# ENGINEERING ASPECTS OF CHILEAN EARTHQUAKES OF MAY 21 AND 22 - 1960.

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## 1. INTRODUCTION.

The earthquakes of Chile on May 21 and 22, 1960 have afforded an excellent opportunity to re-examine the performance of man made structures when subjected to seismic action.

It was also a severe test of the Chilean Earthquake Code, drafted in 1940, one year after the major 1939 shock.

The short time elapsed since the disaster, obviously has not permitted a comprehensive analysis of their effect. A group of scientists and engineers have conducted a thorough survey of the field. Scientific groups from the U.S.A., Mexico and the country sponsoring this Conference, Japan, fully conscious of the importance of this big experiment performed by nature, have visited Chile in an effort to increase the common knowledge for the benefit of all.

The shaken area comprises 10 provinces of Central Chile that also in the past have suffered from earthquake and tsunami effects.

If we take for instance the city of Concepción, originally built at the present location of Penco, we find it was destroyed by earthquakes and tsunami effects on 1570, 1657, 1730, 1751 and 1835 being moved thereafter to its present site.

We still find destructive earthquakes in Concepción on the years 1835, 1939, 1953 and 1960 to mention only the most important.

The city of Valdivia badly damaged by the May 22 earthquake was also destroyed on 1520, 1562, 1575, 1737 and 1837. A tsunami and a landslide temporarily blocking the Riñihue Lake outlet to Río San Pedro followed the 1575 shock, causing 4 months later a destructive avalanche. Today, almost 400 years later, this condition has repeated itself.

## 2. THE SHOCKS OF MAY 21 AND MAY 22 - 1960.

On May 21 at 6.02 AM there occurred an earthquake of 7 3/4 (RICHTER) magnitude. The epicentral area has been located in the Península of Arauco, south of Concepción. This shock of a magnitude comparable to

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the Chillán earthquake 1939, caused considerable damages and loss of lives in Concepción and the adjacent area. It affected mainly the provinces between Linares and Malleco. In all, the dead and missing were reported to exceed 500. Intensities of 9 of the Modified Mercalli Scale were reported in the city of Concepción.

Next day, on May 22 at 15.10 a more violent earthquake affected the southern part of the country. The shock was at its worst between Cautín and Chiloé. The epicenter has not been clearly defined but some evidence shows that it might be under the ocean, between Valdivia and Ancud. This second earthquake was reported as having magnitude exceeding 8 3/4 (RICHTER). Its intensity reached degree 11 at several points in the vecinity of Valdivia. At the same time a tsunami traveling across the Pacific Ocean and reaching as far as the Artic and Indian Ocean developed in front of Valdivia. Greater damages by the tsunami were produced between Puerto Saavedra and Chiloé. Fortunately the ports further north were not seriously damaged because the sea wave was deflected by the Península of Arauco.

In Valparaiso the tidal wave amplitude was less than 1,50 mts. to be compared with a wave larger than 7 m. in Juan Fernández Island at the same latitude of Valparaiso.

The loss of lives has been estimated as surpassing 4000.

The tsunami also caused considerable damages in California, Hawai and Japan.

Coastal settlements in the south of Chile have been estimated at 1,5 m. in front of Corral and Valdivia and 0.30 m. at Puerto Montt. Along the shore in front to Lebu an uplift of 1.20 was observed. At Isla de Guafo the uplift is of the order of 2 mts.

Big landslides were observed, mainly in the lake district. Some of these, as mentioned above, have blocked out the Riñihue Lake outlet to Río San Pedro, creating a new and dangerous threat for Valdivia. All possible engineering measures were taken to prevent a sudden destructive flood over Valdivia. The flow of the 3000.000.000 $m^3$ stored by the increase in 24 m. on the water level of the lake, caused a flood in Valdivia of only 2 mts. high.

The only volcanic activity reported was the eruption of Volcán Puyehue, which lasted only a few days.

A considerable number of replicas have been registered, some as high as 7 (Richter).

The earthquake affecting more than 80.000 square miles of Chilean territory are responsible for at least 5.000 persons either dead or missing, hundred of wounded, over a million homeless and damages estimated at about half a billion dollars.

## 3. STRUCTURAL DAMAGES.

The effectiveness of the seismic design was clearly shown; the better behaviour of structures specifically designed to resist shocks was quite impressive.

The vast majority of dwellings that collapsed were of a very poor type of construction.

It is most significant that on the May 21 shock only 500 people were killed as compared with 40.000 in the 1939 earthquake. In Concepción the collapsed buildings were in general "survivors" of the 1939 shock. The city, seriously damaged on that occasion, has since been rebuilt with a better type of constructions.

The situation in Valdivia and Chiloé was entirely different. The last destructive earthquake felt in the zone dates back to 1837, consequently a larger amount of dwellings were damaged.

These present comments are related generally to earthquake resistant types of construction. We will not discuss the very poor type of constructions that collapsed as they are not important from an engineering point of view.

No specific comment will be offered on tsunami effects on structures.

To present in an orderly manner the considerable amount of information collected up to now, the examples of failures have been analyzed as follows:

1.- Group where failure might be attributed to design considerations.

2.- Group where failure might be attributed to construction considerations.

Group 1.

1.1 Impact between adjacent structures. Insufficient clearance to allow independent vibration.
1.2 Horizontal torsional effects.
1.3 Weak details.
1.4 Incorrect judgement of relative rigidities.
1.5 Structures on top of buildings.
1.6 Construction joints.
1.7 Soil and foundation failure.
1.8 Effects on special structures.
1.9 Parapets, miscellaneous, etc.

Group 2.

2.1 Poor quality of reinforced concrete.
2.2 Poor bond between masonry and concrete or between masonry and steel columns.
2.3 Defective weldings.
2.4 Miscellaneous.

In many cases the classification of a specific example has not been easy to decide, since the misbehaviour could be attributed not to one but to several reasons. Nevertheless an attempt has been made to emphasize the most significant factor.

The photographs appended illustrate the previously specified cases.

In addition to the above reported damages, a large number of steel and reinforced concrete structures resisted the earthquake with negligible or no damage, proving the excellent result of good design, construction and inspection.

An obvious implication of the observed damages is the question whether these damages could have been avoided by a full compliance to the Chilean Code. This is particularly important at the present time when a revision of our Code has been officially requested.

It is necessary to point out in the first place that in addition to the Code a standard general practice has been developed and that the situation should be analyzed accordingly. It is of course mandatory to incorporate into the Code those prescriptions of the standard practice that to this date have proved successfull.

Only a small percentage of damages observed can be attributed to loads not considered in the design, the failures are mainly related to poor construction practice, lack of inspection or both causes.

If the failures described above under design considerations are analyzed in detail, it may be concluded that certain changes and additions should be incorporated to the code, mainly in relation with paragraphs 1.1, 1.5, 1.6, 1.8 and 1.9.

The lateral coefficient will be certainly changed in the future-normal present design basis is $c = 0.12$ uniform through the height, with increased stresses of 20 % over normal - but we strongly believe that it should not be increased on account of the experience collected in these earthquakes.

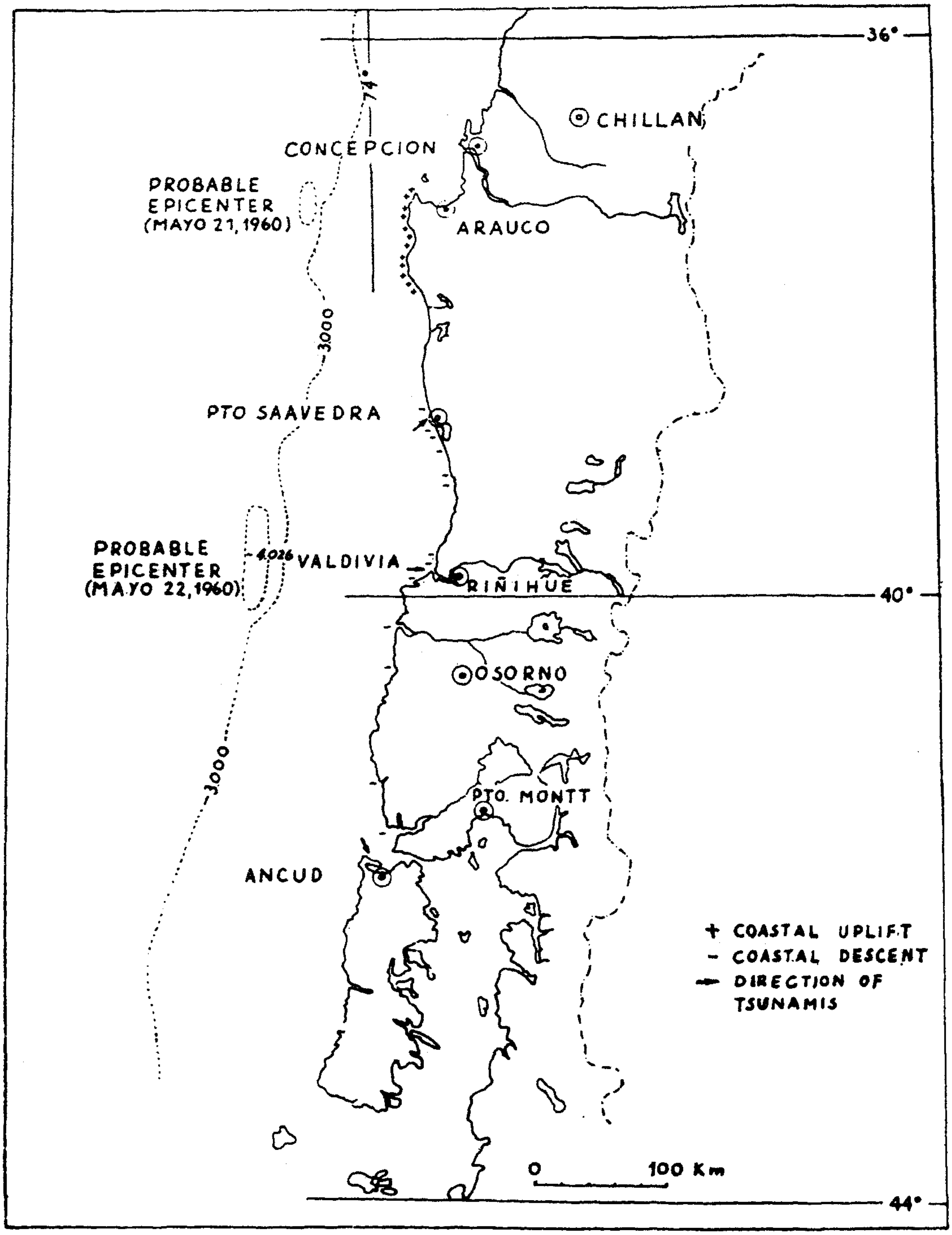
A comment will be presented on the effects of the earthquakes on special structures, mainly due to the baffling failure of diagonal bracing members in many steel mill type buildings without further consequences for the structures. One way of considering the problem is to require for such a structure earthquake provisions based on dynamical analysis covering their plastic properties and realistic damping characteristics.

## 4. CONCLUSION.

The earthquake of May 21 and 22, 1960 in Central Chile affected an area having a large amount of structures built before and after the 1939 shock, thus providing a good control of the efficiency of the 1940 Code.

Almost in every case where design, construction and inspection were performed in compliance with the Chilean specifications and standard general practice the result was outstanding. However, a few exceptions were reported, mainly in special structures.

In spite of the general good result of the Code, a revision will be made, directed to a better conformity with modern theory and practice which strive for increased safety and economy in construction.




**The area affected by the earthquakes.**

Fig. 1.11 School in Coronel. Two buildings 50 m. long each collided in third floor causing considerable structural damages.

Fig. 1.12 Ditto. Broken wall and column are shown.

Fig. 1.14 Regional Hospital in Valdivia. General view.

Fig. 1.13 Church in Valdivia. Unreinforced masonry wall destroyed by impact of adjacent buildings.

Fig. 1.15 Ditto. Collision between main building and central aisle (7th floor).

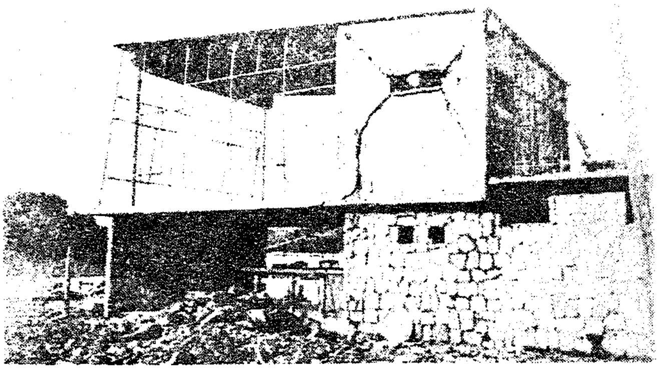


Fig. 1.21 Club in Concepción. Effect of horizontal torsion.

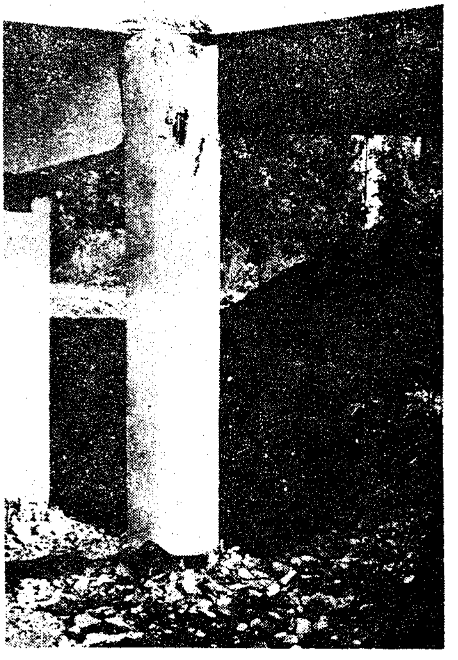


Fig. 1.23 Damage in upper and lower ends of central columns.

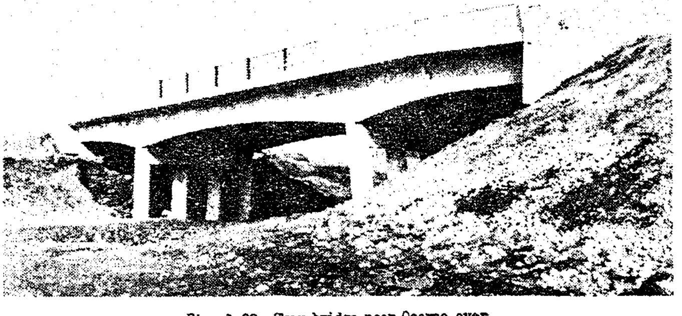


Fig. 1.22 Skew bridge near Osorno over Panamerican highway, Gerber type. The settlement of foreground abutment caused a horizontal torsion which destroyed upper and lower end of supporting columns. General view.

Fig. 1.25 Traumatological Hospital in Valdivia. Highly asimetric disposition of supporting elements. General view.

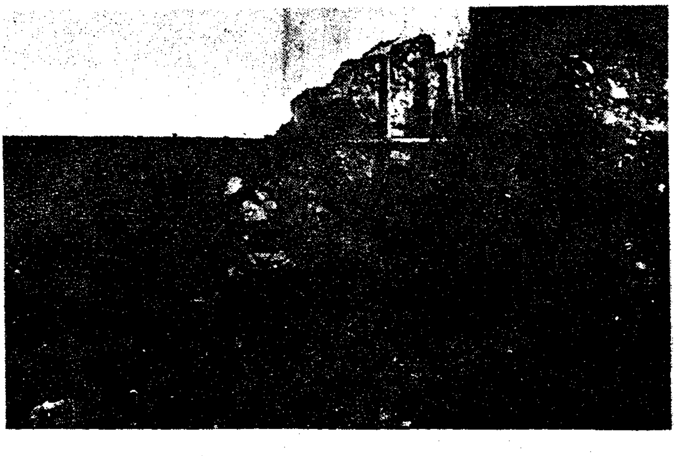


Fig. 1.24 Considerable lateral displacement at upper end of extreme columns.

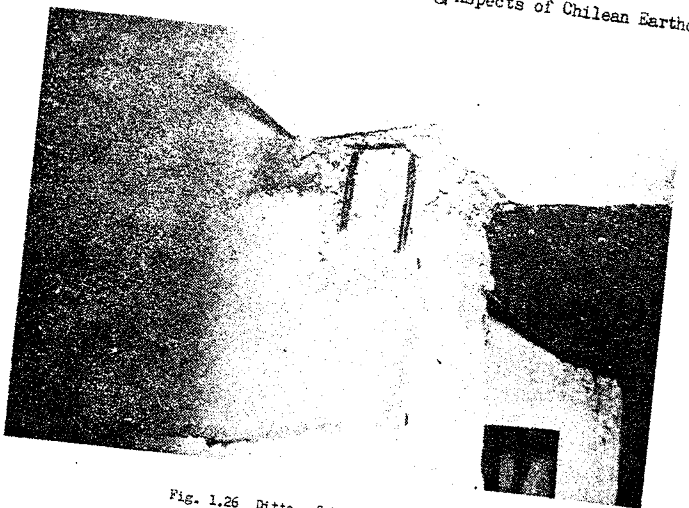


Fig. 1.26 Ditto. Column in first floor.

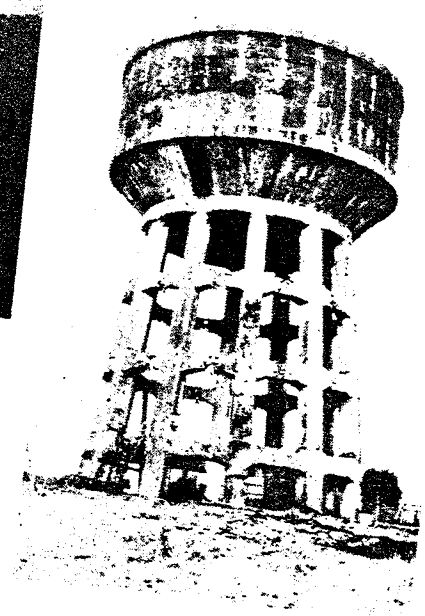


Fig. 1.31 Water tank in Rio Negro. General view.

Fig. 1.27 Ditto. Shear cracks in reinforced concrete wall in first floor.

Fig. 1.32 Ditto. Close up.

Fig. 1.35 Regional Hospital in Valdivia. Unreinforced masonry. Lack of anchorage to main structure.

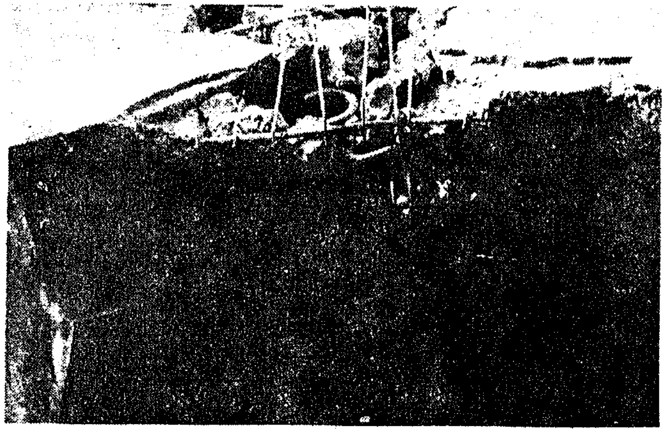


Fig. 1.33 Ditto. Observe the hooks ending at the same section and open stirrups.

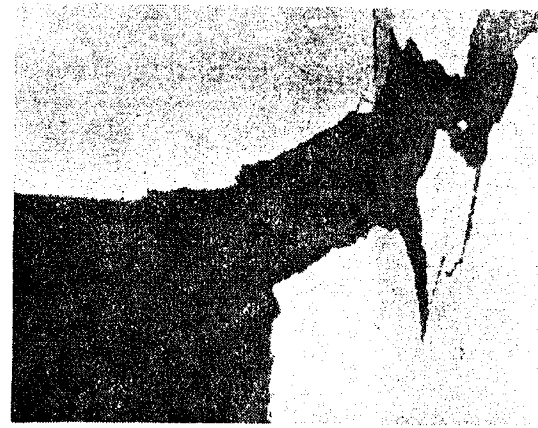


Fig. 1.34 Traumatological Hospital in Valdivia. Insufficient anchorage of steel bar in reinforced concrete beam.

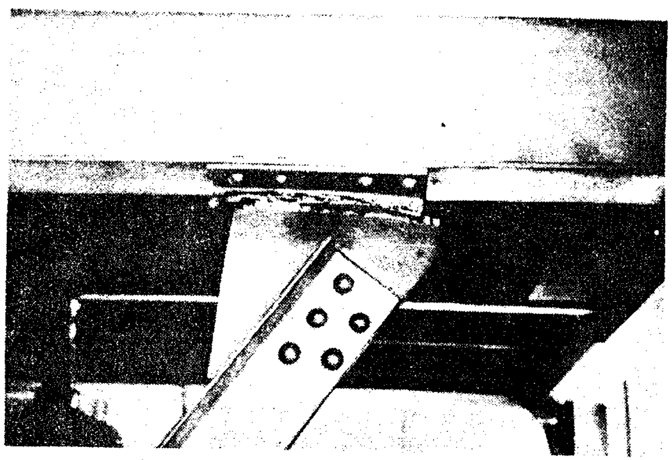


Fig. 1.36 Incorrect connection between beam and diagonal member.

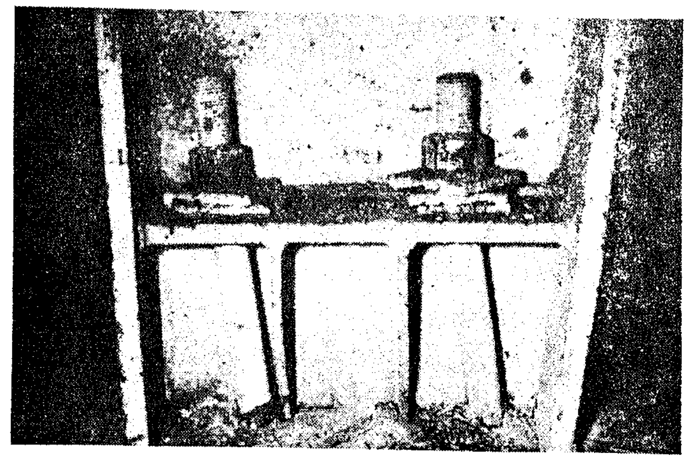


Fig. 1.37 Appreciable sliding between column and base plate.

Fig. 1.38 Diagonal member tored out web of column which has no transversal rigidity.

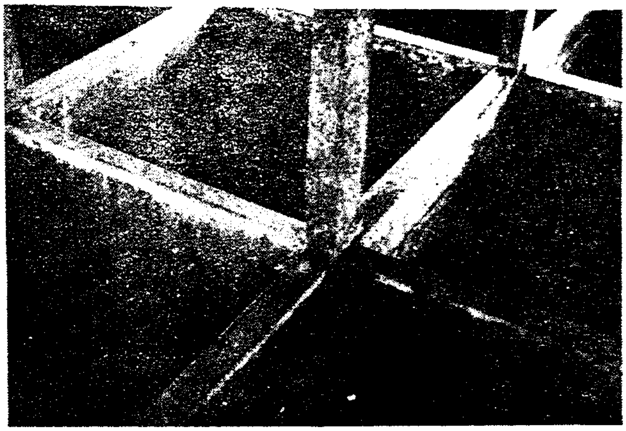


Fig. 1.42 Damage at base of roof columns.

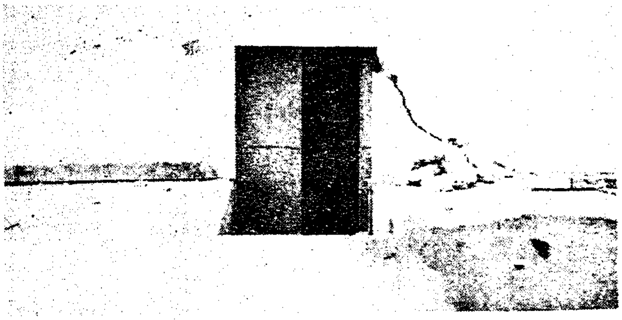


Fig. 1.43 Cracks in wall of staircase.

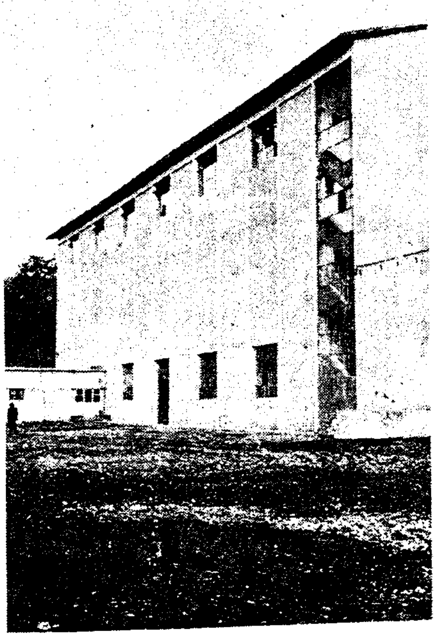


Fig. 1.41 Silos in Osorno. Main structure composed of silos of large lateral rigidity. Roof supported on top of silos through flexible columns. Reinforced staircase of less rigidity than main structure. Considerable damages at the level of top of the silos and in staircase. General view.

Fig. 1.44 Ditto. Close up.

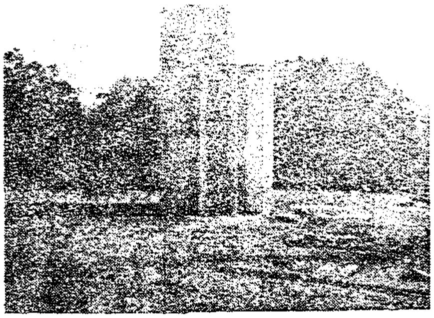


Fig. 1.45 water tank in Valdivia. General view.

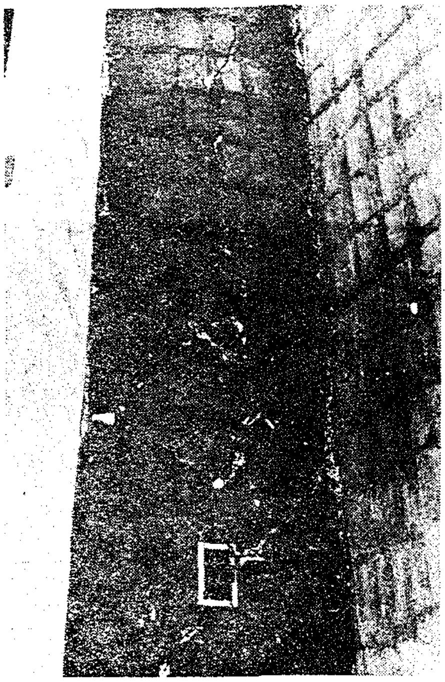


Fig. 1.46 Ditto. Damage in cylindrical mentel wall.

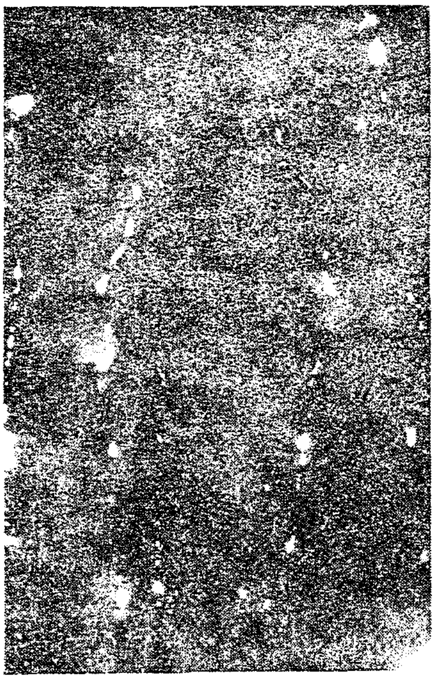


Fig. 1.47 Ditto. Inside view.

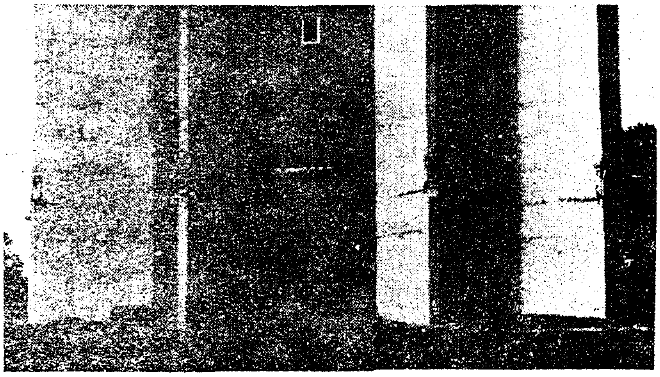


Fig. 1.48 Ditto. Damage in stiffening columns.

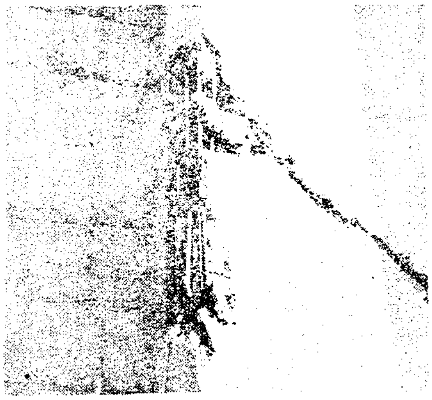


Fig. 1.49 Ditto. Damages in columns. The incorrect of steel bars in one section is shown.

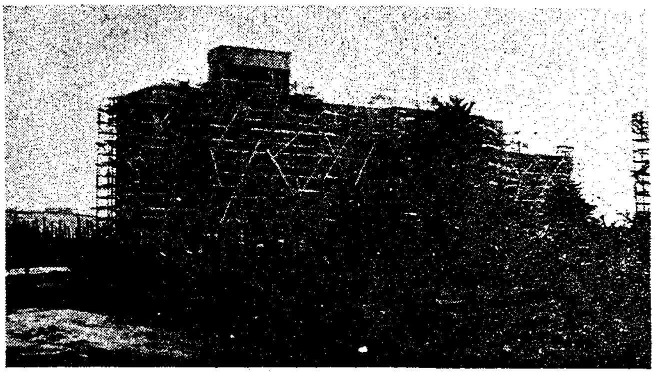


Fig. 1.51 Building development in Concepción. Reinforced concrete water tank supported by masonry wall. The walls collapsed partially. Reconstruction work is shown.

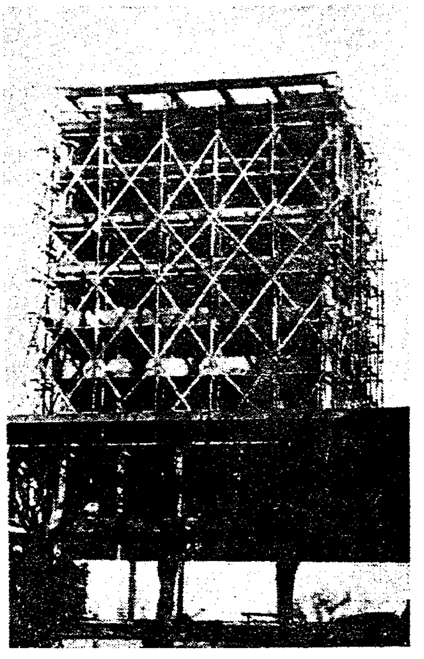


Fig. 1.52 Building in Osorno. Considerable damages on highly unsimetrical top structure. General view.

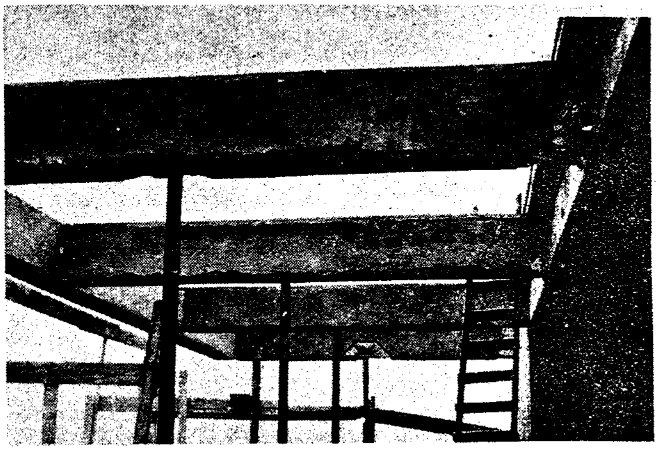


Fig. 1.53 Ditto. Overhanging top structure supported on steel pipe columns.

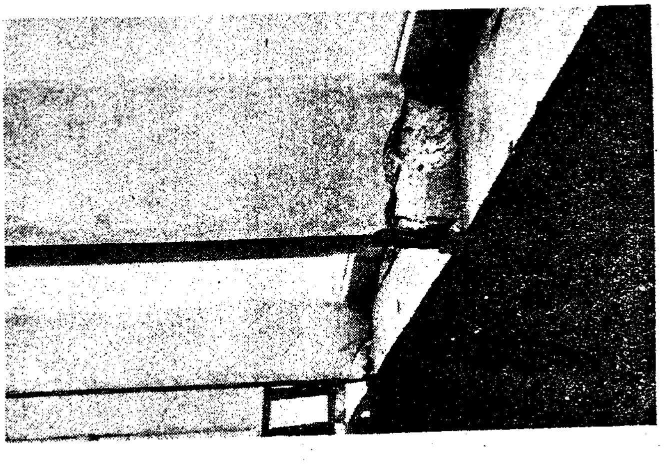


Fig. 1.54 Ditto. Cracks at the fixed end of structure.

Fig. 1.55 Steel mill, Concepción. Light fan collapsed.

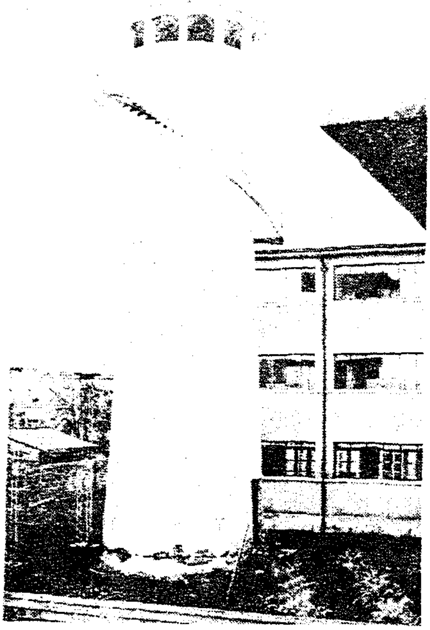


Fig. 1.61 Osorno. Water tank on girl's highschool. General view.

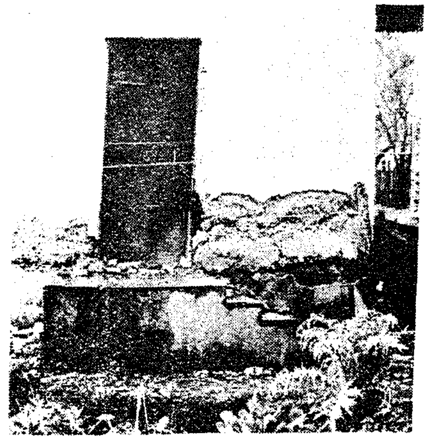


Fig. 1.62 Ditto. View of failure in construction joint.

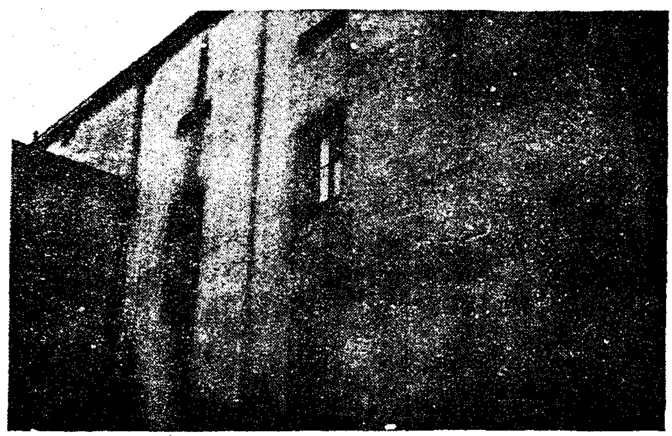


Fig. 1.63 Theater in concepción.

Fig. 1.64 Industrial Plant near Valdivia. Power Plant. Reinforced concrete chimney collapsed at construction joint.

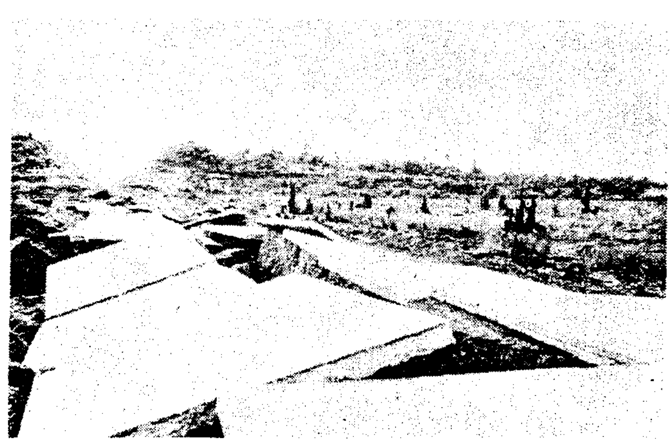


Fig. 1.71 Soil failure in highway connectin Puerto Montt and Puerto Varas. Loose fill over a swamp.

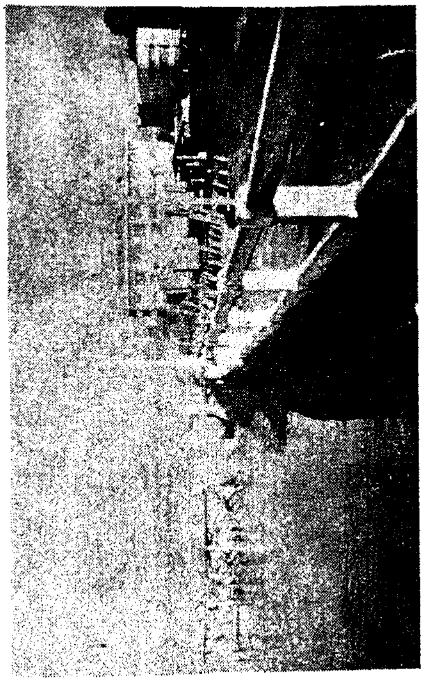


Fig. 1.72 Hotel Puerto Montt. Big sliding on the foundation toward the sea. General view.

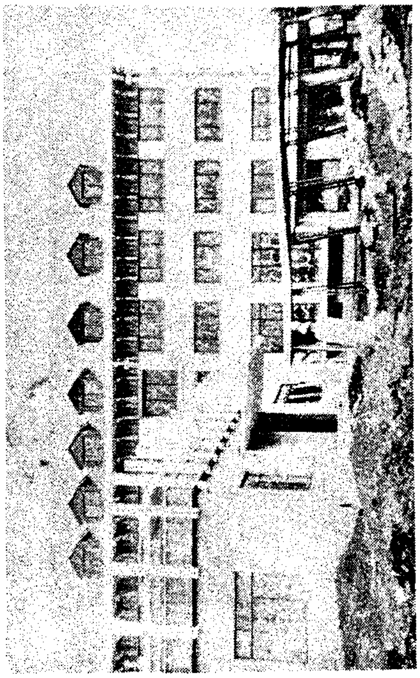


Fig. 1.73 Ditto.

Fig. 1.74 Cracks on exterior masonry wall filling an ancient window.

Fig. 1.75 Severe damage in basement ceiling.

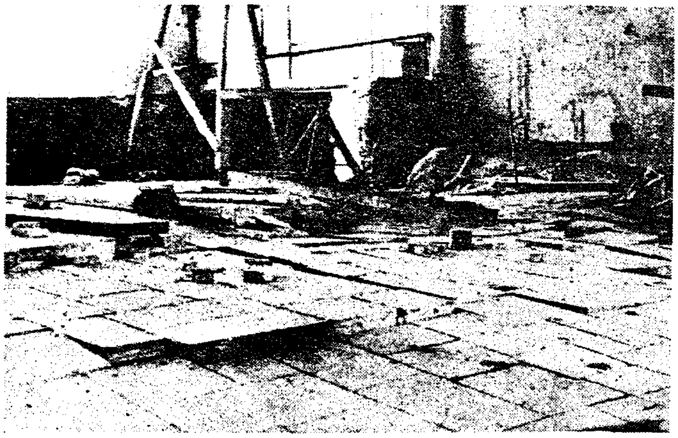


Fig. 1.76 Ditto. Interior view on first floor.

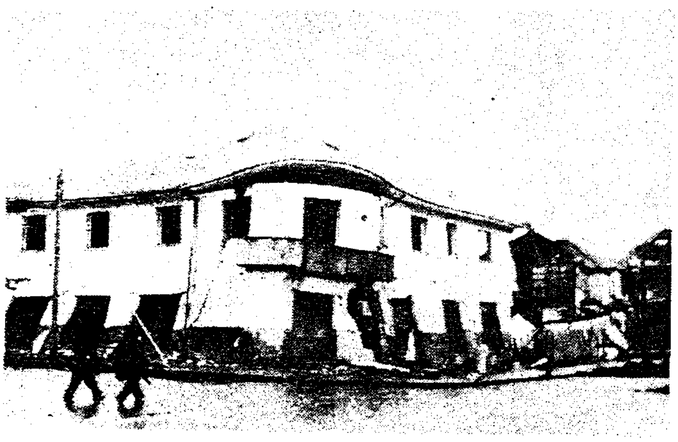


Fig. 1.77 Settlement of a house in Valdivia.

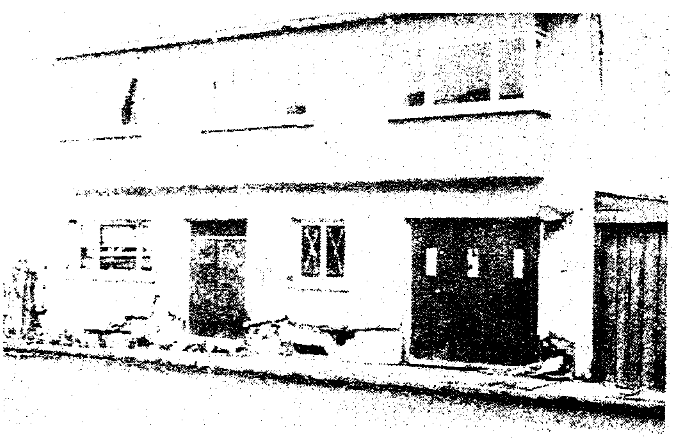


Fig. 1.78 House in Osorno. Settlement and sliding of soil foundation toward a small ravine.

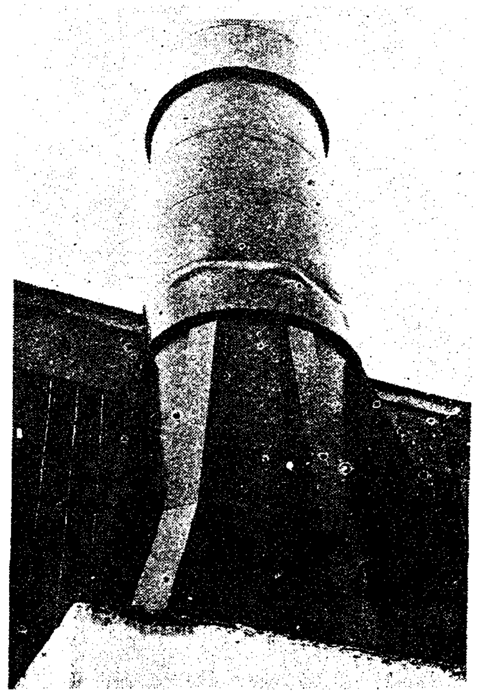


Fig. 1.81 Llanquihue Sugar Plant. Chimney in power house. Buckling of Steel mantel.

Fig. 1.83 Ditto. Close up of the failure zone.

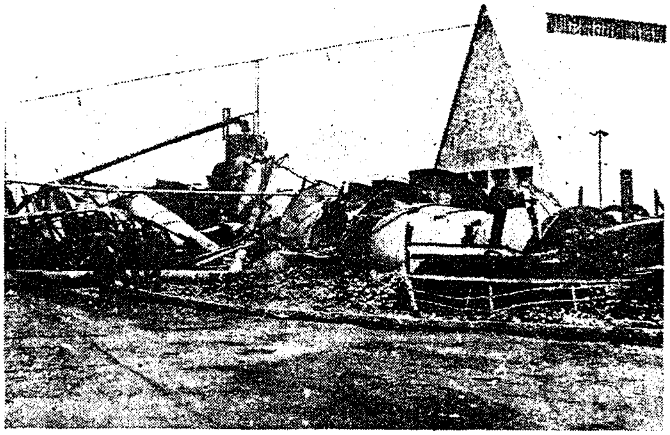


Fig. 1.82 Llanquihue Sugar Plant. Limestone furnace. The 30 mts. high tower collapsed due to the failure of the first row of rivets.

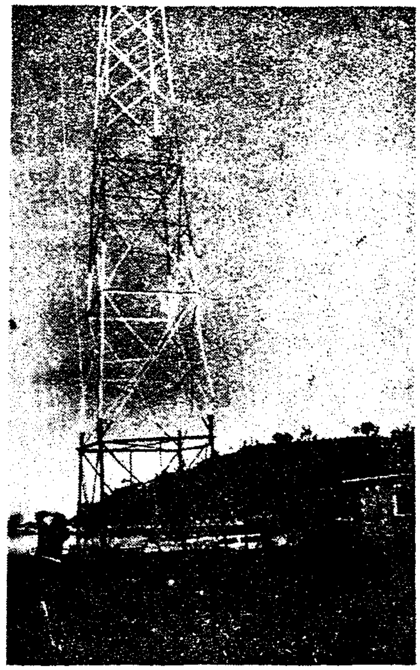


Fig. 1.84 Buckled member in steel structure.

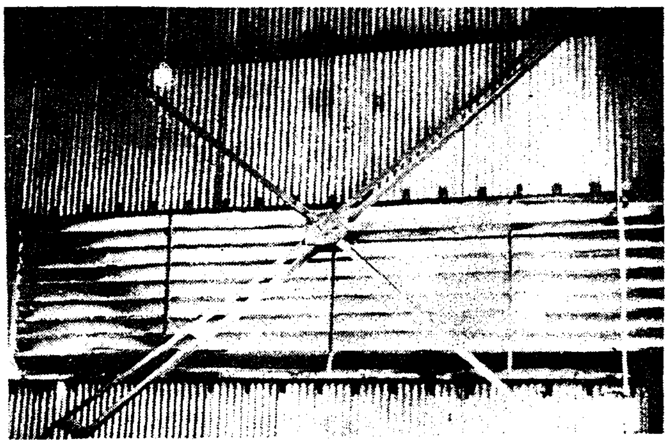


Fig. 1.85 Ditto.

Fig. 1.86 Buckling of a chimney in steel mill in Concepción.

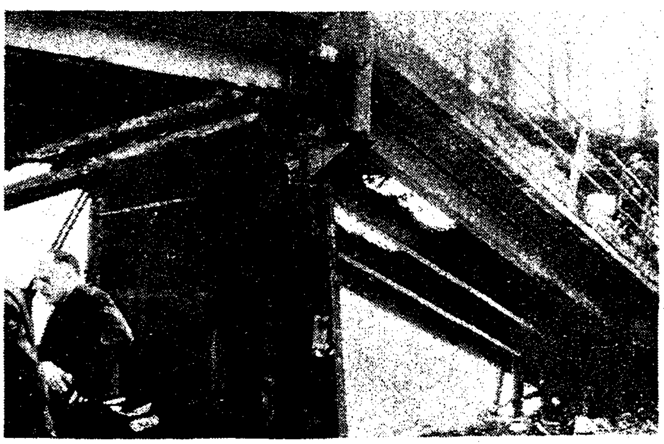


Fig. 1.87 Bridge over Bío-Bío. Lack of lateral resistance of piers.

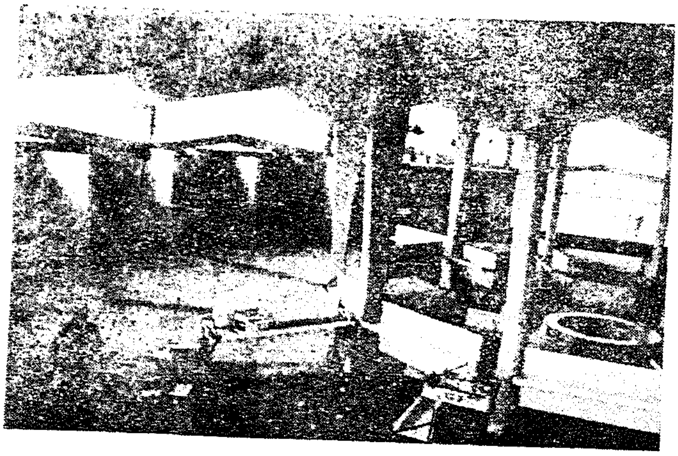


Fig. 1.88 Market in Concepción.

Fig. 1.89 Ditto. Failure in exterior rigid columns.

Fig. 1.91 Industrial building near Valdivia. General view.

Fig. 1.94 Ditto. Detail of failure in parament.

Fig. 1.92 Ditto. Collapsed curved tie beam.

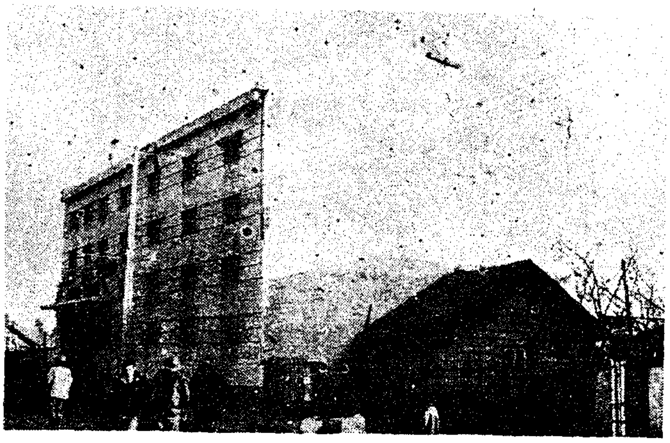


Fig. 1.93 Industrial building in Purranque. General view.

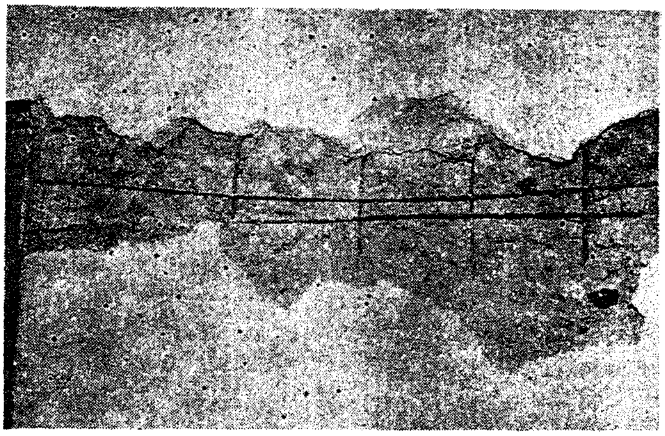


Fig. 2.11 Regional Hospital in Puerto Montt. Faulty disposition of reinforcing bars in reinforced concrete wall.

Fig. 2.21 Ditto. Poor bond between masonry and supporting structure.

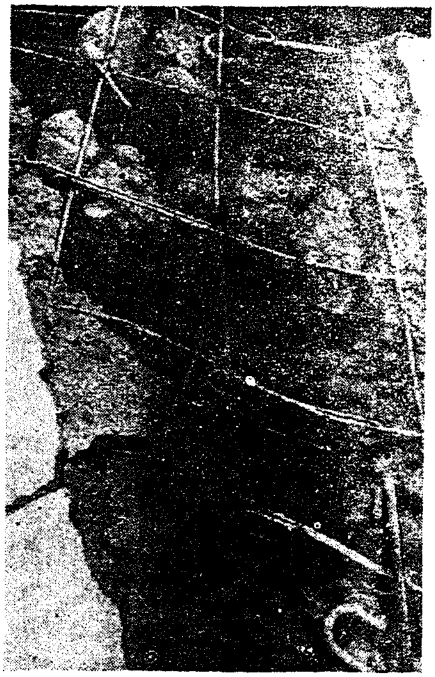


Fig. 2.12 Ditto. Oversize stones in the concrete of reinforced concrete wall.

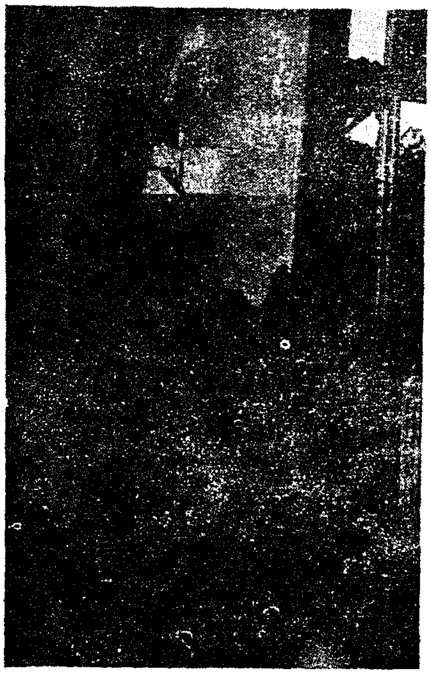


Fig. 2.13 Regional Hospital in Valdivia. Poor construction of reinforcing steel of a column in the second floor. Lack of stirrups.