Chilean Earthquakes of May, 1960:
A Brief Trip Report

by

Karl V. Steinbrugge*
Ray W. Clough**

Introduction:

The series of major earthquakes which struck Chile in the latter part of May and during June, 1960, caused widespread damage and destruction. Of earthquake engineering interest is the fact that in and near the epicentral region there were many structures which were designed to resist earthquakes.[1]

As soon as it became apparent that a major disaster had occurred in Chile and that it had earthquake engineering significance, the Earthquake Engineering Research Institute formed a team of engineers in order to obtain first hand knowledge of the problems. With the financial assistance of the National Science Foundation it was possible to send a reconnaissance team composed of Professor C. Martin Duke (University of California, Los Angeles), and the authors. At this writing, William K. Cloud is continuing the team's studies in Chile in co-operation with the Chilean scientists and engineers. This trip report is based on the personal observations of the two week survey by the American team, and generally will not contain information which was not personally verified. A comprehensive report on the damage effects and analyses of the damage mechanisms observed in these earthquakes will be published at a later date; only general observations of the principal earthquake effects are presented herein.

General Remarks:

The area which was shaken severely by the Chilean earthquakes was very extensive. The Earthquake Engineering Research Institute team inspected damage over a region 300 miles long, extending from Concepción to Puerto Montt, and undoubtedly the heavily shaken area extended to the relatively uninhabited regions south of Puerto Montt. Severe damage was observed in the Chilean central

*Secretary, Earthquake Engineering Research Institute, San Francisco.
**Professor of Civil Engineering, University of California, Berkeley.

1 The status of earthquake resistant construction in Chile has been described in the paper, "Development of Earthquake-Proof Construction in Chile," by H. Bertling, published in World Conference on Earthquake Engineering, Berkeley, 1956.

valley as well as along the coastline. Both tsunami effects and volcanic activity were produced by these earthquakes, but only observations with regard to structural engineering and soils and foundation engineering will be discussed in this report.

It should be recognized from the outset that a reconnaissance trip in which personal observations are made without benefit of strong motion instrumental data tends to lead to subjective interpretations. However, preliminary earthquake magnitudes determined from teleseismic records indicate that within a one-month period Chile experienced no less than 13 earthquakes of magnitude 6 or greater, with one being at least as large as the San Francisco shock of 1906 (magnitude = 8. 3). It was apparent that, while well defined correlations between magnitudes and intensities are not yet possible in most earthquakes, many if not all of the cities between Concepcion and Puerto Montt had been subjected to severe shaking at least once during the series of shocks. The locations of the epicenters of the major shocks have been tentatively identified as near but not directly at any major city. A clearer evaluation of the data regarding damage distribution will become possible after the epicenters are more accurately determined. Although intensities at a given locale were variously estimated by different observers, there could be no doubt that on a general basis the shaking must be considered as severe. Remarks on subjective interpretation of the severity of the shocks may at first glance seem obvious and not requiring comment, but such remarks are of importance in view of the extreme variations in the damage observed in a given town or area.

The previous discussion should not be interpreted to mean that intensities within a town were uniform; the reverse was often ture. By "severe" in this report is meant that tectonic energy was great in the area, but its effects may have been tremendously modified by local geology or construction practices. The definition of "good construction" is subject to very wide interpretation; for example, unreinforced masonry laid only in cement mortar in some earthquake-prone areas of the world is considered "good," while in other areas reinforcing steel would be required in good construction. Similar comments could be made with regard to Chilean construction.

Observations in Concepción:

Concepción and environs were the first areas inspected. Loss of life and property damage in Concepción were largely associated with unreinforced unit masonry structures which had survived but probably were weakened by the 1939 shock. These older structures were not earthquake resistive by today's standards. In general, newer structures with earthquake bracing performed well, although some exhibited interesting damage. A noteworthy example was found at the University of

Concepción where two steel frame structures, each 3 stories high, had diagonal braces in the first story broken during the first major shock. Subsequent shocks caused very little additional structural damage, although at some time the anchor bolts stretched due to column bending. These two structures will be the subject of much further study since their architecture is quite modern and since they vividly portray the problems involved in rigid versus flexible design. Failure occurred in the welds, and this has suggested defective welding as a source of weakness in addition to the problems in analysis.

A circular one story reinforced concrete market building was just completed and suffered most interesting damage between the low roof and high roof lines. Both low and high roofs were of reinforced concrete folded plate construction. The high roof was about 125 feet in diameter while the low roof formed an outside rim about the building, giving an over-all building diameter of about 160 feet. A clerestory existed between the low and high roofs. Earthquake damage was largely confined to the 12 columns located in the clerestory area; interior columns were not damaged due to their much greater relative flexibility. Considerable analysis has already been given to this structure, and no doubt it will be repeatedly discussed in future papers.

Several multistory buildings in Concepción were also briefly inspected and they had no apparent structural damage. An exception was the City Hotel in which some structural damage was noted in the frame.

Several spans of the multiple span highway bridge (reinforced concrete deck on steel beams) crossing the Bio-Bio River at Concepción collapsed. The reinforced concrete bridge piers were on piling, but the piers overturned and where inspected, showed the wooden piling broken at the pile cap. A careful examination of the piers yet standing gave evidence that perhaps all the piers were not plumb prior to the shock and that the structure may have been in a weakened condition.

Near Concepción at Talcahuano is the integrated steel plant Compania de Acero del Pacifico (CAP). This major steel plant, valued at about $150,000,000 (U.S.), suffered less than 1% loss according to preliminary estimates. The damage to the steel stacks, equipment, and buildings is described in more detail in these "Proceedings" by Vignola and Arze.[2] Detailed theoretical investigations of the earthquake effects are in progress both in Chile and in the United States, and these should prove to be of particular interest since the plant was designed to be earthquake resistive.

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[2] The preliminary report, "Behaviour of a Steel Plant under Major Earthquake" by Raul Vignola and Elias Arze, n.d. (1960), is also worthy of careful study.

South of Concepción and across the Bio-Bio River was the paper plant Padeles y Cartones. The main structure was a long reinforced concrete rigid frame building; the high roof was about 30 feet above the ground while a leanto roof attached to the main bay was about half this height. Transverse lateral forces on this building were taken in column bending. A total of 21 of 36 columns broke on the side having the leanto (i.e., apparently the more rigid side) while 7 cracked on the other side. Again, damage was of a type to warrant a detailed study of the structure.

A steel water tank at this location also was damaged although lateral forces apparently had been considered in its design. This 4 column elevated tank was of a design commonly found in California; the damage in the form of stretched X-bracing rods was typical of that found in the 1952 Kern County (California) earthquake and suggests a similar magnitude of lateral forces.

The Valdivia Area:

Valdivia was the next principal city visited by the team. Buildings in this city as well as in the surrounding regions were subjected to a regional subsidence of perhaps 5 to 7 feet in addition to the more usual horizontal vibratory motions. This vertical drop was noted along the shorelines of streams which, at Valdivia, have the characteristics of a tidal estuary. Thus the water level was perhaps 5 to 7 feet higher throughout the area.

The actual vertical drop at a given site was often confused by the local ground lurching and local subsidence along the riverbank. However, a series of photographs taken of the shoreline a few minutes after the earthquake -- just as the water began to rise in the river -- give vivid graphic proof of the regional vertical subsidence due to tectonic movements.

The combined effects of horizontal and vertical motions were spectacular in Valdivia. Certain areas, possibly old river beds and drainage channels, subsided and of course materially contributed to the damage of the structures in these poor ground regions. These areas were plotted, and damage conditions tabulated for future study. In this regard the American team was accompanied by geologists who are continuing their studies (preliminary reports are in preparation at this writing.)

Loss of life was remarkably small in Valdivia and environs. The U. S. military medical team in Valdivia has estimated 120 killed plus about 120 seriously injured. This, no doubt, was due to a number of factors including the fact that earthquake resistive design was commonly employed in the major structures, and numerous wood frame buildings existed. Wood frame structures were of light mass and with their numerous partitions were not likely to collapse even if they dropped from their foundations (which many of them did).

Several structures in Valdivia are of particular interest and warrant special mention. The six story Orthopedic Hospital (Hospital Traumatologica Valdivia) was structurally complete at the time of the earthquakes, but was not yet occupied. Lateral force resistance was provided by reinforced concrete shear walls, and it appeared that the unsymmetrical arrangement of these may have led to torsional deformations. Shear wall failure was common, but no collapses occurred. The shear walls were thick in some cases; the heaviest wall with fractures which was inspected was about 10 inches thick and reinforced with a double curtain of 6 mm bars at about 6 inches on center both ways. Failures in the shear walls were often associated with construction joints, just as has been noted in many other earthquakes.

The Regional Hospital in Valdivia had spectacular and newsworthy damage as well as features of engineering interest. It was built between about 1932 to 1935, was 8 stories high, and was constructed of reinforced concrete. Structural damage varied in amount, with the principal spectacular structural damage being in one wing and one nearby portion of the main structure. The wing was structurally independent of the main building, and extensive pounding occurred between them. Shear wall failures were spectacular; these failures in one case were distributed in a vertical alignment rather than horizontal alignment as is so often assumed in analysis. This vertical shear failure tended to make the wing act as two units instead of one. A fuller understanding of vertical shearing effects will come from a more detailed study of this structure. Elsewhere the structural damage was clearly associated with poor construction joints and with the problems of relative rigidity.

Many older non-earthquake-resistive structures in Valdivia collapsed, notably the Weiss Shoe Factory which was built in 1906. The collapsed portion was a one-story structure with a sawtooth roof. Buildings around the plant did not give witness to excessive intensity of ground motion, nor did the tall chimney at the plant which had only minor damage.

One so-called steel frame building in Valdivia which was examined was a 3 story grain warehouse near the waterfront. The exterior steel columns were badly bent, but did not collapse. The relatively few steel frame buildings known to be in the earthquake zone made it difficult to compare the performance of steel frame construction with its counterpart of reinforced concrete on any statistical basis.

Unquestionably numerous buildings in Valdivia suffered severe structural damage, including some designed to be earthquake resistive. It would be premature to completely attribute the failures known to have occurred to the earthquake resistive structures as being the result of faulty design, faulty construction, or excessive shaking in any building; in each instance of failure all three factors were present and the careful study which is in progress at present may determine the relative significance of these factors in some instances. Soil conditions often added a fourth factor. Conversely, numerous major reinforced concrete structures exhibited no significant structural damage. For one example, we may cite the Hotel Pedro Valdivia which is a reinforced concrete building 5 stories high which had only negligible non-structural damage.

Two major reinforced concrete bridges at Valdivia were inspected. Damage was noted primarily at the abutments, and the damage was clearly due to the earth fill settling behind the abutments and also due to the abutments shifting toward the river. An analysis of the soil and an inspection of the substructure below grade should provide valuable information as to the mechanism of failure. It is to be recalled that these bridges, as well as the city, dropped vertically due to regional tectonic movement, vibrated horizontally, and suffered local ground displacement due to lurching and settlements. Both bridges were usable with relatively simple repairs, although major repairs will eventually be required.

Two reinforced concrete elevated water tanks in Valdivia warrant special mention due to their unusual structural characteristics and their performance in the earthquake. Adjacent to the previously mentioned Regional Hospital was an elevated reinforced concrete water tank, 23 meters in diameter by almost 12 meters high. The designed water depth was about 10 meters, but no water was in the tank at the time of the shocks. The elevated concrete tank was supported on a reinforced concrete cylindrical shell 30 meters high by 14.5 meters in diameter. The thickness of the shell was 20 cm and it was stiffened by 30 cm thick reinforced concrete "fins" which projected externally from the shell. The tank structure was supported by reinforced concrete spread footings, and the soil appeared to be quite firm. Damage was severe throughout the entire tank structure, and daylight could be seen through numerous cracks in the reinforced concrete walls. This was remarkeable since the tank was empty at the time of the earthquake, and since the water load in these tanks is usually a major part of the total load. In the design of this structure it apparently had been assumed that the lateral forces would be resisted by the "fins," but the cylindrical shell was much stiffer than the fins, and thus it was called upon to resist lateral forces which may not have been considered in its design.

An undamaged reinforced concrete tank was located near the Valdivia airport, and was of the inverted pendulum type (i.e., a cylindrical concrete tank on top of a single column). Recent controversy regarding the stability of reinforced concrete inverted pendulum structures will make an analysis of this tank of value, although it should be noted that the capacity of this tank was much less than the one mentioned above. (It is appropriate to mention in addition that the canopies over the passenger loading and unloading areas at the Concepción Railroad Station were of the inverted pendulum type, and also did not collapse.)

The Region from Osorno to Puerto Montt:

The only example of a steel inverted pendulum water tank was seen outside of Llanquihue (Puerto Montt is the nearest major city). This steel cylindrical tank had about a 6 foot diameter riser and was about 65 feet above grade. There was no evidence of distress in this structure whatever. However, in the town itself severe damage was noted in the poor ground areas; this damage was in the form of slumping of the railroad roadbed under freight cars, displacement of bridges from their foundations, collapsed buildings, etc.

Smaller cities such as Osorno and Rio Negro had some interesting examples of damage which have not had the attention that the structures in the larger cities have had. For example, in Osorno, a two story automobile sales building suffered severely. The classic design problem of the relative rigidity of short and long columns having about the same diameters was graphically portrayed in the column failures.

The small town of Rio Negro appeared to have been damaged as severely as any of the larger cities; there is some evidence that it may have been more severely shaken than other areas on comparable soils. Destruction was generally severe, and poor construction practices did not seem to account entirely for the increased severity of the damage. Of especial interest was the reinforced concrete water tank which had a capacity of 700, 000 liters although the actual contents at the time of the earthquake was estimated at 600, 000 liters. This tank was supported on 10 legs. Lateral stability was provided by horizontal struts between columns, with these struts taking both moment and vertical shear. In essence, the tank was braced by a rigid space frame of columns and beams arranged in the form of a truncated cone beneath the elevated tank. Damage was in the form of shear failure in most of the struts (vertical shear) plus "working" where the columns met the tank shell.

The standard elevated reinforced concrete water tank used by the railroad system was of similar basic design, but smaller in scale than the tank described for Rio Negro. Interestingly, vertical shear damage to the struts was also found in these smaller tanks, and suggests a design consideration rather than construction deficiencies.

Puerto Montt:

Puerto Montt was the southernmost city visited by the American team. It was in this city that the most spectacular damage with respect to soil conditions was noted. Over 500 meters of concrete quay wall failed, and elsewhere along the waterfront other types of walls failed including steel sheet piling. Apparently, liquifaction of the loose fine sandy soil was the primary cause of the quay wall collapse. Nearly all buildings in this area were badly damaged or destroyed due to failure of their supporting soils. Not all of the seawalls failed, although numerous evidences of ground motion could be found in the backfills.

A most interesting case of a building which experienced liquifaction of its foundation materials was the reinforced concrete Hotel Perez Rosales on the Puerto Montt waterfront. This hotel, almost completed at the time of the earthquake, had a 5 story center section with 1 and 2 story wings on either side. Footings were of the reinforced concrete spread type. All earthquake bracing in the main structure was in the form of reinforced concrete shear walls. During the earthquake the building sank, with the waterfront side settling 15 inches more than did the opposite side. The smaller wings did not settle as much as did the main building; this resulted in differential settlement between the main structure and its wings which caused spectacular structural damage, particularly at the junctions. Details of the failures were interesting, and some of these warrant comment. Reinforcing bars having hooked ends pulled free from the embedding concrete without straightening the hook, and bond failures were more common than tension failures in the reinforcing steel. Basement floor slabs were tied to the reinforced concrete spread footings; as the footings settled, the floor slabs appeared to rise (i. e., due to differential settlement between them). Interestingly, vibrational damage was slight in the upper stories of the main structure. A careful soils analysis will undoubtedly be of considerable importance in determining the details of the damage pattern to this building.

Damage along the waterfront was most spectacular and in great contrast to conditions elsewhere in Puerto Montt where firmer soils were found. Total collapses elsewhere were rare although interesting examples of damage were numerous. One such example was provided by the Seminario, located on a hill overlooking the city. This 4 story building has a reinforced concrete frame with brick panel walls and is "L"-shaped in plan. Floors are reinforced concrete, but the roof is corrugated metal on wood framing. Damage was noted particularly at the re-entrant corner of the "L", as well as across from the re-entrant corner. Obviously the shape factor and the high stresses resulting therefrom were sources of damage. Glass and partitions were generally damaged indicating appreciable deflection between stories. Some accentuated damage was noted in the top story, probably due to the ineffective roof diaphragm. The poor quality material used in the partition walls gave this building none of the secondary strength found in structures having strong interior walls.

Summary:

The Chilean earthquakes gave repeated tests to numerous earthquake resistive structures. These earthquakes are, in essence, the best major laboratory test of earthquake resistive structures to date, particularly for buildings with the more modern architectural treatments.

In general, where modern buildings failed, construction practices and design practices were poor. Undoubtedly building code enforcement left something to be desired in these cases.

The term "total devastation" or "total destruction" has often been applied to the entire earthquake area. These terms are not accurate and should be applied only to small areas such as the Puerto Montt waterfront -- even then damage was not truly total. In other words, the numerous examples of undamaged buildings gave positive evidence that structures of reinforced concrete, of structural steel, and of wood frame can be successfully designed and constructed to withstand a major series of shocks.

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