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A TECHNICAL REVIEW OF THE SISRA PROJECT

A PART OF THE CERESIS PROGRAM

Prepared for

Office of Foreign Disaster Assistance
United States Agency for International Development

June 25, 1985

Prepared by:

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July 15, 1985

Paul Krumpe
Science Advisor
OFDA/USAID
Washington, D.C.

Re: A Technical Review of the SISRA Project and Assessment of the March 3, 1985 Earthquake of Central Chile

Dear Mr. Krumpe:

Transmitted with this letter is a report reviewing the status, achievements, and fiscal aspects of the project Seismic Hazards Mitigation in the Andean Region (SISRA). Included in this report is an evaluation of the effects of the destructive March 3,1985 earthquake of central Chile.

It has been a pleasure working with you and OFDA. Should you have any questions or if I can be of further assistance please do not hesitate to contact me.

Sincerely,

K. Michael Cline

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A TECHNICAL REVIEW OF THE SISRA PROJECT

A PART OF THE CERESIS PROGRAM

INTRODUCTION

On behalf of the Office of Foreign Disaster Assistance (OFDA) U.S. Agency for International Development (USAID) a technical and fiscal review has been completed for the project Seismic Hazards Mitigation in the Andean Region (SISRA). In a related activity, the effects and impact of the March 3, 1985 earthquake of Central Chile were also investigated. The report on the earthquake is treated separately from the SISRA report. It accompanies this report as Appendix A.

Background

The SISRA project is under the technical supervision of the U.S. Geological Survey (USGS), International Branch. The work is being coordinated by the executive committee of the Centro Regional de Sismologia para America del Sur (CERESIS), a pre-existing organization made up of scientists and engineers of most South American countries. The organization was designed to promote technical communication and scientific research between South American countries. CERESIS, under the direction of Alberto Giesicke (Peru), submitted the SISRA proposal to USAID in 1979. The primary purpose of the proposed work was to compile and synthesize existing data on historical seismicity and neotectonics to assess seismic hazards in the Andean Region, and to develop a model to accurately estimate casualty and economic losses from future earthquakes. The proposal requested the technical assistance of the USGS. At the request of OFDA, the USGS resubmitted the proposal in 1980 to fund the project directly through a PASA. CERESIS then submitted a grant proposal to the USGS for support of the SISRA project. After extensive proposal review the project was implemented in October 1981.

The SISRA project was scheduled to be completed March 31, 1985. However, the monumental coordination effort for completing the products has lead to a request by the USGS for a "no cost" extension. Dr. Ted Algermissen, principal investigator for the USGS, submitted a request to extend the project through December 31, 1985. Under the "no cost" extension, Dr. Algermissen intends to complete the original objectives of the project, compile additional maps on ground response and estimated damage from future earthquakes, and to monitor the after shocks of the March 3, 1985 earthquake of Central Chile.

Under the "no cost" extension the USGS temporarily installed six "state-of-the-art" digital event recorders designed and built by the USGS. This equipment recorded after shocks for approximately one month. The results will provide important information on how the ground responded at selected sites in the March 3, earthquake.

Scope of Work

On behalf of the USAID Office of Foreign Disaster Assistance (OFDA), this author conducted an independent review of the SISRA project and March 3, 1985 earthquake of Central Chile. The specific objectives included:

1. Review technical, programmatic, and fiscal information at the USGS offices in Reston, Virginia and Golden, Colorado. Assess USGS involvement with its counterparts and the objectives to be completed under the "no cost" extension.

2. Visit the CERESIS headquarters in Lima, Peru to review technical and fiscal documentation for the SISRA project.

3. Attend the SISRA technical review meeting in Santiago, Chile.

4. Formulate recommendations for OFDA possible future involvement with CERESIS and hazards mitigation programs in the Andean region.

5. Review effects of March 3, 1985 earthquake of central Chile and the USGS after shock program under the "no cost" extension.

6. Send appropriate briefing cables during TDY and prepare report summarizing above activities, conclusions, and recommendations for OFDA action.

The review of the SISRA project and March 3 earthquake was completed between March 19 and April 12, 1985. OFDA's efforts to initiate this review in a timely fashion are appreciated.

An itinerary of activities and individuals contacted is presented in Annex A. The list consists primarily of USGS professionals and the SISRA review committee.

CERESIS HISTORY AND ACTIVITIES

The CERESIS program was initiated in 1965 through a grant between UNESCO and participating governments principally of the Andean region, i.e., Chile, Argentina, Peru, Ecuador, Bolivia, Colombia and Venezuela. Presently many more South American countries are members of CERESIS. With the termination of UNESCO funding in 1970, all participating countries agreed that CERESIS should be kept as a functioning organization. Consequently, each country began contributing annually to the CERESIS program. In addition, CERESIS continues to receive grants from UNESCO and OFDA for special projects. CERESIS activities include:

1. Periodic reports on earthquakes and related items.
2. Training courses in seismology and instrumentation.
3. Scholarships
4. Publication and distribution of educational material on earthquake preparedness in earthquake prone countries.
5. Translate textbooks and manuals related to seismology.
6. Support of crustal dynamics program being completed by NASA. A laser measurement program to accurately measure plate convergence along south American coast.
7. Periodic meetings for technology transfer and exchange.
8. Maintains continuous radio contact with offices in other countries for emergency action.
9. Responsible for preservation of important earthquake documentation prior to 1962.
10. Supports the Uruguay seismograph station which is important to understanding South America seismology.
11. Member of the International Commission on Seismic Risk.
12. Member of International Seismic Commission.

Dr. Alberto Giesicke, geophysicist, realized the importance of the CERESIS program and took it upon himself to see to its formulation and organization. Because of this he was made its first director and the headquarters was established in Lima. Dr. Giesicke remains its director.

SISRA PROJECT

The SISRA project (earthquake Hazards Mitigation in the Andean Region) was initiated in October 1980 under a PASA between the USGS and OFDA, however, the project was not implemented until October 1981 under a grant between the USGS and CERESIS. A chronological calender of the SISRA project history is shown in Annex B. This calender was completed by Paul Krumpe, Programs Officer for OFDA.

The purpose of the project was to compile, coordinate, summarize and unify information on Seismic hazards in the Andean region. In other words, the information or data base would be uniform and regional. Political boundaries would not uniform and affect the geology and seismology. The original objectives of this project were to:

1. Collect, summarize, catalogue and publish on a consistent basis all historic earthquake information in South America.

2. Compile, summarize and edit on a map all significant quaternary geologic and tectonic information of the Andean region for evaluating seismic hazards and assessing their risk.

3. Collect and compile data on levels of ground motion from past earthquakes. Indicate on a map maximum levels of ground motion.

4. Develop an economic, geophysical and engineering model for estimation of economic loss and casualties associated with damaging earthquakes in South America.

5. Provide training for South American technicians and scientists in the areas of seismology, earthquake engineering, fault hazard evaluation and mitigation, and disaster preparedness.

6. Develop a prototype satellite seismograph-telemetry link utilizing the GOES satellite for possible future data transmission.

Most of the products of these objectives are complete or are now in final preparation. The actual products consist of 12 volumes, maps, a series of publications without volume numbers, and numerous scholarships and trainee programs. The first nine volumes, consisting of more than 4000 pages, are historical earthquake catalogues. The volumes, each representing a participating country (Peru has two volumes), are the result of exhaustive studies to compile and edit national earthquakes historical

records dating back to the mid sixteenth century. Volume 1 of the nine volumes is an information and explanation volume. Volumes 2 through 9 are the historical earthquake catalogues and are in alphabetical order by country. The nine volumes are complete and are now being printed. A sample page of the first nine volumes is shown in figure 1. The data from the nine volumes is also being put on magnetic tape for computer use so that research institutions and industry can easily access the data.

The CERESIS executive committee has decided to publish a series of epicenter maps to accompany these nine volumes. These maps are being prepared under the "no cost" extension. The maps, will be in a series of four showing. 1) large to great historic earthquakes, 2) shallow historic events, 3) intermediate historic events, and 4) deep historic events. The shallow, intermediate and deep historic events may be printed on overlays that can be superimposed on a base map. The map sets will then be divided into quadrants for convenience.

Volume ten is the neotectonic map of South America with explanation (objective 2). The scale of this map will be 1:5000.000. The map will be printed in color on two sheets dividing South America into northern and southern halves. Included on the map will be zones of uplift and subsidence, active volcanoes, postulated and known active faults and other significant tectonic features. Essentially it will include all aspects of known Quaternary deformation. In March 1985 this map was in preparation for final printing. This reviewer had the opportunity to review the draft and have input on the Quaternary geology of Colombia. It was to be printed by the Instituto Geografico Militar de Chile.

Volume eleven contains two maps with reports on maximum groundshaking or maximum intensity (objective 3) based on historic events. A base map delineates areas of historic maximum ground shaking. An overlay (second map) indicates where ground failure (landsliding, liquifaction, lurch cracks, etc.) has been associated with groundshaking from historic events. The maps are complete and only require printing.

Volume twelve is a model developed to estimate casualty and economic losses in future earthquakes (objective 4). The seismologic, geologic and engineering effects of the earthquakes of Caracas, Venezuela (1970), Peru (1972), and San Juan, Argentina (1979) were used in developing the model. Dr. Jose Grases, the developer of this model, hopes to test it against the damage of the March 3, earthquake. The development of this model is the only new research to come out of the SISRA project. If successful, it will make a significant contribution to science

and will be directly applicable to evaluating seismic risk and earthquake hazards preparedness activities elsewhere in earthquake prone regions. The document is presently being edited for publication.

All twelve volumes are being designed so that they may be expanded and modified in the future. During this reviewer's attendance of the technical review meeting, discussions were held on when volumes should be updated. There seemed to be general agreement on every five years.

Reports not designated as volumes but included in the SISRA project are; 1) a report on historic earthquakes during colonial times based on a review of archival records in Lima and Spain, 2) the proceedings of the 1984 International Conference on Earthquake engineering and Seismic Risk held in San Juan, Argentina.

The products of the SISRA project are very extensive and quite voluminous. It is easily understandable why a "no cost" extension was requested. With the extension the products will be completed and published.

In addition to the volumes and other reports being published, the SISRA grant also supported eight graduate theses in Peru and Argentina. The grant also supported seven professionals from Chile, Bolivia, Ecuador and Columbia for training in instrumentation seismology and earthquake engineering.

The prototype satellite seismograph-telemetry link utilizing the GOES satellite (objective 6) has not been tested. The prototype system has been assembled in Golden, Colorado, but problems with permits for access to the GOES satellite has not permitted testing it. A remote site in Peru has been selected as the test site for the remote station.

Proposed SISRA Activities Under the "No Cost" Extension"

Dr. Algermissen, realizing the SISRA project would not be completed by March 31 as originally scheduled, requested a "no cost" extension through December 31, 1985. He also realized funds were still available and that such could be gained from the March 3, earthquake. Consequently, the proposed scope of work under the "no cost" extension included new and expanded objectives.

The primary purpose of the extension is to allow time to complete the review process of all the products, and their publication. At the time the "no cost" extension was requested most products were in final draft form; however, they lacked final review by the USGS.

Dr. Algermissen indicated in his extension request that additional epicenter maps will be published to go with volumes 1 through 9. During the technical review meeting in late March it was apparent these maps were already being prepared.

The extension will also permit the USGS to test the GOES satellite seismograph-telemetry system in South America. The system was prepared in Golden; however, it was not tested because of difficulties the Peruvian government has had in acquiring space on the GOES satellite. The equipment in Golden consists of a satellite receiving station which will receive and record in a digital mode telemetered seismic data and a seismoneter designed for remote station transmitting to the GOES satellite. Now that space is available the system can be tested. The test will be a demonstration in the capability of a prototype system for possible future use on a worldwide basis. The testing of this system is part of a larger program to assess the feasibility of replacing the existing Worldwide Seismic Network stations with satellite telemetry and digital recorders. The existing worldwide Seismic Network is old, inefficient, and unreliable.

With the occurrence of the March 3, 1985 earthquake, additional significant work can be completed under the "no cost" extension. Since sufficient funds remain, Dr. Algermissen requested that the USGS report on the seismological, geological and engineering aspects of the earthquake; and monitor the after shocks using six GEOS digital event recorders (seismographs). These are sophisticated instruments that will provide data that can be used in interpreting ground response of past and larger events. The ground response of the March 3 earthquake can be estimated more accurately for selected sites. This information will then be applicable to hazard zoning. Without the use of this equipment ground response from the earthquake can only be grossly estimated.

The March 3 earthquake also allows Dr. Grases to test his earthquake casualty and economic loss model which was developed for accurately estimating casualty and economic losses from future earthquakes. Dr. Grases can test his model on Chile then compare the results to the recent earthquake. The results will be most interesting. As stated earlier the model, if applicable, could be a significant tool for government institutions and insurance companies working in earthquake preparedness.

TECHNICAL ASSISTANCE

The U.S. Geologic Survey has been providing technical assistance throughout the duration of this project. The executive committee of SISRA is made up of a team of highly qualified professionals; therefore, the primary role of the USGS has been that of technical review and transferring data from the earthquake catalogues to magnetic tapes for computer use. The USGS has also provided training for technicians in seismology, instrumentation, and data analysis. This project has been of particular interest to Dr. Algermissen (primary investigator), consequently the project has had a top priority for him. During the technical review meeting in late March he acted strictly as an advisor. His comments were generally weighed heavily by the SISRA committee.

Although most of the objectives are the responsibility of CERESIS, the GOES satellite seismograph telemetry test is primarily the responsibility of the USGS. The ultimate goal of such a program will be justification for a new Worldwide Seismograph Network utilizing satellite telemetry to a central receiving station and replacing the existing seismographs with more sophisticated instrumentation. The new system would allow for immediate and more accurate location capability. This new system would also allow for immediate emergency response capability to earthquake stricken areas and areas expected to be hit by tsunamis. The earthquake information would be received within minutes of the event allowing for immediate location, determination of magnitude and depth, and estimates on damage and tsunami potential. The plan of the USGS under the SISRA project is to test a "state of the art" digital event recorder (seismograph) in a remote location, such as central Peru, utilizing space on the GOES satellite for telemetry transmission to Golden. The USGS has satellite receiving capability in Golden and the equipment for the remote station. CERESIS has secured space on the GOES satellite. The equipment only needs to be set up in Peru. Dr. Algermissen intends to complete this objective under the "no cost" extension.

Another key activity of the USGS under the SISRA project is the review of the March 3 earthquake and monitoring the after shocks. A review of the seismological, geological and engineering effects of the earthquake were completed by the USGS in late March. Dr. Algermissen was responsible for the seismology component, Dr. George Plafker was evaluating the geological aspects and Mehnu Celebi evaluated engineered structures. Dr. Algermissen spent much of his time working with his USGS team installing and relocating the six GEOS event recorders. These are three component, digital seismographs. They are designed to filter out noise and only record earthquake data in a digital mode. Sophisticated analyses can be made of the data recorded.

The ultimate goal of this exercise is to determine how the ground responded at selected sites during the March 3 earthquake. Dr. Algermissen's approach was to spend three weeks in Chile first setting up near Santiago, then leap-frogging westward to the Pacific Coast. The leap-frogging westward was done to capture after shocks first in the Santiago area before they significantly diminished as time elapsed after the main shock. The team hoped to re-occupy all the sites of the existing accelographs in central Chile. The accelograph data from the earthquake will be used as a standard for this investigation. The survey was completed and the data is presently being analyzed.

FISCAL ASSESSMENT OF SISRA PROJECT

The original SISRA budget was $500.000. The original budget has been augmented four times, bringing the total cost of this project to $1,235.650. To date, CERESIS has invoiced $812.00 under the grant to offset accrued expenses. USGS expenses have amounted to a little more than $285,000. As of March 1985, at the time of the request for a "no cost" extension, approximately $135,000 remained unspent under project funds. Under the extension, the additional work and publication costs will be covered by the remaining balance.

During 1984 and early 1985, remittance of certain CERESIS invoices had been delayed by Dr. Algermissen. Of the $812,000 invoiced under the CERESIS grant $732,000 had been remitted by the USGS. The CERESIS invoices and USGS remittances are shown in table 1. The delays were due to some confusion between the USGS and CERESIS accounting systems and assessment of SISRA progress. Based on the results of the March technical review meeting, Dr. Algermissen was satisfied with the progress and has authorized payment of the $80,000 outstanding.

A review of financial documentation in Lima, Reston, and Golden indicate that all accounts balance. Dr.Giesicke has kept a very elaborate accounting of all expenses accrued under the SISRA project. The accounts were presented to this reviewer while in Lima. Each receipt has been numbered and listed. Expenditures under the grant are fully accountable. Dr. Giesicke pointed out that the OFDA/USGS grant made up only a portion of the total project costs. He has prepared a statement of total project costs and counterpart contributions. This statement is presented in Table 2. Through 1983 counterpart commitments outweighed the OFDA/USGS grant by 10:1. These were only estimates made by the CERESIS project office, but nevertheless indicate a significant contribution on the part of the counterparts.

CONCLUSIONS

The SISRA project has been successful in its attempt to compile, synthesize and edit earthquake and neotectonic information on the Andean region. Political and personal ego influence have been significantly controlled. Specific conclusions are presented below:

1. The SISRA project has achieved many of its objectives and will complete all its objectives by December 31, 1985.

2. The end products of the SISRA project will consist of:

   a) Nine volumes in alphabetical order by country of historic earthquakes of South America (over 4000 pages).
   b) Four epicenter maps to support historical seismicity catalogues (nine volumes).
   c) Neotectonic map of south America with supporting report (volume 10).
   d) Maximum ground shaking or intensity maps of South America showing ground failure based on historic events (volume 11).
   e) Model developed to estimate economic and casualty losses from future earthquakes (volume 12).
   f) Reports on the effects of pre-instrumentally recorded earthquakes in South America.
   g) Publication of the proceedings of the San Juan, Argentina conference on earthquake engineering and seismic risk.

2. In addition to the specific end products mentioned above, the SISRA project has also supported eight scholarships for graduate studies in seismology and earthquake engineering in Peru and Argentina. The project has also supported seven professionals for training programs in instrumentation, seismology, and earthquake engineering.

3. Based on the extent of work that has been completed, and the end products being completed, a "no cost" extension is clearly justified through December 31, 1985.

4. Under the "no cost" extension the following should to be achieved.

   a) USGS will complete technical review of all products.
   b) All end products will be published.
   c) The earthquake catalogues (Vol. 1-9) will be put

d) The USGS has reviewed the effects of the March 3, 1985 earthquake and has monitored the after shocks using GEOS digital event recorders. They will prepare reports on the March 3 earthquake and will qualify ground motions of the earthquake at selected sites based on after shocks monitoring.

e) Dr. Grases will test his economic loss and casualty model for future earthquakes using the March 3, 1985 earthquake as his standard.

f) USGS will test the GOES satellite telemetry capability for a remote station in Peru as part of the over-all feasibility program for a new worldwide seismic network.

4. The USGS technical assistance has been primarily that of technical review. With the exception of number six, the objectives have been principally the responsibility of the CERESIS professionals.

5. A brief review of the fiscal aspects of the project indicate all accounts (CERESIS and USGS) balance. Also the USGS is now caught up in payments of CERESIS invoices. The CERESIS headquarters in Lima has a detailed accounting of all its expenditures for the SISRA project. It is fully accountable.

6. The OFDA/USGS grant to CERESIS, for the SISRA project makes up about one tenth of the total project contributions. Most contributions came from the participating countries.

RECOMMENDATIONS

1. The SISRA project as presently being completed is a full compilation of all data related to earthquake and volcanic hazards. The data compiled under the project will be directly applicable to hazards mitigation investigations for specific areas. The natural fallout of this project will be requests for hazards mitigation investigations for specific population centers in the Andean region. It is recommended that OFDA openly receive and consider supporting these expected proposed investigations.

2. OFDA may wish to consider financial support to CERESIS at the time the present products require upgrading. Based on a general agreement by the CERESIS reviewers, the products will be upgraded in five years.

3. The economic loss and casualty model for future earthquakes being developed by Dr. Grases will be a very important contribution to the studies of earthquake risk and hazards

preparedness. It is very important that his results be clearly described and properly presented. The results could be a very useful tool for OFDA. Additional funding may be necessary here to fully develop a usable model.

4. After the economic loss and casualty model is fully developed OFDA may wish to support projects where the model is applied to selected earthquake prone regions around the world; however, prior to its random use, the model's limitations must be fully understood. An independent evaluation may be necessary for this.

5. Dr. Giesicke is an excellent director and the CERESIS organization has been very successful. A reflection on Dr. Giesicke; however, he is nearing retirement and a successor needs to be selected and trained. It is recommended that OFDA and the USGS play a role in this selection process to assure the continued success of CERESIS.

6. The prototype satellite seismograph telemetry project for the GOES satellite is important to the overall feasibility of a new worldwide network. It is recommended that the test in Peru be completed; however, no further funding for this prototype project is recommended under the CERESIS program. If a new worldwide network utilizing satellite telemetry becomes a reality in the near future, then CERESIS may be the most likely organization in South America and perhaps Central America and the Caribbean as well as to organize and manage the networks installation and operation for that region. If CERESIS is being considered, then OFDA may want to consider support in this area.

7. No additional funding is expected under the present SISRA project.

FIGURE 1: Sample page from volume of earthquake catalogue

Id		F-E Reg	Date			Time				Location			Depth		Num Sta	Hyp Src	mb		MS			Other Magnitudes						Foc Mec	Intensity				Assoc Phenc	
Country	Number	Number	Year	Month	Day	Hour	Minute	Second	Qual	Lat	Long	Qual	Kms	Qual		Code	Mag	Source	Mag	Comp	Source	Mag	Scale	Source	Mag	Scale	Source	Source	Data	Max Int	Scale	Source	Iso Map	Dist Geo	Tsun Obs	No
CO	22910	103	1968	06	30	18:40:45.50	•			5.800	-74.000	I	40.0	E	3	HYP	3.0	IGE												3M	IGE					XXXXX
CO	22920	99	1968	06	30	22:53:25.40	•			6.200	-75.000	I	40.0	E	3	HYP	2.9	IGE												3M	IGE					XXXXX
CO	22930	99	1968	07	03	18:39:43.00	X			7.000	-73.500	I	123.0	I	15	ISC	4.0	ISC												4M	R-I					XXXXX
CO	22940	99	1968	07	04	02:46:51.00	•			6.200	-73.700	I	40.0	E	3	HYP	3.1	IGE												3M	IGE					XXXXX
CO	22950	105	1968	07	06	18:33:10.40	X			5.300	-73.600	I	40.0	E	4	HYP	4.0	IGE												5M	IGE					XXXXX
CO	22960	99	1968	07	07	00:39:40.10	•			7.200	-74.300	I	40.0	E	3	HYP	3.7	IGE												4M	IGE					XXXXX
CO	22970	103	1968	07	07	08:02:49.50	•			4.600	-75.800	I	40.0	E	3	HYP	3.8	IGE												4M	IGE					XXXXX
CO	22980	99	1968	07	08	10:25:58.00	•			6.200	-73.700	I	40.0	E	3	HYP	3.7	IGE												4M	IGE					XXXXX
CO	22990	103	1968	07	08	11:34:14.10	X			2.310	-75.900	I	33.0	I	45	ISC	4.5	ISC												5M	R-I					XXXXX
CO	23000	103	1968	07	09	21:47:15.10	•			4.700	-75.400	I	40.0	E	3	HYP	3.4	IGE												4M	IGE					XXXXX
CO	23010	103	1968	07	09	21:59:31.50	•			5.900	-74.100	I	40.0	E	3	HYP	2.9	IGE												3M	IGE					XXXXX
CO	23020	99	1968	07	11	20:10:15.00	•			7.900	-74.800	I	40.0	E	3	HYP	3.1	IGE												3M	IGE					XXXXX
CO	23030	103	1968	07	12	06:40:02.10	•			4.200	-75.400	I	40.0	E	3	HYP	2.5	IGE												2M	IGE					XXXXX
CO	23040	103	1968	07	14	22:00:10.30	•			4.800	-75.600	I	40.0	E	3	HYP	3.3	IGE												4M	IGE					XXXXX
CO	23050	99	1968	07	15	06:21:30.70	•			6.500	-73.700	I	40.0	E	3	HYP	3.7	IGE												4M	IGE					XXXXX
CO	23060	103	1968	07	15	16:14:53.70	•			5.800	-73.900	I	40.0	E	3	HYP	2.5	IGE												2M	IGE					XXXXX
CO	23070	103	1968	07	16	02:47:29.00	•			5.700	-74.000	I	40.0	E	3	HYP	3.1	IGE												3M	IGE					XXXXX
CO	23080	103	1968	07	16	21:39:00.80	•			4.000	-75.100	I	40.0	E	3	HYP	3.1	IGE												3M	IGE					XXXXX
CO	23090	103	1968	07	18	03:29:34.60	•			4.100	-76.000	I	40.0	E	3	HYP	3.5	IGE												4M	IGE					XXXXX
CO	23100	103	1968	07	18	03:39:18.20	•			4.400	-73.900	I	40.0	E	3	HYP	3.3	IGE												4M	IGE					XXXXX
CO	23110	99	1968	07	21	04:28:10.20	X			6.870	-72.940	I	170.0	I	19	ISC	3.9	ISC												5M	R-I					XXXXX
CO	23120	99	1968	07	21	21:39:45.00	•			6.200	-73.700	I	40.0	E	3	HYP	3.4	IGE												4M	IGE					XXXXX
CO	23130	103	1968	07	22	01:08:38.50	•			5.200	-76.800	I	40.0	E	3	HYP	3.1	IGE												3M	IGE					XXXXX
CO	23140	99	1968	07	23	00:35:45.50	•			6.000	-74.000	I	40.0	E	3	HYP	3.0	IGE												3M	IGE					XXXXX
CO	23150	99	1968	07	24	13:25:27.90	X			6.700	-73.370	I	179.0	I	15	ISC	4.1	ISC												5M	R-I					XXXXX
CO	23160	103	1968	07	24	18:18:31.90	•			4.500	-75.400	I	40.0	E	3	HYP	2.5	IGE												3M	IGE					XXXXX
CO	23170	103	1968	07	26	16:45:23.20	•			5.800	-74.100	I	40.0	E	3	HYP	2.7	IGE												3M	IGE					XXXXX
CO	23180	99	1968	07	26	18:29:54.80	X			6.760	-73.080	I	174.0	I	49	ISC	4.4	ISC												5M	R-I					XXXXX
CO	23190	103	1968	07	28	17:00:04.80	•			5.400	-74.400	I	40.0	E	3	HYP	2.3	IGE												2M	IGE					XXXXX
CO	23200	103	1968	08	01	00:44:47.80	•			5.800	-74.100	I	40.0	E	3	HYP	2.0	IGE												3M	IGE					XXXXX
CO	23210	103	1968	08	01	18:49:30.40	•			5.800	-73.900	I	40.0	E	3	HYP	3.8	IGE												4M	IGE					XXXXX
CO	23220	103	1968	08	01	20:08:02.70	•			5.800	-74.000	I	40.0	E	3	HYP	3.2	IGE												3M	IGE					XXXXX
CO	23230	103	1968	08	03	02:54:48.30	•			4.600	-73.200	I	40.0	E	3	HYP	2.3	IGE												2M	IGE					XXXXX
CO	23240	103	1968	08	04	10:34:37.70	•			5.700	-74.000	I	40.0	E	3	HYP	3.1	IGE												3M	IGE					XXXXX
CO	23250	103	1968	08	05	20:21:25.60	•			5.000	-74.800	I	40.0	E	3	HYP	2.5	IGE												2M	IGE					XXXXX

United States Department of the Interior
GEOLOGICAL SURVEY
BOX 25046 M.S.
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

IN REPLY REFER TO:

March 1
~~February~~ 11, 1985

Memorandum

To: S.T. Algermissen, Technical Officer, MS 966

From: Contracting Officer, Central Region

Subject: Payment Schedule on Grant No. 14-08-0001-G-670

Following is the payment schedule for subject Grant:

Invoice #	Amount	Date Sent to Finance	Paid Under
1	$117,000.00	09/25/81	Basic
2	$100,000.00	12/17/81	Basic
3	$100,000.00	04/15/82	Basic
4	$ 50,000.00	08/17/82	Basic
6	$ 80,000.00	11/18/82	Mod 1
7	$ 30,000.00	06/01/83	Mod 1
8	$ 30,000.00	06/06/83	Mod 2
9	$ 30,000.00	08/03/83	Mod 2
10	$ 25,000.00	08/03/83	Mod 2
11	$ 10,000.00	01/16/84	Mod 2
12	$ 10,000.00	01/16/84	Mod 2
13	$ 25,000.00	02/28/84	Mod 2
15R	$ 70,000.00	09/05/84	Mod 3
16	$ 55,000.00	8/15/85	" "

If you have any questions concerning the foregoing, please call me at 236-5880.

Deborah S. Boles

Deborah S. Boles

TABLE 1: Fiscal information provided by the Contracts Dept. of the USGS, Golden, CO.

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COUNTERPART FUNDING

	ARGENTINA	BOLIVIA	CHILE	COLOMBIA	ECUADOR	PERU	URUGUAY	VENEZUELA	TRIN.TOB
1. PERSONNEL	126800	54000	130000	32400	47500	205400	10800	235000	16200
Catalogues	63000	27000	58000	10800	21000	150000	------	70000	-----
Neotectonic Map	43200	18000	42000	10800	12000	43000	10800	80000	-----
Seismic Risk Map	20600	9000	30000	10800	14500	12400	------	85000	-----
2. INFRASTRUCTURE	374800	232200	366000	353000	163300	483200	20700	192000	69660
Information - Data	100000	45000	60000	52000	51000	60000	3600	20000	-----
Transportation	20000	5400	15000	6000	3000	6200	---- -	27000	-----
Instruments/computer	75300	115500	65000	148000	42500	195000	450.	5000	-----
Stations,bldgs Offic.	97500	55500	165000	102000	37800	175000	7200	130000	-----
Library,offic.equipm.	82000	10800	61000	45000	29000	47000	5400	10000	-----
TOTALS:	501600	286200	496000	385400	210800	688600	31500	427000	85860

Subsidy to "Asignacion" a Paises

Basic Grant	217500
Mod. No. 1	115200
	332700

TOTAL COUNTERPARTS: 3112960

TABLE 2: ESTIMATED COUNTERPART CONTRIBUTIONS TO THE SISRA PROJECT THRU 1983

ANNEX A

Travel Itinerary and Professionals Contacted

March 22 p.m.	Left Washington
March 23 a.m.	Arrived Santiago, Chile Met with "Disaster Assistance Team of: Paul Bell, Salvadore Pinzino, Paul Fritz, Craig Baier and Agusta Carino Also met with economic attache in embassy and acting MDRO Weindell Belew Met with USGS team: Ted Algermissen, Paul Thenhaus, and Eugene Sambera
March 24 a.m.	Began earthquake review of the northern and western sector of the affected zone.
March 25 a.m.	Attended SISRA technical review meeting Participants: Edgar Kausel (Chile) Oscar Gonzales (Chile), Juan Carlos Castano (Argentina), Alberto Giesicke (Peru) Jose Grases (Venezuela), and Ted Algermissen (USGS)
March 26 a.m.	Reviewed the central sector affected by the earthquake
March 27 a.m.	Reviewed southern sector affected by the earthquake
March 28 a.m	Attended final day of SISRA technical review meeting.
p.m.	Toured Department of Geophysics, University of Chile.
p.m.	Toured the Instituto Geografico Militar de Chile where maps are being printed
March 29 a.m.	Reviewed earthquake damage in Santiago and began trip to Mendoza, Argentina to assess damage there and debris avalanche problem on the Rio El Plomo.
March 30 a.m.	Reviewed damage in Mendoza, discussed avalanche problem with local military at "Puente de los Andes" and returned to Santiago.
March 31 a.m.	Arrived in Lima
April 1 a.m.	Met with Alberto Giesicke to discuss CERESIS and SISRA in detail

April 2	a.m.	Visited the Instituto Geofisico de Peru to discuss their programs. Met with director Ronald Woodman and chief geophysicist Daniel Huaco
April 3	a.m.	Left Peru for U.S.
April 4	a.m.	Arrived in Washington
April 8		Met with with Helen Willingham, Kimi Anne Lee and Kathleen Bohan, comptrollers and contracts personnel for Office of International Geology, USGS, Reston, Va.
April 15		Traveled to Denver
April 16		Met with Ted Algermissen on results of after shock program and with Debbie Boles, contracts officer.
April 17		Personal business
April 19		Returned to Washington

17

ANNEX B

Chronological Events of the SISRA Project

Prepared By:

Paul Krumpe
Science Advisor
OFDA/USAID

Sept. 8 CERESIS meeting held in Paris to determine project goals, objectives, deliverable

Oct. 27 CERESIS forwards draft SISRA project proposal to Washington and Council Member

Nov.

Dec.

Jan.

Feb.

Mar.

Apr.

May

Jun.

July 15 USGS prepares draft proposal for CERESIS project based on Paris meeting 9/79 and CERESIS Implementation Plan

Aug. 14 USGS submits draft proposal for a program in the Andean Region to OFDA

Sept. 1 OFDA prepares PIO/T and forwards to FM and AID SER/CM (Contracts)

Oct.	29 USGS signs PASA with AID (IC/PDC-11-3-80) for $500,000 FY 1980 funds (18 months
	1 USGS receives copy of PASA from AID
Nov.	18 CERESIS Coordinators for Project SISRA meet in San Juan Argentina to draft final CERESIS proposal to USGS.
	1 CERESIS submits their proposal to USGS with copy to AID
	15 CERESIS proposal submitted to USGS contracts section in Denver
Dec.	10 CERESIS proposal enters technical review by USGS
Jan.	19 USGS continues technical evaluation of CERESIS project SISRA (5 year plan)
Feb.	4 USGS completes final review of CERESIS SISRA proposal to USGS
Mar.	26 USGS prepares sole source justification for selection of CERESIS to execute pla
	2 USGS submits all documents needed to USGS contracts section for action
Apr.	14 USGS begins work on satellite telemetry task on behalf of CERESIS
May	8 U.S. Dept. Interior approves proceeding with CERESIS sub-contract under AID PAS
Jun.	
July	14 USGS requests PASA extension from AID to March 1, 1983 due to contracts delay
	15 OFDA requests SER/CM to amend PASA completion date at no additiional cost
	26 USGS submits Progress Report on Satellite telemetry task
Aug.	16 USGS completes internal legal review of proposed USGS/CERESIS grant under PASA
Sept.	13 USGS/CERESIS grant signed by CERESIS (Regional Project commences under USGS)
	19 USGS and OFDA document CERESIS counterpart project support for life of project.
	21 USGS and CERESIS agree to fix date of first meeting of SISRA Project (Oct. 4-10)
	11 USGS submits request to OFDA for PASA amendment ($201,000)supplemental activity
	15 USGS grant to CERESIS is officially signed by USGS Contracts Officer
	24 USGS submits preliminary progress report on Project SISRA

Oct.

5-9 First CERESIS SISRA project meeting held in Lima, Peru

Nov.

10 USGS Submits preproposal FY 82 request for OFDA support of economic/loss study
10 USGS submits second major progress report on SISRA Oct. meeting in Lima

Dec.

Jan.

Feb.

8 USGS formal request for FY-82 SISRA incl. earthquake loss study. Budget too.

Mar.

USGS meets with CERESIS Exec. Council in Santiago to Plan Colorado technical meeti

Apr.

SISRA Project meeting in Golden ,CO. with USGS,AID and SISRA participants

May

10 OFDA submits PIO/T amendment ($219,650) for SISRA CERESIS to SER/CM

20 USGS requests PASA extentsion date to June 30, 1983

Jun.

17 CERESIS requests USGS/AID continued support of SISRA ($140,000)

24 AID-USGS PASA amendment for $219,650 signed by USGS and AID, Completion 12-31-83

July

31 CERESIS financial statement of SISRA as of 7-31-82 submitted to USGS

Aug.

CERESIS/SISRA Coordinator meets with SISRA sub-task coordinators

Sept.

Oct.

Nov.

Dec.

USGS meets with SISRA Coordinators in LIMA and Santiago to scope out proj. compl
schedule. Catalogues nearly complete, seismotectonic maps drafted, hazards comp
USGS finishes GOES sat. event detection system configuration. Final testing and
software development required.

Jan.

Feb.

Mar.

Apr.

5 SISRA Advisory Committee meets in Colorado with Project Coordinators and CERESIS
Evaluation of SISRA project progress and recommendations presented.

29 USGS/CERESIS SISRA project supplemental funding proposal (FY1983)

May

24 PIO/T completed by OFDA and sent to SER/CM -- $304,000 PASA amendment

Jun.

20 USGS requests PASA no-cost amendment for SISRA to March 30, 1985 completion dat

July

21 USGS submits Progress report for Project SISRA by USGS/CERESIS
29 USGS/AID PASA BOF-0000-P-IC-3126 ($305,290) signed by AID and USGS

Aug.

15 Subcontractor report to CERESIS on Phase II of earthquake loss study (Caracas)
22 USGS presents tech. results of prototype seismic event detector devl. under PAS

Sept.

Oct.

Nov.

Dec.

Jan.

Feb.

Mar.

Apr.

May

Jun. 20 USGS request to OFDA to extend PASA completion date at no cost

July

Aug. 6 OFDA request to SER/CM for no-cost extension of USGS PASA to March 30, 1985

Sept. 23-29 CERESIS/SISRA technical Meeting in San Juan Argentina. Project results presented. Advisory Committee evaluated, AmEmbassy attended.

Oct.

Oct.

Nov.

Dec.

USGS Progress Report on SISRA is reviewed by USGS

20

Jan.

Feb.

USGS submits Dec. 84 Progress Report following internal review and clearance

Mar.

USGS Coordinator travels to Lima, Santiago and Buenos Aries to finish final review of catalogues, maps and reports by SISRA personnel.

30 CERESIS/SISRA USGS-AID Project is completed

Apr.

May

30 USGS Final Report submitted to AID/OFDA with deliverables.

15 AID/OFDA initiates CERESIS/SISRA USGS project evaluation

Jun.

July

Aug.

APPENDIX A

ASSESSMENT OF THE MARCH 3, 1985 EARTHQUAKE OF CENTRAL CHILE

INTRODUCTION

At 22:47 GMT (7:47 pm local time) on March 3, 1985 a destructive earthquake registering M-7.8 occurred in the subduction zone off the coast of central Chile, approximately 40 kms. southwest of Valparaiso. The National Earthquake Information Service located the earthquake 33.1 south and 72.0 west and assigned a focal depth of 33 kms. (shallow). A small tsuanami (1.1 m. near shore) was associated with the earthquake. The ground shaking was felt along much of the Chilean coast and as far east as Buenos Aires. The felt duration of the earthquake was about two minutes. An area of approximately 65,000 sq. kms. was affected by the earthquake. The ground shaking was most severe in an area of 17,000 sq. kms which included Valparaiso (northwest), San Antonio (southwest). Rengo (southeast), and Santiago (northeast). Ground shaking was most severe in the area of San Antonio where peak horizontal acceleration on fill was measured at .75 g. Figure 1 is a modified mercalli intensity map showing the area affected by the earthquake.

Nearly one million people were affected by the earthquake and approximately 450,000 were left homeless. Life loss was limited to 177; however, injuries were approximately 2,660. Damage to structures, particularly adobe, was very widespread. Extensive damage to rural infrastructure occurred and the ports of San Antonio and Valparaiso were severely damaged. In total, the economic loss both directly and indirectly related to the earthquake is estimated to be greater than $1.25 billion. The port damage will have a long term economic effect.

TECTONIC SETTING

Central Chile is an area of prominent geomorphic expression with abrupt change in relief. The physiographic provinces include (east to west) the Andean Cordillera approaching 6950 ms., an intermontane basin, the coastal range with moderate relief and a very narrow coastline. The Cordillera consist of Upper Cretaceous metasediments and metavolcanics intruded by Tertiary granodiorties and overlain by Quaternary volcanics. The pre-Quaternary rocks are steeply dipping, tightly folded, and faulted by north trending high-angle faults. East of Santiago a high angle fault with prominent geomorphic expression bounds the western flank of the Cordillera in this region.

The intermontane valley (Central Valley) consists of thick flysch deposits overlain by modern fluvial and other alluvial sediments. The coast range consists of Paleozoic marine sediments intruded by pre-Jurassic granociorites and overlain by Tertiary marine sediments. Northwest trending faults cut the range. The coast range of Central Chile is abruptly cut off along the coast creating a very narrow playa. The ocean floor dips steeply toward the north trending Peru-Chile trench some 80 to 100 kms. offshore. Figure 2 is a profile of Chile, through Valparaiso at 33. south. It shows the prominent relief.

Central Chile is located on the leading edge of the South American plate. The interacting Nazca plate is actively being subducted under the South American plate. The earthquake occurred along the interface of these two plates (see figure 2). The occurrence of a small tsunami (1.1 ms., nearshore affect) suggests surface faulting occurred in the trench. This particular segment of the Peru-Chile trench is very active. The conversion rate has been calculated at 9 cms. per year. It is also the site of three other large to great historic events.

SEIMICITY

Dr. Ponce of the Universidad de Mexico was in Chile with a team of seismologists and portable instruments in less than two days after the earthquake. He indicates the rupture zone along the plate interface to be between 32.5 and 34.25 south and 71.33 and 72 west (approximately 200 kms. x 70 kms.) Dr. Ponce's estimates are preliminary in nature. The data acquired has to be fully analyzed. The Departamento de Geociencias, Universidad de Chile has a 16 station permanent array, but at the time of this reviewers visit had not had an opportunity to fully analyze records in any detail. During the month of March thousands of after shocks were recorded. The Department did indicate that eight magnitude six or greater after shocks had occurred during the month of March. According to Dr. Kausel, Director of the Department, the main shock was preceded by an increase in seismic activity now believed to have been foreshocks. The national network of Chile was fully operational prior to the earthquake. It recorded strong foreshocks, the main shock and after shocks. In addition to the seismographs, a series of strong motion accelographs were also operational. This is the first time where a seismograph and strong motion network have recorded an earthquake of this magnitude.

The March 3rd earthquake as well as the 1906, 1822, 1730 and 1647 events all are believed to have occurred within the zone defined by McCann et. al. (1978) as the central Chilean "seismic gap." A seismic gap (Kelleher, 1972) is defined as a segment

along active convergent or transform plate boundaries that has not experienced a large to great intraplate earthquake for more than a few decades and thus is considered a likely site for future large to great events. The gap comprises a segment of the Peru-Chile trench having a strike length of 380 kms. between 31 30' and 35 south. The 1906, earthquake is believed to have ruptured the entire gap. The March 3rd event ruptured only about 150-200 kms. or the northern segment of the gap. The southern segment of the gap did not rupture suggesting stress continues to build making this segment the possible site of the next large to great earthquake in Chile.

Dr. Ponce observed that after shock activity was absent in the upper 18 kms of the subduction zone (i.e. from the trench to a focal depth of 18 kms.). The lack of seismicity in the upper 18 kms. of the plate interface suggests either the upper part of the interface did not rupture or the stress in the upper 18 kms. was fully released in the March 3rd event.

Nisenko (1985) forecasted the March 3rd event. He suggested the central Chilean seismic gap is the most probable site for the next large to great earthquake in Chile. He estimated this event would occur within the next 20 years. His analysis is based on statistical recurrence patterns, a deterministic approach based on earthquake monitoring, estimated past rupture areas, and coastal uplift. He concludes the recurrence of large to great earthquakes along the central Chile segment of the trench to be between 79 and 86 years. The last large to great earthquake along this segment of the gap occurred in 1906, 81 years ago.

The April 8, M-7.2 earthquake located near Rapel caused considerable damage. The epicenter location of this event is 34 17' south and 71 54' west. The assigned focal depth has been set at 33 Kms. (shallow.) The relationship of this event to the March 3rd event is not clear. If Dr. Ponce's estimates are correct, this event occurred south of the March 3rd rupture zone.It must then be considered a separate event. In late March a series of shocks, one registered M-6 1/4, occurred in the April 8th epicentral area. These shocks may have been foreshocks to the April 8th event. Analysis of after shock data related to the April 8th event will help clarify its relationship to the March 3rd event. The after shock data will also indicate the zone of rupture and whether or not this event represents stress release in the southern segment of the gap.

EARTHQUAKE RELATED PHENOMENA

Ground Shaking

The earthquake was felt along the entire coast of Chile and as far east as Buenos Aires. The area affected by strong ground shaking was 65,000 ms., a very large area. This area of strong ground shaking included the Chilean physiographic zones IV, V, VI, VII, and the zona Metropoletana; and as far east as Mendoza, Argentina. The most severe ground shaking and most prominent earthquake phenomena occurred in an area of approximately 17,000 kms . This area includes Santiago, Valparaiso, San Antonio, and Rengo. In this area the Modified Mercalli Intensity scale reached IX along the coast. Figure 1 presents a preliminary Modified Mercalli Intensity map. The distribution of damage and recorded peak accelerations suggest ground shaking was strongest on fill, alluvium and poorly consolidated soils, and least on bedrock. A case in point is the difference in damage between San Antonio and Cartagena only 5 kms. apart. San Antonio is located on beach, sands and fluvial deposits, where as Cartagena is located on bedrock. Damage to San Antonio was extensive. In contrast Cartagena had very little damage. Table 1 lists the cities with the number of damaged and destroyed structures in the four physiographic zones most affected. This report was prepared by the Oficina Nacional de Emergencias (ONEMI) of the Ministerio Interior. Table 2, also prepared by ONEMI, is a summary of all damaged and destruction in Chile from the March 3 earthquake.

The location of five accelographs are shown in Figure 1. All these stations were operational. The recorded peak (?) accelerations are presented below:

Vaparaiso:	H = .197g	- rock
	H = .16	
	H = .27	- fill
	H = .19	
Llalleo (San Antonio)	H = .75g	- sand
	H = .41	
	H = .82	
Quintay	H = .18	- rock
	H = .203	
Melipilla	H = .5	-alluvium

Ground Failure

Land sliding and rock slides were restricted to road cuts and over steepened slopes. In Valparaiso and Vina del Mar where a steep slope abuts the beach front, some localized slope failure occurred. In some cases this led to the collapse of hillside structures. In the coastal area near the epicenter slope failure was observed locally along road cuts. In the Andes east of Santiago, localized rock falls and slides were common, but none were of any significant size. Damage to concrete avalanche covers on the road to Portillo was the result of rock fall. Movement of large talus blocks (50 to 100 tons) on the over steepened Andean slopes was indicated by impact craters and tracks left behind the blocks.

At the Rapel dam site, about 50 kms. south of San Antonio, massive slope destabilization is believed to have occurred; however, the displacement was minor. The downstream side of the right abutment may have moved a few centimeters toward the river canyon. The movement was implied because of the damage (tensional) to the transmission towers. The amount of movement was unknown at the time of this review; however, dam engineers were engaged in assessing the impact of any movement and the stability of the slope. Along this same slope numerous rock falls covered the access roads to the dam facilities. The inner canyon walls are near vertical.

At the crest of the Andes of central Chile, a large debris avalanche occurred on the northern slope of Volcan Tupungato, temporarily daming the Rio El Plomo. Considerable concern was expressed by the Argentinian government because of the size of the reservoir developing behind the natural dam, and its potential for failure. The Rio El Plomo is a tributary of the Rio Mendoza. The city of Mendoza, Argentina is approximately 175 kms. downstream of the natural dam. The Rio Mendoza is confined to a narrow channel from its confluence with the Rio El Plomo to Mendoza. After review by a Swiss glaciologist, the Argentine military breached the dam to allow de-watering of the reservoir, reducing the risk to Mendoza. According to a military representative at Puente de los Andes (the confluence), the initial breach produced a .5m crest on the Rio El Plomo which diminished at its confluence with the Rio Mendoza. The military is actively enlarging the breach to reduce the potential for future daming, particularly during the Andean Spring runoff beginning in September.

Ground failure related to settlement and liquifaction was very common near the coast in the epicentral area. Settlement

was common at cut and fill localities on paved highways and at overpass approaches. At Vina del Mar, Valparaiso, and San Antonio evidence of liquifaction was widespread. Sand boils, building settlement, sidewalk deformation and subsidence of concrete piers are all evidence liquifaction occurred. Probably the most striking effect of liquifaction and subsequent compaction is the damage to the piers and docking facilities at the harbors in Valparaiso and San Antonio. In Valparaiso a concrete block, docking facility used for Naval vessels was affected. Many of the concrete blocks have rotated and partially subsided. The entire port facility in San Antonio has suffered damage from both liquifaction and subaqueous landsliding. The most seaward docking facility and breakwater is severely damaged and has been rendered unusable for docking. It is constructed of dredged harbor fill forming an embankment overlain with large concrete slabs for the loading area and a line of stacked blocks along the seaward side. The sand fill liquified causing spreading and compaction. The slopes of the embankment are steep and may have failed. The overlying concrete slabs rotated and pitched. This sheared an buckled railroad tracks, caused partial collapse of a concrete warehouse built on slabs, vaulted track mounted cranes, and turned over railroad cars. Presently, a section of track with railroad cars is underwater.

South of San Antonio, the piers of two bridges rotated and subsided causing collapse of the bridge spans. The approaches to the bridge, made of fill, also compacted and spread.

Approximately 13 kms. east of San Antonio a small earth embankment dam failed. It appears the fill material was saturated and liquified during the earthquake. The dam failed along its entire axis producing deep, lateral fissures on the reservior side. The large fissures and a breached section revealed the fill was very coarse and no impervious core material could be seen.

Tsunami

It was reported by the USGS that the earthquake generated a near shore tsunami that measured 1.1 m at Valparaiso. The same tsunami measured less than .5m at Hilo, Hawaii, .15 m at Sand Point, Alaska, and .12m at Kushiro, Japan. Although small, the tsunami came as a surprise at Hilo. The Tsunami Watch Observatory of Hilo mislocated the earthquake on land indicating no tsunami threat.

DAMAGE ASSESSMENT

The Chilean Oficina Nacional de Emergencia (ONEMI) of the Ministerio de Interior was very well organized and has a

systematic procedure of reporting damage. This system begins at the municipality level where local officials compile damage records. Some municipalities have pre-existing data forms and questionnaires to assess damage and losses, while others are not quite as structured. Without a standarized data form the results may be somewhat skewed; however, it provides an excellent approximation of damage and losses and very quickly. From the municipality the data is fed to the governors office of the Providence then to the Ministry. Composite data forms are compiled in ONEMI and updated daily. Tables 1 and 2 are representative data forms prepared by ONEMI. Table 3 is an example of a data form from the Provence of Curico (zone VII). The OFDA emergency team worked very closely with ONEMI in assessing damage and aiding in the distribution of emergency supplies and goods to the earthquake victims. To provide immediate emergency shelter, OFDA distributed plastic tarps large enough to cover collapsed roofs on houses or to be used as tents.

Damage, although widespread was most common to adobe and masonry structures; however, structural damage to reinforced concrete structures was apparent in Vina del Mar, Valparaiso, Melipilla, San Antonio, and to a lesser extent Santiago. In some of the smaller rural communities within the most severely affected zone 80-90% of all the homes were either severely damaged or destroyed. It is apparent the widespread damage is directly related to building construction, conditions, and duration of ground shaking. Abode construction, soil is by far the most common type of construction in the rural communities, coastal cities, and older residential districts of Santiago. Damage and complete failure of adobe structures was common throughout the affected area. Adobe construction does vary in quality and composition of the brick. In Melipilla much of the adobe construction included vertical and diagonal wooden timbers tying the floor to the roof, and bailing wire wrapped around both the wood and the inset adobe bricks. This method of construction did not prevent the abode from shearing but did help prevent collapse. The abode bricks clearly varied in composition depending upon region. For instance in the Rengo area the adobe brick appeared much more erodible and less consolidated than the adobe in the Melipilla area. The quality of the adobe brick is dependent on the properties of the barrow material used the use of straw, and drying time.

The location of structures relative to bedrock played a very important role in performance. Those structures located on thick alluvium generally suffered much more than those located near to or on bedrock. San Antonio and Cartagena are classic examples. San Antiono is an alluvium and Cartagena is on bedrock. San Antonio suffered much more damage. Essentially the area zoned intensity VIII on the preliminary Modified Mercalli Intensity map (figure 1) consists primarily of alluvium and fluvial deposits.

The duration of the earthquake has been estimated to have been approximately two minutes. This had a significant impact on the adobe and rigid reinforced concrete structures in Santiago where peak horizontal acceleration did not exceed 11%g. Although acceleration was not strong the duration was long enough to cause widespread damage to Santiago, particularly to the colonial sections where adobe construction was prevalent.

Institutional facilities such as schools, hospitals, and government buildings throughout the affected area suffered damage. Many of these structures, particularly the older ones, are either heavy masonry or adobe construction. The Chilean government reported 26 regional hospitals were damaged. Of the 26, 12 were damaged beyond repair and the remainder were 50% operational. International emergency funds were being provided for reconstruction of critical facilities such as hospitals. OFDA funds were being utilized for reconstruction of the hospital at Rengo, a primarily adobe structure.

CONCLUSIONS

The March 3 earthquake, which registered 7.8 on the Richter scale, ruptured a portion of the central Chilean seismic gap. This earthquake itself may not have fully released the stress that has been accumulating since the 1906 event in which the entire seismic gap (380 kms.) may have ruptured. Presently, little data is available on the April 8, M - 7.2 event; however, its epicenter is located south of the March 3 rupture zone suggesting that this earthquake may have ruptured a portion of the southern segment of the "gap." If the southern segment of the "gap" ruptured in the April 8 event, then the "gap" may have been filled or the stress released.

The impact of this earthquake was widespread. It was felt along the entire Chilean coast and as far east as Buenos Aires, Argentina. The affected area comprises about 65,000 kms. The most severely affected area makes up about 17,000 kms. Although reinforced concrete structures performed reasonably well, damage to adobe and masonry structures was extensive.

Ground shaking, ground failure and liquifaction were the most apparent phenomena associated with the March 3 earthquake. This was particularly apparent at Valparaios, San Antonio, and east of San Antonio.

The homeless count has exceeded 450,000. The direct and indirect economic loss from the earthquake is estimated to exceed $1.25 billion. With the loss of the port facilities at San Antonio and Valparaiso, the long-term impact on the Chilean economy may be significant.

ONEMI has been very effective in assessing the damage related to the earthquake. During the entire month of March they were continually revising the damage and loss estimates. The OFDA emergency team worked very closely with ONEMI. They were heavily involved in coordinating disbursement of emergency supplies and distributing plastic tarps for shelter of the homeless. Their efforts had a significant impact on aiding the victims of the earthquake.

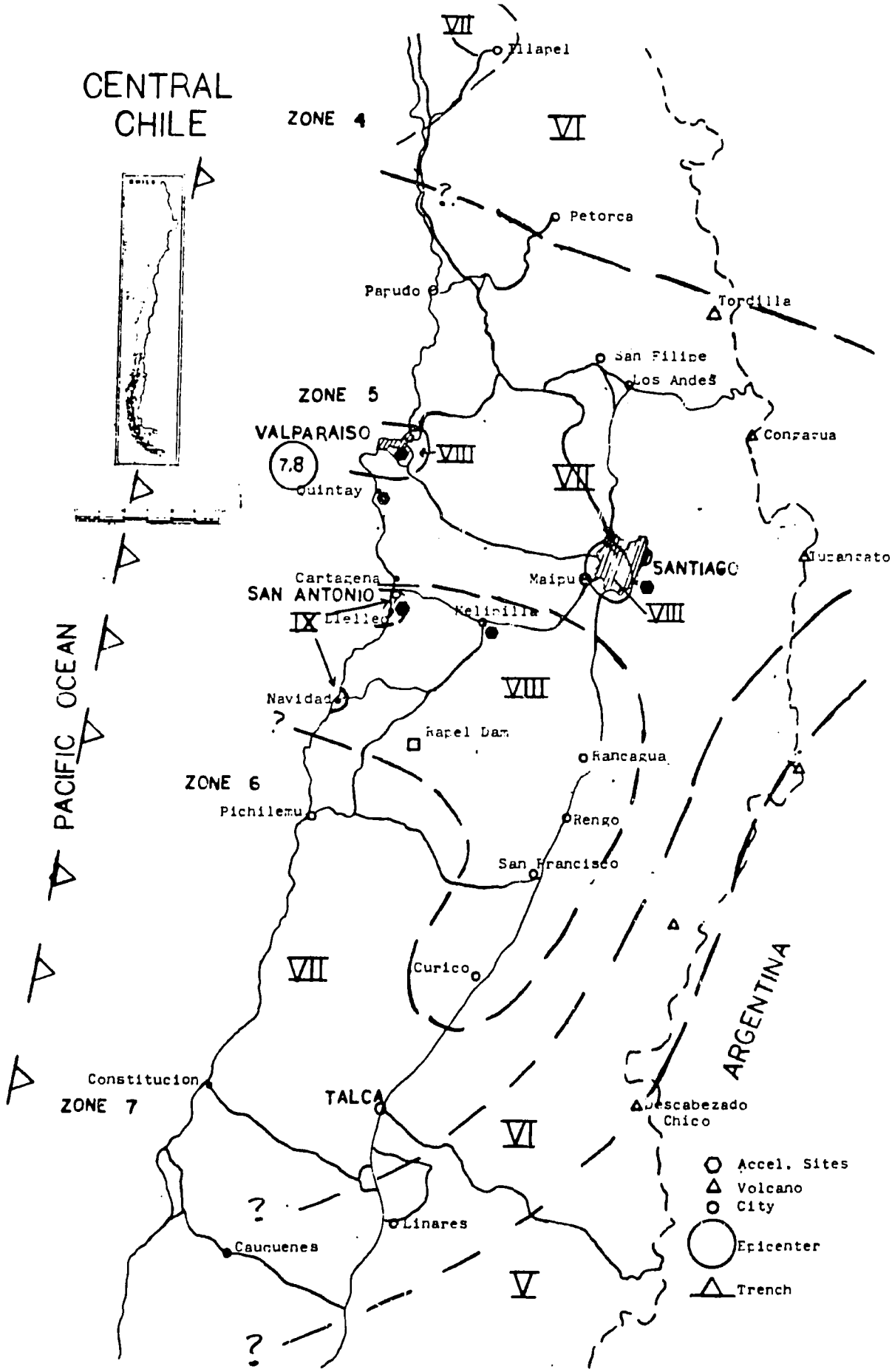

FIGURE 1: PRELIMINARY MODIFIED MERCALLI INTENSITY MAP OF THE MAR. 3, 1985 EARTHQUAKE OF CENTRAL CHILE BASED ON FIELD OBSERVATIONS AND ONEMI DATA

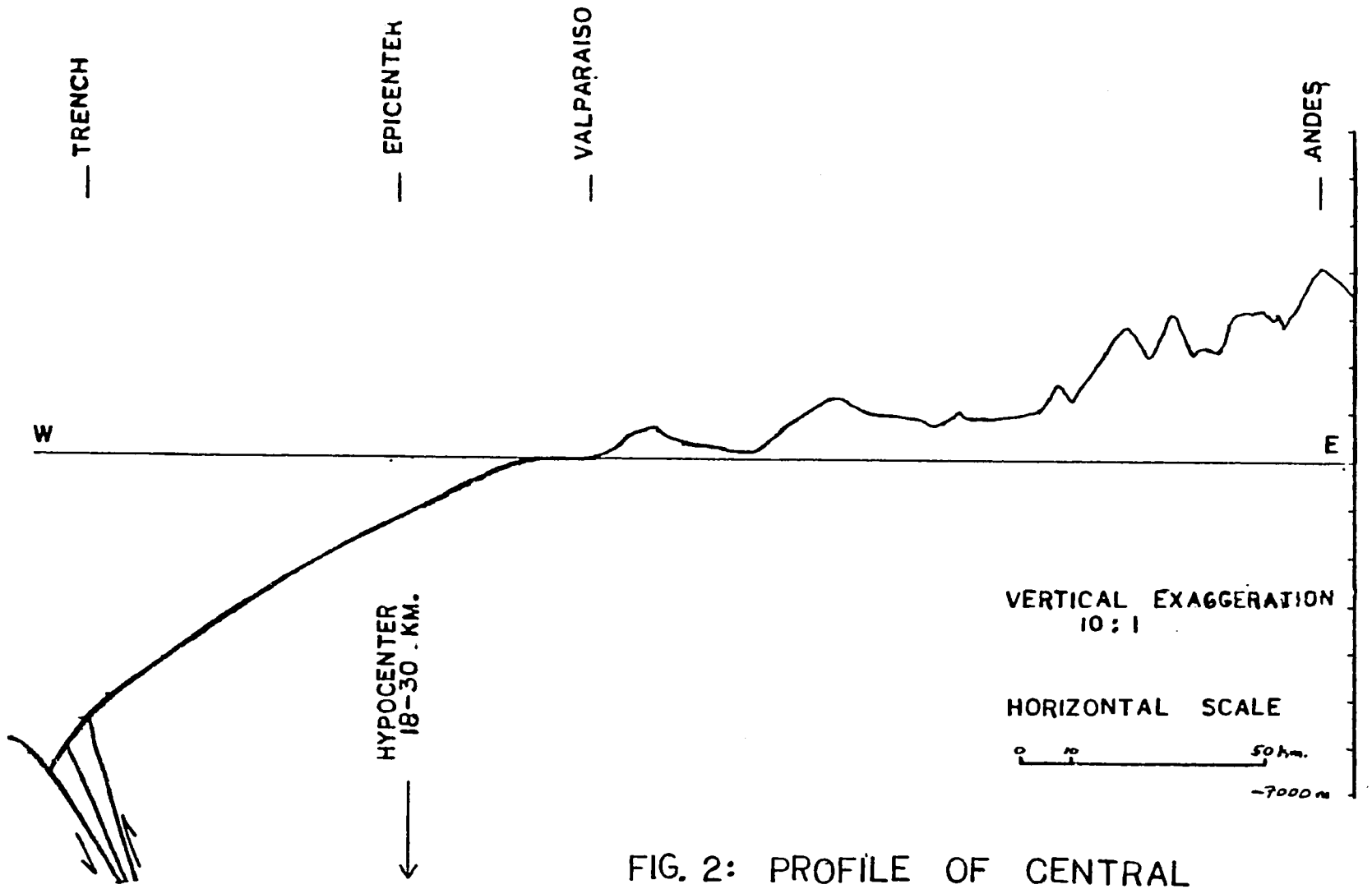

FIG. 2: PROFILE OF CENTRAL CHILE AT LAT. 33

TABLE 1

Intensities and damage to structures in physiographic zones IV, V, VI, and VII of central Chile

	INTENSIDAD	DESTRUCCION Y DAÑOS		
		DESTRUIDAS	-	DAÑADAS
IV REGION :				
LA HIGUERA	VI	3		
LA SERENA	V			
COQUIMBO	V			
VICUÑA	IV - V			
PAIHUANO	IV - V			
ANDACOLLO	IV - V			
OVALLE	IV - V			
RIO HURTADO	IV - V			
MONTE PATRIA	IV - V			
COMBARBALA	IV - V			
PUNITAQUI	IV - V			
ILLAPEL	VI - VII	14		
MINCHA	V			
SALAMANCA	VI	3	-	10
LOS VILOS	VI	2		
V REGION :				
PETORCA	VI	3	-	48
CABILDO	VI - VII	34	-	30
LA LIGUA	VI - VII	29	-	33
PAPUDO	VI	2	-	1
ZAPALLAR	V - VI		-	7
PUTAENDO	VI - VII	65	-	95
SANTA MARIA	VI - VII	73	-	41
SAN FELIPE	VI - VII	216	-	851
PANQUEHUE	VI - VII	35	-	20
CATEMU	VI - VII	113	-	212
LLAILLAY	VI - VII	721	-	558
SAN ESTEBAN	VI - VII	33	-	103
LOS ANDES	VI - VII	45	-	163
RINCONADA	VI	8	-	29
CALLE LARGA	VI - VII	82	-	52
PUCHUNCAVI	VI - VII	67	-	66
NOGALES	VI - VII	98	-	66
QUINTERO	VI - VII	62	-	58
LA CALERA	VI - VII	186	-	405
HIJUELAS	VI - VII	66	-	94
LA CRUZ	VI	10	-	38
QUILLOTA	VI - VII	118	-	314
OLMUE	VI - VII	152	-	180
SAN FCO. DE LIMACHE	VI - VII	204	-	422
VILLA ALEMANA	VI - VII	257	-	664
QUILPUE	VI - VII	307	-	1.613
VIÑA DEL MAR	VII - VIII	2.119	-	1.343
VALPARAISO	VII - VIII	2.212	-	2.155
CASABLANCA	VII	826	-	303
ALGARROBO	VI - VII	117	-	2.224
EL QUISCO	VI - VII	45	-	31
EL TABO	VI - VII	50	-	1.952
CARTAGENA	VII - VIII	2.241	-	1.591
SAN ANTONIO	VIII	4.250	-	7.446
ROCAS DE SANTO DOMINGO	VII	399	-	561

Table 1 continued

REGION METROPOLITANA :

TILTIL	VI	- VII	233	-	7[illegible]
COLINA	VI	- VII	136	-	42[illegible]
LAMPA	VI	- VII	278	-	33[illegible]
QUILICURA	VI	- VII	220	-	41
CONCHALI	VI	- VII	750	-	2.322
SANTIAGO	VII		1.350	-	14.418
LAS CONDES	VII		15	-	190
PROVIDENCIA	VI			-	1.646
LA REINA	VI		7	-	770
ÑUÑOA	VI	- VII	781	-	3.041
PEÑALOLEN	VI	- VII	49	-	631
MACUL	VI	- VII	464	-	387
LA FLORIDA	VI	- VII	93	-	201
MAIPU	VII		1.230	-	4.602
QUINTA NORMAL	VII		2.119	-	8.000
PUDAHUEL	VII		1.100	-	4.500
LO PRADO	VI	- VII	204	-	2.275
CERRO NAVIA	VI	- VII	300	-	3.700
RENCA	VII		2.043	-	3.200
SAN MIGUEL	VI	- VII	440	-	10.200
LA GRANJA	VI	- VII	155	-	97
SAN RAMON	VI	- VII	87	-	4.051
LA PINTANA	VI	- VII	112	-	241
LA CISTERNA	VI	- VII	322	-	964
PUENTE ALTO	VI	- VII	180	-	852
SAN JOSE DE MAIPO	VI			-	17
ISLA DE PIRQUE	VI	- VII	147	-	259
SAN BERNARDO	VII		904	-	1.965
CALERA DE TANGO	VI			-	77
PAINE	VI	- VII	400	-	145
BUIN	VI	- VII	413	-	431
TALAGANTE	VI	- VII	205	-	535
PEÑAFLOR	VI	- VII	567	-	229
ISLA DE MAIPO	VI	- VII	82	-	209
EL MONTE	VII		1.960	-	780
MELIPILLA	VII	- VIII	7.560	-	3.240
CURACAVI	VI	- VIII	1.258	-	916
MARIA PINTO	VII		807	-	102
SAN PEDRO	VI	- VII	624	-	264
VILLA ALHUE	VI	- VII	536	-	

VI REGION

MOSTAZAL (SAN FCO. DE)	VI	- VII	170	-	314
CODEGUA	VI	- VII	93	-	200
GRANEROS	VII	- VIII	1.081	-	1.280
RANCAGUA	VI	- VII	76	-	546
MACHALI	VII		786	-	335
DOÑIHUE	VII		760	-	534
COINCO	VI	- VII	260	-	720
COLTAUCO	VII		657	-	1.673
REQUINOA	VI	- VII	200	-	40
OLIVAR	VI		28	-	73
RENGO	VII	- VIII	1.204	-	1.800
MALLOA	VII		691	-	352
QUINTA DE TILCOCO	VI	- VII	293	-	189
SN. VICENTE DE TAGUA TAGUA	VII	- VIII	1.672	-	1.550
PICHIDEGUA	VII		737	-	1.067
PEUMO	VI	- VII	16	-	1.052
LAS CABRAS	VII		873	-	
SAN FERNANDO	VII		578	-	1.072
CHIMBARONGO	VI	- VII	184	-	125
PLACILLA	VI	- VII	228	-	802
NANCAGUA	VI	- VII	314	-	254
CHEPICA	VI		36	-	134
SANTA CRUZ	VII		313	-	350
LOLOL	VI	- VII	36	-	148
PUMANQUE	VI	- VII	45	-	320
PALMILLA	VI	- VII	156	-	918

Table 1 continued

		DESTRUIDAS	-	DAÑADAS
Continuación VI REGION :				
PERALILLO	VI	14	-	193
NAVIDAD	VII	1.000	-	
LITUECHE	VII	931	-	200
LA ESTRELLA	VI - VII	286	-	364
PICHILEMU	VII	365	-	240
MARCHIGUE	VI - VII	122	-	231
PAREDONES	VI - VII	50	-	820
VII REGION :				
CURICO	VII - VIII	1.449	-	1.356
TENO	VI - VII	51	-	183
ROMERAL	VI - VII	20	-	50
MOLINA	VI - VII	162	-	43
SAGRADA FAMILIA	VI - VII	182	-	1.817
HUALAÑE	VI - VII	16	-	45
LICANTEN	VII	352	-	752
VICHUQUEN	VI - VII	39	-	228
RAUCO	VI - VII	36	-	323
TALCA	VII	300	-	3.676
PELARCO	VI - VII	117	-	51
RIO CLARO	VI - VII	25	-	221
SAN CLEMENTE	VI	5	-	31
MAULE	VI - VII	26	-	107
EMPEDRADO (s/i)				
PENCAHUE	VI - VII	29	-	30
CONSTITUCION	VI - VII	15	-	326
CUREPTO	VI - VII	29	-	43
LINARES	VI	3	-	
LONGAVI	VI	1	-	4
COLBUN	V - VI		-	2
PARRAL	V - VI		-	3
RETIRO	V - VI		-	1
VILLA ALEGRE	V - VI		-	41
SAN JAVIER	V - VI		-	15
YERBAS BUENEAS (s/i)				

STGO., 15 de Marzo de 1985.-

ANEXO N° 3.-

REPUBLICA DE CHILE
MINISTERIO DEL INTERIOR
OFICINA NACIONAL DE EMERGENCIA
DEPARTAMENTO PROTECCION CIVIL

ESTADO DE LA SITUACION NACIONAL

Tipo de Emergencia: SISMO
Período del: 3-3-85 Al: 25-3-85

INFORME GENERAL N° 46
Fecha: 25-3-85 Hora: 1100
Año: 1985

REGIONES AFECTADAS	PERSONAS: MUERTAS	PERSONAS: HERIDAS	PERSONAS: DESAPARECIDAS	DAMNIFICADOS EN ALBERGUES: FAMILIAS	DAMNIFICADOS EN ALBERGUES: ADULTOS	DAMNIFICADOS EN ALBERGUES: MENORES	DAMNIFICADOS EN ALBERGUES: SUB TOTAL PERSONAS	DAMNIFICADOS FUERA DE ALBERGUES: FAMILIAS	DAMNIFICADOS FUERA DE ALBERGUES: ADULTOS	DAMNIFICADOS FUERA DE ALBERGUES: MENORES	DAMNIFICADOS FUERA DE ALBERGUES: SUB TOTAL PERSONAS	TOTAL PERSONAS DAMNIFICADAS	VIVIENDAS: DESTRUIDAS	VIVIENDAS: DAÑADAS	ZONAS SIN SERVICIOS DE: AGUA POTABLE	ZONAS SIN SERVICIOS DE: ENERGIA ELECTRICA	ZONAS SIN SERVICIOS DE: GAS	ZONAS SIN SERVICIOS DE: ALCANTARILLADO	ZONAS SIN COMUNICACIONES: TELEFONICAS	ZONAS SIN COMUNICACIONES: TELEGRAFICAS	CAMINOS CORTADOS O INUNDADOS	PASOS BAJO NIVEL INUNDADOS	RIOS, ESTEROS, CANALES DESBORDADOS	PUENTES DESTRUIDOS	PASOS FERROCARRIL INTERRUMPIDOS	LOCALIDADES AISLADAS	TRANQUES O EMBALSES AFECTADOS	PRECIPITACIONES ULT. 24 HRS. (MM)	EDIFICIOS PUBLICOS DESTRUIDOS	EDIFICIOS PUBLICOS DAÑADOS	MAMIFACTOS
I																																
II																																
III																																
IV				3	6	5	11	32	66	96	162	173	24	10																		
V	69	923		1450	3409	3.124	6.553	[illegible]	[illegible]	95972	201.360	207.913	16.132	30.174	2				3	11	3			11	1	4	6			56	
METROP.	70	1322		[illegible]	7945	6.104	14.357	[illegible]	200.396	222894	513.342	527.399	35831	81.630							2			2			3		96	296	
VI	99	254		471	1.108	1.003	2.114	[illegible]	93.945	81738	177.786	179.900	20.111	19.956					3											53	
VII	2	62		79	229	114	353	14159	43.415	20.101	63.569	63.922	3626	10.611							3			5						104	
VIII																																
IX																																
X																																
XI																																
XII																																
TOTALES	177	2575		5143	12728	10.360	23.088	[illegible]	[illegible]	[illegible]	1956 210	979.307	75724	142.381	2				6	11	10			18	1	4	9		96	509	
T. INF. N°																																
VARIACION																																

Table 2: ONEMI summary sheet on damage and homeless as of March 25, 1985.

COPORACION PRIVADA DE DESARROLLO
DE CURICO /

DAÑOS EN POBLACION Y VIVIENDAS EN LA PROVINCIA DE CURICO

	POBLACION AFECTADA						VIVIENDAS AFECTADAS				
			DAMNIFICADOS				IRREPARABLES		REPARABLES		
COMUNAS	MUERTOS	HERIDOS	EN ALBERGUES	EN CASAS PARTICULARES	EN CARPAS	TOTAL PERSONAS	DESTRUIDAS	POR DEMOLER	CON DAÑOS MAYORES	CON DAÑOS MENORES	TOTAL VIVIENDAS AFECTADAS
CURICO	1	32	226	6.841	187	7.254	200	612	700	1.580	3.092
TENO	-	4	49	392	1.287	1.728	51	85	40	105	281
ROMERAL	-	-	-	23	-	23	-	24	38	12	74
RAUCO	-	-	-	188	277	465	4	68	3	39	142
HUALAÑE	-	-	-	1.016	-	1.016	16	62	101	900	1.079
LICANTEN	-	3	52	677	-	729	99	653	301	451	1.504
VICHUQUEN	-	-	-	525	-	525	13	37	18	210	278
MOLINA	-	-	7	1.247	123	1.377	17	80	71	179	347
SAGRADA FAMILIA	-	-	108	1.128	190	1.426	13	169	196	1.439	1.817
TOTAL PROVINCIA	1	39	442	12.037	2.064	14.543	129	1.790	1.496	4.915	8.614

CURICO, 20 de Marzo de 1985.

Table 3: Example of documentation prepared by ONEMI representatives at the provence level.