mine were damaged but principally in the upper 20 m, where 75 percent of the mine shafts suffered various degrees

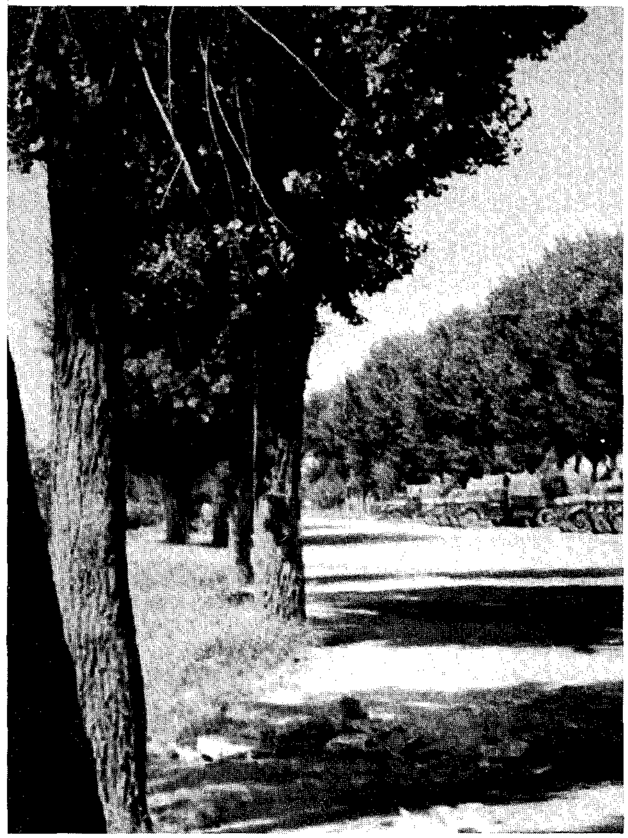


FIGURE 4.20 Offset in row of trees due to horizontal tectonic movement, in Tangshan.

of damage and collapse. The flow of water into the mines increased after the earthquake, markedly in some cases. The belief was expressed that the increased flow resulted from added fracturing and opening of fractures in bedrock, although some small amount may have been contributed by liquefaction of near-surface sand units. There were no reliable data about ground shaking in the mines at depth.

Surface faulting also occurred during the $M = 7.1$ aftershock near Luanhsien (Wang, 1974), with faults having strikes of both N20°W and N30°E. The northeast-striking faults displayed right-lateral strike-slip and the northwest-striking faults displayed left-lateral strike-slip. The city of Luanhsien was built over perhaps one of the largest coal mines in China. Ground subsidences were widespread over areas where coal mining had removed underlying formations.

In Tientsin, Ningho, and Tangku, shallow water tables apparently contributed to greater damage through the effects of liquefaction and subsequent ground failure. Along the banks of some rivers, for example, considerable damage was apparently related to lateral spreading, although nearby building damage attributable to shaking was relatively light.

Localized damage according to the Chinese, differed according to topographic effects. For example, at the base of a 200-m high ridge, the damage degree was only VI, whereas at the crest of the ridge, the degree was XI. In some localities, small buildings on liquefiable soil showed little damage, whereas on nearby bedrock, similar buildings were damaged. An interpretation was suggested that the soil unit susceptible to liquefaction was also effective in absorbing the strong shaking.

DAMAGE TO BUILDINGS DURING THE TANGSHAN EARTHQUAKE

At the Institute of Engineering Mechanics in Harbin the delegation was given an overview summary of building damage in the Tangshan earthquake. T. Y. Chang spoke on general features of the Tangshan earthquake, Yang Yu-chen spoke on damage to multistory brick buildings during the Tangshan earthquake, and C. C. Yin spoke on damage to mill buildings. In addition, 13 technical papers dealing with the Tangshan earthquake were given to the Delegation. Five of them deal with structural damage, and information from these is also presented here.* The description of structural damage presented at IEM was mainly about brick buildings and mill buildings, although some information about lifeline systems was also presented. The technical papers contained information on damage to other types of structures. It was reported that the behavior of soft soil had an appreciable effect upon damage sustained by structures (see section below on behavior of soils); significant ground subsidence was experienced as far away as 50 km from Tangshan.

No strong-motion accelerograms were recorded in or near Tangshan during the M = 7.8 earthquake (see section below on strong-motion records), and this severely hampered the engineering assessment of the damage.

Few of the buildings in the Tangshan region were designed to resist earthquakes. We were informed that the building code had zoned Tangshan for intensity VI, which did not require buildings to be designed for earthquake forces, so only a few special structures had been so designed. Most of the 916 substantial buildings in the Tangshan area were built of brick and were two to four stories in height; however, some were as tall as eight stories. They were mainly used for offices, schools, and factories. It was reported that over 75 percent of the larger brick buildings collapsed or were severely damaged by the Tangshan earthquake and its aftershocks, and only 1 percent suffered no damage. In many cases the failure pattern for these large buildings began with diagonal tension cracking in the shear panels, followed by crushing and collapse as the deformation of the structure increased. In many cases it was observed that the exterior walls failed first, followed by failure of the interior walls, and there were many evidences of failures of connections. It was reported that buildings located on thin soil, on thin layers of

*A list of 51 technical papers given to the delegation is presented in Appendix III to this report. Thirteen of these deal with the Tangshan earthquake.

rock, or on thin layers of soil over rock did not exhibit the same degree of severe damage as buildings located on less firm soil. Studies of the response characteristics of buildings after the earthquake showed considerable differences in the periods of damaged buildings as compared to undamaged buildings. Dwellings were mostly one- and two-story buildings that had little earthquake resistance, and these were reported to have collapsed over large areas of the city.

Detailed studies were made of the damage in Tangshan, and the statistics are most impressive. In one study, 14 districts in Tangshan, shown in Figure 4.21 were selected for detailed damage compilations. The results are shown in Table 4.4. There were 352 multistory brick buildings in the 14 districts and of these, 117 collapsed completely, 85 suffered partial collapse, 99 suffered severe damage, 34 sustained moderate damage, 13 sustained slight damage, and 4 received no damage at all. Approximately one third of the buildings were in these 14 districts.

Another interesting study involved applying the building code requirements in reverse. For each story of a building a computation was made

TABLE 4.4 Tangshan City Damage to Multistory Brick Buildings in the 14 Selected Districts Shown in Figure 4.21 (Institute of Engineering Mechanics, 1978)

District	Collapse		Damage			
Number	Complete	Partial	Severe	Moderate	Slight	None
1	21(70)[a]	6(20)	3	0	0	0
2	15(52)	9(31)	5	0	0	0
3	11(64)	3(18)	3	0	0	0
4	18(42)	15(35)	6	4	0	0
5	8(38)	5(24)	6	2	0	0
6	16(40)	10(25)	13	1	0	0
7	9(22)	14(35)	16	1	0	0
8	0	2(11)	10	2	4	0
9	0	3(43)	4	0	0	0
10	0	2 (9)	11	3	5	1
11	0	8(25)	12	7	3	3
12	0	0	3	6	0	0
13	0	8(42)	3	7	1	0
14	19(79)	0	4	1	0	0
Total	117(33)	85(24)	99(28)	34(10)	13(4)	4(1)

[a] Numbers in parentheses are percentages.

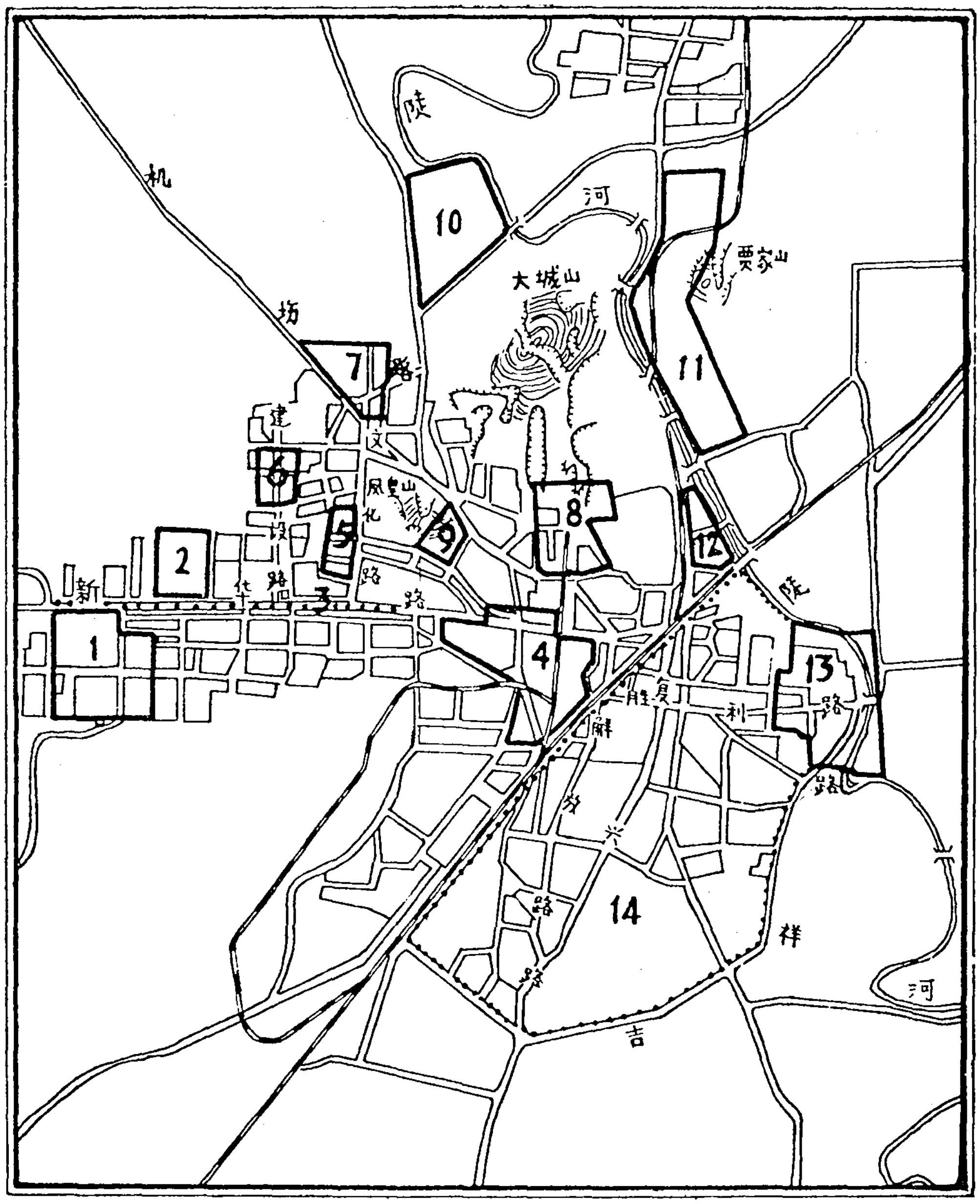


FIGURE 4.21 Plan of Tangshan City showing the 14 districts in which special damage studies were made (Table 4.4). Three hundred and fifty-two multistory buildings in these 14 districts were studied; a total of 916 multistory buildings were in Tangshan. Most of these buildings were unreinforced brick structures.

of the seismic coefficient corresponding to the area of brick shear walls, as the code would view it. Such calculations were made for 219 buildings; a few examples are shown in Table 4.5. Each number in Table 4.5 represents the base-shear coefficient that would correspond to the area of shear walls in that story. Figure 4.22 shows the results of the calculations for seven of the 14 districts plotted in a very informative way. It is seen that buildings for which the computed seismic coefficient was less than 0.25 almost all collapsed. On the other hand, special buildings for which the smallest computed seismic coefficient was greater than 0.7 mostly survived with only a small amount of damage and, in a few cases, with little or no damage. Figure 4.23 shows a plot made of the calculated seismic coefficient versus epicentral distance at which cracking in the brickwork was just initiated.

Chinese investigators have made comprehensive classification studies of the damage, and summaries of some of this work are contained in the papers given to our Delegation. In these investigations, considerations were given to such variables as type of building, degree of damage, seismic resistance of the building (as designed, and including consideration of ductility and material properties), location in Tangshan City, foundation conditions, etc. It was said that some buildings that had been strengthened after construction fared somewhat better than those that had not received retroactive strengthening.

TABLE 4.5 Code Base-Shear Seismic Coefficients, Corresponding to the Code Strength of the Story, for Five Buildings From Two to Five Stories High

	Story					
	1	2	3	4	5	Damage
Building 1						Partial collapse
L	0.0854	0.0805	0.0738	0.0897	0.158	
T	0.154	0.137	0.131	0.155	0.254	
Building 2						Complete collapse
L	0.144	0.146	0.170	0.298		
T	0.0658	0.069	0.084	0.156		
Building 3						Complete collapse
L	0.098	0.109	0.167			
T	0.157	0.170	0.258			
Building 4						Serious damage
L	0.332	0.506				
T	0.342	0.539				
Building 5						Serious damage
L	0.273	0.304	0.486			
T	0.199	0.226	0.375			

L, longitudinal; T, transverse. Calculated coefficients for 219 buildings are given in Yang et al. (1978).

As pointed out in the beginning of chapter 3, buildings in China are classified into three groups ranging from mud and adobe houses to modern brick and concrete structures. A summary of damage to these three types of buildings as a function of intensity is shown in Table 4.6. (The Chinese intensity scale is essentially the same as the Modified Mercalli scale.) Most class I buildings collapsed in areas where the intensity

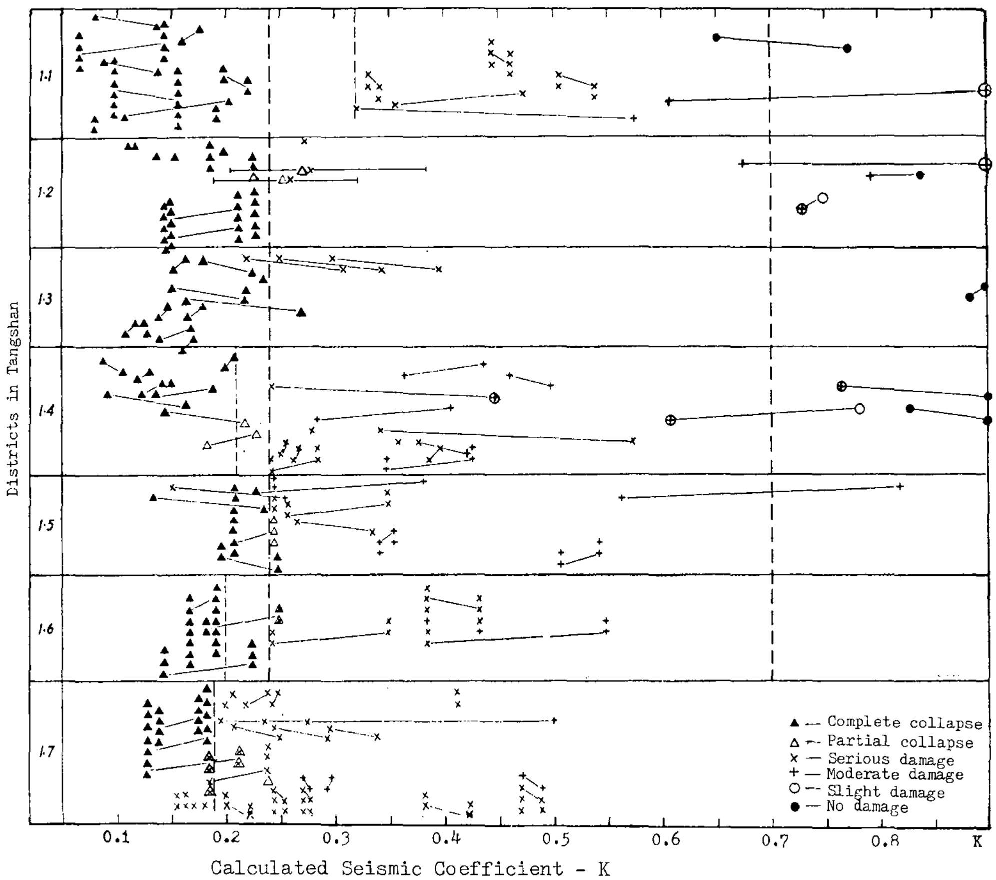


FIGURE 4.22 Plot of seismic coefficients for seven districts in Tangshan. This is a plot of calculated base-shear seismic coefficients, according to the building code, corresponding to the area of shear walls in a story. The minimum base-shear value is plotted except when only one story was damaged, and then the seismic coefficient corresponding to this story is plotted (see Table 4.5 and Figure 4.21). This plot shows clearly how the nominal code strength of the building relates to the degree of damage. When the seismic coefficient was less than about 0.25, most structures collapsed; when the seismic coefficient was greater than about 0.7, the structure survived with little or no damage (from Yang et al., 1978).

TABLE 4.6 Lower-Bound Effects of Different Intensities Greater Than VI, Tangshan Earthquake

Intensity	Water Tower Supported on Brick Cylinder	Brick Smokestack	Class I Buildings	Class II Buildings	Class III Buildings	Other Phenomena
VI	--	Slightly collapsed	Few collapsed	Walls collapsed occasionally	--	Sand blows and mudspouts may be observed
VII	Slightly cracked in the lower portion	Generally, but not all, cracked, upper portion fallen	Most collapsed	Few collapsed	Walls collapsed occasionally	Serious liquefaction occurred
VIII	Generally cracked with a few collapsed	--	Nearly all collapsed	Most collapsed	Few collapsed	--
IX	--	Generally, but not all, broken into several sections, the upper portion fallen	--	Nearly all collapsed	Most collapsed	--
X	Nearly all fallen down and collapsed near ground surface	Nearly all collapsed near the ground surface	--	--	Nearly all collapsed	--

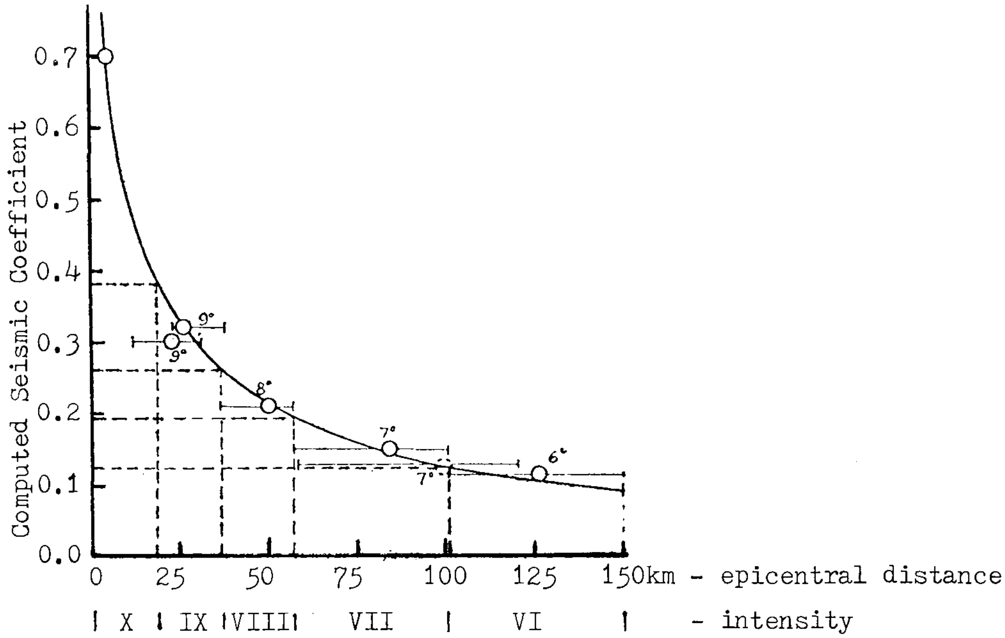


FIGURE 4.23 Plot of seismic coefficient versus intensity that produced the initial cracking, Tangshan earthquake. This is an idealized plot for the Tangshan earthquake, showing the intensity and epicentral distance at which buildings experienced initial cracking (reproduced from Yang et al., 1978).

was as low as VII. There is no doubt that class I buildings, which presumably were mainly dwellings, had very low earthquake resistance and were extremely hazardous to the occupants. Table 4.7, which was presented by T. Y. Chang, shows the percentages of structures of various categories that suffered collapse or serious damage as a function of intensity.

A summary of damage to elevated water tanks, elevated storage containers, and ground-based liquid storage tanks is given in Table 4.8. Many elevated water tanks were supported on brick or stone cylindrical silo-type structures, and these were severely damaged by the earthquake.

It was reported that many mill (industrial) buildings were located in zones experiencing intensity X and XI damage. Most of the mill buildings were single story, but in a few cases there were multistory rigid-frame mill buildings. The one-story mill buildings had reinforced concrete columns or brick (unreinforced) columns, though a few were reported to have had steel columns. The information in Table 4.7 about mill buildings refers particularly to those buildings with brick columns, which would naturally have low resistance against earthquake forces. In the evaluation of the damage the roofing systems were divided into two

TABLE 4.7 Percentage of Structures of Each Category in Tangshan Suffering Collapse or Serious Damage as a Function of Intensity

Zone Intensity	Buildings More Than Three Stories	Two-Story Brick Buildings	Mill Buildings (with Brick Columns)	Water Tanks on Brick Cylinders	Brick Smokestacks (30-40 m High)
XI	95.5	77.6	96	100	100
X	65.0	23.6	75	88	78
IX	11.0	--	95	89	--

groups, the heavy type described as consisting of reinforced concrete slabs on steel trusses and a light type consisting of an asbestos corrugated roofing on steel trusses or steel purlins. In some cases, mill buildings had reinforced concrete frames that served to support lighter framed stories above the heavier mill building. Some of the mill buildings had adjacent attached bays, typically with roofs at lower levels. Usually, the buildings were not symmetrical in cross section. The gable end walls and the long unsupported side walls were described as weak elements, and many of these were lost in the earthquake.

Fifty percent of the damage to mill buildings occurred in the roofing system, most of it in the heavy-type roofing systems. In such cases, the roof slabs were reported to have fallen when bracing failed between the trusses. In the case of Vierendeel trusses, a number collapsed from apparent overstress.

Some heavy cranes fell during the earthquake, but many of them were reported to have stayed in place. The primary cause of crane failure was the poor bracing of the beams supporting the crane rail and poor connections to the supporting columns. It was noted that the mill buildings had been designed only for low levels of wind loading and thus did not have much resistance against earthquake forces.

A number of columns were reported to have failed because of poor lateral support. In cases where folded-plate roofs were used (often these were prestressed concrete slabs with reinforced concrete connections), failure of the connections and loss of the panels led to column overstress. Frames with infilled walls between the columns seemed to fare better than those without infilled walls. It was noted that frequently changes in stiffness (for example, points of attachment of X-bracing, or short columns supporting heavy roofs) were points of overstress susceptible to damage. Flexible stories were also susceptible to damage. It was concluded that much damage was caused by injudicious practices that induced force concentrations and stress concentrations.

According to Table 4.7, approximately 90 percent of the mill buildings in Tangshan either collapsed or were seriously damaged. This damage would strongly affect industrial production so that the loss to

TABLE 4.8 Summary of Damage to Tanks in Tangshan Earthquake (from Chang, FY, 1978)

Tank	Undamaged	Slightly Damaged	Moderately Damaged	Seriously Damaged	Collapsed
Elevated water tank					
Brick	0	2	7	7	5
Stone	0	1	9	2	1
Reinforced concrete	1	1	2	0	0
Elevated storage container	0	2	0	3	4
Liquid ground-based storage tank	31	25	6	29	1

Elevated storage containers consist of reinforced concrete columns supporting containers for coal, cement, etc. Liquid ground-based storage tanks are 9-36 ft in diameter, 9-36 ft in height.

society would greatly exceed the cost of repairing or rebuilding the mill buildings. Photographs of earthquake damage in Tangshan were given to the delegation. A selection of the more interesting photographs is shown in Figures 4.24-4.53. Although most buildings were severely damaged, it is significant that some well-designed structures survived with little damage, as shown in Figures 4.51-4.53.

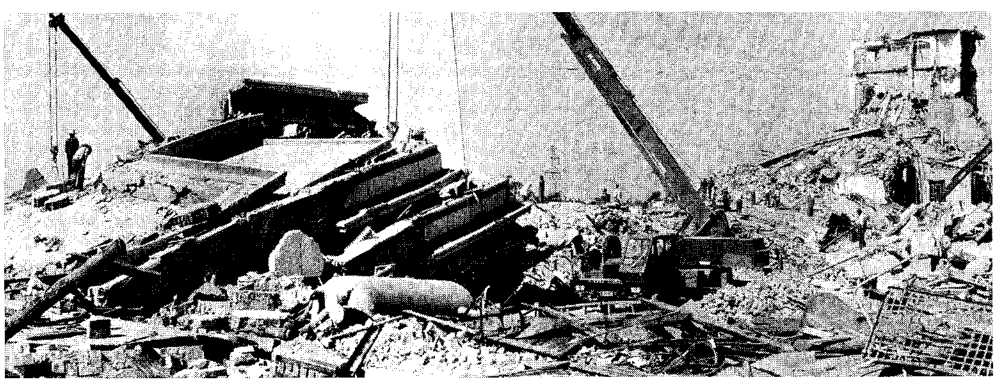


FIGURE 4.24 Collapsed out-patient service building of the Kailuan coal mine general hospital, Tangshan.

FIGURE 4.25 Collapsed top story of the three-story Kailuan coal mine dormitory, Tangshan.

FIGURE 4.26 Collapsed four-story Tangshan Mine-Metal Institute residence building.

FIGURE 4.27 Collapsed five-story physics-chemistry building of the Tangshan Mine-Metal Institute.

FIGURE 4.28 Collapse of Kailuan coal mine reception building, Tangshan.

FIGURE 4.29 Collapsed five-story office building, Tangshan. The lower three stories had concrete columns, and the upper two stories were unreinforced brick without concrete columns.

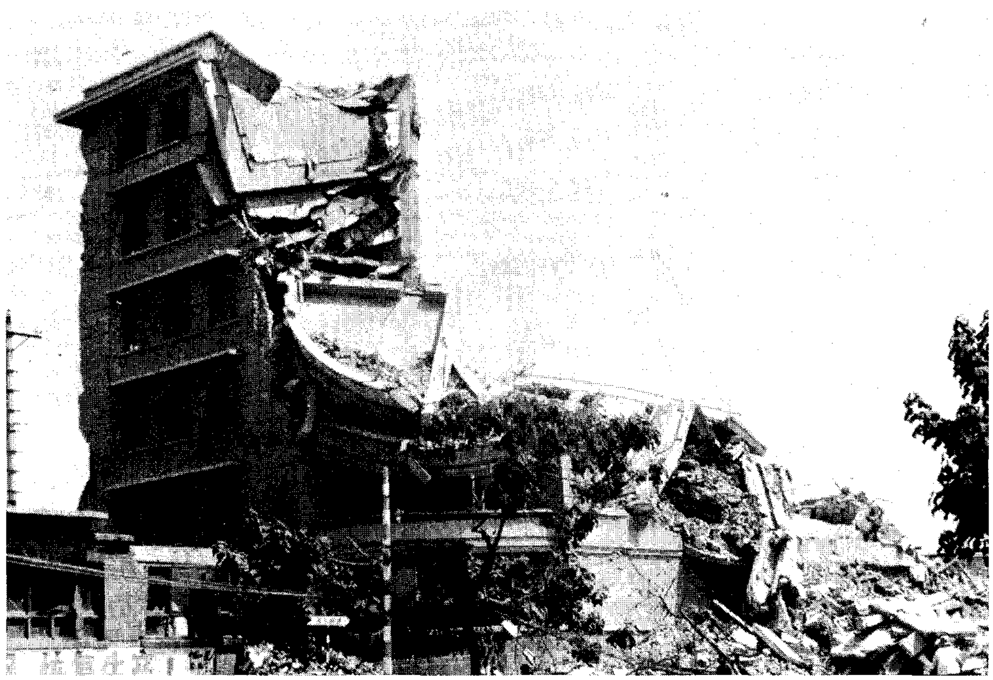


FIGURE 4.30 Collapse of six-story building at the Kailuan coal mine hospital, Tangshan.

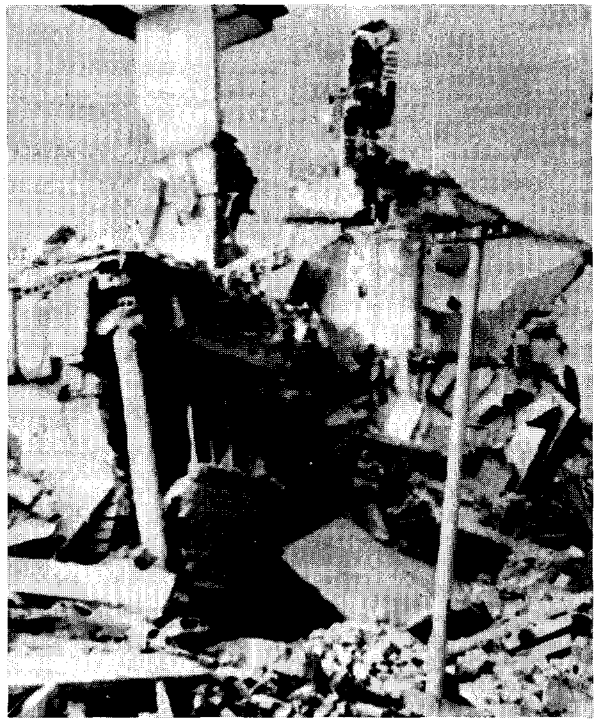


FIGURE 4.31 Collapsed building, Tangshan.

FIGURE 4.32 Eight-story Hsinhua Hotel in Tangshan was badly damaged at the fifth-story level but remained standing. In the foreground is a collapsed six-story building.

FIGURE 4.33 Collapsed workers' cafeteria building of the Chinkechuang coal mine.

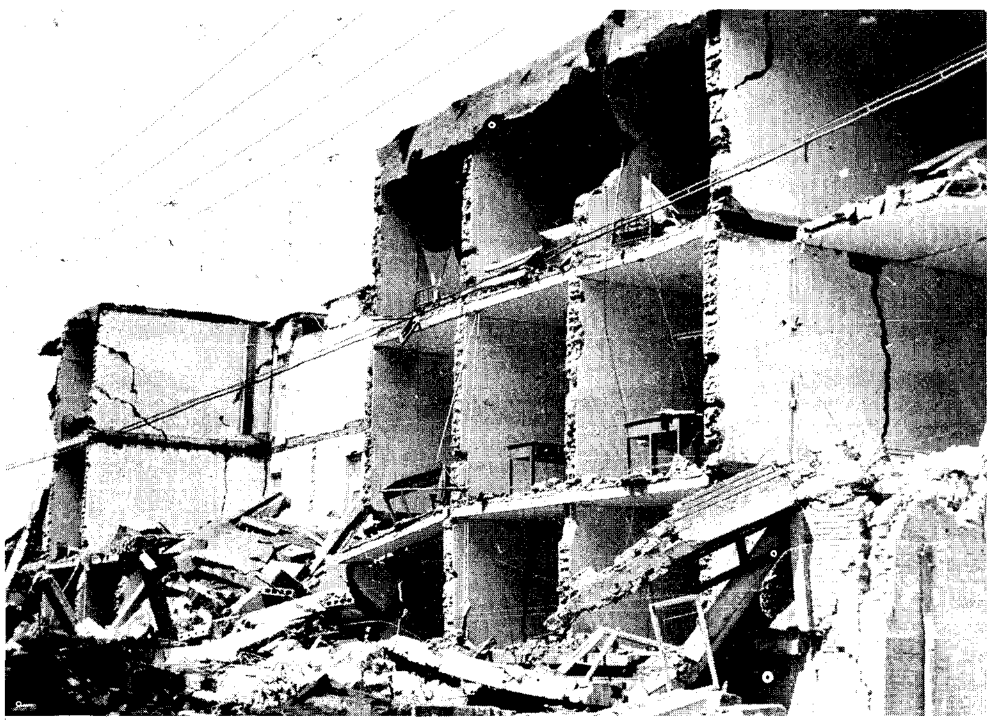


FIGURE 4.34 Partly collapsed residence building showing the type of construction: unreinforced brick bearing walls and precast concrete floor slabs.

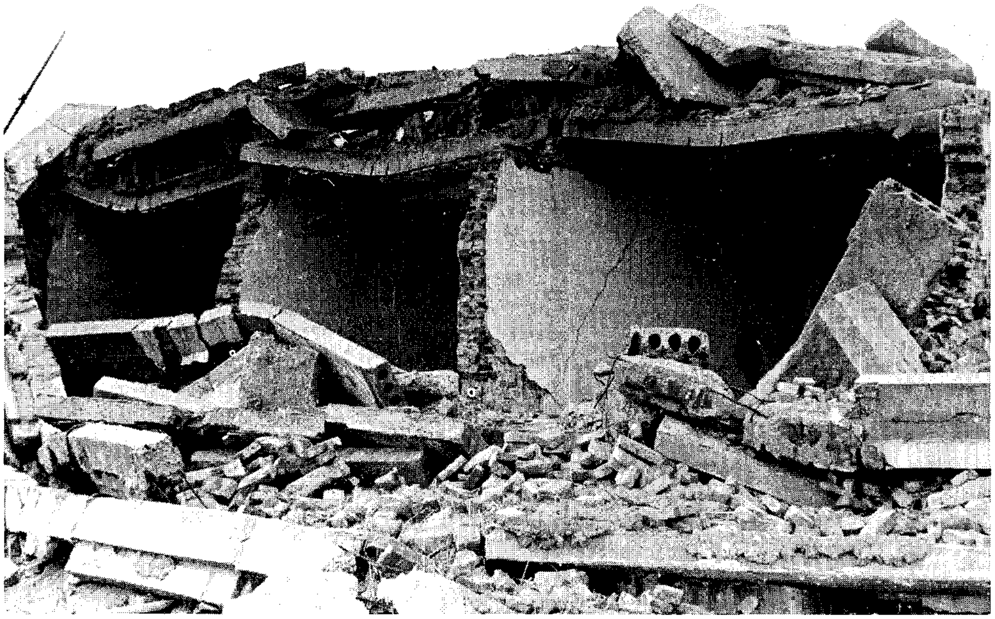


FIGURE 4.35 Collapsed building showing the type of construction: precast concrete floor slabs made of four-hole beams, simply supported on bearing walls.

FIGURE 4.36 Badly distorted brick building on the verge of collapse. The second floor appears to be of precast concrete slabs supported on precast concrete beams, which, in turn, are supported on unreinforced brick piers.

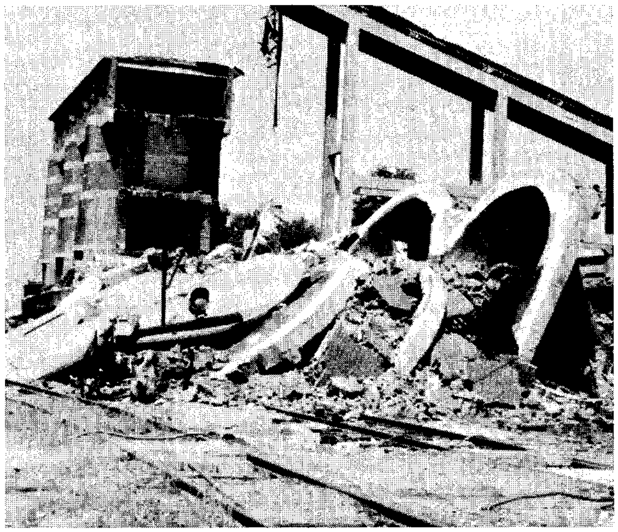


FIGURE 4.37 Collapsed brick cylindrical storage bin at the Fankechuang mine.

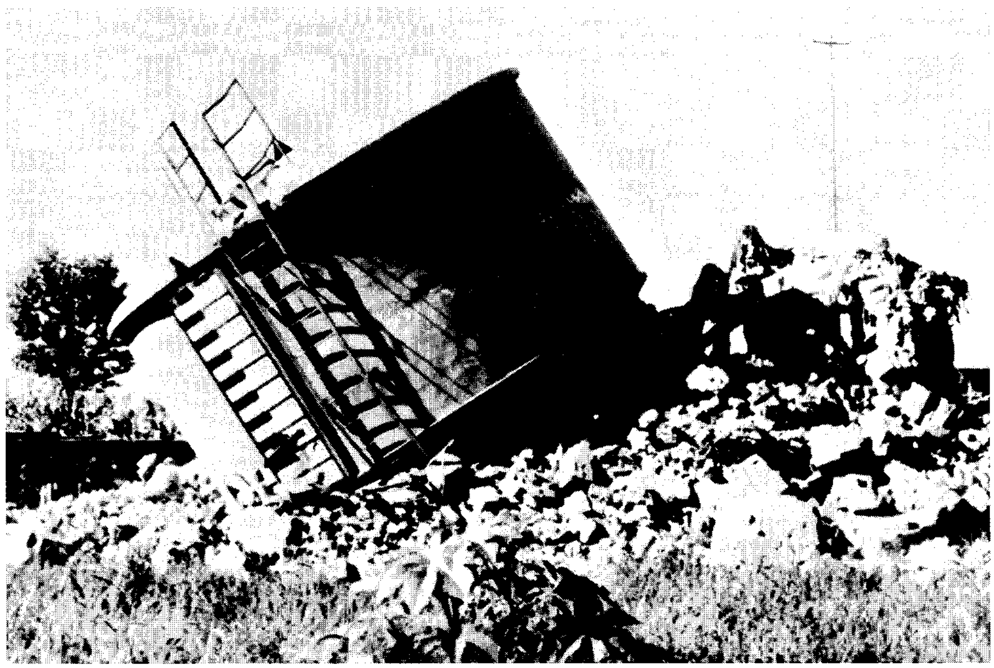


FIGURE 4.38 Collapsed elevated storage tank that had been supported on a brick cylindrical tower, Tangshan scale factory.

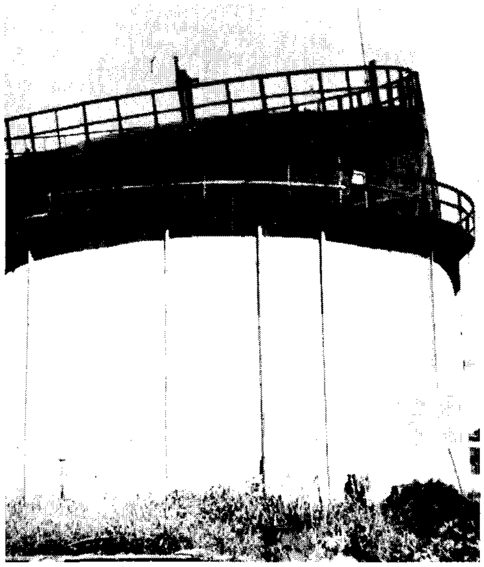


FIGURE 4.39 Damaged gas holder at Tangshan fertilizer factory.

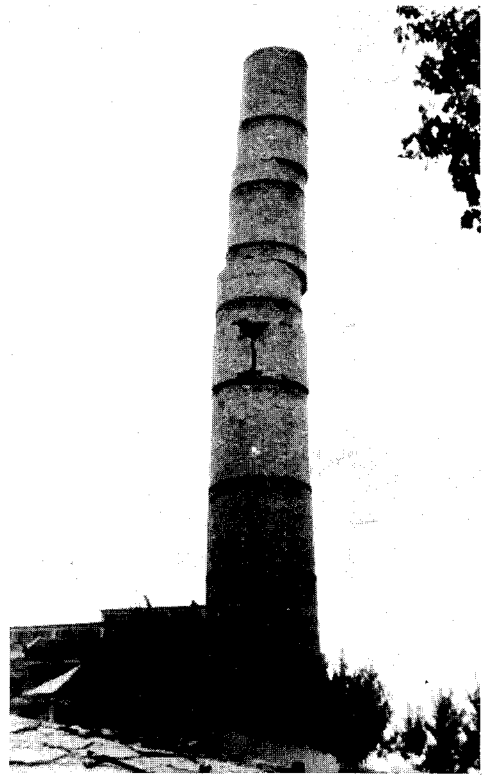


FIGURE 4.40 Damaged brick chimney at Chaokenchuang mine. The top of the chimney fell off, and four horizontal cracks appeared in the remaining portion.

FIGURE 4.41 Damaged brick chimney.

FIGURE 4.42 Tilted ventilation tower at Tangshan coal mine.

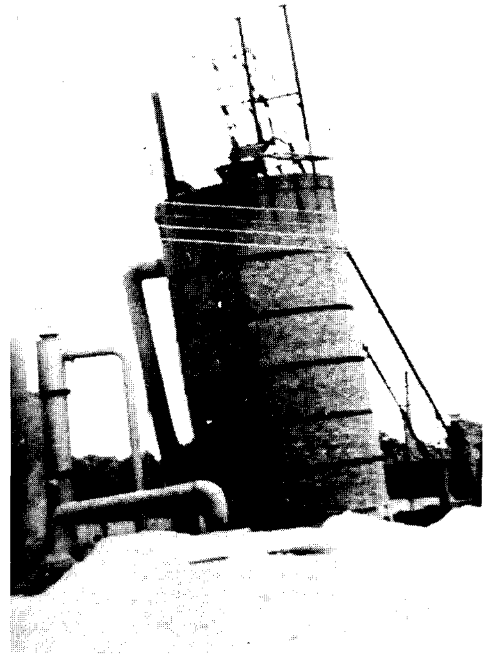


FIGURE 4.43 Tilting of a lime firing tower.

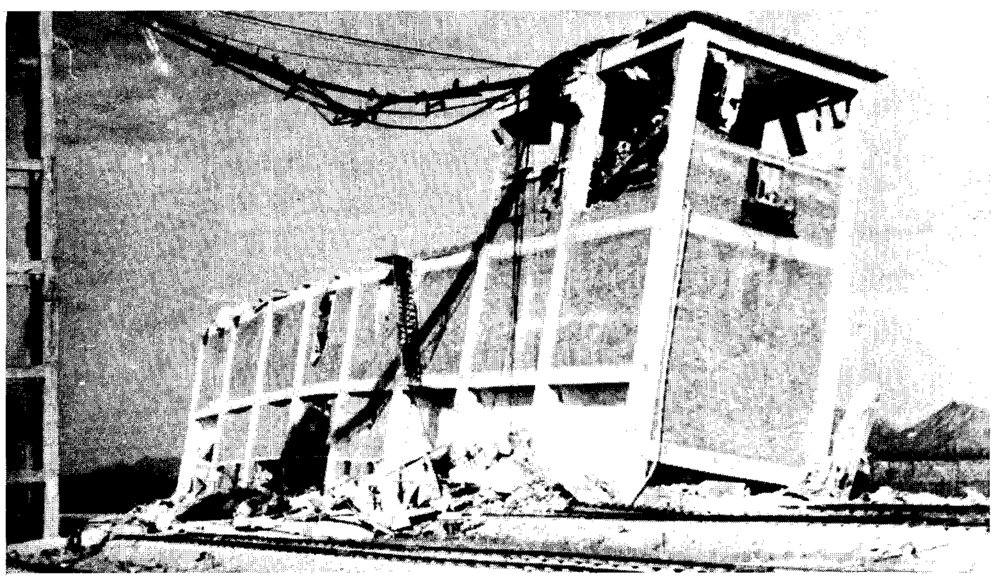


FIGURE 4.44 Collapsed coal storage structure at Chinkechuang.

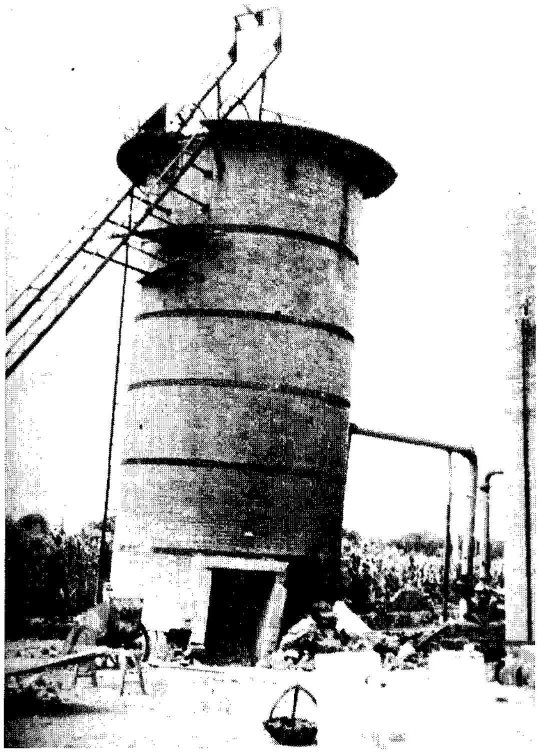


FIGURE 4.45 Tilting of brick cylindrical storage bin.

FIGURE 4.46 Partly collapsed five-story building at Coal Mine Design Institute in Tangshan.

FIGURE 4.47 Uneven settlement of office building, Fankenchuang Commune, Luan-nan Hsien.

FIGURE 4.48 Damaged building at Kailuan coal mine general hospital in Tangshan.

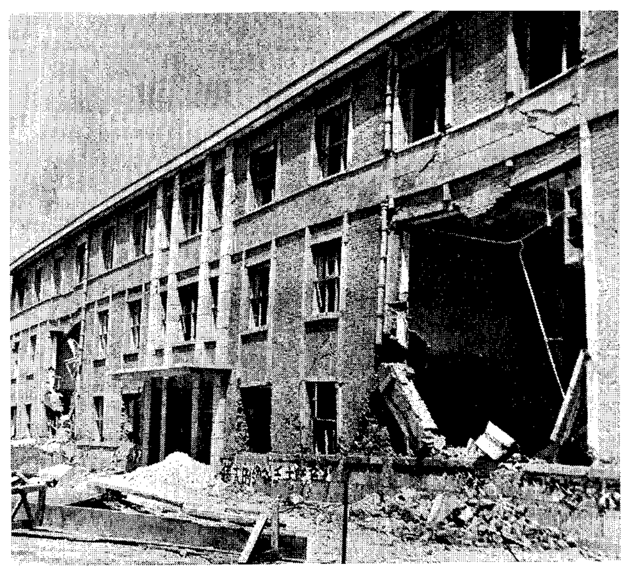


FIGURE 4.49 Damaged reception building in Tangshan.

FIGURE 4.50 Damaged Tangshan second reception building. Although damaged, this two-story brick building remained standing.

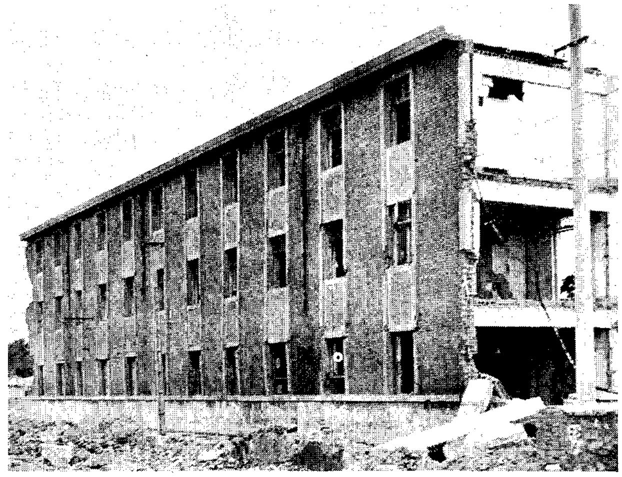


FIGURE 4.51 Damaged car factory dormitory building in Tangshan. The first story was most severely damaged but the building remained standing.

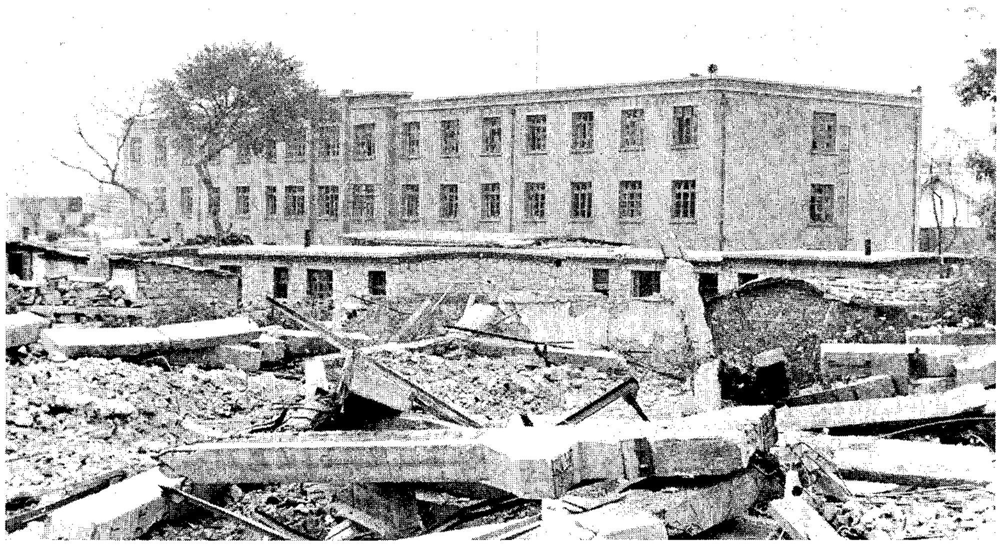


FIGURE 4.52 Tangshan light-machine plant official building. This structure, which was located in district 13 of Figure 4.21, was only slightly damaged. The remains of a collapsed building can be seen in the foreground.

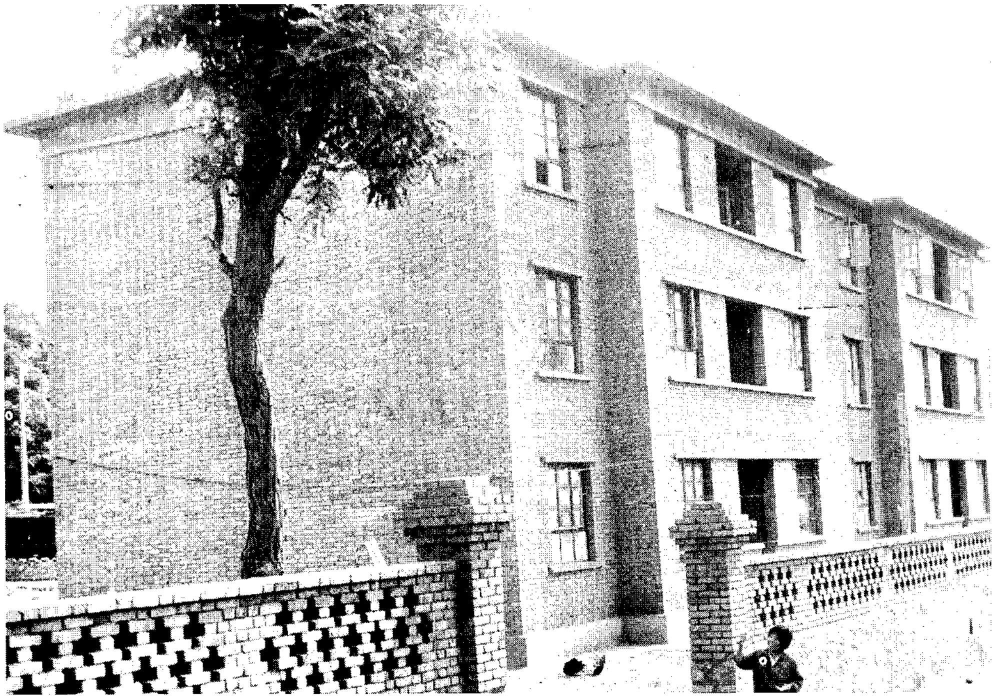


FIGURE 4.53 Cement factory worker apartment building 422. This structure was located on bedrock north of Tangshan and received only slight damage.

DAMAGE TO BRIDGES

The Tangshan earthquake caused extensive damage to the highway and railway system in the general vicinity of Tangshan. Highway pavements and railroad lines were extensively damaged by soil settlement, soil spreading, and soil deformation. Twenty highway bridges collapsed or were seriously damaged, and an additional 211 were damaged to a lesser degree. In addition, railway bridges were also damaged. Most of the damage to bridges was caused by poor behavior of the soils: soil spreading caused inward movement of bridge abutments and subsequent failure or collapse of the deck. Similar damage to bridges was caused by the great 1964 Alaska earthquake and, in fact, is commonly found in regions where very soft soils are stressed by strong ground shaking. The general soil conditions in the Tangshan region of heavy damage were quite poor; the soils consisted mainly of weak materials such as marine deposits and thick layers of silty sands. During the earthquake, upward water flow that caused sand venting was a common occurrence, thus indicating that liquefaction had occurred at depth. Two types of soil failure were responsible for most of the damage to bridges. In one type a circular

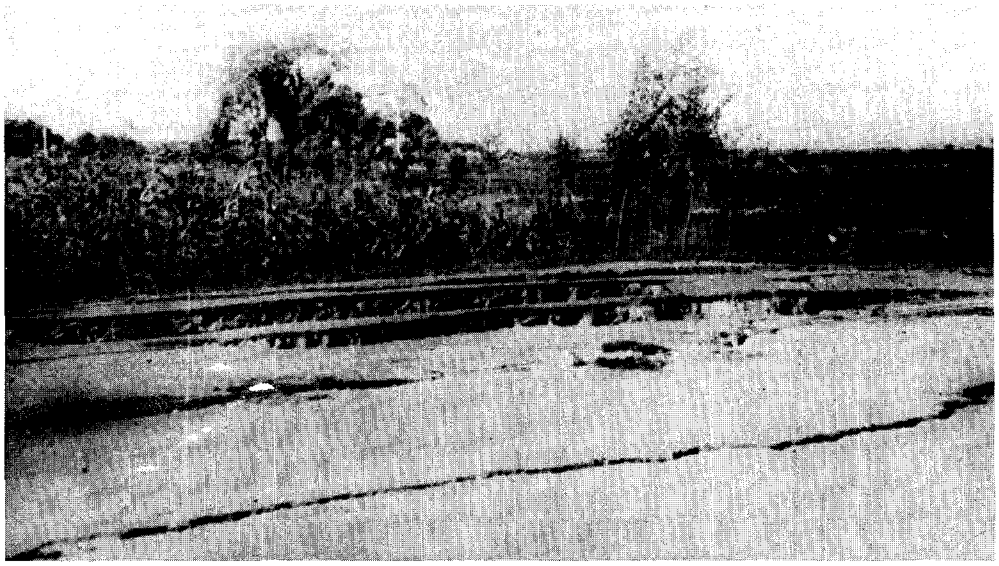


FIGURE 4.54 Large landslide at east bank of Tanshan River, which caused damage to the Yenchuang Bridge.

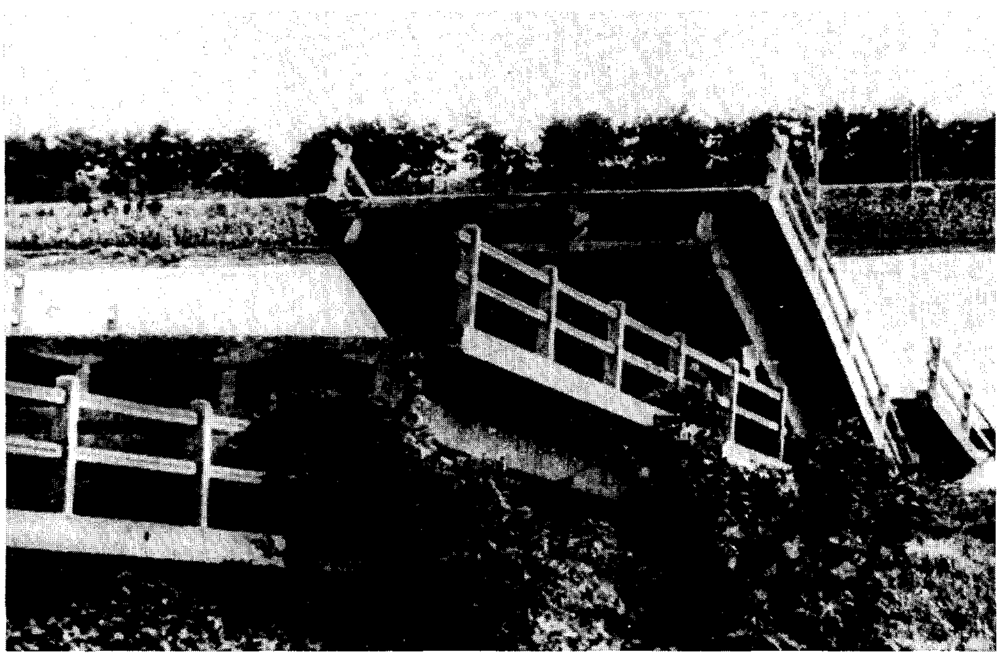


FIGURE 4.55 Deck spans of Yenchuang Bridge were pushed off their supports by the landslide.

failure surface developed under the abutment, and in the other type, high earth pressures behind the abutment caused it to slide toward the center of the bridge (Ho and Kao, 1978). In both types of failure, large settlements occurred behind the abutments and large transverse cracks developed. There was evidence that liquefaction of the loose backfill materials contributed to many of the soil-abutment failures.

The inward movement of bridge abutments caused an inward shifting of the deck spans which progressively closed the joints separating them, thus transferring abutment backfill loads to supporting columns and piers, causing them to fail in many cases. This compressive action also caused some failures to deck spans and, in the case of railroad bridges, caused buckling of the steel rails.

Some Representative Cases of Bridge Damage

To illustrate the type of bridge damage that occurred during the Tangshan earthquake, four cases will be described briefly: the Yenchuang and the Janshan highway bridges and two railway bridges located on the Tangshan-Kenhua and Peking-Shanhaikuan lines.

Yenchuang Bridge

This bridge crossed the Tanshan River at a location where the earthquake intensity equaled IX on the Chinese scale. The deck was supported by simple span-reinforced concrete girders, which in turn, were supported on double-column piers. A large slide occurred at the east bank, shown in Figure 4.54, which forced the abutment to move inward and many of the piers to tilt eastward, thus allowing the first 14 spans from the east abutment to fall into the river, as shown in Figure 4.55.

Janshan Bridge

This bridge crossed the Jan River at a location where the earthquake intensity equaled IX. The deck consisted of 35 simple spans supported on built-up block piers approximately 15 m high. Each simple span had a hinge support at one end with a roller support at the other. The roller support was positioned 0.5 m in from the edge of the pier. The earthquake caused the piers to tilt sufficiently to allow many spans to fall into the river, as shown in Figure 4.56.

Railway Bridge on Tangshan-Kenhua Line

This bridge crossed the Tou River at a location where the earthquake intensity was X. Soil fracture at the right abutment, shown in Figure 4.57, forced it to move inward, causing the deck to move to the left and to tilt two piers and break the left abutment at midheight. The steel rails on the deck buckled into an "S" shape.

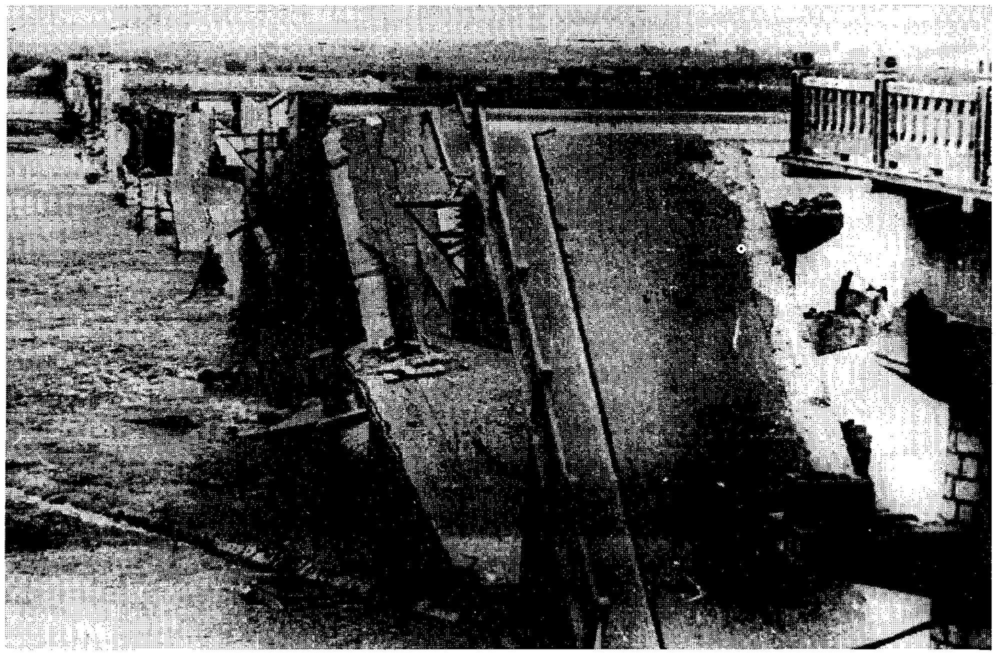


FIGURE 4.56 Fallen spans of the Janshan Bridge.

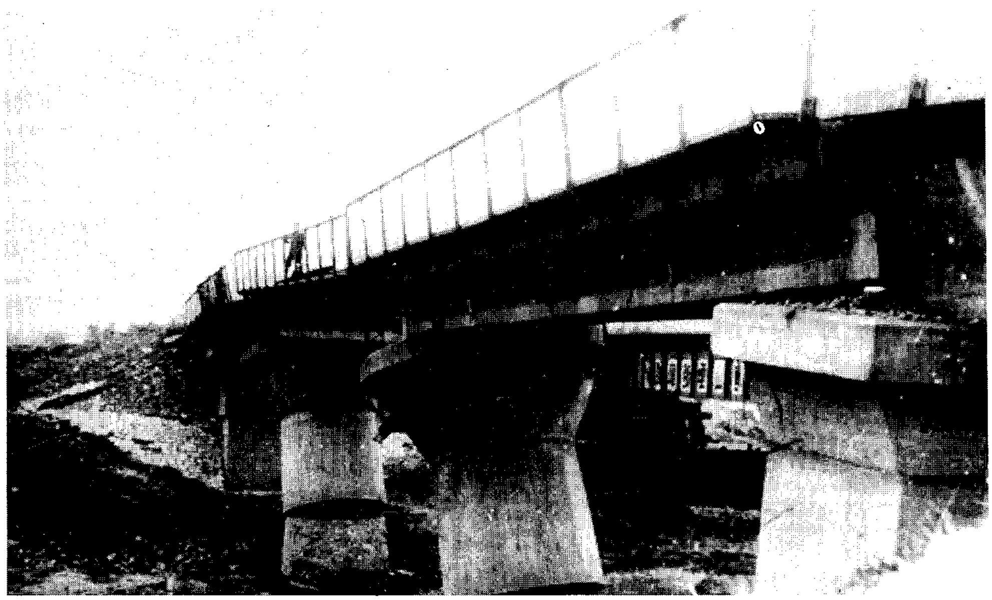


FIGURE 4.57 Tilted piers and broken abutment of the railway bridge on Tangshan-Kenhua Line.

Railway Bridge 55 on Peking-Shanhaikuan Line

This bridge crossed the Chi Canal at a location where the earthquake intensity was IX. During the earthquake both abutments moved inward and shortened the distance between them by 2.1 m. This compressive movement caused buckling of the steel rails (Figure 4.58) and fracturing of a supporting pier (Figure 4.59).

FIGURE 4.58 Buckled steel rails on railway bridge on Peking-Shanhaikuan line.

FIGURE 4.59 Broken pier of railway bridge 55 on the Peking-Shanhaikuan line.

BEHAVIOR OF SOILS

All the usual manifestations of soil liquefaction were observed during the Tangshan earthquake. Sand boils, lateral spreading and subsidence, slumping of embankments and of the banks of rivers and canals, and sand entering water wells all occurred during the earthquake (Figures 4.60-4.64). Adverse soil behavior affected buildings with differential settlements, bridge supports settled and collapsed, and irrigation systems were affected. It was reported that in one village near the coast, the ground surface settled 3 m with resulting permanent flooding. Some instances of liquefaction also occurred during the magnitude 7.1 aftershock on November 15, 1976. As shown on the map (Figure 4.60), the effects of liquefaction were especially severe between Tangshan and the coast, and along the old courses of rivers, such as the Luan River, which flowed southward from the Yin Shan Uplift Province to Pohai Gulf. Along the banks of the Hai River there was considerable damage to buildings, apparently related to lateral spreading and subsidence, but there was little evidence of building damage from ground shaking. This apparently was the explanation for the zone of intensity IX embedded within a zone of intensity VIII on the intensity map.

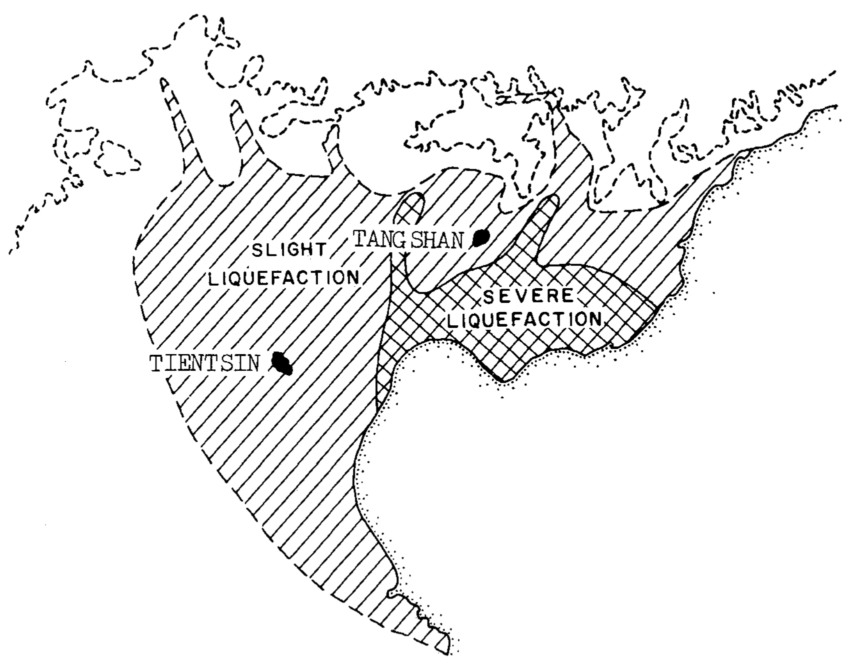


FIGURE 4.60 Map of Tangshan-Tientsin region showing areas of liquefaction.

FIGURE 4.61 Structure damaged by unequal ground settlement.

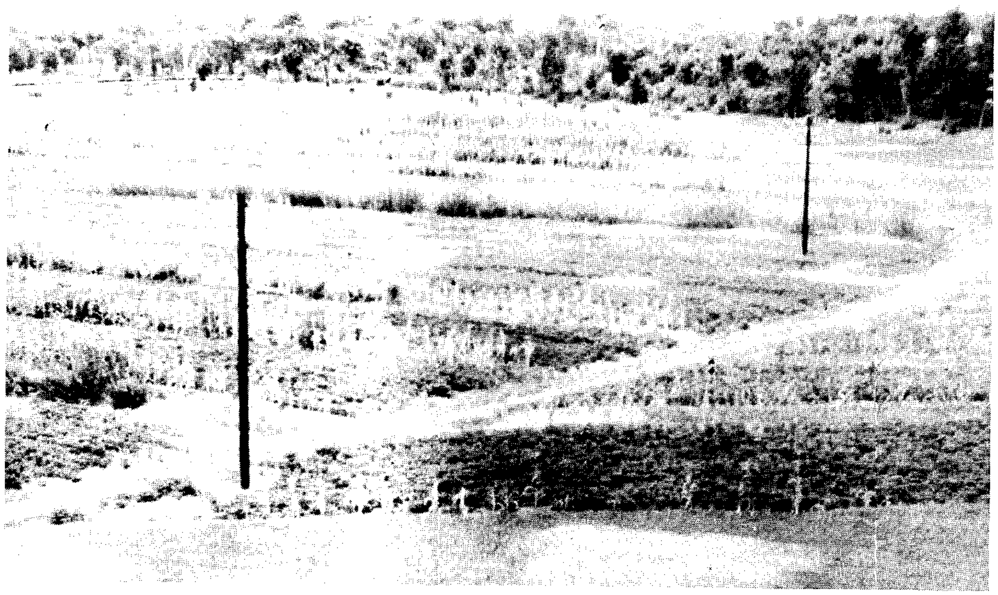


FIGURE 4.62 View of sandblows in a field.

Occasional instances of sand boils, filling of wells, and bank slumping occurred within the much larger area of "slight liquefaction" shown in Figure 4.60. In Tangshan City, although there was conflicting testimony, the effects of liquefaction apparently were not severe. One report mentioned that the upper portions of some mine shafts were damaged because they passed through liquefied sands, but other engineers said that the sand had not liquefied. A few buildings along the river apparently were damaged by slide failures. Underground pipes received some damage (Table 4.2).

It was reported that sand boils began to appear a minute or so after the earthquake and continued to flow for several minutes and in some cases for several hours. (A story from the 1970 Tunghai earthquake in Yunnan Province related that a man walked across the river bed immediately after the earthquake but then could not return because of the liquefaction.) Sand blows were quite common in irrigation ditches and caused considerable damage to farmland irrigation systems. One sand blow is reported to have had a height between 2 and 3 m. Figure 4.62 shows sand blows in a field.

The Tangshan earthquake provided relatively little new information about liquefaction, mainly because there were no strong-motion records of ground shaking in the regions where liquefaction occurred. The Chi-

FIGURE 4.63 Damage to a road caused by soil failure.

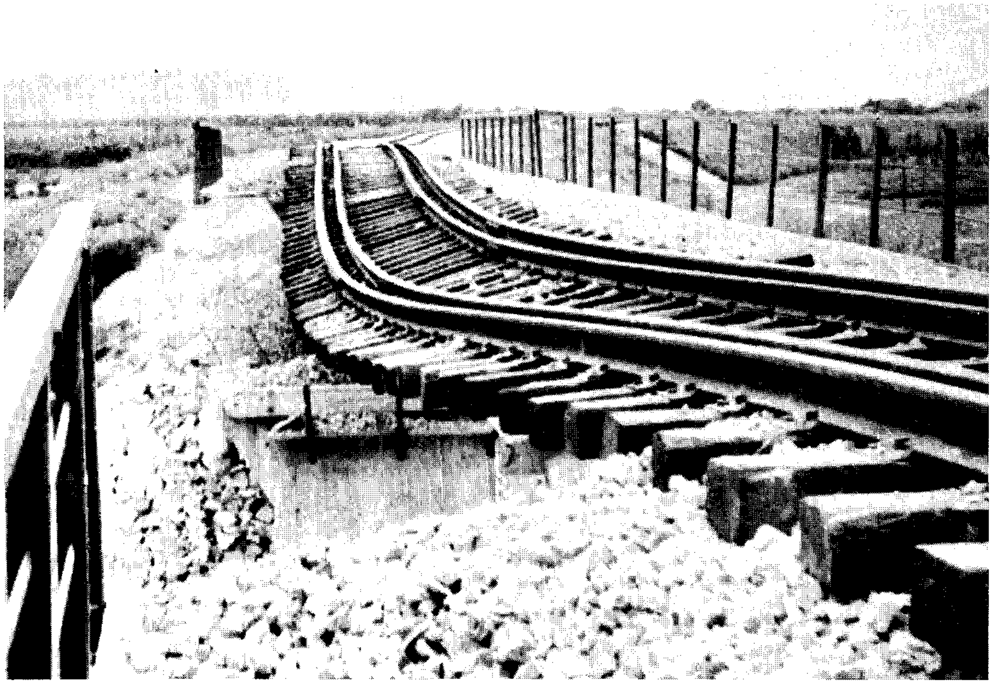


FIGURE 4.64 Damage to railway line caused by loss of support.

nese engineers thought that the relation between threshold intensity and blow count was confirmed by experience during the Tangshan earthquake; however, the report on this subject had not been completed at the time of our visit. A previously published relation between magnitude and greatest distance to liquefaction ($D_{max} = 0.87M - 4.5$) was also felt to have been confirmed. The Tangshan earthquake clearly spurred interest in basic research on liquefaction, and it is expected that there will be many publications on this subject in the future.

Some of the Chinese engineers cited instances of damage that they attributed to the influence of soils, local geology, or local topography. Some of these were (1) in northern Tangshan, brick buildings founded upon limestone outcrops were little damaged, whereas similar buildings built upon class II soil elsewhere in the city collapsed; (2) at a hill 200 m high and some distance from Tangshan, buildings at the foot of the hill were undamaged, whereas a temple on top of the hill collapsed; (3) in Tientsin, multistory buildings built over filled ground were much more heavily damaged than buildings elsewhere in the city; (4) also in Tientsin the damage to underground water supply trunk lines varied with the soil conditions, from 0.2 breaks/km within the best soil, to 4.2 and 10 breaks/km in parts of the city with poorer soils. On the other hand, the coal seams beneath a portion of Tangshan had been left unmined so as to reduce the likelihood of subsidence damage to the railroad, and damage to buildings was observed to be the same over the mined and the unmined areas.

Following the Haicheng earthquake, Chinese engineers reported evidence that buildings founded over soils with a soft layer had been screened from damaging ground motions. They described several similar observations in connection with the Tangshan earthquake: (1) In Tangshan itself, some buildings founded over the soft stratum of silt near the river appeared to be less damaged than similar buildings over soil without a soft stratum; (2) in Tientsin, damage to multistory buildings was least in an area where there was a soft layer within the soil profile. However, in neither of these cases was there instrumental data to support the hypothesis.

The Tangshan earthquake yielded very little direct information concerning the effects of local soil and geological conditions upon strong ground motions. For the main shock the only data comparing motions on soil and rock came from stations at a distance of 400 km from the epicenter; in this case the peak acceleration on soil was somewhat more than twice that on rock. Two records were obtained in or near Tangshan City during the after shock of November 15, which was located some 50 miles away. The recording stations were 6 km apart, one on limestone and the other sited on 100 m of alluvium (20 m of coarse sandy clay and 80 m of sandy gravel) overlying rock. The peak acceleration on the surface of the soil was about 2.5 times that on the rock. Several normalized spectra from the main shock and aftershocks showed amplification in the long-period region for records on soil as compared to those on rock.

BEHAVIOR OF EARTH DAMS

It was reported that 40 earth dams were damaged by the Tangshan earthquake. There was a partial failure of the Paiho main dam at Miyun reservoir. This dam is on the upper reach of the Chao and Pai rivers, 90 km

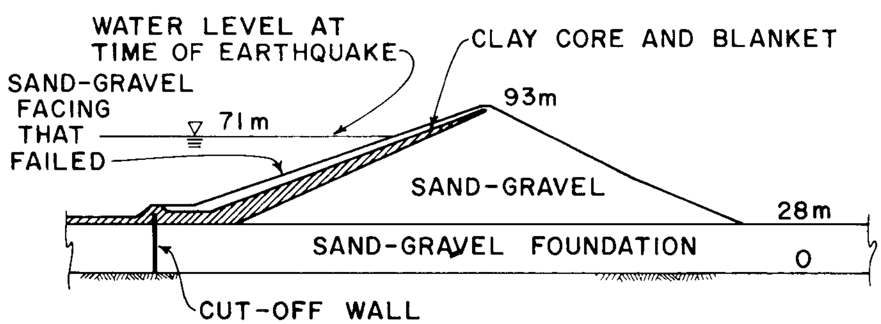


FIGURE 4.65 Cross section of Paiho main dam at Miyun reservoir. During the earthquake the sand-gravel facing on the upstream face of the dam slumped down.

northeast of Peking and about 150 km from the epicenter of the earthquake. The dam was built between 1958 and 1960 and had a maximum height of 66 m and a total crest length of 960 m. It had a thin upstream-sloping clay core with a blanket of sandy gravel 3-5 m thick. A schematic cross section is shown in Figure 4.65. At the end of the earthquake the water level was 21.6 m below the crest. The sand-gravel facing over the clay core failed over almost the entire length of the dam. The upper scarp was close to the water line, ranging as much as 2-5 m above or below the water line. The total volume of slide material was 150,000 m^3. The sliding surface was essentially within the sand-gravel layer; the clay core was exposed and scraped only at a few spots. The slope of the clay core beneath the failed facing was 2.8 on 1 while that of the upstream slope was 3 on 1 and then 3.25 on 1. The slide material came to rest on the bottom of the reservoir within 40 m of the heel of the dam. According to witnesses, the failure occurred during the earthquake. Earthquake-induced settlements of the crest reached a maximum of 59 mm, and permanent horizontal displacement had a maximum of 28 mm. This failure is of special interest because strong-motion recordings were made at the dam. According to reports furnished to the delegation, on the ground surface below the downstream toe the peak horizontal accelerations were 0.097 and 0.058g and the peak vertical accelerations were 0.065g. The corresponding peak horizontal accelerations on the crest were 0.128 and 0.16g. The accelerograms recorded on the crest showed apparent periods of about 0.6 s.

A number of studies had been made at IEM on the failure of the Paiho Dam using a finite element model and a shear beam model to analyze the dynamic response characteristics of the dam. The pseudo-dynamic safety factor for the gravel facing, using the peak observed horizontal accelerations, was 1.1-1.3. Most attention was focused on behavior of the facing material under the action of repeated loading. This material was gap-graded pebbles and fine sand, with pebbles constituting about 60 percent of the weight. Tests on a shaking table indicated that pore pressures would build up in such a soil when the pebbles made up less than 70 percent of the total weight; in such a case, the pebbles are unable to form a skeleton and the overall behavior was controlled by the fine sand. The fine sand itself had an average particle size (D_{50}) of 0.35 mm, a measured permeability of 10^{-3} to 10^{-4} cm/s, and a relative density of about 30 percent. Repeated load tests were made to determine the resistance of this sand to liquefaction using various ratios of principal stresses during consolidation and various criteria for failure. The overall conclusion was that the soil should have failed by liquefaction during the shaking, which was estimated to have had a duration of perhaps 60 cycles of motion.

The Paiho Dam was repaired by removing the remaining upstream facing, then thickening the clay core to resist cracking, and constructing a new facing using broken rocks with a transition layer of crushed stone between the rocks and the core.

A potentially more serious failure occurred at Touho reservoir about 20 km north of Tangshan. This earth dam consisted of a uniform cross section of rolled fill. It was built in 1956, and had a height of 22 m and an overall length of 1700 m. The earthquake produced cracks on both

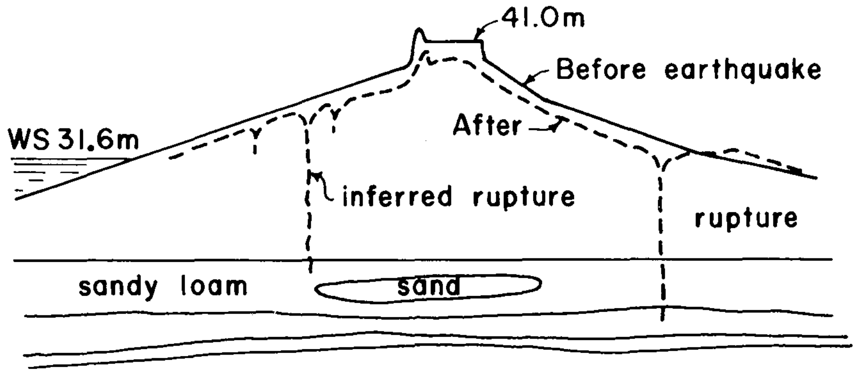


FIGURE 4.66 Sketch showing settlement of the earth dam at Touho reservoir.

the upstream and downstream faces (Figure 4.66), and the crest settled as much as 1 m. Sand boils appeared at the downstream toe and also appeared in adjacent fields. Fortunately, at the time of the earthquake the depth of water in the reservoir was only 10 m. Chinese engineers believe that this failure was the result of liquefaction in the foundation, which consisted of 8 m of cohesive soil overlying 10-12 m of fine sand. Dynamic finite element analyses were made, which, together with test results, indicated that liquefaction should have been expected.

The severity of the damage sustained by the other 38 dams was not described.

STRONG-MOTION RECORDS OF THE TANGSHAN EARTHQUAKE

The standard strong-motion accelerograph (RDZ-1-12-66) in use in China consists of a central recording unit to which 12 pickups can be attached (Figure 3.6). Approximately 18 such recorders, with pickups, were installed in northeast China at the time of the Tangshan earthquake, but there were no strong-motion instruments in place in, or near, Tangshan. Strong-motion records were obtained at 10 permanently installed stations during the main shock of the Tangshan earthquake; of the 10 stations, six produced good records and four produced poor records. Four mobile recorders were brought into the epicentral area to record aftershocks.

The locations of these stations are shown in Figure 4.67. The station at Tientsin Hospital, approximately 80 km southwest of Tangshan, was the closest permanent station to the epicenter, but only a portion of the ground motion was recorded, as the range of the instrument was set for a maximum of 0.10g. The maximum ground acceleration completely recorded during the main shock was 0.097g at Miyun dam, which is located 153 km from the epicenter. The 17-story Peking Hotel, located 157 km from the epicenter, had two RDZ-1-12-66 recorders with 19 transducers distributed throughout the building. The maximum accelerations recorded at the Peking

Hotel during the main shock were 0.040g in the basement (8 m below grade), 0.073g at grade level, and 0.200g at the roof level.

The data traces from the ground stations that produced good records during the main shock have been digitized by IEM, and the records obtained from 14 aftershocks with magnitude greater than 4.0 also have been digitized. This entire data set is summarized in Table 4.9 and is available for further analysis (Institute of Engineering Mechanics, 1978). The computed acceleration, velocity, and displacement and corresponding response spectra from a record obtained by a mobile station during the first of the two listed aftershocks on August 31 are shown in Figures 4.68-4.73.

Several preliminary studies of the strong-motion data from the Tangshan earthquake and its aftershocks have been conducted by IEM. Plots of peak acceleration versus distance exhibit a considerable scatter, and a difference in the records obtained from instruments on soil and on rock was noted. Studies of Fourier spectra from these records indicate that both soil type and propagation path have a significant influ-

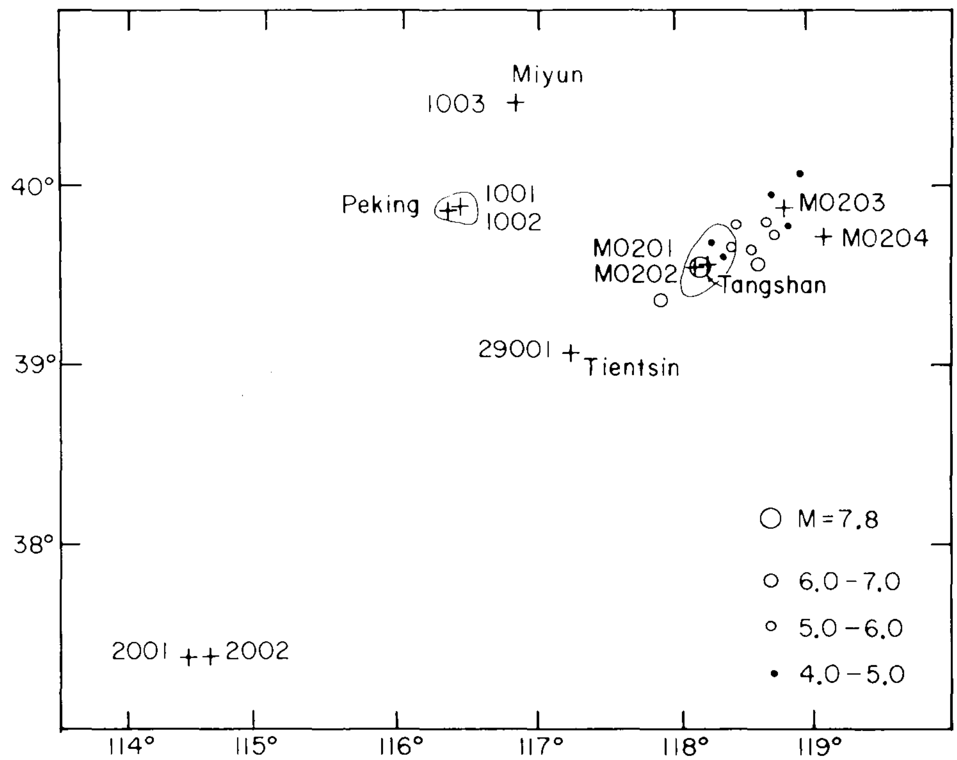


FIGURE 4.67 Locations of strong-motion instruments and locations of main shock and principal aftershocks. Instruments labeled M0201, etc., are mobile instruments installed following the main shock.

TABLE 4.9 Summary of Digitized Strong-Motion Data, Tangshan Earthquake of July 28, 1976, and Aftershocks

Date	*M*	Station	No.	Distance (km)	Acceleration (g)	Duration (s)
July 28	7.8	Miyun dam	01003	153	0.097	114
		Hujailau	01002	153	0.056	135
		Peking Hotel	01001	157	0.073	150
		Hungshan	02002	391	0.007	250
		Fungchien	02001	405	0.017	138
July 31	5.6	Tangshan Airport	M0201	31	0.034	38
Aug. 2	4.7	Tsienan	M0203	12	0.022	5
Aug. 3	4.2	Tsienan	M0203	10	0.059	5
Aug. 3	4.7	Tsienan	M0203	23	0.024	8
Aug. 5	4.2	Tsienan	M0203	12	0.024	5
Aug. 8	5.7	Tsienan	M0203	29	0.056	12
		Tangshan Airport	M0201	34	0.022	5
		Tangshan City	M0202	35	0.020	30
		Chungli	M0204	54	0.012	19
Aug. 9	5.9	Tsienan	M0203	18	0.181	23
		Chungli	M0204	30	0.036	27
		Tangshan City	M0202	51	0.005	20
		Tangshan Airport	M0201	53	0.014	8
Aug. 15	5.1	Tsienan	M0203	13	0.063	8
Aug. 15	4.9	Tangshan Airport	M0201	14	0.022	16
Aug. 18	4.5	Tangshan City	M0202	7	0.028	5
Aug. 31	6.0	Tsienan	M0203	37	0.149	22
		Chungli	M0204	44	0.036	25
Aug. 31	6.0	Tsienan	M0203	37	0.121	22
		Chungli	M0204	44	0.032	22
Sept. 25	5.6	Tsienan	M0203	38	0.042	15
Nov. 15	6.9	Tientsin Hospital	29001	67	0.150	-
		Peking Hotel	01001	140	0.039	65
		Fungchien	02001	369	0.008	64

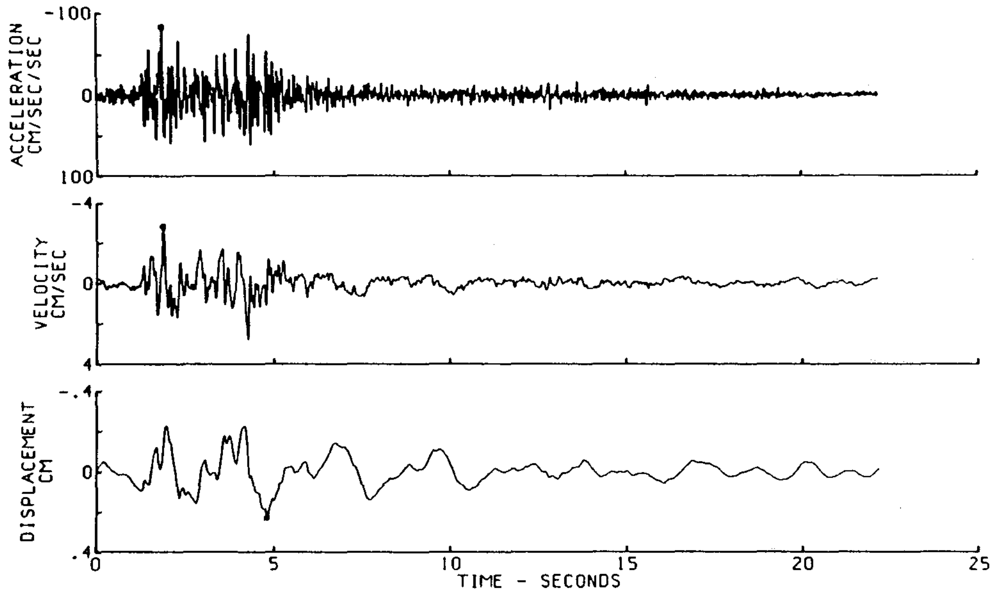


FIGURE 4.68 Corrected acceleration, velocity, and displacement, Tangshan aftershock of August 31, 1976. Tsien-An station M0203, E-W component. Peak values are acceleration, -84.0 cm/s^2; velocity, -2.83 cm/s^2; and displacement, 0.23 cm.

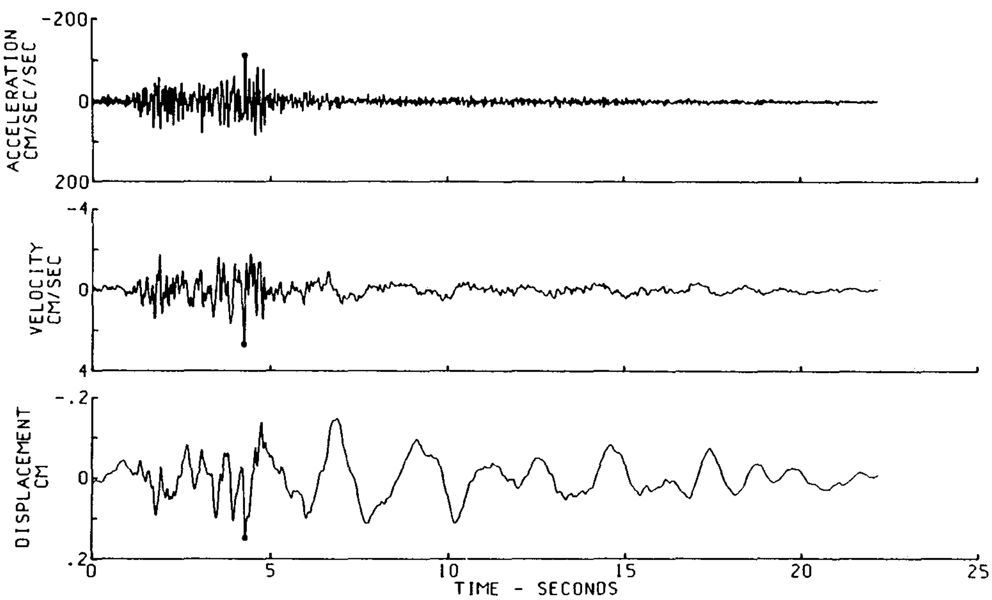


FIGURE 4.69 Corrected acceleration, velocity, and displacement, Tangshan aftershock of August 31, 1976, N-S component. Peak values are acceleration, -113.4 cm/s^2; velocity, 2.71 cm/s; and displacement, 0.15 cm.

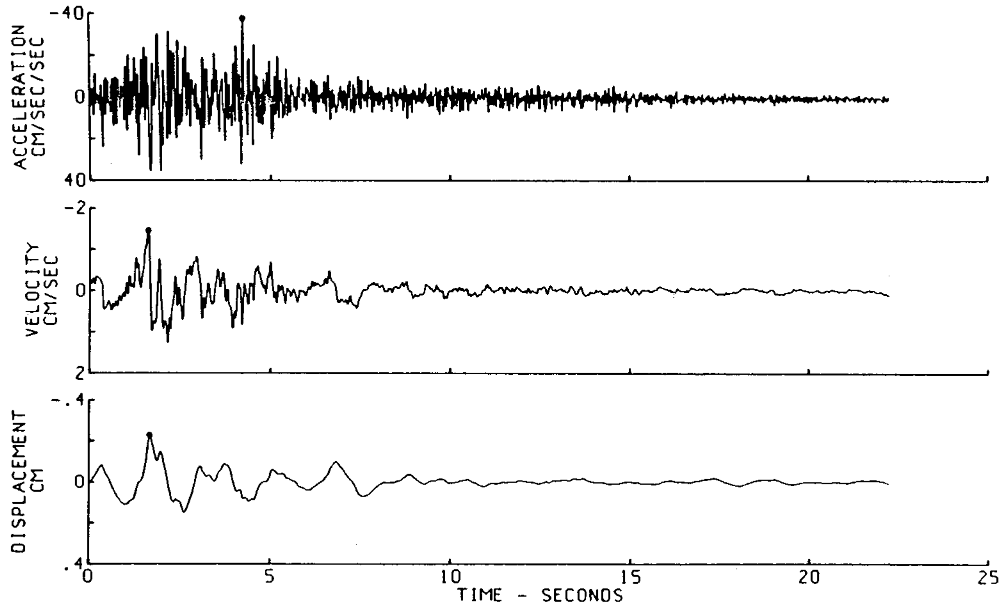
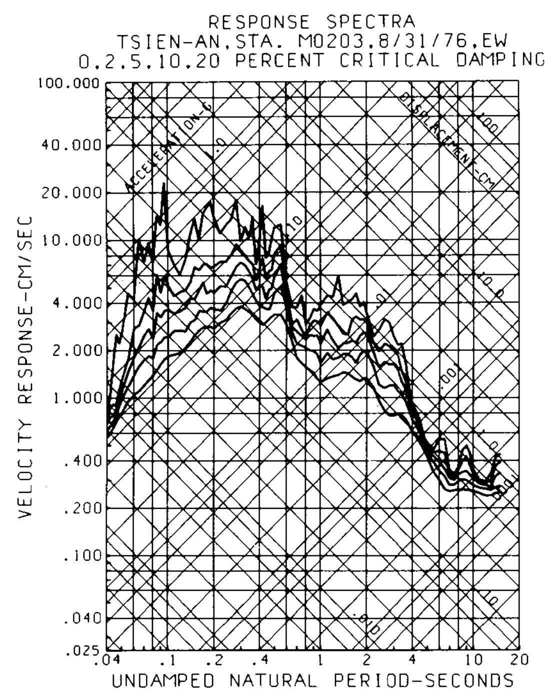


FIGURE 4.70 Corrected acceleration, velocity, and displacement, Tangshan aftershock of August 31, 1976, vertical component. Peak values are acceleration, $-38.0\ cm/s^2$; velocity, -1.45 cm/s; and displacement, -0.23 cm.

FIGURE 4.71 Response spectra for the accelerogram of Figure 4.68. (Seismic Engineering Branch, USGS).



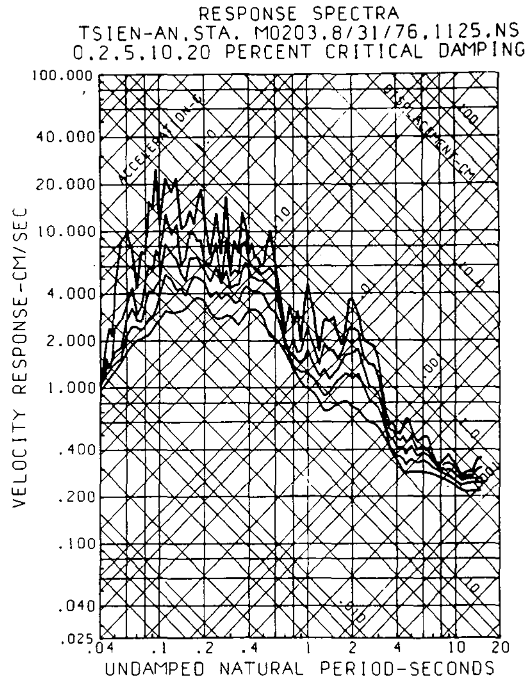


FIGURE 4.72 Response spectra for the accelerogram of Figure 4.69 (Seismic Engineering Branch, USGS).

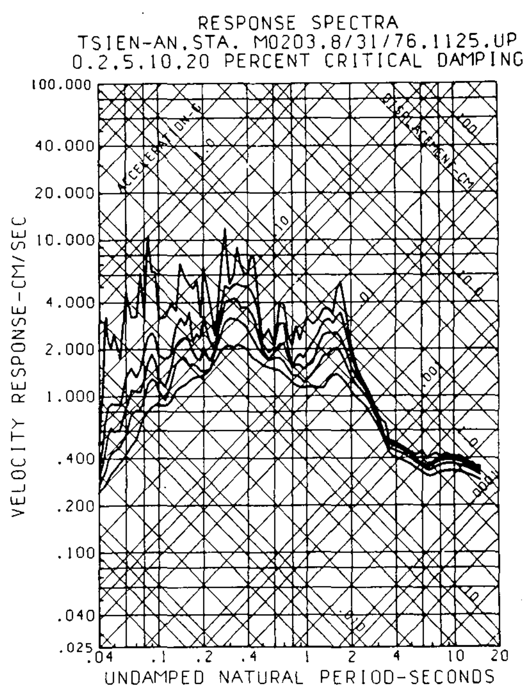


FIGURE 4.73 Response spectra for the accelerogram shown in Figure 4.70 (Seismic Engineering Branch, USGS).

ence on the spectra and the "dominant site period." In one study, the duration of the record was defined as the time span during which the acceleration peaks exceed a value of A_{max}/e, where e is the base of the natural logarithms; and studies of aftershock records indicated that duration defined in this manner increases with increasing magnitude. Analyses are being performed on both the main shock and aftershock records to study the dynamic response of the Peking Hotel and to study the influence that the soils in the Peking region had on the measured ground response. The procedures being utilized by the Chinese investigators in these studies are similar to those used in the United States in similar studies. Further analysis of the entire set of records is required before any final conclusions can be drawn.

SIGNIFICANCE OF THE TANGSHAN EARTHQUAKE

Clearly, the Tangshan earthquake has great significance for earthquake engineers, seismologists, and geologists. Much can be learned from this earthquake in the way of extending knowledge about earthquake mechanisms, earthquake ground motions, and the performance of structures under the action of strong ground shaking, and also about relief and rebuilding operations. This knowledge can be valuable, not only in China, but also in other seismic countries throughout the world. Many studies of the earthquake have been made in China, and such studies are continuing so that much information is being amassed. It is hoped that a comprehensive report on the Tangshan earthquake will be prepared by Chinese earthquake engineers, seismologists, and geologists. The Tangshan earthquake warrants a major report such as that prepared on the great 1964 Alaska earthquake by the U.S. National Academy of Sciences. Hopefully, with increasingly better scientific and technical relations between the United States and China, such a report can be prepared and a version published in the English language.

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5

THE SUNGPAN-PINGWU EARTHQUAKES OF AUGUST 1976

I - PREDICTION OF THE EARTHQUAKES

Introduction

On August 16, 22, and 23, 1976, a succession of three large earthquakes occurred in the Sunpan-Pingwu (SP) area of Szechuan Province. These earthquakes, referred to as the SP events, are of interest in that we were told the main shock and the two large aftershocks that comprise the series were successfully predicted. The number of casualties was not given, but we were informed that the prediction resulted in subtantial reduction in the loss of lives.

The material in this section was presented in a briefing by the Szechuan Provincial Seisomological Bureau, supplemented by information obtained later by T. L. Teng and R. Wallace. In predicting earthquakes, the Szechuan Seismological Bureau adopts what we would call a "shotgun" approach, examining all available precursors and anomalies before making decisions. They freely admitted that their approach was empirical, that they did not understand how to predict earthquakes according to completely scientific methods, and that they did not understand the physical bases for some of the anomalies that seemed to be precursors of earthquakes. Nevertheless, they obviously felt that they had been at least partially successful in having predicted 17 of the last 55 earthquakes of significant magnitude and three of four major ($M > 7$) shocks. The SP earthquakes probably represent their best example of a successful prediction of a major earthquake series.

The prediction process began with field monitoring some 6 years prior to the earthquake and ended in the final issuance of warnings and partial evacuation orders, followed by the earthquakes themselves. Data pertaining to the SP events are given in Table 5.1. The epicenters of these events propagated from north to south along the Huya fault (Figure 5.1). The greatest intensity reported was IX and isoseismals were crudely elliptical, with the long axis parallel to the trend of the Huya fault. The predictions were made with a reasonably good magnitude window (less than 0.5 magnitude unit), a rather large space window (about 150 × 150 km), and a remarkably narrow time window (within a day). A summary of the evolving sequence of events that constituted the prediction process is given in Table 5.2.

TABLE 5.1 Pertinent Data of the Sungpan-Pingwu (SP) Earthquakes

Date	Origin Time	Latitude	Longitude	Focal Depth (km)	M_S
August 16, 1976	2206:46	32°42'	104°06'	15	7.2
August 22, 1976	0549:50	32°36'	104°08'	10	6.7
August 23, 1976	1130:04	32°30'	104°08'	22	7.2

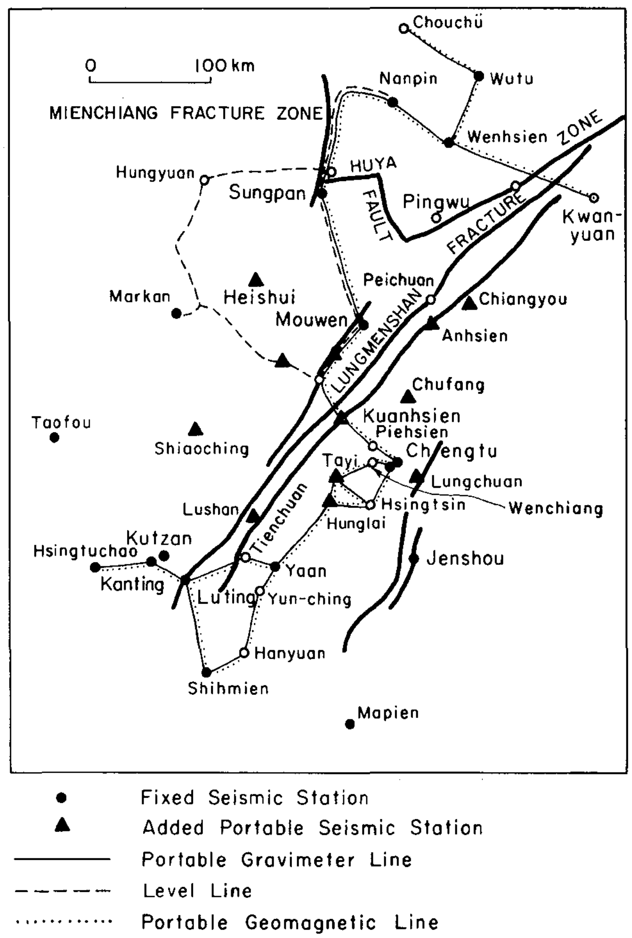


FIGURE 5.1 A portion of Szechuan Province showing the instrumentation established prior to the earthquakes. Sungpan and Pingwu are in the top central portion of the figure. See Figure 5.2 for a general map of the region.

TABLE 5.2 Evolution of Events in the Prediction of the SP Earthquakes

Time	Occasion	Principal Content of Action
November 1975	Szechuan Provincial Earthquake Tendency Conference, convened by Provincial Seismological Bureau (PSB)	An earthquake of $M \geq 6$ might occur in Sungpan-Mouwen area during the first 6 months of 1976
January 1976	National Earthquake Tendency Conference (Peking)	The above prediction opinion was accepted and the concerned area was designated as a high-risk target area for prediction
June 14, 1976	Emergency conference convened, issuance of earthquake report 2 by Szechuan PSB	An $M \sim 6$ earthquake was to occur within 1-2 months in the midsegment of the Lungmenshan fracture zone from Mouwen, Peichuan to Kanting
Late June 1976	National Earthquake Tendency Conference convened to discuss specifically the Peichuan-Kanting area	An $M \geq 6$ earthquake might occur within 1-2 months in the area
End of June 1976	Issuance of a special document by the Szechuan Provincial Revolutionary Committee, the governing political body	Based on the above results and a briefing by Szechuan PSB, announcement was made that within 1-2 months there was a high likelihood of an $M > 7$ event over the middle-south segment of the Tungmenshan fracture zone
July 16, 1976	Issuance of earthquake report 3 by Szechuan PSB	Confirmed the approaching seismic risk, but assigned low likelihood for the predicted event to occur before the end of July 1976
July 24, 1976	Issuance of earthquake report 4 by Szechuan PSB	Confirmed the approaching seismic risk, but assigned low likelihood for the predicted event to occur before the end of July 1976

TABLE 5.2 (continued)

Time	Occasion	Principal Content of Action
August 2 and 7, 1976	Issuance of earthquake reports 5 and 6 by Szechuan PSB	Pointed out the predicted time window: in August 1976, particularly around (±1 day) 13, 17, and 23. Space window: midsection of the Lungmenshan fracture zone over Mouwen-Peichuan or Kanting-Luting areas; magnitude window: M = 6 to over M = 7
Early morning of August 12, 1976	Directive from Szechuan Provincial Revolutionary Committee instructing the Anti-Earthquake Command and PSB to promulgate order by emergency telephone calls	Ordered all earthquake offices, professional observatories, mass observation posts and Mienyang-Ahbar-Wenchiang area to enter the state of preshock alertness. Large-scale partial evacuation followed immediately
August 16, 1976	Sungpan-Pingwu area along Huya fault	The first of the SP events occurred, M = 7.2
August 22 and 23, 1976	PSB provided a prediction update warning of large aftershocks 12 hours prior to each of the two remaining large earthquakes	The second (M = 6.7) and third (M = 7.2) SP earthquakes occurred

Tectonic and Seismological Settings

The provinces of Szechuan and Yunnan together form one of the most active seismic regions of China. Large earthquakes ($M \geq 6$) have occurred to the west of 104°E in these two provinces, mostly along known fracture zones. Three major fracture zones are recognized in Szechuan: Hsienhuiho, Lungmenshan, and Anningho. As illustrated in Figure 5.2, they together form a Y-shaped fracture pattern that dominates the major seismic activities in western Szechuan.

The SP earthquakes were generated near, but not on, the Lungmenshan fracture zone, which is a set of NE-trending high-angle reverse faults, dipping NW. Geologic evidence for recent (Quaternary) faulting is available on one branch of the Lungmenshan zone, the Chiangyou-Kuanhsien

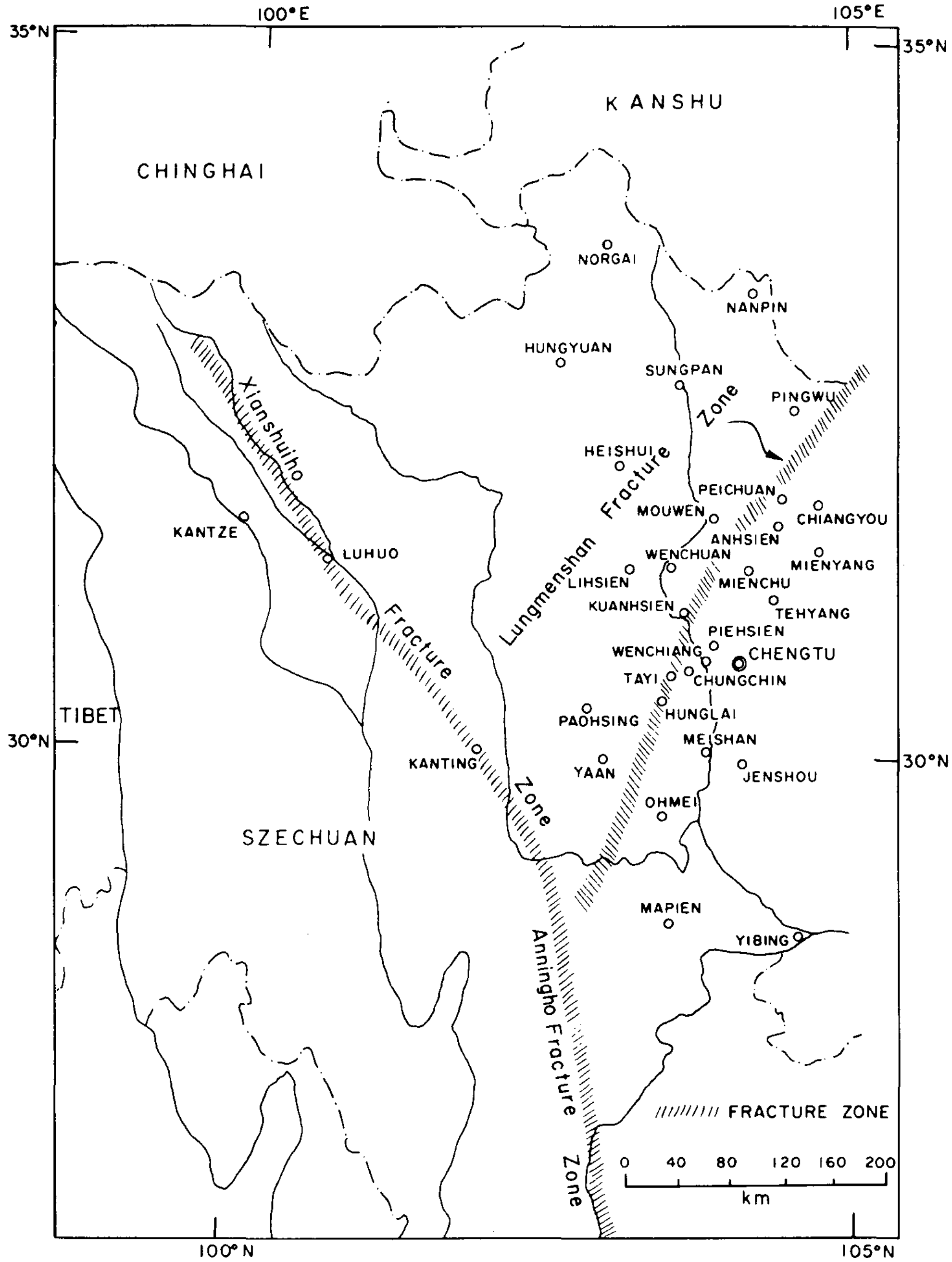


FIGURE 5.2 Map of the area affected by the Sungpan-Pingwu earthquakes of August 1976. The major fault zones in the region are indicated.

fault, and we were shown photographs of Quaternary sands and gravels in fault contact with Cretaceous rocks.

From 166 B.C. to date, there have been at least 180 $M \geq 5$ events, of which 12 were larger than $M = 7$, and 40 had magnitude between 6.0 and 6.9, along the Lungmenshan fracture zone. Between 1958 and the SP events, the records of earthquakes there included two $M = 6$-6.9 events; 25 $M = 4$-5.9 events; and 243 $M = 2$-3.9 events. Focal depths were predominantly between 10 and 25 km, although some were between 25 and 40 km. Fault plane solutions of the SP events showed the first earthquake to be primarily thrusting, the second to be primarily strike-slip, and the third to be strike-slip with some thrusting.

The Prediction

According to the Chinese seismologists, an analysis of the historical seismicity of Szechuan Province has shown that the occurrence of a moderate or large earthquake in the Lungmenshan fracture zone was usually followed by a similar event in the Sungpan area, and vice versa. Therefore on February 24, 1970, when an $M = 6.25$ event occurred near Tayi on the southern part of the Lungmenshan fracture zone (Figure 5.2), Chinese scientists were alerted to the possibility of a subsequent earthquake near Sungpan. This led to an extensive program of seismic monitoring and strain measurements as well as field geology work, principally in the Mouwen, Sungpan, Peichuan, and Machong area. This early start permitted the collection of a great deal of baseline data long before the occurrence of the SP events. Figure 5.1 shows the established seismic stations (16 of these are denoted as fixed seismic stations), portable gravimeter line, portable geomagnetic line, and the level line. The seismometers used were Chinese standard model DD-1 three-component short-period sensors coupled with a triple drum recorder. The gravimeters and radon instruments were comparable to those used in earthquake work in the United States.

In November 1975 at an earthquake tendency conference called by the Szechuan Provincial Seismological Bureau (PSB), seismological workers submitted for the first time their opinion that an earthquake of $M > 6$ might happen during the next 6 months in the Sungpan-Mouwen region. This opinion, not yet considered as a prediction, was said to have been based on the following observations:

Seismicity Seismicity in this region had increased since the occurrence of the $M = 7.9$ Luhuo earthquake on the Hsienshuiho fracture zone in February 6, 1973. We were shown seismicity data for two periods: 1970-1972 and 1973-1976. The latter, duplicated in Figure 5.3, appeared to show twice the seismicity of the previous years. An $M = 5.2$ event occurred on May 8, 1973, with epicenter on the northwest extension of the Huya fault. Between 1973 and the time prior to the conference, four $M > 5$ events took place in this region, and one of them had a magnitude of 6.2. Moreover, close monitoring of the development of the spatial distribution of microearthquakes showed that a group of small events had emerged along a narrow belt northwest of Mouwen. In the

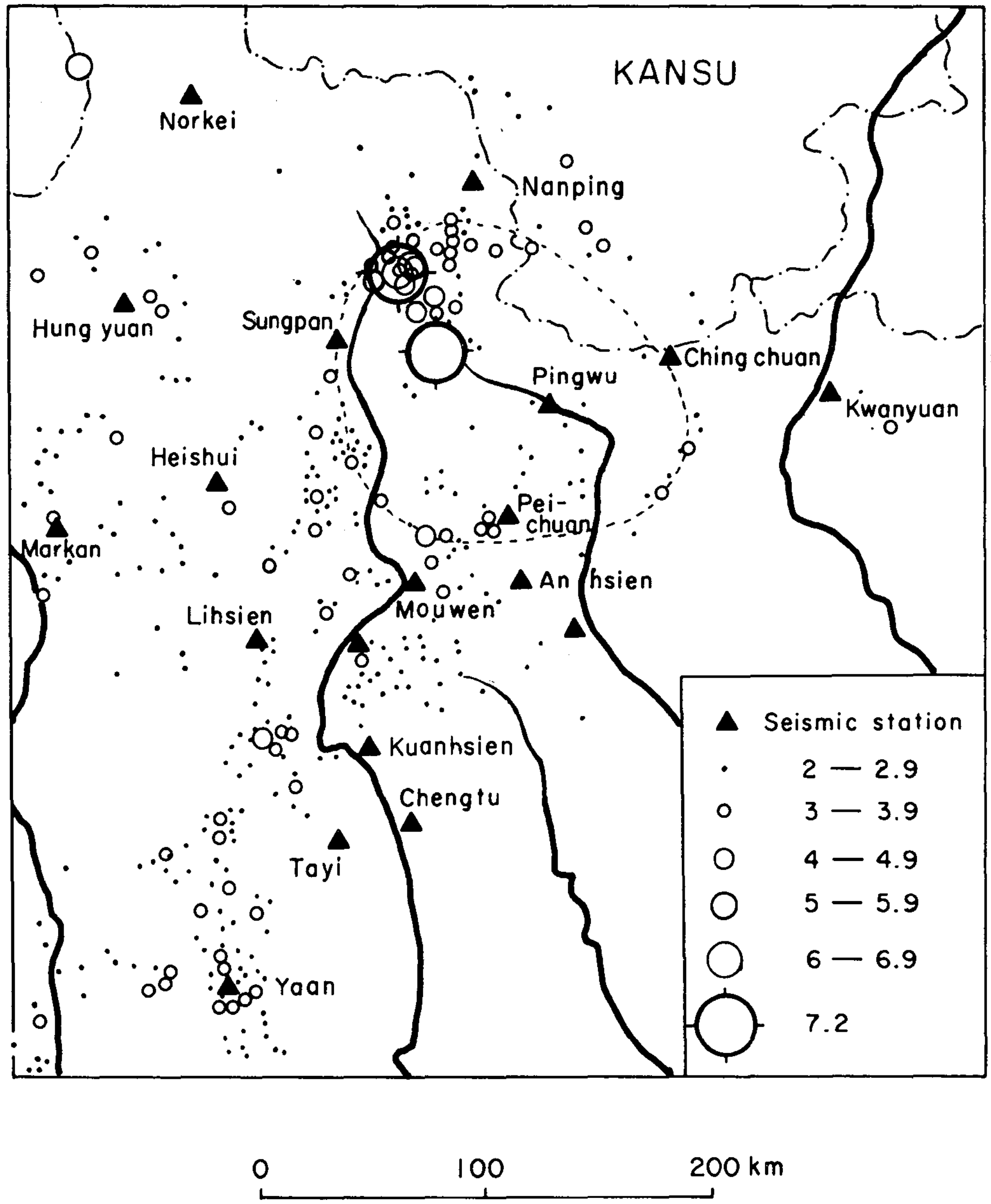


FIGURE 5.3 Seismicity of the Sungpan-Pingwu area for the period from January 1973 through August 1976.

meantime, the eventual causative fault for the SP events, the Huya fault, was relatively quiet, thus forming what was interpreted as a seismic gap (Figure 5.3, area encircled by dashed line).

Seismic Velocity Anomalies The Chinese seismologists make the standard plots of dilational wave speed (V_p) divided by shear wave speed (V_S). Since 1972, a 4-year dip was observed in the V_p/V_S diagram for an area including Sungpan, Pingwu, Mouwen, and Peichuan (Figure 5.3). This is the same area in which the seismic gap was identified. The duration of the dip was interpreted as indicating an M = 6.5 forthcoming event.

Leveling Data We were shown two types of leveling data. A regional long-distance leveling program (routes shown in Figure 5.1) was performed in 1960 and repeated in 1975. Figure 5.4 is an example of 1960-1970 elevation changes over a distance of about 200 km from Wenchuan to Nanping. The maximum change is seen between Sungpan and Nanping, where a total change in elevation was recorded of more than 312 mm (1 ft) over a 15-year period, or an average of 20 mm/year. In addition, short-baseline leveling was performed across the Mienchiang fracture zone near Sungpan. These leveling data were interpreted as showing local subsidence and tilting on the scale of 1-2 mm/yr.

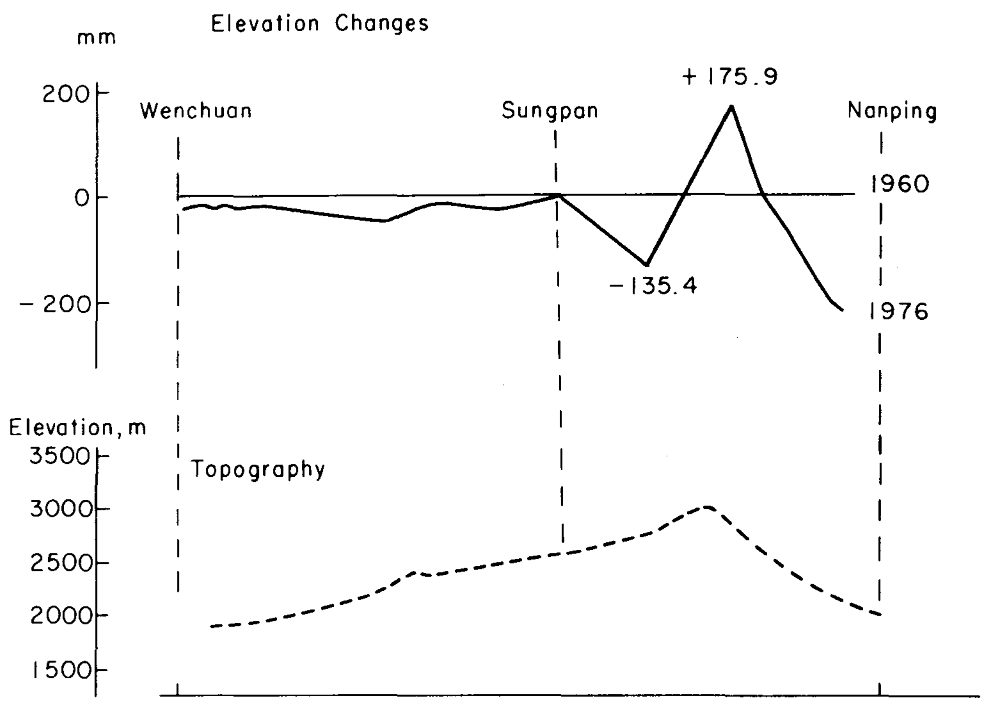


FIGURE 5.4 Elevation changes between 1960 and 1970 on a level line about 200 km long. See Figure 5.1 for the location of the line.

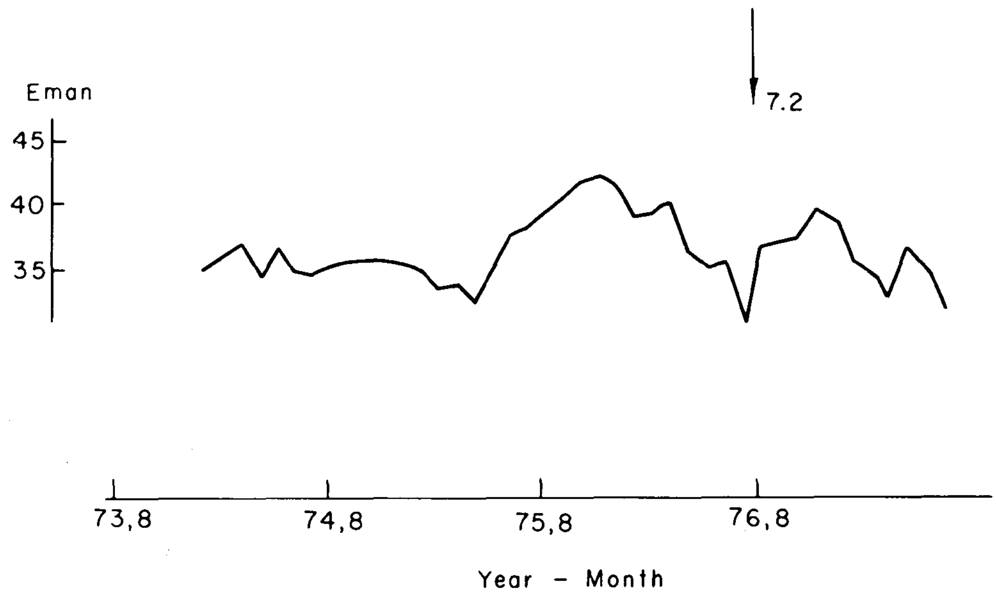


FIGURE 5.5 Radon concentration in groundwater at the Sungpan station. The arrow marks the occurrence of the first of the three Sungpan-Pingwu earthquakes.

Radon Anomaly The groundwater radon concentration at the Sungpan station started to increase in March of 1975, reaching a level 29 percent above the baseline toward the end of 1975 (Figure 5.5). An increase of 29 percent is not unusual in routine measurements in the United States; however, the presence of high radon concentrations over a year-long period perhaps makes the data in Figure 5.5 significant. Radon anomalies, if they exist, seem to come in all sizes and shapes. The Sungpan radon anomaly between March 1975 and July 1976 differs markedly from the spikelike anomalies recorded at the Kutzan station, shown in Figures 5.6 and 5.7.

Groundwater Since July 1975, the groundwater level had been dropping in the Sungpan, Pingwu, and Nanping area. Some water wells showed anomalous reduction of flow. Others became completely dry. Bamboo plants died for lack of water, affecting the lives of the pandas.

In January 1976, a national earthquake tendency conference was held in Peking. At this conference the opinion that had been submitted to the Szechuan Provincial Conference in November 1975 received a general confirmation. The SP area was then designated as one of a few high earthquake potential areas of the country. After this designation was

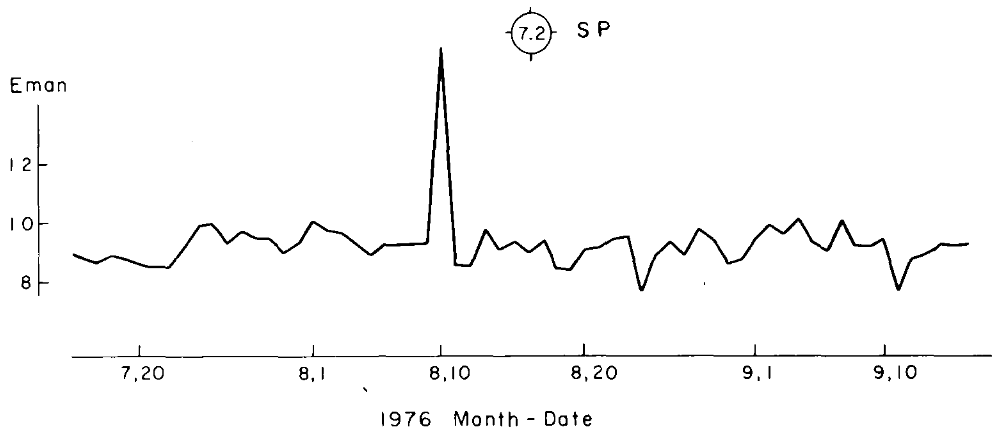


FIGURE 5.6 Radon concentration in groundwater at the Kutzan station prior to and after the Sungpan-Pingwu earthquakes. The earthquake indicated is the first of the series of three.

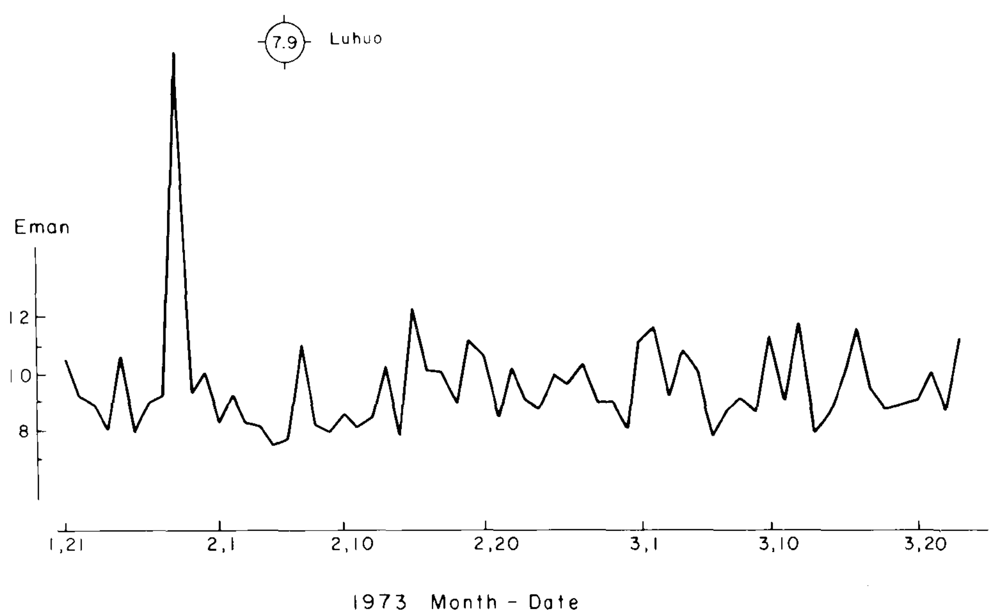
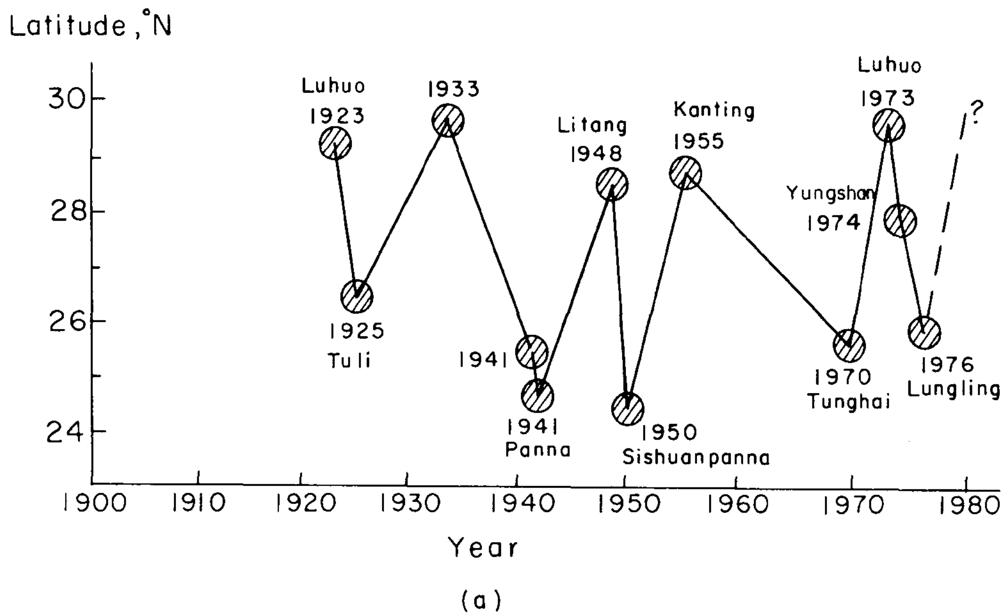


FIGURE 5.7 Radon concentration in groundwater at the Kutzan station prior to and after a major earthquake near Luhuo in 1973.

made, the construction of the two seismic stations in Nanping and Pingwu was accelerated.

From March of 1976 on, various physical, or macroscopic, anomalies were observed over a broad region. For example, in Mouwen the levels in eight water wells were found to have dropped in late 1975; by the spring of 1976 the wells were almost dry. In more distant areas, such as Tayi and Hunglai, drops in groundwater level were observed from May 1976 on. Accompanying the reductions in the level of groundwater were other phenomena such as changes in the taste, odor, and color of the well water. At Wanchia commune in Chungching county, outbursts of natural gas from rock fissures caught fire and were difficult to extinguish even by dumping dirt over the fissures. Unusual bubbling of wells was reported also. In addition to these physical phenomena, anomalous animal behavior was observed with high frequency in April and May of 1976.

During this time the Lungling earthquake ($M = 7.6$, May 29, 1976) occurred in western Yunnan province. The Chinese seismologists have noted an earthquake migration phenomenon in their analysis of historical seismicity. They have observed that large earthquakes along the north-south earthquake belt (approximately along the western half of Szechuan and Yunnan provinces) have had a tendency to occur in a north-south migration pattern as summarized in Figure 5.8a. This observation, plus the fact that historical large events in Szechuan mostly occurred in the month of August as shown in Figure 5.8b (the high rate of occurrence of major earthquakes in August could not be explained but is believed factual), caused the Szechuan Provincial Seismological Bureau to call an emergency conference on June 14, 1976. The conference resulted in earthquake report 2 being submitted to the provincial authority with the statement that along the Lungmenshan fracture zone from Peichuan to Kanting (over a 400-km region), there was a high probability for an $M > 6$ earthquake within 1-2 months. This was still not considered to be a formal prediction; instead, such an earthquake report usually is considered to be a scientific briefing to the provincial authority. This report, however, led to a national conference held in late June in Chengtu to discuss specifically the short-term earthquake tendency in this area. The general concensus was that along the south-central section of the Lungmenshan fracture zone, the area at issue, there was a high likelihood of an $M \geq 6$ event within 1-2 months. Some scientists argued for an $M \geq 7$ event. Following this conference, the Szechuan Provincial Revolutionary Committee adopted the more conservative opinion and issued an urgent announcement stating that an $M \geq 7$ event was to be expected within 1-2 months along the south-central section of the Lungmenshan fracture zone. The announcement further requested that prediction work be strengthened in the Ahbar, Mienyang, Yaan, Wenchiang, and Kantze regions. In these regions, anti-earthquake commands were immediately established. Professionals from 13 provinces, cities, or autonomous regions were ordered by the SSB to converge on the suspected source region, bringing with them a variety of instruments. More than a dozen seismic stations were added in places such as Heishui, Lihsien, and Chiangyou (triangles in Figure 5.1). Gravity, magnetic, and leveling networks were augmented. Along the Lungmenshan fracture zone, particularly around the Sungpan area, the number of observation posts manned by the masses rapidly



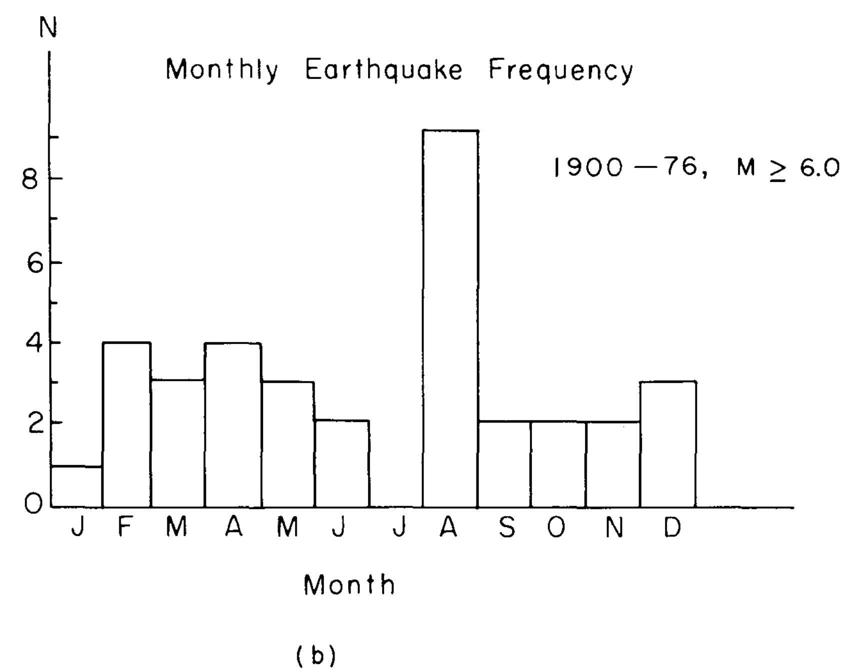


FIGURE 5.8 (a) North-south alternation of major earthquakes in the north-south seismic belt. (b) Monthly pattern of occurrence of major earthquakes in Szechuan.

increased from 280 in 1975 to 4,800 prior to the SP events. Despite these special scientific efforts, for some reason, no strong motion accelerographs were moved into the area, and the small-amplitude records of strong motion that were subsequently obtained were recorded in neighboring Kansu Province, where members of that provincial seismological group had set up two strong-motion instruments at the Szechuan-Kansu border, some 100 km from the epicentral area.

The accumulation of new data, mainly noninstrumental, prompted the issuance on August 2 and August 7, respectively, of earthquake reports 5 and 6, indicating that around (± 1 day) August 13, 17, and 23 there would be an earthquake of magnitude $M \geq 7$ occurring either in the Mouwen-Peichuan or Kanting-Luting areas. This conclusion was based on a variety of data including changes in telluric currents, geomagnetic readings, groundwater levels, radon concentration, and the increased reporting of unusual animal behavior. The basis for predicting the above dates, we were told, was derived from empirical formulas, but the details of the procedures were not given. An example was, however, cited to explain how one such empirical formula was determined. The ground water radon content at Kutzan station generally displays a peculiar anomaly prior to large earthquakes occurring on the Y-shaped fracture zone in western Szechuan (Figure 5.2). Kutzan (Figure 5.1) is located approximately at the juncture of the "Y" formed by the three fracture zones (Figure 5.2). At Kutzan, samples are taken from a warm spring twice daily. If a sudden jump in radon content is observed, another sample is taken to confirm the observation. What is peculiar about these sudden jumps is their duration, which usually is only 1 day, with a value 70-120 percent above the ambient. Data given to us in Table 5.3 and in Figures 5.6 and 5.7 seem to document a useful correlation with subsequent earthquakes in the "Y," even though the underlying mechanism giving rise to such a spikelike anomaly is not understood. Their experience has shown the spikelike radon anomalies at Kutzan station indicate that a large earthquake may occur on the "Y" fracture, 6-11 days after the Kutzan radon spike.

Short-term anomalies of telluric current were observed in June and July of 1976. In addition, ground outgassing and the occurrence of fire balls, unusual animal behavior, changes in weather and changes in groundwater levels, as reported by indigenous observers, displayed two peak episodes; one each toward the later part of June and July 1976 (Figure 5.9). Areas of these macroscopic anomalous incidents were watched and were considered to be prime sites for the expected large earthquake. The first episode in June (Figure 5.10) occurred in the Paohsin-Tienchuan area. The second episode, in July, was northeastward of the first in the Kuanhsien-Penghsien area. During the first week of August 1976, a rapid increase in the number of reports about anomalous animal behavior gave rise to a third episode, which was still further to the northeast in the Peichuan-Chiangyou-Anhsien area. These three episodes made the PSB seismologists move their predicted epicenter progressively northeastward. Of particular importance seemed to be the appearance of a sudden 70 percent jump in groundwater radon at the Kutzan station on the morning of August 10, 1976 (Figure 5.6). These developments led the Szechuan PSB to submit an urgent report on August 11, 1976, to the Szechuan Provincial Revolution

TABLE 5.3 Sudden Jumps of Radon Value at Kutzan Station

Earthquake	Magnitude	Δ(km)	On "Y" Fracture Zone	Time of Occurrence	Sudden Jumps (Days Before Earthquake)	Percent Above Ambient
Sahteh, April 8, 1972	5.2	70	yes	March 28, 1972	11	55
None	--	--	--	March 29, 1972	--	38
Takung, Sept. 27, 1972	5.8	54	yes	Sept. 16, 1972	11	34
Luhuo, Feb. 6, 1973	7.9	220	yes	Jan. 29, 1973	8	120
Luhuo, Feb. 16, 1973	5.3	220	yes	Feb. 15, 1973	1	35
Yiliang, July 22, 1973	5.2	340	yes	April 9, 1973	13	41
Sungpan, May 8, 1973	5.2	345	yes	April 25, 1973	13	40
Mapien, June 29, 1973	5.8	200	yes	June 21, 1973	8	89
Nanping, Aug. 11, 1973	6.5	420	yes	--	no jump	--
Sungpan-Pingwu, Aug. 16, 1976	7.2	320	yes	August 10, 1976	6	70

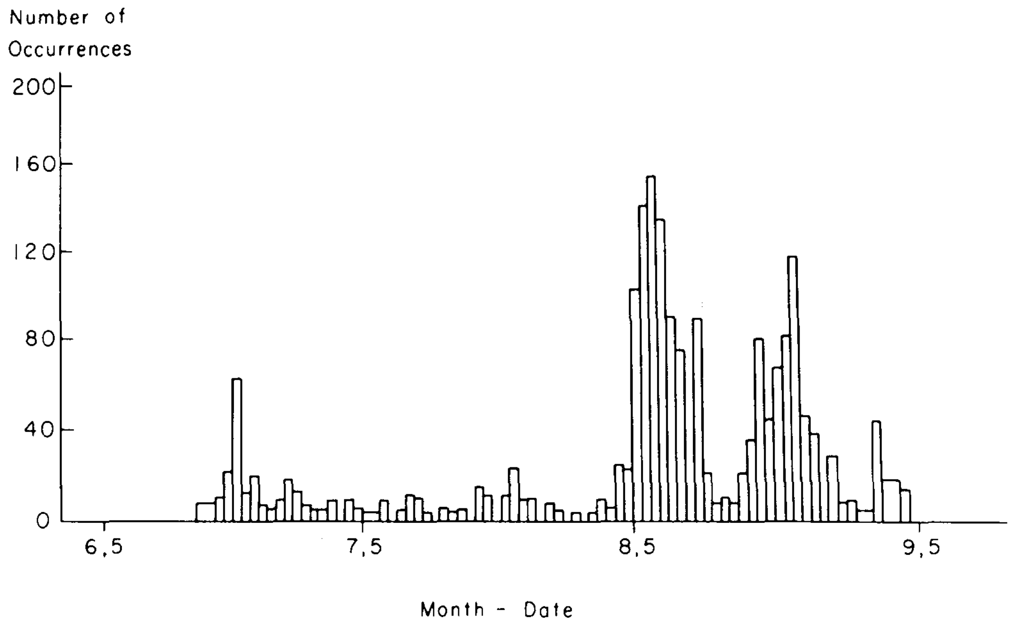


FIGURE 5.9 Plot of the number of reported occurrences of macroscopic anomalies such as unusual animal behavior and changes in groundwater.

Committee and the State Seismological Bureau. The former took immediate action by issuing an emergency directive in the early morning of August 12, 1976, that instructed the Szechuan anti-earthquake command and the Szechuan PSB to order all local earthquake offices and professional seismic stations as well as all mass observation posts to enter an emergency state of alertness. Limited evacuation was carried out in an area from Meinyang to Wenchiang for 200-300 km along the Lungmenshan fracture zone and its neighborhood. From a population of about 20 million people in the designated area, only women, children, and older people were told to move out of their houses. Adult workers remained on their jobs. It was said that the percentage of people that were evacuated was about 40 percent in the cities and was much lower in rural areas. An intensity VI was predicted for Chengtu, the provincial capital, but no evacuation was suggested there. Four days after the order of a state of alert, an earthquake of magnitude 7.2 occurred at 22:06 local time on August 16, 1976, 3 days after the first of the three predicted time windows. The epicenter was later determined to be on the Huya fault between Sungpan and Pingwu. Casualties were reported to be very low, and we were told that it was difficult to estimate how many lives were actually saved by the prediction.

Twelve hours prior to both the August 22 and 23 earthquakes, the Provincial Seismological Bureau provided an update of its original prediction, warning of the likelihood of large aftershocks. Telluric currents, anomalous animal behavior, and seismic quiescence (instead of heavy

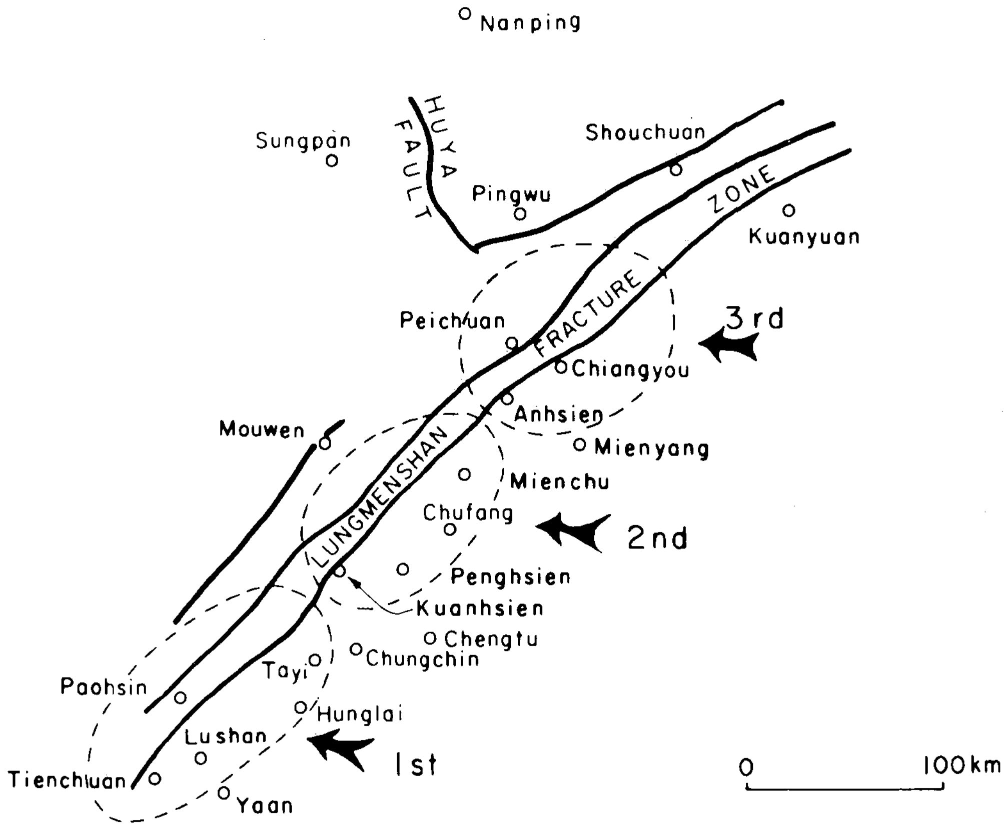


FIGURE 5.10 Location of areas reporting increased occurrence of macroscopic anomalies.

aftershocks) after the main shock were the principal bases for the predictions of the two later shocks.

Discussion

Although these three predicted time windows corresponded very closely to the actual times of the three earthquakes, we were uncertain whether the three windows were intended to imply three earthquakes of approximately equal size, or whether it was only evidence following the first earthquake that led to additional predictions of the second and the third earthquakes; it seemed to most of us that the latter was the case.

One particular feature of the predictions of the SP events is that there were no foreshocks, as happened before the Haicheng earthquake.

The predicted spatial window varied and evolved with time. It first became localized in the SP area during the middle-term (November 1975) prediction. The areal extent of anomalous observations expanded subsequently; this enlarged and shifted the predicted spatial window southwestward so as to include the Kanting area. At that time the spatial window almost covered an area 400 × 400 km. It was not until the imminent prediction (August 2 and 7, 1976) that the spatial window was again shifted northeastward and shrank in size, so as to make evacuation more practical. Our Chinese colleagues remarked: "This type of shifting perhaps indicates our lack of understanding of many of the macroscopic anomalies which form the principal data considered before issuing imminent predictions." Indeed, accurate imminent prediction is the key to a practical earthquake prediction program. To achieve this level of forecasting, the Chinese seismologists presently lean heavily on empirical interpretation of anomalous observation, both instrumented and as reported by the populace.

Accounts of Anomalies and Precursors

The significance of several anomalies in the prediction of the SP earthquakes has been discussed above, but additional general information and eyewitness accounts of anomalies and precursors were described to us.

In the briefing by Lo Shoh-li, Deputy Director, Szechuan Seismological Bureau, and members of his staff, we were told that the indigenous methods, also referred to as "macroscopic methods," strongly influenced the imminent predictions. It was stated, surprisingly to us, that they found it easier to predict the time and magnitude of the impending earthquake than the place. As the short lead-time anomalies began to occur, the anomaly shifted south and then to the north to the final predicted area in which the SP earthquakes actually occurred. For example, Figure 5.10 illustrates the shift in the expected epicentral area from south to north based on animal behavior. Before July 1976, anomalous animal behavior, predominantly of small animals, was concentrated several hundreds of kilometers south of the final predicted area. By late July 1976 the concentration of anomalies, predominantly of large animals, had shifted considerably to the northeast. In the few weeks before the earthquake, 1,297 indigenous anomalies were reported and evaluated. Some of those that were counted as a single case represented the summation of several actual observations reported together by a local brigade or group. The frequency of occurrence of these anomalies is shown in Figure 5.9.

Among the 1,297 anomalies were observations of outgassing from the ground, unusual lights and sounds, abnormal animal and plant behavior, and telluric currents. We were presented with an album of photographs illustrating some of these anomalies.

Lights and Outgassing Earthquake lights, at least some of which were seen prior to the earthquake, were described in the forms of columns, fans, balls, and sheets. Chu Chieh-cho of the Provincial Seismological Bureau described personally seeing a fireball 75 km from the epicenter on the night of July 21 while in the company of three professional seismologists and a TV crew. The fireball originated at the ground surface about 100 m from where he stood. At first it was about 1 m in diameter. It then shot up to a height of 10 or 15 m, whereupon the volume started shrinking, finally to ping pong ball size. After reaching the maximum height, the ball curved over in an arcuate trajectory and disappeared as it fell to the earth; resembling a meteor in appearance as it moved. The light would dim, then brighten again. Small wisps of white smoke swirled around the light, a slight crackling sound was heard, and an odor of garlic or sulfur was detected. A radio compass and telluric currents were unaffected. A small funnel-shaped hole in the ground was found where, it was thought, gas had been blown out of the ground.

At another place a fireball started near a house, rose up along an arbor, and burned a hole in the roof of the house. A total of about 1,000 fireballs were sighted, and in one evening 50 fireballs were counted. During the daytime, small smoke balls were reported, presumably representing the same phenomenon as the fireballs seen at night. Mr. Chu reported that a correlation with the seasons had been recognized and, possibly as a precursor to the SP earthquakes, a great many fireballs occurred the week of July 25, 1976. More were seen during the evening and predawn than at other times of the day. Most fireballs occurred along intersections of riverbeds and fractures, according to Mr. Chu. Upon specific questioning, he expressed the belief that the phenomenon of fireballs perhaps related to the burning of gas. Natural gas does occur in the Szechuan Province, and an unusual sight to us was to see buses in Chengtu powered by natural gas carried in large rubber bladders on the tops of buses.

Other events which seemed to be related to "outgassing" before the earthquake were described as fairly common. For example, a few hours before the SP earthquakes, a technical member of the provincial seismological group returned to the seismic station and was surprised to find that the water in the well at the station was bubbling violently. In May 1976, seven water wells were reported to be bubbling, and one sample of the gas was taken for chemical analysis which showed a high CO_2 content.

In addition to the occurrences of fireballs, gas fires were reported in other earthquakes. In one such event, an old water well in a field outside of Haicheng had been filled in with rocks and covered with soil, and crops had been planted over it. Prior to the 1975 Haicheng earthquake, gas exploded from the well and caught fire, burning the crops in the field. After the Tangshan earthquake, Kao Wen-hsueh of the Institute of Geology reported that leaves in a bean field were scorched and had burned-through holes. Radioactivity was ruled out as the cause in the subsequent testing.

In addition to the fireball lights, other larger scale lights were described as glowings in the sky. The descriptions were not very specific in relation to the SP earthquakes, but such sightings apparently were made during earthquakes rather than before, and were considered rather common. Li Yun-shan of the Shensi Provincial Seismological Bureau related his personal experience before large aftershocks of the 1976 Lungling earthquake in Yunnan. He was stationed in a tent in the epicentral area after the main shock. One night, it was pouring rain and was pitch-black with low clouds. Returning to his tent, he saw the ground and bushes as if they were illuminated under the full moon, yet the rain was still pouring down from the low clouds. The next day, an $M = 6$ aftershock occurred. On another night, when it was still raining, with low clouds, Li Yun-shan woke up at midnight and walked from his tent to the outhouse. He saw a fireball (~ 50 m in diameter) about 200 m away. Not believing his own eyes, he woke up a co-worker. Both stared at the fireball for almost half an hour before they could mutually agree on what they had seen. The next morning, an $M = 5$ aftershock occurred. Walking over to the location where they saw the fireball, they found that in the middle of the rice field there was extensive evidence of the occurrence of sand spouts.

Earthquake Sounds Earthquake sounds, which in China are called "sounds of the mountains" have been recognized for centuries, and experience with these sounds is apparently so widespread that for a long time people have left their houses upon hearing "sounds of the mountains" for fear of an impending earthquake. Accounts told to us were similar to those described in the report entitled "Predicting Earthquakes by Earth-Sound" by the Office of Synthesis, Analysis, and Prediction Research, by the Lanchow Seismological Brigade (see translation in Evernden (1976, pp. 391-402)). The sounds are said to take many forms. A few months before the earthquakes the sounds are generally reported as low rumblings, whereas near the time of an earthquake the sounds are of higher frequency. Commonly, the sounds are in a short burst followed by double bursts, likened to the sound of frogs. Following this the sounds become more continuous like the sound of a torrent of water, or the sound of ripping cloth. Another sound was likened to the rubbing together of objects. We were told that some high school students had recorded some of these sounds on tape.

The group from the Szechuan Seismological Bureau that briefed us said that many of the sounds were clearly not related to foreshocks because good data were available from seismic records which showed the absence of foreshocks at the time of the sounds. On one occasion several seismologists, including some of those briefing us, were watching a seismograph when they heard sounds they believed to be earthquake sounds. The instrument did not record an event when they heard the sounds, but a minute or so afterward the arrival of P waves was recorded by the seismograph.

The group reported that before several other earthquakes, such acoustical events were reported. A few months before the Luhuo earthquake ($M = 7.9$) of 1973, an especially noteworthy series of acoustic emissions was reported. None of those present had any explanation for the phenomena. Li Yun-han of the Shensi Provincial Seismological Bureau also reported that before the 1976 Lungling earthquake, he personally heard low-frequency sounds a few seconds before the main shock.

Plants Abnormal growth or withering of plants is believed by the Chinese to foretell earthquakes, and such anomalies were noted, particularly before the SP earthquakes. Fruit trees, including grapefruit, apple, and peach trees that had bloomed in the spring of 1976 and developed fruit, bloomed again in July and August while fruit was on the trees. While this overlapping blooming is a common occurrence in

California, it was said to be very rare in Szechuan. Bamboo seemed very sensitive, withering apparently because of a drop in groundwater. As noted earlier, as a result of the withering of bamboo, pandas suffered. The effect was reported to be most noticeable along fault traces.

Nausea and Shock It was reported that some people experienced nausea before the SP and Tangshan earthquakes, as well as the 1556 Huahsien earthquake, and a few even have gone into shock. No explanation of the cause of this was given by the Chinese, but some of their scientists suspect that the nausea may be related to a possibly increased level of microseismic activity. The Institute of Geophysics at Peking has a laboratory devoted to on-line spectral analysis of microseisms.

Animal Behavior Many stories of abnormal animal behavior in China prior to earthquakes have been previously reported. (American Seismology Delegation, 1975; Haicheng Earthquake Study Delegation, 1975). The SP earthquakes similarly were preceded by reports of unusual animal behavior. Examples included an unusually high number of rats on telephone and power lines, a rabbit climbing a thatched roof apparently to get off the ground, the departure of a species of bird from the epicentral area prior to the earthquake, and pigs that tried to escape from their pen. Abnormal behavior prior to earthquakes has been a part of the Chinese folk wisdom for so long that the Chinese scientific community seems to accept it as a fact with little skepticism, although they are admittedly unsure of how to explain it. We were told that at the Biophysical Institute laboratory work on neurophysical responses of animals to various physical-chemical stimuli is being done to place the evidence on a sounder scientific footing. A booklet (Chinese Academy of Sciences, 1977) for the lay public has been published, giving some basic facts on

TABLE 5.4 Earthquake Precursory Time of Various Animals (Chinese Academy of Sciences, 1977)

Animal Type	Precursory Time
Dog	Half an hour to 2 days
Chicken	1-3 days
Rat	1-5 days, or even 2 weeks
Fish	A few hours to 10 days
Pigeon	A few hours to 1 day
Pheasant	1-2 days
Snake	2-3 days (about 10 days if it comes out of hibernation)
Hog, cow, horse, sheep	A few hours to 1 day
Tiger	A few hours
Bear	A few hours
Parrot, canary, swan	15 min. to a few hours

the sensitivity of several animals' sensing systems. In this booklet, various anomalous animal behaviors were cited. Of interest is Table 5.4, which purports to summarize the empirically determined precursory times of various animals.

The degree and duration of anomalous responses are considered to be related to the magnitude of the forthcoming earthquake. Animals with anomalous behaviors are frequently sighted at the intersections and terminations of active faults, as well as in regions of future high seismic intensity.

II - EARTHQUAKE DAMAGE

The Intensity map we were shown of the three Sungpan-Pingwu earthquakes, taken together, assigned Intensity IX damage in the epicentral areas, with lesser intensities at greater distances in what appeared to be typical fashion. A description of the damage was given to the delegation by Lung Kin-cheng, a local (Chengtu) structural engineer.

The most common type of residential construction in the epicentral area is shown in Figure 5.11. The wooden frame is of mortise-and-tenon

FIGURE 5.11 Wood framing is the most common residential construction in the mountainous epicentral area of the Sungpan-Pingwu (SP) earthquakes.

construction, using dowels of a special type. The infilled walls are generally of wood in the mountainous epicentral area; a few walls are of stone. The roofs are usually of tile, with wood sometimes used. Most of these structures in the Intensity IX zone were damaged, with a few partial collapses. The most common damage was described as a single inclination of the structure (this type of frame would be very flexible). In the Intensity VIII areas, only a small number of such buildings with wooden infilled walls inclined, and there was no damage to this type of construction in areas of Intensity VII. For infilled walls of stone, some walls fell out even in zones with intensities as low as VII. The reasons given for the generally successful performance of this type of housing were its light weight and high ductility. Also, the quality of the construction in the mountainous areas, where lumber originates and is plentiful, is usually better than it is in the cities. The resistance is apparently not a by-product of design for heavy snow loads, as we were told that there is not much snow in this region.

There were a small number of brick buildings in the area of strongest shaking. This second type of construction has a timber roof, brick columns, and brick walls, as shown in Figure 5.12. The external and internal walls were about 12 cm thick and were constructed with lime mortar. The damage to this type of construction was rather heavy: most collapsed in areas of Intensity IX. A small portion suffered partial collapse in areas of Intensity VIII, and most were heavily damaged. Most of this type of construction were cracked in areas assigned as Intensity of VII. The buildings were not designed to resist earthquakes, and were reported to

FIGURE 5.12 A second less common and less resistant type of construction consists of brick columns and walls, with wooden roof trusses.

have low-strength brickwork and construction defects; much earthquake damage was also attributed to the effects of openings for windows and the settlement of foundations.

There were some brick buildings with precast concrete slab floors. These were mostly two-story structures, with some up to three stories. They were located only in areas with Intensity VI, not in the higher zones. Many cracks were observed in the walls of these buildings. The reasons given for this degree of damage were lack of strength in the brickwork, the effects of large openings for doors and windows, and the effects of unequal settlements of foundations.

A primary feature of the earthquakes was the large number of rockfalls, landslides, and mud flows that occurred. The mountainous epicentral region is high, over 5,000 m in some places, and steep. The potential for slides was increased by the occurrence of heavy rains between the three earthquakes. The slides disrupted communications in many cases and also caused damage to structures. Some of these effects are shown in Figures 5.13-5.19.

The landslides and rockfalls were very numerous in some areas; in one 20-km section of a valley in the epicentral region, one third of the zone was affected in a major way by landslides. In addition, many of the landslides were noted to have flowed up to 1 or 2 km, and in some cases, mud flows and slides ran out from the bases of the mountains for 2-3 km, an awesome observation. One slide dammed a major river, forming a lake with an area of about 48,000 m^2 and a maximum depth of 30 m (Figure 5.20).

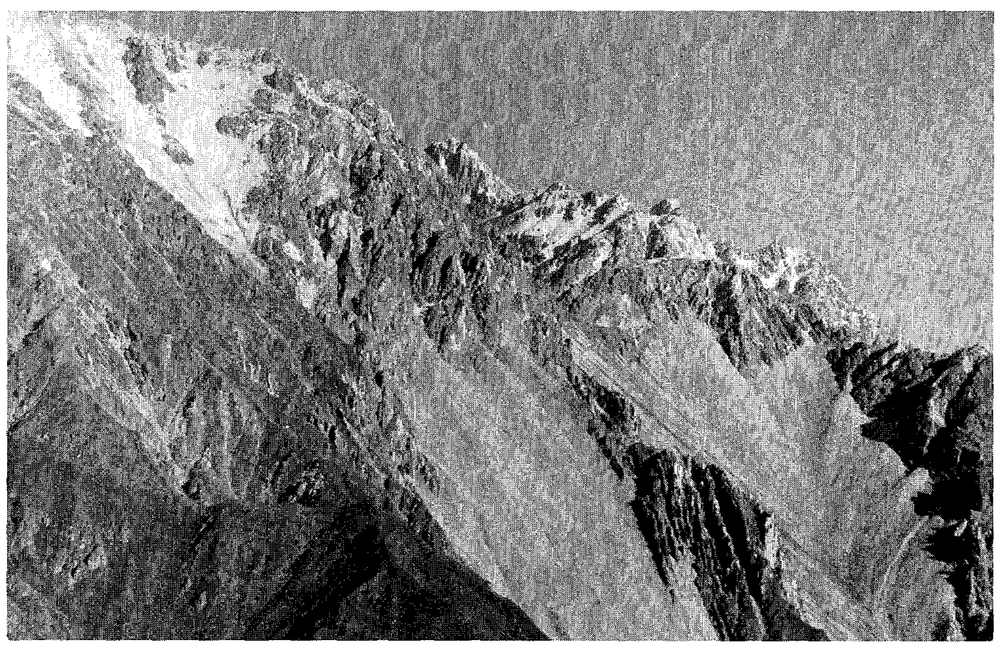


FIGURE 5.13 Slides and rockfalls in the mountainous terrain affected by the SP earthquakes.

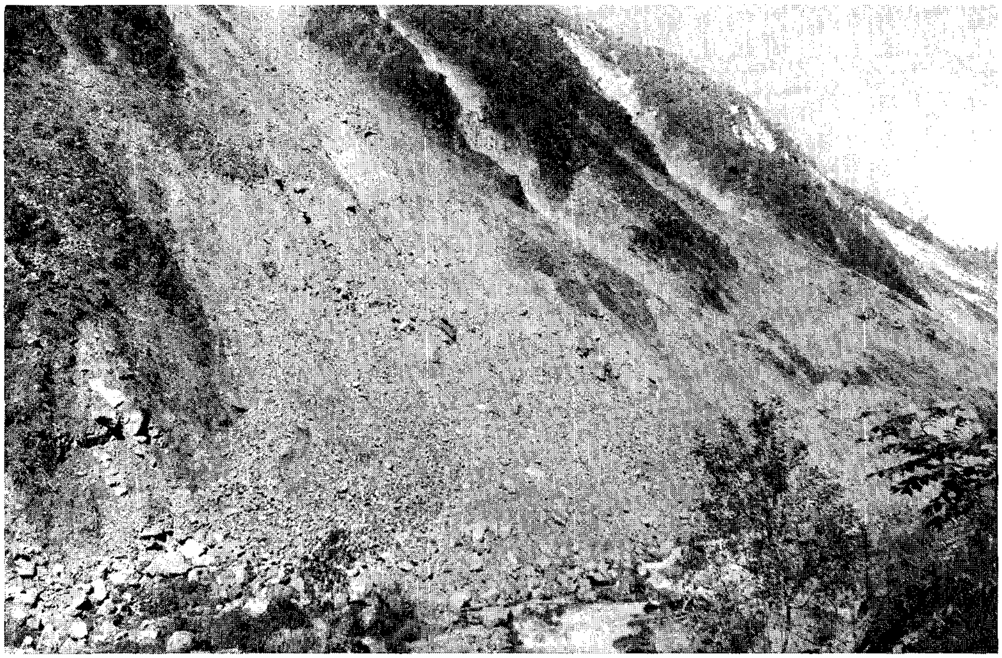


FIGURE 5.14 Rockslide in a canyon, SP earthquake.

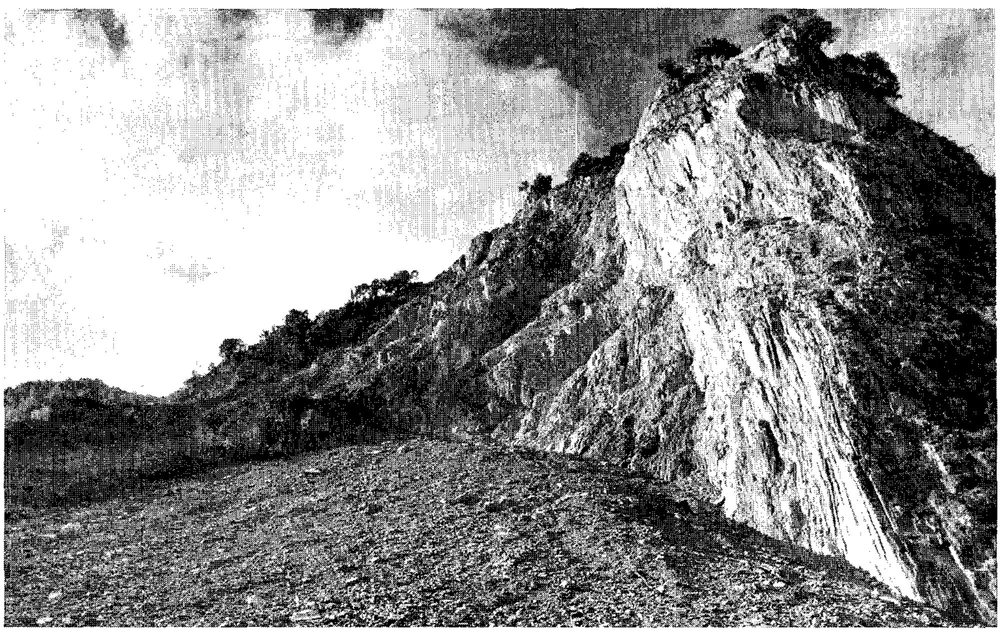


FIGURE 5.15 The head of a rockslide in the mountainous terrain, the SP earthquakes. Slides, without earthquakes, are common in this region.

FIGURE 5.16 Large conglomerate boulder that fell during the SP earthquakes. Note also the structural damage to the building.

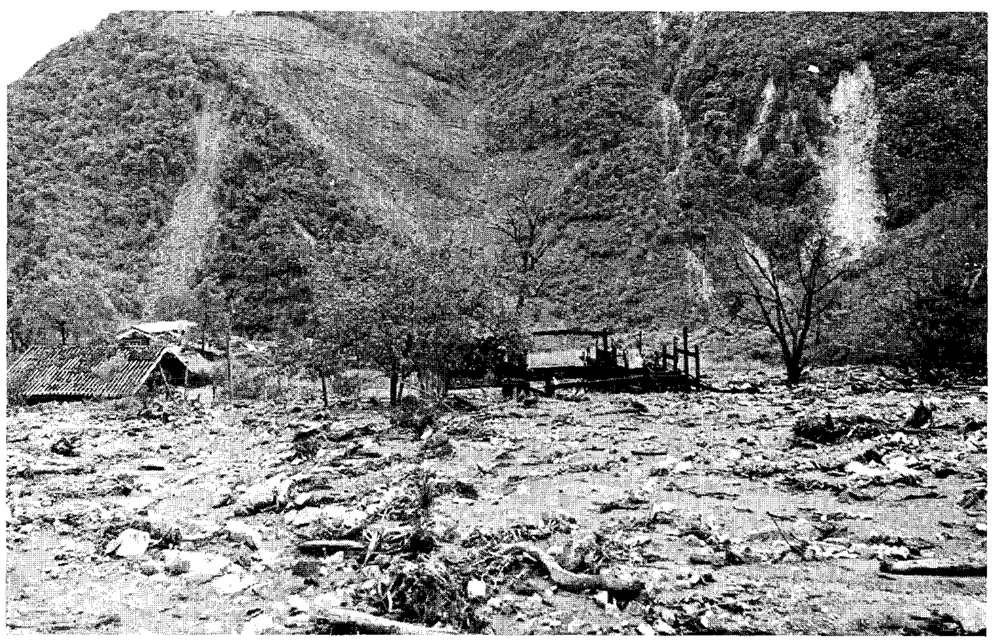


FIGURE 5.17 Mud flow damage from the SP earthquakes. Heavy rain occurred before the second and third shocks, and many mud flows occurred.

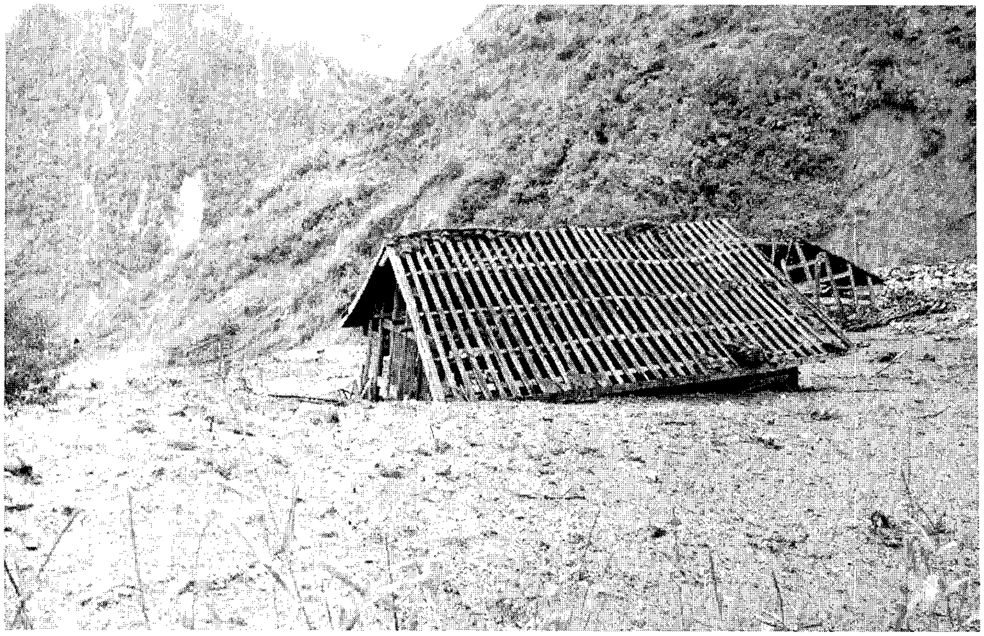


FIGURE 5.18 Mud flow damage from the SP earthquakes.

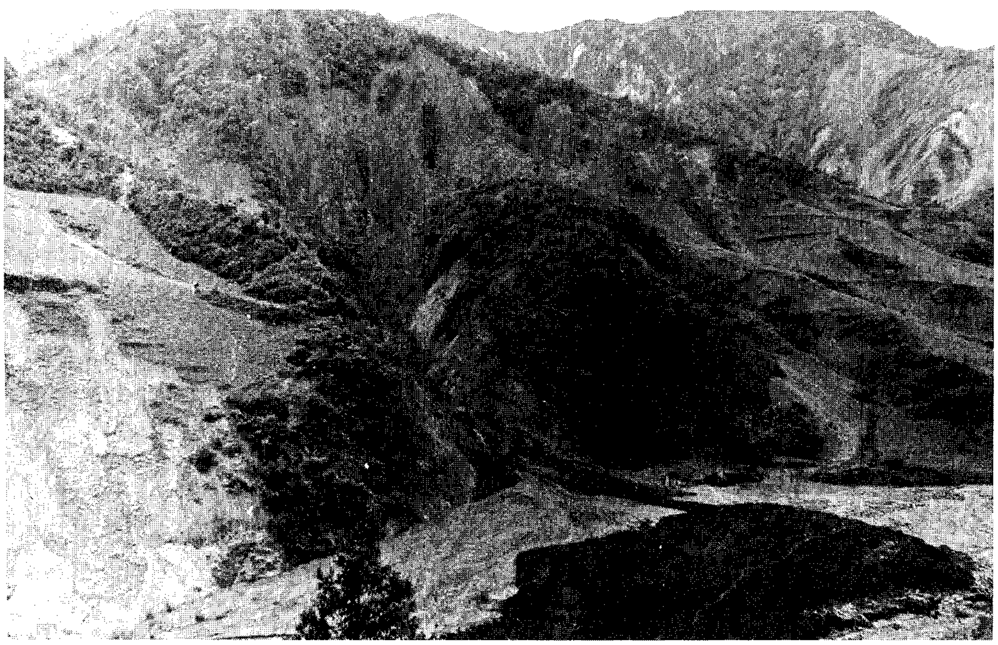


FIGURE 5.19 Fresh mud flow (light colored material) on a recent alluvial fan, SP earthquakes.

FIGURE 5.20 "Earthquake lake" formed during the SP earthquakes by a rockfall.

It was reported that although the mud flows damaged some villages in the second and third earthquakes, casualties were avoided because the people had been evacuated from hazardous locations. The evacuation was done primarily to avoid the effects of shaking, but sometimes also because of landslide hazard shown to exist by previous earthquakes or slides. Large landslides are common to the area, even in the absence of earthquakes.

Strong-Motion Installations

There were no strong-motion accelerographs in the affected area of Szechuan Province at the time of the earthquake, although an instrument in Kansu Province, about 60 km from the epicentral region, did record ground motions. Apparently, this instrument had been moved from elsewhere in Kansu because of the prediction, but a similar action was not taken in Szechuan, nor was IEM in Harbin asked to install strong-motion instruments. Since the earthquakes, three installations have been made in the epicentral region, with another six stations installed elsewhere in Szechuan Province.

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I: ITINERARY OF THE EARTHQUAKE ENGINEERING AND HAZARDS REDUCTION DELEGATION

July 24	
Afternoon	Arrived in Peking in the afternoon. Discussion of itinerary and agenda while in Peking.
July 25	
Morning	Discussions at the State Seismological Bureau. Visit to the Palace Museum (Forbidden City).
Afternoon	Visit organized by the State Capital Construction Commission to three construction sites.
Evening	Welcoming banquet hosted by the State Seismological Bureau.
July 26	
Morning	Visit to Tsinghua University and tour of three of its laboratories.
Afternoon	Lunch and sightseeing at the Summer Palace.
Evening	Left Peking for Harbin by train.
July 27	
Morning	Arrived in Harbin at noon.
Afternoon	Met with hosts at the Institute of Engineering Mechanics (IEM) around 2:00. Received a general report on the Tangshan earthquake.
Evening	Welcoming dinner hosted by Heilungkiang Provincial Scientific and Technological Committee.
July 28	
Morning	Reports on Tangshan earthquake and other research activities by personnel of IEM.

Afternoon	Lectures given by part of delegation to an audience of about 150 at IEM. Other delegates visited museum and antiquities store.
Evening	Attended musical and dance concert.
July 29	
Morning	Reports on research activities by personnel of IEM.
Afternoon	Lectures given by part of delegation to audience of about 150 at IEM. Other delegates visited fine arts and crafts factory.
Evening	Attended a performance of a circus.
July 30	
Morning	Reports on research activities by personnel of IEM. Simultaneous sessions on structures and soils.
Afternoon	Lectures by part of delegation to audience at IEM. Other delegates visited Harbin Polytechnic Institute.
Evening	Meeting of delegation.
July 31	
Morning	Tour of facilities at IEM. Lectures by delegates to audience at IEM.
Afternoon	Two simultaneous panel discussions. Panel A, strong motion seismology and ground motions; Panel B, theory and design of structures. Wallace and Teng left for Sian.
Evening	Dinner with staff of IEM.
August 1	
Morning	Two simultaneous panel discussions. Panel A, microzoning and soil liquefaction; Panel B, experimental study of aseismic structures.
Afternoon	Boat trip on Sungari River and visit to Harbin Childrens' Park.
Evening	Left around 6 p.m. for Peking by train.
August 2	
Morning	Arrived in Peking just before noon.
Afternoon	Presentations by personnel of the State Capital Construction Commission and the Peking Seismological Brigade, at Tsinghua University. Wallace and Teng rejoined delegation.

August 3	
Morning	Delegation split into parts. Some delegates lectured at Tsinghua University, others at Geological Institute. Activities continued until after lunch.
Afternoon	Part of delegation met with personnel of State Capital Construction Commission.
Evening	Cocktail party at U.S. Liaison Office followed by return banquet hosted by delegation.
August 4	
Morning	Sightseeing at Great Wall.
Afternoon	Sightseeing at Ming Tombs.
Evening	Departure for Chengtu by air at 6 p.m.
August 5	
Morning	Driven to Kuanhsien. Visit to historic irrigation project.
Afternoon	Briefing on geology and seismology of Lungmenshan fracture zone; visit to a nearby active fault. Return to Chengtu.
Evening	Dinner hosted by Szechuan Provincial Seismological Bureau.
August 6	
Morning	Presentations by personnel of the Szechuan Provincial Seismological Bureau concerning Sungpan-Pingwu earthquakes.
Afternoon	Part of delegation visited construction sites; others went sightseeing at temples.
Evening	Attended musical and dance concert.
August 7	
Morning	Left Chengtu for Kweilin around eight in the morning.
Afternoon	Sightseeing at Reed-Pipe Caves.
Evening	Dinner hosted by Kuangsi Provincial Scientific and Technological Committee.
August 8	
Morning	Sightseeing on river cruise.

Afternoon	Continuation of morning's activity.
Evening	Attended concert.

August 9

Morning	Sightseeing, for which delegation broke into several groups.
Afternoon	Departure for Canton after lunch. Presentations by personnel of Kuangtung Provincial Seismological Bureau.
Evening	Dinner hosted by Kuangtung Provincial Seismological Bureau.

August 10

Morning	Presentations by personnel of Kuangtung provincial Seismological Bureau.
Afternoon	Lectures by members of delegation to audience of about 60 local engineers.
Evening	Two simultaneous discussions, one on dams and one on structures.

August 11

Morning	Lectures by members of the delegation.
Afternoon	Trip to seismological station and spa at Tsunghua.
Evening	Dinner given by delegation for accompanying Chinese hosts.

August 12

Morning	Meeting of delegation and visit to reservoir and waterfall.
Afternoon	Return to Canton.
Evening	Farewell banquet hosted by Kuangtung Provincial Seismological Bureau.

August 13

Morning	Depart Canton for Hongkong by train.
Afternoon	Arrived in Hongkong shortly after noon.

II: PARTIAL LISTING OF EARTHQUAKE ENGINEERS, EARTH SCIENTISTS, AND OFFICIALS MET IN THE PEOPLE'S REPUBLIC OF CHINA BY THE EARTHQUAKE ENGINEERING AND HAZARDS REDUCTION DELEGATION

PEKING

Scientific and Technical Association

周培源	Chou Pei-yuan (ZHOU Peiyuan)	Acting President
卢景霆	Lu Ching-ting (LU Jingting)	Responsible Member International Department

State Scientific and Technological Commission

錢皓	Chien Hao (QIAN Hao)	Staff

Ministry of Foreign Affairs

梁桂萱	Liang Kwei-hsuan (LIANG Guixuan)	Staff Member
廉正保	Lian Cheng-pao (LIAN Zhengbao)	Chief, America and Australia Department

State Seismological Bureau

卫一清	Wei Yi-ching (WEI Yiqing)	Deputy Director
丁國瑜	Ting Kuo-yu (DING Guoyu)	Responsible Member
馬宗晉	Ma Chung-chin (MA Zongjin)	Deputy Chief, Division of Seismic Analysis and Earthquake Prediction
徐宗和	Hsu Chung-ho (XU Zonghe)	Technical Staff
刘鹏心	Liu Peng-hsien (LIU Pengxin)	Interpreter

余德紅	Yu Teh-hong (YU Dehong)	Staff
姜維岐	Chiang Wei-chi (JIANG Weizhi)	Instrumentation Design
林庭煌	Lin Ting-huang (LIN Tinghuang)	Staff

Institute of Geophysics

顧功叙	Ku Kung-hsu (GU Gongxu)	Deputy Director
曾融生	Tseng Rung-shen (ZENG Rongsheng)	Surface Waves, Crustal Structures
林中洋	Lin Chung-yang (LIN Zhongyang)	Staff

Institute of Geology

罗焕言	Lo Huan-yen (LO Huanyan)	Geologist
高文学	Kao Wen-hsueh (GAO Wenxue)	Responsible Member
姚其昌	Yao Chi-chang (YAO Qichang)	Research Staff
鄧起東	Teng Chi-tung (DENG Qidong)	Research Staff
李桂茹	Li Kwei-ruh (LI Guiru)	Hydraulic Engineering Geology
郭順民	Guo Shunmin (GUO Shunmin)	Soil Mechanics and Liquefaction

Peking Seismological Brigade

周錫元	Chou Shi-yuan (ZHOU Xiyuan)	Research Member
徐 渭	Shu Wei (XU Wei)	Research Member
王开順	Wang Kai-shun (WANG Kaishun)	Research Member

Chinese Academy of Sciences

馮因复	Feng Yin-fu (FENG Yinfu)	Responsible Member
邱秉均	Chew Ping-chun (QUI Bingjun)	Staff Member

Institute of Geophysics

陈宗基	Cheng Zung-chi (CHEN Zongji)	Director
傅承义	Fu-Chen-yi (FU Chengui)	Responsible Member

Academy of Building Research

龔思礼	Kung Shih-li (Gong Sili)	Director of Building Research
龔永松	Kung Yung-shong (GONG Yongsong)	Engineer
趙 玲	Chao Ling (ZHAO Ling)	Interpreter

Peking Buildings and Engineering Bureau

刘永生	Liu Yung-sheng (LIU Yongsheng)	Engineer

Tsing Hua University

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杜庆华	Tu Ching-hua (DU Qinghua)	Professor of Engineering Mechanics
裘中連	Chou Chung-lian (QIU Zhonglian)	Lecturer of and Deputy Director of Special Program in Structural Engineering
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程朝陽	Cheng Chao-yang (CHENG Chaoyang)	Professor of Hydraulic Engineering Department
譚 清	Tan Ching (TAN Qing)	Vice Chairman, Engineering Mechanics Department
程 道	Cheng Dau (CHENG Dao)	Professor of Structural Engineering

HARBIN

Institute of Engineering Mechanics

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胡聿賢	Dr. Hu Yu-hsien (HU Lüxian)	Professor on Structural Design and Strong Ground Motion
車俊如	Che Chun-ju (CHE Junru)	Chief, Division of Scientific Research and Planning
章在庸	Chang Chai-yung (ZHANG Zaiyong)	Chief, Division of Strong Ground Motion
朱継澄	Chu-Chi-cheng (ZHU Jicheng)	Chief, Division of Earthquake Resistant Structures
刘穎	Liu Ying (LIU Ying)	Chief, Division of Soil Dynamics
王志勇	Wang Chi-yung (WANG Zhiyong)	Research on Earthquake-Resistant Structures
肖光先	Hsiao Kuang-hsien (XIAO Guangxian)	Research on Civil Engineering and Structures
刘貞荣	Liu Chen-yung (LIU Zhenrong)	Research on Computer Software
李沙白	Lee Sha-pai (LI Shabai)	Research on Strong Ground Motion
黄浩华	Huang Hao-hua (HUANG Haohua)	Design Engineer
郭玉學	Kuo Yu-hsueh (GUO Yuxue)	Strong Ground Motion
彭克中	Peng Kuan-chung (PENG Kezhong)	Structural Design

CHENGTU

Szechuan Provincial Seismological Bureau

刘興懷	Liu Hsing-huai (LIU Xinghuai)	Director
羅灼礼	Lo Chuo-li (LO Zhuoli)	Deputy Director
李兴海	Li Hsing-hai (LI Xinghai)	Chief, Administrative Office
龍庆章	Long Chien-chang (LONG Qingzhang)	Earthquake Engineering Research
韓渭浜	Han Wei-pin (HAN Weibin)	Geologist
唐榮昌	Tang Yung-chang (TANG Rongchang)	Seismologist

姚玉良	Yao Yu-liang (YAO Yuliang)	Chief, Szechuan Foreign Affairs Office
朱皆佐	Chu Chieh-chou (ZHU Jiezuo)	Earthquake Prediction Research

KWANGCHOW

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IV: THE CHINESE INTENSITY SCALE

Intensity	Type of Observation	Description of Effect
I	Response of buildings.	No damage.
	Response of other structures.	No damage
	Ground surface phenomena.	No response.
	Other phenomena.	Not felt. Tremor is recorded by sensitive seismographs.
II	Response of buildings.	No damage.
	Response of other structures.	No damage.
	Ground surface phenomena.	No response.
	Other phenomena.	Felt by individuals who are very sensitive and at rest.
III	Response of buildings.	No damage.
	Response of other structures.	No damage.
	Ground surface phenomena.	No response.
	Other phenomena.	Felt indoors by people at rest. Vibrations like the passing of a truck. Slight swinging of hanging objects noticed by attentive observers.

Intensity	Type of Observation	Description of Effect
IV	Response of buildings.	Doors, windows, and ceilings with paper make slight creaking sounds.
	Response of other structures.	No damage.
	Ground surface phenomena.	No response.
	Other phenomena.	Felt indoors by most people and outdoors by a few. A few people awakened. Hanging objects swing. Liquids in vessels slightly disturbed. Unstable vessels near to each other clink.
V	Response of buildings.	Doors, windows, wooden floors, ceilings, and joints of wood frame houses creak slightly. Open doors and windows swing back and forth. Dust disturbed. Minor cracks in plaster and plaster dust visible.
	Response of other structures.	No damage.
	Ground surface phenomena.	Small water waves in pools.
	Other phenomena.	Felt indoors by most persons and outdoors by a majority. Most people awakened. Domestic animals become uneasy. Hanging objects swing noticeably. Pendulum clocks stop. Small amounts of liquid spill from well-filled containers. Unstable objects overturn or topple from shelves.
VI	Response of buildings.	Moderate damage in many class I buildings but few seriously damaged. Poorly built houses and sheds may collapse. Slight damage in many class II and III buildings, but few class II buildings moderately damaged.
	Response of other structures.	Slight damage to memorial monuments, masonry towers, and garden walls.
	Ground surface phenomena.	In isolated cases, minor fissures in wet or loose ground. A small number of landslides, earthslumps, and sink holes in mountainous regions.

Intensity	Type of Observation	Description of Effect
VI (cont.)	Other phenomena.	Many run outdoors and stand with difficulty. Domestic animals run out of their stalls. Liquids in containers seriously disturbed and spilled. Some books and objects on shelves overturned or fall. Light furniture may move.
VII	Response of buildings.	Moderate damage to most class I buildings, many seriously damaged, and a few collapse. Moderate damage to most class II buildings; a few seriously damaged. Slight damage to most class III buildings and some moderate to serious damage.
	Response of other structures.	Serious damage to a few garden walls and some may collapse if not well built. Moderate damage to well-built garden walls. Moderate damage at many locations and serious damage at some locations in city walls that are not well built. Moderate damage in some locations in well-built city walls. A few parapet walls collapse. Memorial monuments, masonry towers, and factory stacks may be moderately damaged. Slight damage in many stone pillars and monuments. Open caves in loess blocked by slides. Minor cracks in isolated cases in roads. Occasional slumps in earth embankments, newly built road, and dikes.
	Ground surface phenomena.	Minor fissures in dry ground in some locations. Many large cracks in wet and loose ground. Sandblows in some locations. Slides on steep slopes in isolated cases. Moderate amount of landslides and slumps in mountainous regions, particularly in loose soils. A change may be seen in the flow of springs or level of water table.
	Other phenomena.	People are frightened and run out of doors. May be felt by motor car drivers. Hanging objects swing violently and may fall. Light furniture may move. Books and objects on shelves fall.
VIII	Response of buildings.	Serious damage to most class I buildings, may collapse. Serious damage to many class II buildings, a few collapse.

Intensity	Type of Observation	Description of Effect
VIII (cont.)		Moderate damage to most class III buildings, a few seriously damaged or collapse.
	Response of other structures.	Serious damage and partial collapse in poorly built garden walls. Some serious damage in well-built garden walls. Serious damage at many locations and collapse at some locations in city walls that are not well built. Many parapet walls collapse. Serious damage at some locations in firm city walls. A few masonry parapet walls collapse. Many memorial monuments damaged. Moderate damage in masonry towers and factory stacks, some with serious damage or collapse if not well built. Unstable stone pillars or monuments displaced or overturned. Moderate damage to many stable monuments, some overturned. Moderate slumps on steep road embankments or cuts. Serious damage to underground pipelines in isolated cases.
	Ground surface phenomena.	Cracks of several centimeters in firm ground. Cracks greater than 10 cm on loose soil slopes and wet riverbanks. Sand and mud boils in regions of shallow water table. Considerable sliding and slumping in regions of broken rock or loose soil, which may block rivers and form new pools. Wells may dry up or new springs may occur.
	Other phenomena.	People stand with difficulty. People and animals injured in damaged buildings. Furniture displaced and may overturn.
IX	Response of buildings.	Most class I buildings collapse. Many class II buildings collapse. Serious damage and some class III buildings collapse.
	Response of other structures.	Most poorly built garden walls collapse. Serious damage and partial collapse in well-built garden walls. Serious damage at many locations in well-built city walls. Collapse of many parapets. Serious damage to memorial monuments. Serious damage and some collapse of many

Intensity	Type of Observation	Description of Effects
IX (cont.)		masonry towers and factory stacks. Many stable stone pillars and monuments overturned. Cracks in roads and embankments. Rails bent locally. Breaks and damage in underground pipelines.
	Ground surface phenomena.	Many cracks about 10 cm wide in soil. Cracks of tens of cm cross each other and extend for great lengths on loose sediments and slopes of river banks. Many landslides and earth slumps. Well water dries up or new springs occur in many locations.
	Other phenomena.	Furniture overturned and damaged.
X	Response of buildings.	Collapse of many class III buildings.
	Response of other structures.	Serious damage in many monuments. Masonry towers and factory stacks collapsed. Stable stone pillars and monuments overturn. Embankments and dikes destroyed. Roads deformed and extensively cracked. Underground pipelines broken.
	Ground surface phenomena.	Several-centimeter wide cracks in ground, some 1-m wide in isolated cases. In sediments, cracks may form wide bands and extend for several kilometers. Cracks occur in rock in isolated cases. Slides occur on steep slopes in mountainous regions and riverbanks. Many earthslumps in loose soils. Water waves splash the banks of rivers and pools.
	Other phenomena.	Furniture and other objects indoors damaged.
XI	Response of buildings.	Buildings destroyed, generally.
	Response of other structures.	Embankments and dikes destroyed, generally. Rails bent in many areas. Underground pipelines out of service, generally.
	Ground surface phenomena.	Many broad cracks formed on ground with a great amount of loose and saturated sediment ejected from cracks in some cases. Numerous landslides and slumps.

Intensity	Type of Observation	Description of Effects
XI (cont.)		Considerable horizontal and vertical surface faulting. Surface water and underground water table changed significantly.
	Other phenomena.	Many people, domestic animals, and property buried in collapse of buildings.
XII	Response of buildings.	Buildings destroyed in an extensive region.
	Response of other structures.	Other structures destroyed, generally.
	Ground surface phenomena.	Significant topographic changes in an extensive region. Serious surface water and underground water table changes in an extensive region.
	Other phenomena.	Animals and crops destroyed from the effects of landslides and slumps in mountainous regions.

V: A DISCUSSION OF THE CHINESE BUILDING CODE

In 1974 the State Capital Construction Commission of the People's Republic of China approved a new building code entitled "Earthquake-Resistant Design Code for Industrial and Civilian Buildings (TJ11-74)." The Code had an effective date of December 1, 1974. It is published (in Chinese) by the China Building Publishing House, Peking. An English translation was made available by Andrew C. S. Chang.*

In order to understand the basic design philosophy and criteria of the Chinese structural engineers, a short abstract of the Code is presented here. It combines a method of specifying the basic lateral forces with empirical rules to be followed for different types of materials. It must be remembered that most of the construction before the Tangshan and Sungpan-Pingwu earthquakes was built before the adoption of the 1974 Code.

The Code starts with a statement of general principles. Instead of the usual "zones" as used in many other codes, design "intensities" corresponding to the Chinese intensity scale (Appendix IV) are assigned to various cities and localities. The Code applies to intensities of VII, VIII, and IX; intensity VI does not require earthquake-resistant design. Where the design intensity is greater than IX, special investigations and design procedures are required.

The basic intensity may be modified according to the importance or use of the structure.

1. For buildings of prime importance the design intensity may be one unit higher, when approved by the State.
2. Important buildings, high-rise buildings, structures needed after a disaster, those storing dangerous or vital materials, etc., are to be designed for the basic intensity.
3. Ordinary buildings not falling in the above classes may be designed for one intensity less than the basic intensity but not for less than intensity VII.
4. Temporary buildings and structures need not be designed for earthquakes.

*Available from the John L. Klug Corporation, 760 Exchange Street, Rochester, New York 14608.

The Code specified criteria for the choice of sites and foundation capacities. If founded on rock, the forces specified are the same as for other soils, but the empirical construction requirements may be dropped one intensity if the basic intensity is VIII or IX. A criteria for liquefaction is presented.

The forces are calculated for each of the major axes of the structure and are to apply to buildings less than 50 m (165 ft) in height, with relatively uniform weight and rigidity, and with shear deformations dominating the response. The same method applies to single-story industrial buildings.

The base shear $Q_0 = C\alpha_1 W$, where C, the structural influence factor, equals 0.30 for steel, wood, and reinforced concrete buildings; 0.35 for brick buildings with or without interior columns; 0.40 for chimneys, water towers, and tall slender structures; 0.45 for combined shear wall frame action; and 0.40 for multistory buildings higher than 50 m.

$$C = \frac{0.2\alpha}{T} \text{ max for class I soils (rock)}$$

$$= \frac{0.3\alpha}{T} \text{ max for class II soils (firm stable)}$$

$$= \frac{0.7\alpha}{T} \text{ max for class III soils (soft, miscellaneous)}$$

$$\alpha \text{ max} = 0.23 \text{ for intensity VII}$$

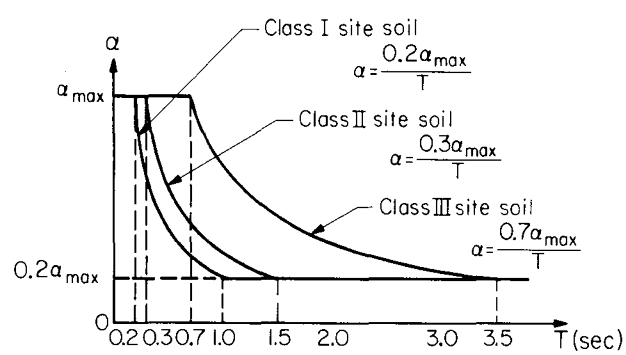
$$= 0.45 \text{ for intensity VII}$$

$$= 0.90 \text{ for intensity IX}$$

$$\text{The minimum } \alpha_1 = 0.2\ \alpha \text{ max}$$

A plot of α_1 is included in Figure V.1.

FIGURE V.1 Plot of α_1.



Seismic Influence Factor α

T is the period of the building that may be determined by field measurement, testing, or analysis. Approximate formulae may be used. For multistory reinforced concrete frames with shear walls or solid masonry infill walls,

$$T = 0.22 + 0.035 \frac{H}{D^{1/3}}$$

H is height, in meters, and D is length of frame, in meters. Special formulae are presented for chimneys. W is the total dead load, operating loads, and actual live load. Where uniform live load is used (offices and apartments, etc.), the actual live load may be assumed at 50-70 percent of the live load design. The base shear is distributed along the height by the formula

$$P_i = \frac{W_i h_i}{\sum W_i h_i} Q$$

the usual triangular loading.

These forces may be compared with the requirements of the 1973 and 1976 Uniform Building Codes (UBC's), as follows:

For the UBC calculation, consider an ordinary shear wall brick building, 60 ft wide and 30 ft high in zone 4 (e.g., San Francisco or Los Angeles). Consider a similar building, founded on firm type II soil, in a Chinese city where the basic intensity is IX. For an ordinary building the design intensity for the Chinese building is one less than the basic intensity.

For the 1973 UBC,

$$V = ZKCW \qquad \text{where } Z = 1.0$$

$$C = \frac{0.05}{T^{1/3}} \qquad T = \frac{0.05h}{D^{1/2}} = \frac{0.05 \times 30}{(60)^{1/2}} = 0.194$$

$$C = \frac{0.05}{(0.194)^{1/3}} = 0.0864$$

$$V = 1 \times 1.33 \times 0.0864W = 0.115W \text{ (dead load only)}$$

For the 1976 UBC,

$$V = ZIKCSW \quad \text{where} \quad Z = 1.0,\ I = 1.0,\ K = 1.33,\ S = 1.5$$

T is 0.194 (same as 1973 UBC)

$$C = \frac{1}{15(T)^{1/2}} = \frac{1}{15(0.194)^{1/2}} = 0.189$$

but the product of CS need not be over 0.14.

$$V = 1 \times 1 \times 1.33 \times 0.14W = 0.186W \text{ (dead load only)}$$

For the Chinese building,

$$\alpha_0 = C\alpha_1 W \quad H = 30 \text{ ft} = 9.09 \text{ m}$$

$$D = 60 \text{ ft} = 18.2 \text{ m}$$

C for brick building is 0.35

$$T = 0.22 + 0.035 \frac{H}{(D)^{1/3}} = 0.22 + 0.035 \frac{9.09}{(182)^{1/3}}$$

$$= 0.341 \text{ s}$$

$$\alpha_1 = \frac{0.3\alpha \text{ max}}{T} \quad \alpha \text{ max} = 0.45 \text{ for intensity VII}$$

$$= \frac{0.3 \times 0.45}{0.341} = 0.396$$

$$\alpha_0 = 0.35 \times 0.396W$$

$$= 0.14W \text{ (dead load plus actual live load)}$$

Coupled with the force requirements are specific construction requirements that are recommended for various materials of construction and types of framing. For example, in brick buildings the distance between bearing walls must not exceed those given in Table V.1; the height limits and mortar strengths are given in Table V.2; wall (bond) beam requirements are given in Table V.3. The structural layout also has height limits as given in Table V.4 (see also Figure V.2) and limits upon certain component dimensions are listed in Table V.5. There are other detailed requirements for each of the construction materials, for which the reader is referred to the translation of the Code.

TABLE V.1 Maximum Distance Between Transverse Bearing Walls (meters)

Roof Construction	Design Intensity		
	VII	VIII	IX
In-situ reinforced concrete	25	20	12
Precast reinforced concrete	20	16	9
Wood	12	8	4

TABLE V.2 Limit of Total Height and Minimum Mortar Strength of Multi-level Brick Buildings

	Design Intensity				
	VII	VIII	IX	VII, VIII	IX
Construction Type	Height Limit (m)			Minimum Mortar Strength (kg/cm^2)	
Solid wall 24 cm or more in thickness	18	15	6	10	25
18-cm solid wall	9	6	NR[a]	25	NR
Hollow wall	6	6	NR	25	NR

[a]NR means not recommended.

TABLE V.3 Wall Beam Requirements

Location of Wall Beams and Reinforcements	Design Intensity		
	VII	VIII	IX
Along interior and exterior longitudinal walls. Gable walls.	Must be provided at roof level.	Must be provided at roof level. For larger rooms, shall be provided at each floor level or at alternate floors if the transverse walls are closely spaced.	Must be provided at roof and each floor level.
Along transverse walls.	Same as non-seismic regions.	Provided at 12-16 m apart in plan.	Provided at 8-12 m apart in plan.
Reinforcement (cm^2).	Same as non-seismic regions.	3.2 (4 10-mm bars)	4.5 (4 12-mm bars)

TABLE V.4 Structural Layout Requirements of Multilevel Brick Buildings With Reinforced Concrete Interior Columns and Floors

Classification	Design Intensity VII	VIII	IX	Maximum Distance Between Earthquake-Resistant Transverse Walls (m)
	Limit of Total Height (m)			
Frame at bottom level. See Figure V.2a.	18	15	7	For brick construction at upper levels, see requirements of Table V.1. For bottom frames, not greater than 2.5 times the building width.
Several rows of interior columns. See Figure V.2b.	18	15	NR[a]	Not greater than 45 m, nor greater than 2.0 times the building width.
Single row of interior columns. See Figure V.2c.	15	12	NR	Conform to requirements of Table V.1.

[a]NR means not recommended.

NOTE: Brick earthquake-resistant transverse walls shall not be less than 24 cm thick and shall be continuous through the full span and height of the building.

TABLE V.5 Limiting Dimensions of Building Components (meters)

Limiting Dimensions	Design Intensity	
	VII, VIII	IX
Minimum width of bearing brick walls between two windows.	0.60	1.00
Minimum distance between end of exterior wall to door or window opening.	1.00	1.20
Maximum height of unanchored parapet wall (24 cm thick and with mortar strength 25 kg/cm^2).	0.80	NR[a]
Maximum cantilever length of precast reinforced concrete eaves with anchorage.[b]	0.80	0.40
Maximum cantilever length of balconies and canopies from face of wall.[b]	1.50	1.00

[a]NR means not recommended.
[b]It is not recommended to design these components without proper anchorage. If they are monolithically connected to reinforced concrete slabs, the limiting lengths may be greater.

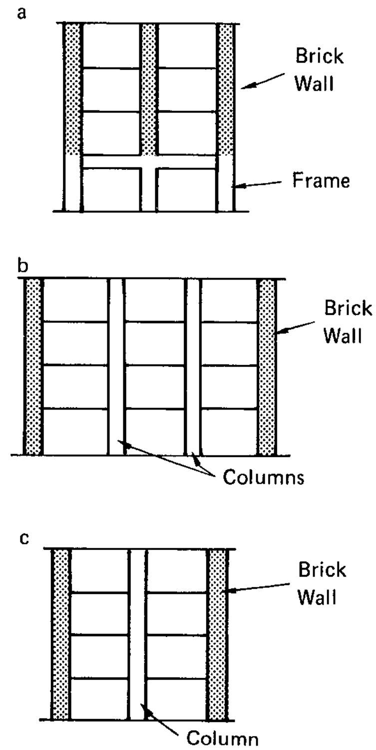


FIGURE V.2 Structural schemes of multi-level brick buildings with reinforced concrete interior columns and floors (described in Table V.4): (a) frame at bottom level, (b) several rows of interior columns, and (c) single row of interior columns.

One aspect of the Chinese Code should be emphasized. The Code uses language such as "recommended" rather than "must." Since all design and virtually all construction are done by the state agencies, it is presumed that the recommendations would be followed, but there is the implication that a certain latitude may be permitted.