THE US-CHINA COOPERATIVE STRONG GROUND MOTION PROJECT

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SUMMARY

This paper describes a cooperative research project on strong motion earthquake studies which is being conducted by the United States and China. The project involves the installation and operation of a strong motion instrument array in China. The majority of the instruments are normally deployed in an operational configuration called a parking array in the seismically active western outskirts of Beijing. The instruments in this array may be rapidly redeployed either in response to an earthquake prediction, or for use in aftershock studies. In addition, a number of instruments are deployed as stand-alone stations in some of the most seismically active regions of China. A number of specific studies have been undertaken in the aftershock region of the Tangshan earthquake.

INTRODUCTION

China is located in one of the most tectonically active regions in the world. With the Indian subcontinent colliding from the south and the Philippine seaplate closing in from the east, large earthquakes have occurred often throughout the country's history. Documented seismicity in China dates back to 780 B.C. and formal accounts of disastrous earthquakes have been recorded since the beginning of the Ming Dynasty (1368 A.C.).

Recognizing the high seismicity of China and the potential for obtaining valuable ground motion data, a cooperative project on strong ground motion measurement was established in 1981. This project was undertaken jointly by the Institute of Engineering Mechanics in China and a U.S. team consisting of representatives from the California Institute of Technology, the University of Southern California, and the U.S. Geological Survey. When the initial phase of the project is completed in 1984, 40 strong motion accelerographs will be operating in special arrays and networks within China. Day-to-day operation of the system is carried out by the Beijing Motion Observatory Center which operates under the Institute of Engineering Mechanics.

The specific objectives of the cooperative project are:

1) To establish a mobile array of instruments which can be rapidly deployed anywhere in China in the event of a credible earthquake prediction or to make aftershock measurements,

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2) To be ready on a continuing basis to make coherent measurements of strong earthquake ground motion over a fairly small geographic area in a highly seismic region, and

3) To expand the coverage of strong motion instruments in China generally in order to help assure that significant records will be obtained from future major earthquakes in that country.

To meet these objectives, a unique fixed/mobile instrument network has been developed.

INSTRUMENTATION

In selecting instruments for this project, several considerations were made. Stand-alone field instruments deployed in remote regions need to be extremely reliable and rugged, should require little maintenance and should draw minimal power. The standard photographic analog strong motion accelerograph is ideally suited for this type of application. Many years of experience have been gained with this type of instrument, and servicing is relatively straightforward.

Instruments which are to be deployed in dense array configurations should have provision for accurate timing. In addition, it is highly desirable for such instruments to be able to record not only the S-wave, but also the P-wave information. For internally triggered instruments, this requires a pre-event memory which is only available in newer digital instruments. Digital instruments also have a potentially wider frequency band and dynamic range than analog instruments, particularly if they employ gain ranging. Furthermore, digital instruments offer the advantage of faster and easier data handling of the high volume of data that can be obtained from an array.

Based on the above considerations, a hybrid analog-digital system was selected for this project. At the present time, predominantly analog instruments are used for remote stand-alone stations. These units may be operated with internal clocks disconnected so as to minimize the standby power requirements. However, all analog instruments are equipped with internal clocks so that they may be integrated into arrays of digital instruments as necessary. Dense array instruments are predominantly digital with some analog instruments as backup or for calibration purposes.

When the initial phase of the project is completed, there will be 22 analog Kinemetrics SMA-1 and 18 digital Kinemetrics PDR-1 instruments installed. All instruments have a 2 g maximum range and are equipped with TCG-1B Time Code generators. The digital instruments have automatic gain ranging with a specified dynamic range of 102 dB, a 2.5 second pre-event memory, and a programmable trigger. Because of the extreme cold that may be encountered in certain regions in China, the instruments have been designed for a temperature range of -20° to 70°C. The transducer used with the PDR-1 instruments is the Kinemetrics FBA-13 Force Balance Accelerometer.

INITIAL INSTRUMENT DEPLOYMENT

Different deployment strategies were required to meet the three different objectives of the joint project. Considerations of seismicity, logistics, and environment played important roles in the choice of regions for initial deployment of the instruments.

Beijing Parking Array

With the limited number of instruments available, it was not feasible to instrument all of the promising sites of interest in China. It was therefore necessary to consider a deployment strategy which provided for a significant number of instruments to be a part of a mobile array which could be dispatched to particularly promising sites as required. Whether for the purpose of responding to a short-term earthquake prediction or for recording the largest aftershocks of a major event, a high degree of mobility is essential to such a deployment strategy. Rather than simply stockpile the instruments in strategic locations throughout the country, it was decided to temporarily deploy the instruments in an operational state or parking array in some seismically active region which is easily accessible and near a major transportation center.

The parking array has been established on the western outskirts of Beijing in the region of the Baboshan Fault. The site of the parking array is shown in Fig. 1. Two separate, but integrated strong motion arrays, will eventually be installed in this area. They are: 1) The parking array which consists of a dense 2-dimensional free-field array (see Fig. 2) with a linear extension traversing laterally heterogeneous geology and topography ranging from alluvium cover to bedrock, and 2) A structural array of instruments in a medium rise apartment building. The structural array is being provided by the Institute of Engineering Mechanics as part of a separate project.

The State Seismological Bureau, operates several strain measurement stations and a 21 station, three component, telemetered seismic network in the general area of the parking array. The seismological stations will provide excellent data on source characterization for all but the largest ground motions which may be recorded by the parking array. All instruments in the parking array have been placed in the field in such a manner as to minimize the time required for retrieval and transport to another location. In order to insure rapid response, field personnel and an adequate number of field vehicles are maintained nearby on a continuous basis.

Tangshan Special Array No. 1

The intent of the parking array is to have a store of instruments available for redeployment to regions of projected or observed high levels of seismic activity. One such region is the aftershock region of the 1976 Tangshan earthquake. Therefore, as an initial test of the deployment concept, a special free-field array was installed in this region from July 1982 to March 1983. The array consisted of 12 PDR-1 stations located as indicated in Fig. 3.

During the period of deployment of this array, a total of 285 near-source accelerograms were obtained from 132 earthquakes of magnitude ranging from M_L = 1.2 to 6.2. Most of these accelerograms contain the complete P- and S-wave motion along with accurate absolute time information. The largest event recorded was the M_L = 6.2 Lulong earthquake of October 19, 1982. Nine instruments were triggered by this event. The epicentral distance from the recording stations for this event ranged from 4 to 41 km. The corresponding peak horizontal acceleration ranged from 0.009 to 0.232 g. Rural masonry buildings in the town of Xiazhe near the epicenter suffered moderate damage. Results of the preliminary analysis of the data obtained from Tangshan Special Array No. 1 are discussed below.

Expanded Coverage and High Potential Regions

As noted above, one of the objectives of the project is to provide expanded strong motion instrument coverage in regions of high seismic potential in China. In support of this objective, a number of SMA-1 instruments have been temporarily deployed in Yunnan and Szechuan provinces. These instruments are being used to supplement existing networks in these regions. The potential for recovering data from an event of $M_L > 6.0$ is believed to be very high.

PRELIMINARY RESULTS

The results of measurements obtained from Tangshan Special Array No. 1 are still being analyzed. However, a number of interesting preliminary observations have been made.

Attenuation Law

The accelerograms from earthquakes ranging in magnitude from 2.9 to 6.2 were used in a regression analysis of the parameters of the attenuation law for peak horizontal and vertical acceleration. The resulting attenuation law was found to be:[1]

$$\text{Horizontal:} \qquad a_{max}(q's) = 10.52 \times 10^{0.236 M_L} \Delta^{-0.913}$$

$$\text{Vertical:} \qquad a_{max}(q's) = 6.964 \times 10^{0.211 M_L} \Delta^{-0.838}$$

where Δ is the epicentral distance in kilometers. The standard deviation of these fits is rather large and additional data will be required to refine the attenuation law for this region.

For the approximately 90 accelerograms with good horizontal and vertical data, a statistical analysis was made of the ratio of the peak vertical to horizontal acceleration. The distribution of this ratio has a shape resembling a Rayleigh distribution with a mean value of 0.68 and a standard deviation of 0.29. The ratio of vertical to horizontal peak acceleration observed in this near-source data appears consistent with other recent observations.

Local Variation in Ground Acceleration

As part of Tangshan Special Array No. 1, four instruments were installed in very close proximity to one another within an area of about $0.3 km^2$ in the town of Tuozitou (stations 4-7 in Fig. 3). The terrain is very flat in this area and there are no large structures. A preliminary study has been made of the variation in peak acceleration over this sub-array for eight recorded earthquakes ranging in magnitude from $M_L = 2.3$ to 6.2 and having epicentral distances ranging from 2.0 to 24.9 km. The results are shown in Table 1[1]. The mean value of the ratio of the standard deviation to the average peak acceleration for all components is 0.248. The difference between peak acceleration at individual stations was as large as 300%. The results of this simple experiment indicate that the variation in peak acceleration over a local area may be quite significant and reinforce the need for further investigation of this matter.

Epicentral Locations Using Strong Motion Data

Because of the good quality of the digital data obtained during aftershock measurements and the availability of accurate absolute time on each record, the time of occurrence and source coordinates for recorded events may easily be determined from the strong motion data. The epicentral location has been thus determined for six separate events using Ishigawa's chord method. The difference between the epicentral locations obtained from the strong motion data and those obtained from standard geophysical measurements varied from 2 to 15 km, the largest difference being for the Lulong event. In general, the corrections in epicentral location obtained from the strong motion data tended to move the source closer to known fault lines within the region of the array. The strong motion data has also been used to estimate source depth which varies between 8 to 15 km for most of the recorded events.

FUTURE ACTIVITY

The Tangshan region offers a unique opportunity to measure the three-dimensional character of ground motion. A number of inactive coal mines in the area allow the possibility of deploying strong-motion instruments at depth while still maintaining access to these instruments for servicing and inspection. This eliminates most of the serious problems encountered with three-dimensional arrays in boreholes.

An experimental three-dimensional array has been installed in this region. The general layout of the array is shown in Fig. 4. The array consists of 3 below-ground instruments and 10 surface instruments. Additional instruments will be added to this special array as they become available.

The Beijing parking array will be maintained as the primary deployment site for most of the strong-motion instruments when they are not being used for special studies elsewhere. This array and any instruments in temporary special arrays will be kept in a state of readiness for redeployment in response to an earthquake prediction or to measure aftershocks of a major event as originally intended.

CONCLUSIONS

The high seismicity of China makes it an ideal location for strong ground motion investigation. The cooperative project described herein has significantly increased the data-collecting capability within this country. It is believed that the fixed/mobile array deployment concept developed for this project is well suited to the unique technical capabilities and seismological conditions within China. It is anticipated that the project will yield much important data in the years to come.

ACKNOWLEDGEMENTS

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REFERENCES

1. Peng, K., Xie, L., Li, S., Iwan, W., Teng, T., Boore, D., "The Near-Source Strong-Motion Accelerograms Recorded by An Experimental Array in Tangshan, China, XVIII General Assembly, International Union of Geodesy and Geophysics (IUGG), Hamburg, 1983.

TABLE I

Event	M_L	Ave. Epic. Dist. (km)	σ/a_{max}		
			N-S	E-W	V-D
1	2.3	2.0	0.306	0.347	0.357
2	2.4	8.4	0.306	0.218	0.171
3	2.5	7.7	0.473	0.108	0.178
4	2.7	14.4	0.326	0.049	0.375
5	3.1	12.0	0.312	0.262	0.124
6	3.7	7.1	0.296	0.503	0.162
7	4.4	7.1	0.203	0.119	0.200
8	6.2	24.9	0.175	0.247	0.200
Ave			0.300	0.232	0.212

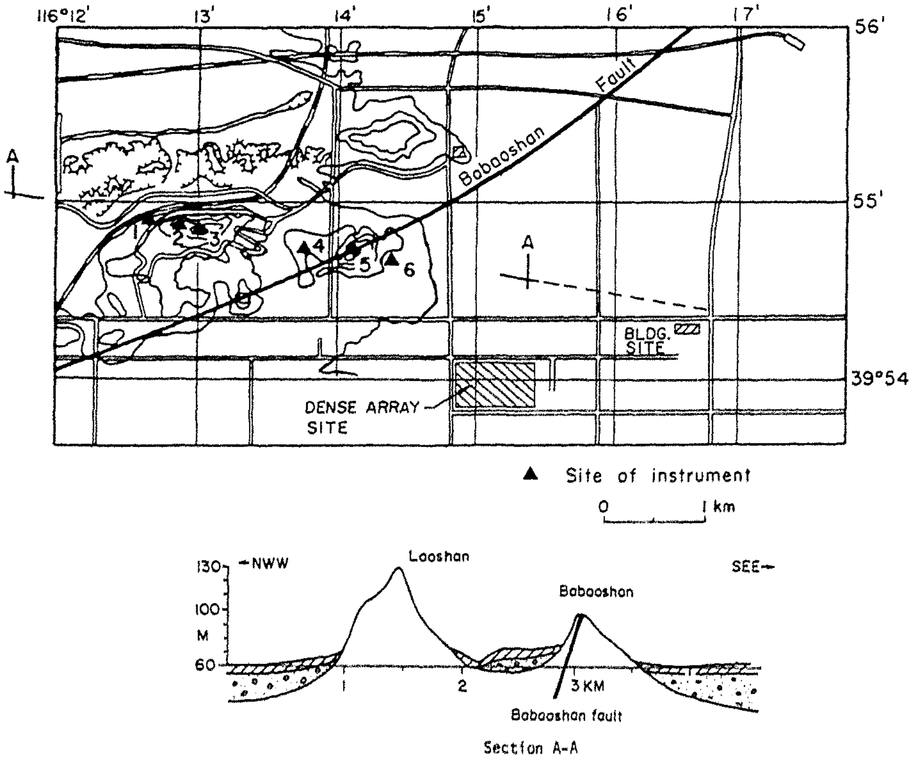


Figure 1 Beijing parking array.

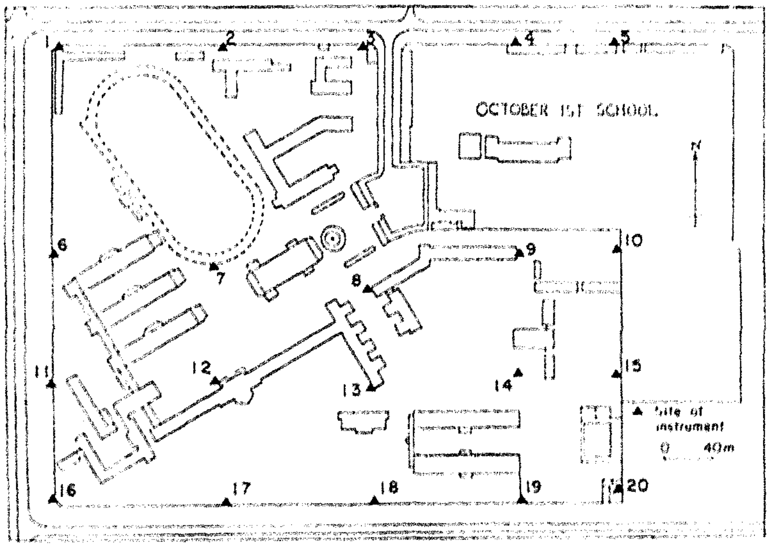


Figure 2 Dense Sub-array in Beijing parking array.

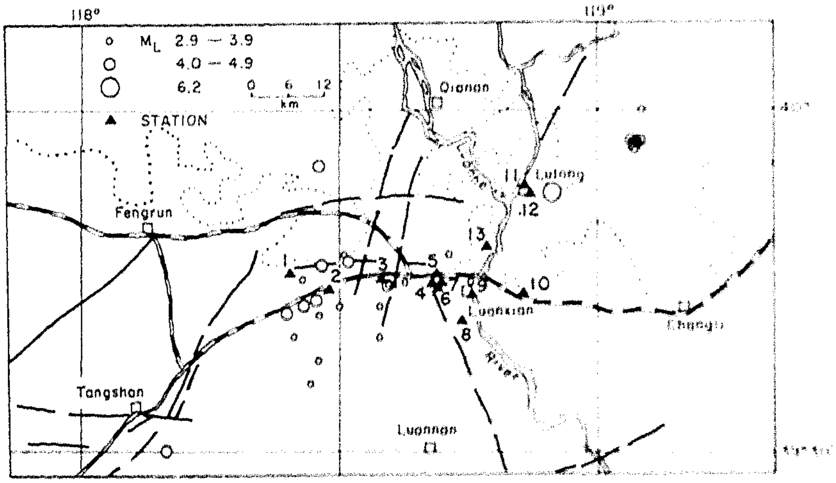
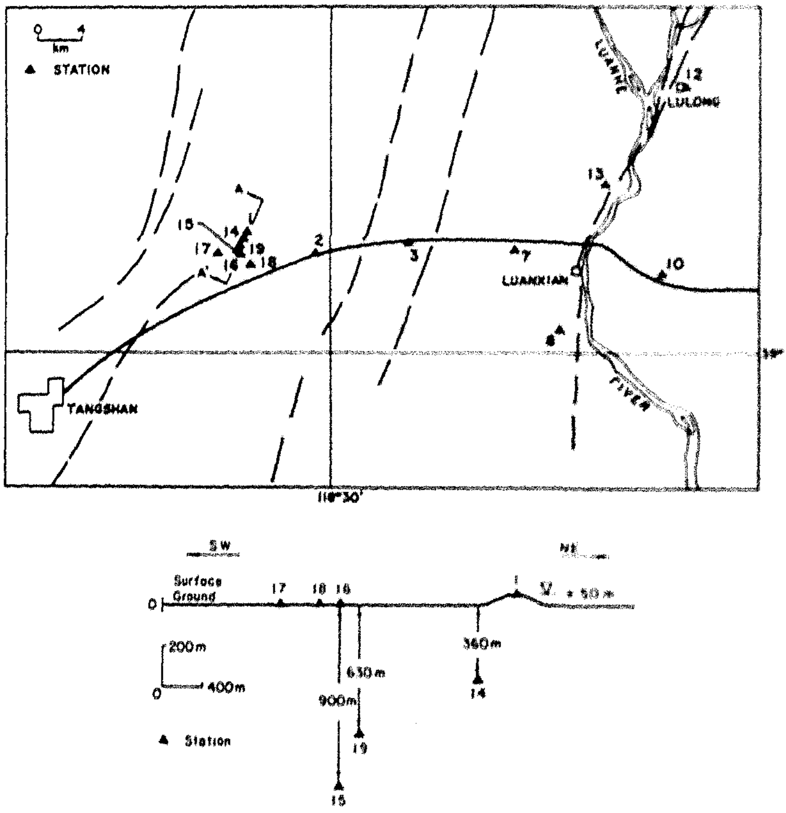


Figure 3 Tangshan special array No. 1



SECTION A — A'

Figure 4 Tangshan special array No. 2