UNIVERSITY OF CHILE - UNIVERSITY OF CALIFORNIA PROGRAM IN EARTHQUAKE ENGINEERING.

by C. Martin Duke[I] and Augusto León R.[II]

SYNOPSIS

The University of Chile and the University of California have completed two years of a four-year cooperative research program in earthquake engineering and the associated engineering and earth sciences. The general objective is to strengthen these fields in both Chile and California. The mechanism of the program is a substantial exchange of faculty and graduate students between the two universities, involving research and teaching at both universities and the procurement of certain equipment.

Principal points of progress are : initiation of a network of 54 strong motion accelerographs in Chile; clarification of structure-soil-damage relationships in earthquakes; experimental studies of soil strength in earthquakes, soil-structure interaction and building vibration; improvement of S-wave velocity measurement; explanation of failures of some earth structures; investigations of several recent earthquakes; improvements in antiseismic design; new earthquake engineering courses; and major increases in thesis work.

CONCEPT AND STRUCTURE OF THE PROGRAM

Introduction

Chile and California have the notoriety of being two of the most earthquake-prone regions of the world. Each has been visited numerous times by highly destructive earthquakes. Because of this, earthquake considerations play a major role in both States in the research and design activities related to the construction industry, and in the education of civil engineers and earth scientists.

For many years at both the University of Chile and the University of California, the teaching and research program in civil engineering and the earth sciences have, as a consequence, given substantial attention to the problems of destructive earthquakes. In each institution there now exist a number of professors who specialize in these problems, as well as courses of instruction, student theses, special facilities, and research programs, all directed toward the improvement of earthquake engineering and its scientific and economic foundations.

I. Professor of Engineering, University of California, Los Angeles, and Profesor Extraordinario de la Cátedra de Ingeniería Antisísmica, Universidad de Chile.

II. Director, Departamento de Obras Civiles, Universidad de Chile. Profesor de la Facultad de Ciencias Físicas y Matemáticas, U. de Chile.

Both Chile and California enjoy the status of professional leadership, on an international scale, in earthquake engineering. One demonstration of this is the fact that the First World Conference on Earthquake Engineering was held at Berkeley (in 1956) and the Fourth in Santiago (in 1969).

The above similarities are no more interesting than a number of differences in the earthquake engineering situations in the two States. Chile has a larger number of destructive earthquakes than California, and a longer historical record of its earthquakes. On the other hand, Chile to date has obtained only two instrumental ground motion records from strong earthquakes (1945 and 1965) compared with the large number of such records obtained in California. The two States have similar topographic and geologic features but important differences in soil types, faulting, and depth of earthquake focus. Chile has been afflicted with major tsunami damage, while in California this aspect of the problem is less severe. Both States frequently experience major permanent surface displacement in earthquakes; in California such movements are often associated with surface fault breaks. There are important differences in type and materials of construction of both buildings and civil works; as an example, modern Chilean design tends to result in more rigid buildings than are prevalent in California.

Similarities and differences on a more general socio-economic level have resulted in recent years in mutual programs of cooperation, notably the former intergovernmental Chile-California program and the convenio of the University of Chile and the University of California. The convenio of the two universities was established in 1965 with the objective of enhancing the research and graduate study programs of each through a carefully planned, relatively large-scale, exchange of faculty and students. The exchanges generally are planned around the accomplishment by groups of faculty in each university of their research and graduate instruction objectives. The Ford Foundation provides financial support.

It was seen that a properly conducted earthquake engineering program could achieve the convenio's objective in large areas of civil engineering and the related engineering and earth sciences. A decision to proceed with serious exploration of this idea was reached in June of 1965 by Dean Enrique d'Etigny of the Faculty of Physical Science and Mathematics of the University of Chile and (then) Chairman C. Martin Duke of the Department of Engineering of the University of California, Los Angeles. A number of discussions were held in both Chile and California. A plan was prepared for a four-year program of research and graduate instruction in earthquake engineering and the associated earth sciences and engineering sciences, giving initial emphasis to the role of soil conditions, to soil-structure interaction, and to the design of foundations and earth structures.

Following approval by the universities, the program began officially on January 1, 1967.

Objectives

The general objective of the cooperative program is to strengthen earthquake engineering and the associated earth and engineering sciences in Chile and in California.

The mechanism is an exchange of approximately 45 faculty and graduate students between the University of Chile and the University of California, covering a period of four calendar years, 1967 through 1970, and involving the procurement of certain equipment.

The central activity is a program of research, of which the objectives are :

1. to increase substantially the earthquake engineering knowledge to be gained from future Chile earthquakes, by instrumenting the country of Chile as a laboratory, somewhat like the existing "laboratories" in California, Japan and the USSR.

2. to contribute to determine and generalize upon such relationships as exist among damage, soil type and structure type from earthquakes in both Chile and California, through scientific examination of earthquake experiences and instrumental records.

3. to improve the understanding of the role of soil-structure interaction in the earthquake response of structures, through experimental and theoretical studies of the response of structures and sites to forced vibration and destructive earthquakes.

4. to improve the present generalizations regarding the strength and deformation of soils in earthquakes through analyses of earthquake failures of soils, foundations and earth structures.

5. to advance the techniques of design of buildings and civil works to resist the effects of earthquakes : shaking, tsunamis, and tectonic movements

6. to accelerate the development of strong indigenous graduate study programs in the relevant disciplines in both universities, including thesis work.

7. to contribute to the progress of earthquake engineering practice in Chile and California.

Organization

The preliminary discussions revealed a high degree of interest among several appropriate organizational units of the University of Chile and the University of California. Each of these units had already done work toward the above research objectives and was planning more. Strong interest also existed among other Chilean universities as well as Chilean governmental agencies and private engineering and architectural offices, in particular the Chilean Institute of Geologic Investigation. Furthermore,

the University of Chile already had a relationship with the Inter-American Program of Massachusetts Institute of Technology, with active participation by Professors R.V.Whitman, J. Roesset, A. Cornell and others. However, the needs was generally recognized by all for a more comprehensive planning effort as well as for a higher level of financial and manpower support.

The following organizations share the responsability of prosecuting the program in its early stages :

University of Chile
Laboratory of Structures
Institute for Investigation
and Testing of Materials (I.D.I.E.M.),
Laboratory of Soil Mechanics
Department of Geophysics and Geodesy
Laboratory of Applied Geology

University of California
Department of Engineering, Los Angeles
Earthquake Laboratory
Soil Mechanics Laboratory
Structures Laboratory
Nuclear Energy Laboratory

Institute of Geophysics
and Planetary Physics, Los Angeles
Seismology Laboratory

Department of Geology, Los Angeles

Administrative responsability is carried jointly by Director Augusto Léon R. of the Department of Civil Engineering of the University of Chile and Professor C. Martin Duke of the Department of Engineering of the University of California, Los Angeles. The University of California participation in the early stages has been primarily from the Los Angeles campus, but other campuses have contributed and are expected to assume more active roles as the program proceeds.

The program is implemented through the earthquake engineering community of scholars, made up of faculty and students of the two universities and embracing the relevant engineering and scientific disciplines. A very important byproduct has been the much greater communication achieved within the individual universities embracing the disciplines of structures, soil mechanics, seismology and geology. Manpower is provided largerly through the organizations listed. The organizations have increased their attention to earthquake engineering and the supporting earth sciences, and have achieved a significant degree of coordination. New courses and seminars have been established at both universities.

A number of the senior investigators spend full time on the research program, and several have already done work in the "opposite" university. To date the faculty exchanges have included Professors Duke, Kenneth L. Lee, R.B. Matthiesen and Dean Chauncey Starr of the University of California, Los Angeles, Dr. Cinna Lomnitz of the University of California, Berkeley, and Professors Eugenio Retamal, Luis A. Rosenberg, Assistant Dean Juan Cassis

and Messrs. Horacio Musante and Elías Guzman of the University of Chile, for time periods of from 1 week to 1 year. Working in Chile for parts of 1968 and 1969 will be 5 or 6 University of California faculty and students, and approximately 8 University of Chile people will work in California.

The efforts of these senior investigators have been augmented by a major increase in student thesis work carried out within the program framework. The students involved are in the several relevant disciplines and work in the University of Chile (six-year Ingeniero degrees), the University of California (M.S. or Ph.D. degrees), or both. Six young staff members of the University of Chile are now at the University of California pursuing Ph.D. degrees, four in engineering at Los Angeles and two in seismology at Berkeley.

Guidance for the individual student is provided in some instances by a faculty member from each University. Regular seminars for the research students and faculty are conducted at both universities to provide continual intellectual interchange in the program. Through the integration of thesis work into the research program, the students involved receive research training which should be of profound value to the two States in future years.

Equipment obtained by the University of Chile includes ten accelerographs, a dynamic triaxial soil testing system, a portable seismic exploration system, accelerometers, strain gages, piezometers, books and publications and a field vehicle. Other equipment planned includes 20 more accelerographs, a drilling rig, and a microtremor recording system.

It was intended to develop the program in such way that it could achieve a state of self-sustaining momentum, that is,so that it could achieve sufficient results in research and train sufficient young men so that its sheer intellectual force could keep it going, and envolving, into the future. The initial four-year time period was made long enough to make such development possible, and it was found convenient to divide it into two two-year segments : Calendar 1967, 1968; and Calendar 1969, 1970. This segmentation was based in part on the fact that the Fourth World Conference on Earthquake Engineering would be held in Chile in January of 1969, providing a logical medium for the presentation of the first two years' research results and the reassessment of goals.

The University of Chile-University of California convenio is supported by a grant from the Ford Foundation, to be used over the whole range of academic disciplines. The Ford grant is used primarily to support exchanges of faculty and students including their operating costs at the "opposite" university, and equipment for the University of Chile specifically related to the program. Support for students and faculty at their home university is not provided by the convenio. In general, those aspects of the earthquake engineering program performed in Chile are financed by the

convenio and by the funds of the University of Chile. Aspects performed in California are financed by the convenio and by the funds of the University of California. A National Science Foundation grant to the University of California, Los Angeles, has facilited the participation of United States nationals at UCLA.

Research Program

The program of research was planned to reflect current research interests and activities of the two universities. Most aspects of the program were already in progress in greater or lesser degree at one or both of the universities. In particular, the programs (1) to instrument the country of Chile and (2) to study structure-damage-soil relationships already had considerable momentum. (3) The soil-structure interaction problem was the focal interest of several faculty members. (4) The soil failure problem in earthquakes was already a strong activity. These four items of the research program were the aspects of earthquake engineering research which were of the greatest interest to those prepared to be most active in the initial phases. It is anticipated that, as the program proceeds, new insights, new people, and progress in the above four areas will call for periodic reassessment of goals and reassignment of resources to new problem areas including (5) design techniques.

New courses in earthquake engineering have been offered, as a result of the program at both universities.

In the following sections the major features of the research program will be described. At the end of each section the work developed by Faculty members and students at both universities is listed. These list includes publications of work already in progress at the commencement of the program as well as work started as part of this cooperative effort. Because of its great potential, the strong motion accelerograph program for Chile will be explained in some detail.

CHILE AND CALIFORNIA AS EARTHQUAKE ENGINEERING LABORATORIES

Accelerograph Network for Chile

As a key element of the program, Chile is being established as an earthquake engineering laboratory, like California, to be used for the scientific investigation of Chile's past an future large earthquakes for the purpose of gaining information to lead to better earthquake resistive design of structures. The initial research emphasis in the "laboratory" is on the role of soil conditions, on soil-structure interaction, and on foundations and earth structures. This initial emphasis was selected because the soil - associated aspects of earthquake engineering stand in need of major clarification internationally. Some thought has also been given to the improvement of instrumentation in California in this respect.

One essential aspect of the investigation of Chilean earthquakes is the installation of strong-motion instruments throughout the seismically active portion of the country. Most urgent among the desirable instrumentations are strong motion accelerographs to record earthquake ground

motions under various conditions of soil and structure. This was the object of intensive study in 1967, and a plan has been adopted which should have Chile reasonably well instrumented with Montana type accelerographs by 1970. Fig. 1 shows the locations.

The essential features of the plan, involving some 57 accelerographs, are given subsequently. Seven instruments were in place at the beginning of 1967, and 10 to 15 more are to be installed in each of 1968, 1969, 1970 and 1971. The locations have been carefully selected with a view to assuring at least one record from a strong earthquake anywhere in the seismically active part of Chile, and with a view to gaining new understanding of the differences of ground motion between soil and bed rock as well as the effect on ground motion of the interaction of the soil with large structures. Timing of the installations has been planned with an eye to maximizing the probability of obtaining records in the next earthquake.

The plan was developed by Professors Enrique Gajardo, Juan Karzulovic, Joaquin Monge, Peter Welkner, Eugenio Retamal, Edgar Kausel and Martin Duke, with the participation of thesis students Pedro Sanhueza and Enrique Blass. Comments are solicited from all interested persons.

Criteria for Accelerograph Locations in Chile

The following criteria were established to guide the selection of instrument sites. Because of the particular relationship of Chilean geography to its general tectonics, it was not considered necessary to include a criterion directly related to active fault locations.

1. A large earthquake ($M \geq 7$) should result in no less than one record. For this purpose, instruments should be located not more than 200 km. apart over the region of relatively high seismicity extending from Arica to Puerto Montt.

2. Every effort should be made to assure the obtaining of records in the next earthquake. For this purpose, the first new instruments should be installed in the regions of higher seismicity.

3. It will be essential after future earthquakes to interpret structural response and damage in terms of accelerograph records. For this purpose the number of instruments installed in a given city should bear some relation to the number of major structures in the city. Furthermore, the instrument locations should be on the soil types which support the majority of structures.

4. Primary attention should be given to the obtaining of accelerograph records which will illuminate the effects of type of soil and the interaction of soil and structure. For this purpose, when more than one instrument is placed in a given city, the accelerographs should be placed in clusters of three, one in each of the Classifications A, B and C described below, preferably not over one kilometer apart.

A.- Bed Rock - Accelerograph is to be founded directly on fundamental rock having P-wave velocity at least equal to 2000 m/s. It may be housed in almost any building except a very large, heavy building.

B.- Typical soil - Accelerograph is to be founded on a soil type which supports a substantial number of structures. It may be housed only in a very light, flexible building, such as a one-story wood building.

C.- Foundation of a large structure - Accelerograph is to be placed on the foundation of a large, heavy building, or other structure, resting on a typical soil type corresponding with the soil of Classification B.

Chile Accelerographs and Records.

The accelerographs to be installed are the Montana type, similar to the accelerographs developed by the United States Coast and Geodetic Survey. The instruments are being fabricated by the University of Chile, incorporating primarily domestic components but using a few imported parts. The first 10 are currently being fabricated in accordance with existing designs, but the subsequent instruments will be improved on the basis of design studies now in progress. A shaking table for calibration is being developed.

Essential features of the Montana accelerographs are as follows :

1. Three torsion pendulums in each instrument, to measure the vertical and two horizontal components of acceleration. Pendulum period 0.07 second. Damping critical.

2. Sensitivity 15 gal. per cm.

3. Photographic paper speed 2 cm. per sec., time lines each 1/2 sec., with zero reference lines.

4. Automatic starting in an earthquake, with automatic recording for 30 seconds thereafter. Instrument continues to operate if earthquake motion continues after the 30 sec.

5. Power supply 12-volt battery with 220 volt AC trickle charger.

Fabrication, installation, operation and maintenance of the instruments will be by the Department of Geophysics and Geodesy. This department will also be the depository of records, and will reproduce and distribute copies of the records after each earthquake.

As for financing, seven accelerographs were in place at the start of the program. Thirty more are to be financed by the convenio of the Universities of Chile and California. It is believed that various industries and public agencies in Chile will be willing to finance the remaining 20 for installation of their respective properties. It is hoped that most of the latter will be accelerographs of commercial manufacture, so as to facilitate the gaining of experience with the designs recently evolved in the United States, Japan and New Zealand.

Selection and Evaluation of Chile Instrument Sites.

Using the above criteria, together with data on seismicity and preliminary data on site conditions, the team of investigators has prepared a detailed accelerograph location plan. A number of visits have been made to the cities selected and to other cities in arriving at decisions on specific sites. Such practical considerations as the availability of suitable housing for the instruments play an important role. Ultimately, value judgements had to be made not only as to the locations but also as to which places should be instrumented first. Undoubtedly a number of changes will need to be made in the plan as the installations proceed and as better data on site conditions are obtained.

Fig. 1 summarizes the location plan and indicates the locations of the seven existing and the first ten new accelerographs. Details of the planned locations appear in another paper.[III] A statistical summary follows :

Existing accelerographs	7
1968 installation	10
1969 installation	15
1970 installation	15
1971 installation	7
Reserved for aftershock studies	3
	57

Site Classifcation A	15
Site Classification B	28
Site Classification C	11
Reserved for aftershock studies	3
	57

Work is under way to obtain the relevant information about the instrument locations. Subsoil conditions are being determined from information on geology, ground water hydrology, topography, soil borings, water wells and geophysical measurements. In a number of cases it is necessary to make special borings and geophysical measurements in the field, with corresponding laboratory tests, to establish with sufficient confidence the dynamic subsoil characteristics.

Also being determined are the structural design features and dynamic properties of the major buildings housing instruments under the C Classification. The structural design features are being determined in conjuction with the subsoil data. The dynamic properties will be the subject of separate investigations.

III. Duke, C.M., "Plan Para la Instalación de Acelerógrafos en Chile". Revista del IDIEM, University of Chile, V. 6, N°1, pp.78-82 May 1967.

Other Aspects of Chile as a Laboratory

Besides the accelerographs there are a number of other instruments of earthquake engineering interest in Chile. These include 3 Hagiwara teleseismic instruments utilized for research studies, of which two are presently in operation in Concepción and one in Valdivia. Also there are approximately 40 seismoscopes, designed to indicate maximum particle velocity at approximately 0.8 - sec. period, of which half are in place in Concepción and the other half are being installed in Valdivia. Beyond this, the University of Chile operates and is extending a teleseismic network.

The program has under consideration developing a system of strain, deflection and settlement instrumentation in selected buildings, foundations and civil structures at and near the locations of the accelerographs. Additionally it is hoped that suitable instrumentation can be installed in soils for the measurement of pore pressure and soil deformation. The design and location of the instruments would need to be planned to maximize the probability of obtaining early records of the earthquake response of representative structures and soils at places where the ground motion is known.

Additional instrumentation will be maintained on a standby basis to be installed in an afflicted area inmediately after a strong earthquake, with the expectation of obtaining records in aftershocks. This instrumentation presumably will be supplemented after a major earthquake by international and foreign agencies.

The Chilean Society of Seismology and Earthquake Engineering (ACHISINA) has been developing standard procedures, data forms and investigation task force organizations to be invoked after a destructive earthquake. The concern of these task forces will be to obtain, rapidly and systematically, all of the non-instrumental data considered of value. As elements of the two - university program, field investigations have been made of the recent earthquakes in Lima, Peru;[IV] Taltal, Chile; Caracas, Venezuela; and Tocopilla, Chile.

The Chilean Institute of Geological Investigation has made substantial contributions to the geologic and soil mapping of a number of cities. Currently a major effort is under way to produce an areal geologic map of Santiago, and the smaller cities of Los Andes and San Felipe are also being mapped. This work is being done in close collaboration with the Earthquake Engineering Program.

IV. Lee, Kenneth L. and Joaquin Monge E., "Effect of Soil Conditions on Damage in the Peru Earthquake of October 17, 1966", Bull. Seis. Soc. Amer., June 1968.

California as a Laboratory.

Some 154 accelerographs and 251 seismoscopes were in place in California as of January 1, 1968. The first accelerographs were installed by the U.S. Coast and Geodetic Survey in 1932, and numerous records have been obtained begining with the 1933 Long Beach earthquake. The number has been increasing rapidly in recent years. The City of Los Angeles has an ordinance requiring the installation of accelerographs in major new buildings. A limited number of installations have been made of devices for recording deformations of buildings.

The University of California, Berkeley, and California Institute of Technology operate networks of sensitive seismographs. The U.S. Environmental Science Services Administration, the U.S. Geological Survey and others are engaged in observations of crustal movements including those associated with the San Andreas fault system. Through the Earthquake Engineering Research Institute, plans have evolved for the coordination of the gathering of non instrumental data following strong earthquakes. The influence of the California Department of Water Resources relative to dam safety, and of the U.S. Atomic Energy Comission relative to nuclear reactor safety, has caused a sharp increase in studies of surface fault breaks. The California Division of Mines and Geology has accelerated its mapping work with special reference to geological hazards including earthquakes.

The accelerograph installations in California were planned with a view to studying the response of structures, with site conditions being a secondary consideration. Due to the recent and current addition of a considerable number of new accelerographs, it is timely to consider locations or relocations of a number of instruments according to site conditions criteria suggested by the Chile program. A study of this possibility is under way.

Related Faculty and Student Work.

4 WCEE Paper

An Earthquake Risk Map of Chile. Cinna Lomnitz.

Theses

Zero-Frequency Focal Mechanism for Shallow Shocks. (PH.D) E. Nyland. (Knopoff.)
Mechanism of Deep Focus Earthquakes. (Ph.D) M.J. Randall (Knopoff).
Investigations into the Nature of Melting. (Ph.D.) J. Shapiro. (Knopoff.)
Quadripartite Telemetric Seismic Net in Santiago. E. Gajardo. (Kausel et al.)
Propagation of High Frequency Compressional Pulses in a Sphere.* Enrique Luco. (Cisternas.)
Bispectral Analysis of Solid Friction (M.S.) J. Green. (Knopoff)
Propagation of Raleygh Waves in an Elastic Wedge.* L.Lopez. (Cisternas.)

*Thesis recently completed.
M.S. or Ph.D. signifies University of California, Los Angeles, theses.
Others are University of Chile Ingeniero theses.

Automatic Determination of Hypocenters and its Application to a Study of Crustal Structure in Northern Chile.* R. Olea. (Cisternas.)
Tectonics of the La Ligua Region. C. Pimstein. (Kausel et al.)
Low Velocity Channel in North America. (Ph.D.) N. Biswas. (Knopoff.)
Geologic and Soil Map of San Felipe. Juan Pallanta M. (Karzulović, Barozzi.)
Geologic and Soil Map of Los Andes. Hugo Delucchi F. (Karzulović, Barozzi.)
Tsunami Problem in Valparaiso and Viña del Mar. Hernán Godoy. (Monge).
Automatic Processing of Seismographs.* R. Madariaga. (Cisternas.)
Development of an Improved Strong Motion Accelerograph. Bernardo Blass. (Gajardo, Kausel.)
Development of an Improved Seismoscope. A. Cafati. (Gajardo.)
Microtremor Studies for Soil Classification. Jorge Cerna. (Monge, Yoma, Rosenberg.)
Site Characteristics of Chile Strong Motion Earthquake Stations. Pedro Sanhueza. (Duke, Gajardo.)

CHARACTERISTICS OF SITE AND STRUCTURE VERSUS PATTERNS OF EARTHQUAKE DAMAGE.

Comprehensive studies have been undertaken to determine, for selected Chilean cities and their past earthquakes, such general relationships as may exist between site and structure characteristics and the patterns of damage distribution. Such studies are in progress in Concepción, Valdivia, Talcahuano, La Calera and Taltal. The goals are twofold : (1) to determine general relationships, from earthquake experience, which may be of fundamental value for use in Chile and other countries; and (2) to develop seismic microregionalization maps for the cities studied.

Relevant theories, and the research findings from elsewhere, are being used to help establish conceptual models to be tested. One such model is the amplification spectrum, modified by damping, finite wave train, and soil-structure interaction.

Effort in both states has been devoted to the development of field techniques for the measurement of shear-wave velocities in surface materials.

A current project is devoted to analysis of California accelerograph records. A attempt is being made to learn how site conditions, including soil-structure interaction, have contributed to the features of the records obtained.

Related Faculty and Student Work

4 WCEE Paper

Techniques for Field Measurement of Shear-Wave Velocity in Soils. C. Martin Duke

Theses

Definition of Intensity based on Response Spectra.* Gustavo Lange. (Arias.)
Intensity and Response Spectra. Peter Arnold.* (Arias.)
The Elastic Constants of a Solid Containing Hollow Spheres of Another Elastic Material. (M.S.) K.J. Lee. (Westmann.)
Development of Laboratory Apparatus for Measuring Shear Waves Velocity in Soils.* Benedicto Cespedes. (Retamal, Ortigosa.)
The Soils of Central Concepción in Relation with Earthquake Resistive Design.* Mauricio Poblete. (Dobry.)
Concepción Damage and Soil Conditions.* Marcel Oppliger. (Rutllant.)
Relation between Damage in the 1960 Earthquake and the Soil Conditions of Valdivia.* Roberto Lástrico. (Retamal.)
Wave Velocities and Amplification in Valdivia. Carmen Norambuena, José Veiga. (Retamal, Duke.)
Microzoning : Talcahuano.* Jaime Carramiñana. (Monge, Karzulović.)
Microzoning : Quillota, Calera, Llay Llay. Eduardo Moreno, Hugo Giacaman. (Monge, Karzulović.)

SOIL AND STRUCTURE DYNAMICS AND INTERACTION

The goals of this phase of the work are : (1) to establish the ranges of soil and structure characteristics for which soil-structure interaction has an important effect on the structure's response to earthquakes; (2) to improve the state of knowledge about the interaction phenomenon; and (3) to determine the dynamic characteristics of typical structures and sites. Methods of attack are both experimental and theoretical.

The experimental methods utilizes the vibration testing equipment of both universities, applied to structures and sites in the field. Improvements have been made in existing equipment, to make it possible to provide higher frequencies, higher dynamic force, and better frequency control. The theoretical method utilizes the computers on both institutions and strives to develop generalizations which explain the experiments and which may be simplified for use in design.[VI] Previous and current experimental and theoretical work of others is heavily drawn upon.

Several buildings vibration tests have been made in each country, including university, industrial and commercial buildings. A small nuclear reactor has been tested for soil-structure interaction.

Related Faculty and Student Work

4 WCEE Paper

The Effect of Gravity on the Collapse of Yielding Structures in Earthquake Excitation. Raúl Husid L.

VI. Luco, J.E., "Interaction of Shear Wall Type Building with the Ground during an Earthquake". Jour. Engr. Mech. Div. ASCE. April 1969.

Theses

Matrix Calculus of Rigid Frames with Computers.* René Luft. (Rosenberg, Roesset.)[VII]
Techniques of Handling Structural Analysis in Dynamics by Substructures. (M.S.) L. Bodnar. (Hurty.)
Comparison of Shear Wall and Frame Design for Reinforced Concrete Buildings. Zeus Aguilera (Rosenberg.)
Program for Computer Analysis of Space Frames. David Cstro. (Rosenberg.)
Study of Dynamic Buckling as Related to Laterally Excited Columns. (M.S.) R. Davidson. (Hurty.)
Program for Computer Analysis of Space Frames by Flexibility Matrix Method. Juan Cabello (Rosenberg.)
Free Vibration of a Rectangular Plate with Variable Stiffness Support. (M.S.) S. Honda. (Roberts.)
Framed Walls by the Finite Element Method.* Rafael Guendelman. (Guendelman.)
Study of Slab Fields by Finite Element Method.Gerardo Rico. (Guendelman).
Comparison of Finite Element and Finite Difference Analyses in 2-dimensional Structures. (M.S.) C. Hiner. (Hurty).
Study of Continuous Space Structures by Finite Element Method.* José Hernandez. (Guendelman,)
A Study of Soil-Structure Interaction. (Ph.D.)* P.B. McCalden. (Matthiesen.)
Building Interaction Effect on Accelerograms.* Rodolfo Saragoni.(Rosenberg.)
Foundation Compliance Field Experiments. Carlos Macho R. (Monge, Yoma,)
Analysis using Averaged Spectra. Santiago Vasquez. (Rosenberg.)
Averaged Spectra, South America. Germán Rojas. (Rosenberg.)
Forced Vibration Test of a 5-Story Steel Frame.* (M.S.) J.S. Benya. (Matthiesen).
Vibration Test of a 6-Story Reinforced Concrete Building.* (M.S.) T.A. Shawaf. (Matthiesen.)
Experimental Determination of Periods and Damping of Reinforced Concrete Buildings.* Hugo Barrera. (Flores, Monge.)
Torsional Vibration of One-Story Buildings.* David Campusano. (Arias.)
Dynamic Analysis of Combined Frame and Shear Wall Buildings. (Ph.D.) R.E. Englekirk. (Matthiesen.)
Vibration of a Nuclear Reactor Fuel Bundle.* (M.S.) R.L. Rudman.(Smith.)
Earthquake Effects on Nuclear Reactors. (Ph.D.) G.E. Howard. (Smith.)

FAILURE OF SOILS IN EARTHQUAKES

A program of sampling and laboratory testing has been undertaken to identify soils that failed in recent earthquakes and to determine their dynamic strength and deformation properties. Analyses of seismic stresses in the failed structures are being made to see if the failures might have been anticipated, based on these properties. The objective is to improve the state of the art of earthquake resistive design of earth structures and foundations.

VII. José M. Roesset, visiting professor from M.I.T.

Problems investigated to date include basic research on soil liquefaction,[VIII] the dry Canyon Dam failure in California, and several problems in Chile such as earth dam and tailings dam[IX] failures, landslides, collapses of harbor fills, and settlements due to vibratory compaction.

Effort is being directed at the improvement of both dynamic soil testing techniques and dynamic stress analysis of foundations and earth structures.

Related Faculty and Student Work

4 WCEE Papers

Pore Water Pressures Developed during Earthquakes. K.L. Lee and H.B. Seed.
Densification of Sand by Vertical Vibrations. Robert V. Whitman (M.I.T.) and Pedro Ortigosa.
Vibratory Compaction of the Soil and Tectonic Subsidence during the 1960 Earthquake in Valdivia, Chile. Eugenio Retamal S. and Edgar Kausel.

Theses

The Effect of Soil Type and Test Conditions on the Strength of Soil for Simulated Earthquake Loading.* (M.S.) J.A. Fitton. (Lee.)
Development of Dynamic Soil Strength Apparatus. Horacio Musante. (Duke, Retamal, Lee.)
Stresses in Earth Structures by the Finite Element Method. (M.S.) C. Hasson. (Dong.)
Failure Analysis of Earth Dams. Fernando Abusleme, Danilo Kalafatovic. (Retamal, Duke.)
An Analysis of Damage Caused to the Dry Canyon Earth Dam During the 1952 Kern County Earthquake.* (M.S.) H. Walters. (Lee.)
Failure Analysis of Tailing Dams. Cristian Geisse, Gonzalo Marambio. (Duke, Foncea.)
Stability of Cut Slopes. (Ph.D.) Z. Yang. (Singh.)
Failure Analysis of Riñihue Lanslides.* Juan Ariztía, Alejandro Vicuña. (Duke, Foncea.)
Some Physical- Chemical Properties of Valdivia Soils.* Pedro Acevedo (Retamal.)
Study of a Possible Vibratory Compaction in Valdivia in the 1960 Earthquake.* Ignacio Mena and Ismael Rengifo. (Retamal.)
Possible Causes of the Compaction of Soils in Valdivia in the 1960 Earthquake. Eduardo Leonvendagar. (Retamal, Ortigosa.)

TECHNIQUES FOR DESIGN

Supplementing the initially emphasized areas above, a segment of the research has been oriented directly toward the planning and design of

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VIII. Lee, Kenneth L. and H. Bolton Seed. "Cyclic Stress Conditions Causing Liquefaction of Sand." Jour. Soil Mech.Fndn. Div. ASCE, V. 93, N°SM1, pp. 47-70, January 1967.

IX. Dobry, Ricardo and Leonardo Alvarez. "Seismic Failures of Chilean Tailings Dams." Jour. Soil Mech. Fndn. Div. ASCE, V. 93, N°SM6 pp. 237-260, November 1967.

buildings and civil works to resist the effects of earthquakes. Work in this design area will be increased in the future, with the objectives of exploiting the basic research of the overall program as well as the work of others.

Related Faculty and Student Work

4 WCEE Papers

University of Chile - University of California Program in Earthquake Engineering. C. Martin Duke and Augusto León R.
The New Chilean Code for Earthquake Resistant Design of Structures. Arturo Arias S., Raúl Husid L., and Joaquín Monge E.
Seismic Behavior and Design of Small Buildings in Chile. Joaquín Monge E.

Theses

Earthquake Resistant Design of Reinforced Concrete Block Houses. Vicente Caruz. (Vives, Lamana, Monge.)
Earthquake Resistant Design of a Tall Steel Building. Francisco Cabello. (Rosenberg.)
Optimum Design of a Single Frame for Dynamic Response and Stability. (M.S.) L.E. Elliott. (Rubinstein.)
Study of 1967 Tocopilla Earthquake.* Issa Kort (Arias, Monge.)
Study of 1966 Taltal Earthquake. Fernando Gonzalez. (Monge, Karzulović.)

CLOSURE

Much has been learned, and will be learned, through this program about how to strengthen universities and their research and graduate training programs through cooperative activities. Certainly both the University of Chile and the University of California, Los Angeles, have grown substantially in earthquake engineering and the supporting earth and engineering sciences as a result of their convenio. The research results and graduate training being achieved exceed substantially the levels of 1966. Furthermore, the general progress of earthquake engineering practice is being accelerated as a result of this joint effort.

It should be emphasized that both universities are benefiting from the association. Both are doing substantially better jobs toward their respective institutional objectives.

The faculty participants look forward to the stimuli and insights to be provided by the Fourth World Conference on Earthquake Engineering. Following the Conference, a meeting will be held in Santiago to evaluate the first two years' progress and to reassess goals.

Appreciation is extended to the two universities, the many faculty and students involved, and the supporting organizations both within and outside of the two universities. Grateful acknowledgement is made for the financial support of the Ford Foundation through the convenio of the Universities of Chile and California and of the National Science Foundation for work at UCLA.

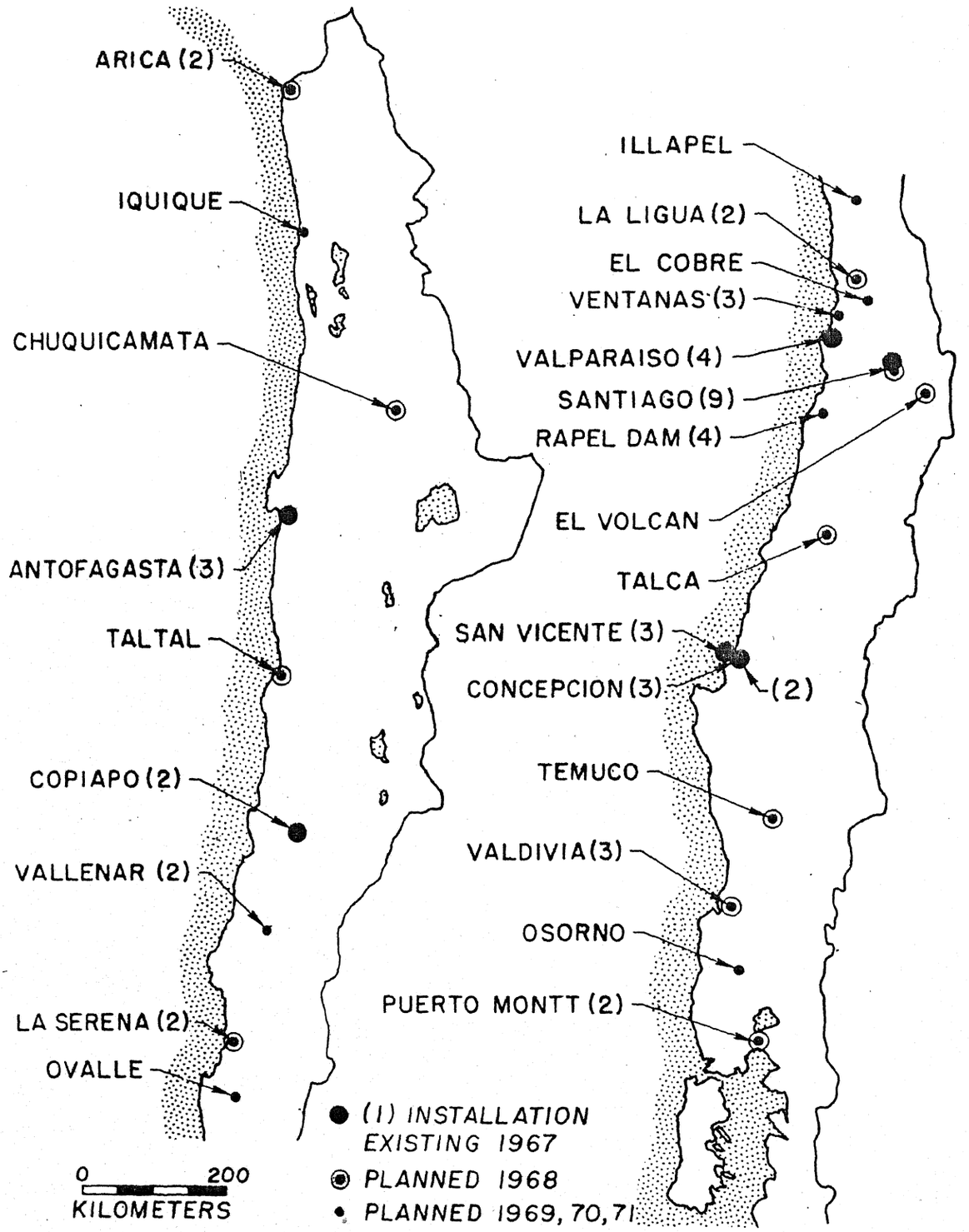

FIG. 1 PLANNED STRONG MOTION ACCELEROGRAPH LOCATIONS IN CHILE