Short communications

BEHAVIOUR OF AN ASEISMIC STRUCTURE DURING CAUCETE EARTHQUAKE OF NOVEMBER 23, 1977

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SUMMARY

After the Caucete earthquake, of intensity 9, on the modified Mercalli scale, only minor damage is seen in Cristo Rey Church's reinforced concrete structure. Dynamic modal analysis using recorded spectrum gives a ductility ratio of 2.6, while structural features allow a much larger ductility.

1. INTRODUCTION

The district of Caucete, Province of San Juan, Argentina, was affected on November 23, 1977, by an earthquake of intensity 9, on the modified Mercalli scale.

Information about this earthquake, including description of damages and records, is available from Reference (1). Spectrum calculated by IDIA (Instituto de Investigaciones Antisísmicas "Ing. Aldo Bruschi" of the Universidad Nacional de San Juan) since their accelerograph record is given in said Reference.

Behaviour of the Cristo Rey Church's reinforced concrete structure is reported through this communication. This church is one of the Caucete buildings which withstood that earthquake with only minor damage.

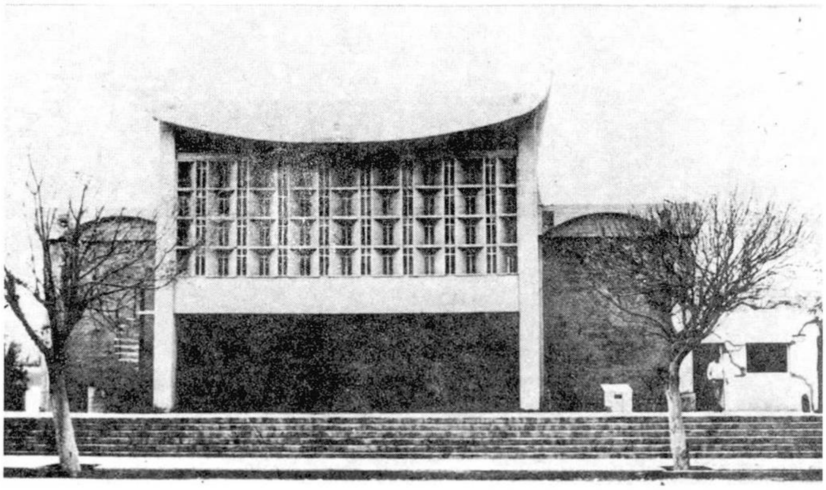


Fig. 1 - Front of the Church

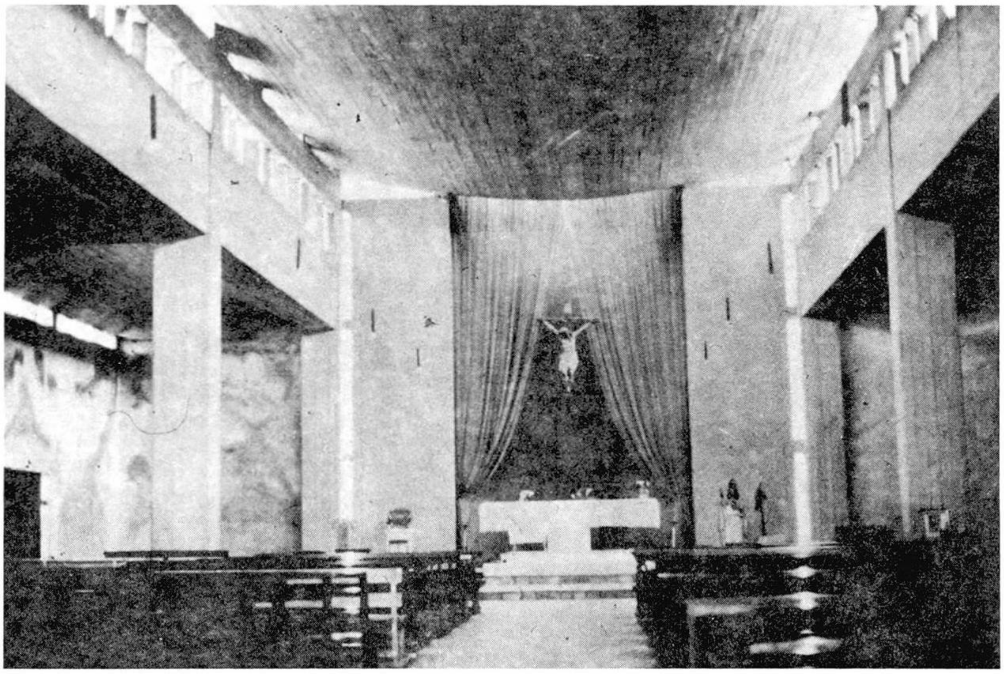


Fig. 2 - Central Nave

To investigate this behaviour we used the spectrum shown on fig. 3, which was obtained from the spectrum calculated by IDIA, by multiplying its ordinates by the ratio between the records of two seismoscopes, one located in Caucete town, about 200 m distant from the structure, and the other beside the IDIA accelerograph in the city of San Juan,

$$\frac{R_{\text{seism. Caucete}}}{R_{\text{seism. San Juan}}} = \frac{0.52}{0.26} = 2$$

These spectra are calculated for a damping ratio of 5% of critical damping. This figure is assumed to occur in reinforced concrete structures reaching yield, according to records from San Fernando earthquake of 1971.

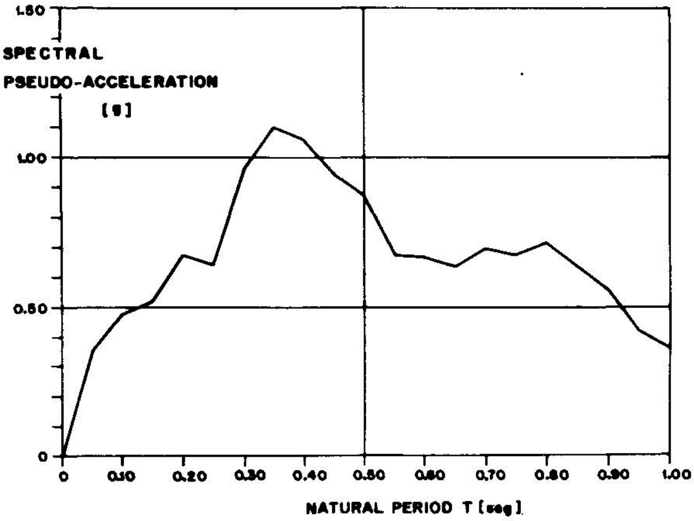


Fig. 3 - Pseudo-accelerations spectrum of Caucete 23.11.77 earthquake

2. DESCRIPTION OF THE BUILDING

The parish church of Cristo Rey has a rectangular plan of approximately 20 m by 35 m, with a nave of 10,30 span and approx. 10 m height, covered by a concave traction shell, while each aisle is covered by a cilindrical, flattened vault.

In the original design, the nave roof was a shell of a different convex shape. Structural design was performed by the writer in 1958. Later, for aesthetical reasons, the roof design was modified, without changing the other structural features. Church was built in 1965.

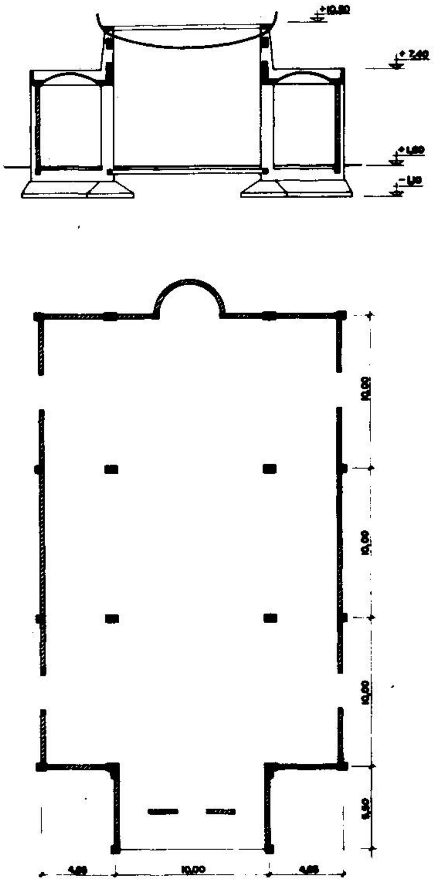
The main structure is formed by four transverse and four longitudinal frames. Perimetral frames are stiffened by brick masonry walls, while the inner ones are free of elements which could affect their structural behaviour.

Building examination after the earthquake reveals no damage in the reinforced concrete elements. The front brick walls show limited cracks, while there are no apparent cracks in lateral walls, but inner plaster spalled in wide areas. Some glass breakage in windows occurred (approx. 10 %), and light damages in masonry can be seen at both sides of apse, where roof shell touches the wall.

In the original conception of the structure, earthquake-resistant elements in the transverse direction were formed by two simple frames in each line, joined together only by the roof whose stiffness in the plane of frames was negligible. These frames were designed in accordance with the Seismic Regulations in force as of 1958, using a seismic coefficient of 0.15; and an increase of 33 % for allowable stresses. Main columns, 50 cm by 80 cm in cross section, were reinforced with a total area of steel of 1.2 % of concrete area; shear reinforcing in provided by stirrups and bent bars in both directions.

Yield stress of steel is 2200 kg/cm2; concrete has a characteristic ultimate stress of 222 kg/cm2, deduced from sclerometer measurements after the earthquake.

The two columns of each frame have a common footing, designed for a maximum pressure on soil of 1.1 kg/cm2. The large stiffness of this foundation ensures a practically perfect fixed end for both columns. Due to the change of roof design these frames were joined by an element of certain stiffness, formed by the shell plus the top compression beams.



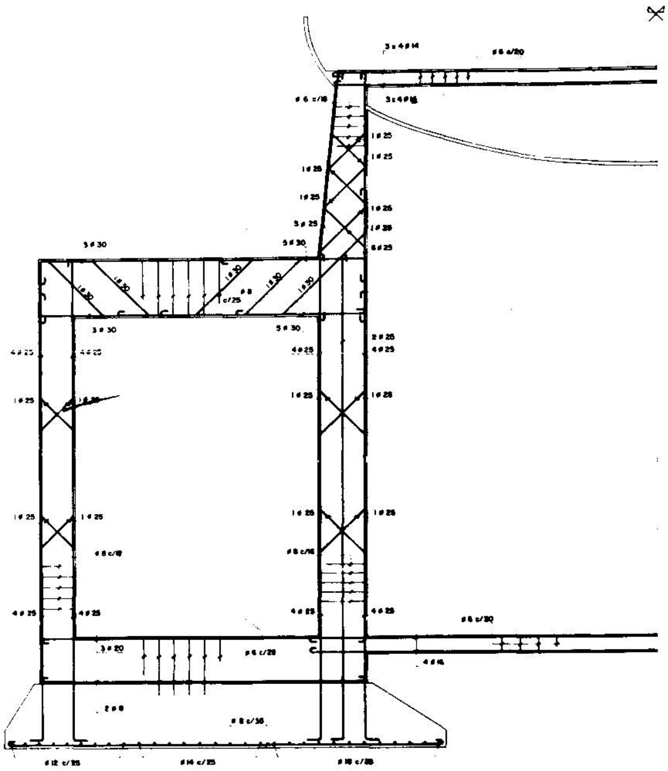


Fig. 5 - Reinforcing of transverse frame

Fig. 4 - Plan and elevation of the building

3. ANALYSIS OF BEHAVIOUR

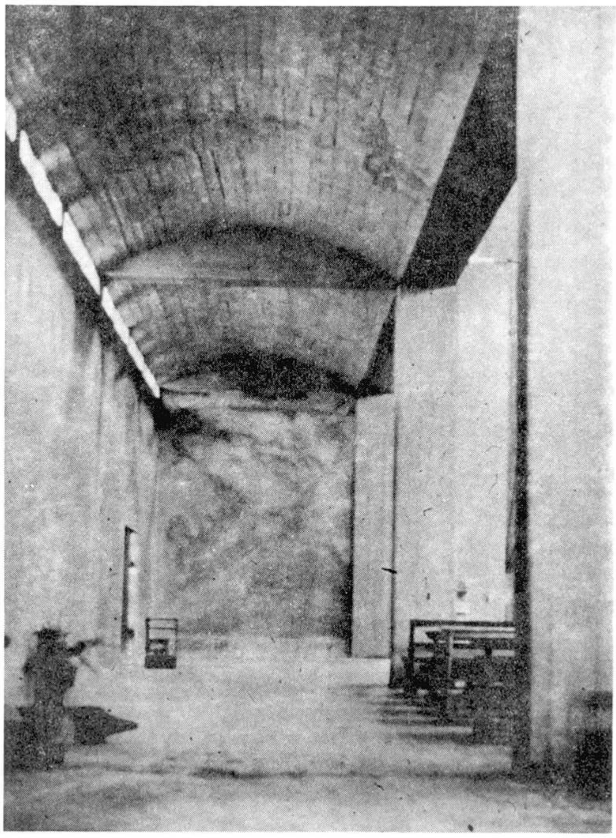
Analyzing the structure as built, the following is observed:

a. Under horizontal static loads the complete frame behaviour, due to slenderness of top beams, is almost the same as originally foreseen. Highest stresses appear at the foot of the inner columns. In this section reinforcing yield would be reached under horizontal loads which corresponds to a seismic coefficient of 0.33. The structure horizontal displacement, under these horizontal loads, would be 1.5 cm.

b. Natural period of structure first mode is 0.43 sec.

c. Dynamic analysis of the structure, assumed fully elastic and subject to spectrum of pseudoaccelerations of fig. 4, gives the following results:

- Maximum displacement of highest points is 3.9 cm.
- Maximum horizontal acceleration of the same point is 0.89 g.
- Bending moments at joints, of columns and beams, are much larger than ultimate moments of that sections.



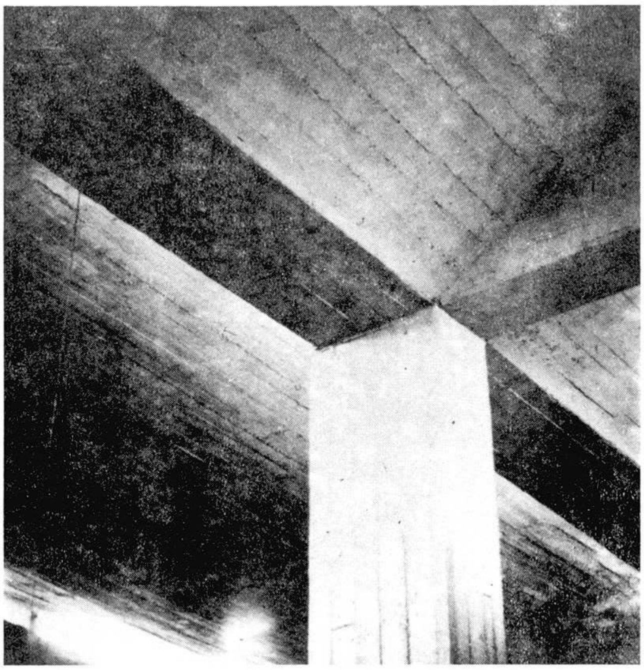


Fig. 7 - Detail of main frame joint

Fig. 6 - Lateral aisle

d. Results of dynamic analysis for elastic structure, inconsistent with its strength and with absence of damages, obviously show that actual behaviour of structure during the earthquake exceeded the elactic range. Assuming that, nevertheless, the actual displacement reached a maximum value very near to the one given by the elastic dynamic analysis, it is possible to deduce that structure has developed a ductility whose value is the ratio between this displacement and the displacement corresponding to the beginning of yield in the most stressed section of the structure:

$$\mu = \frac{3.9 \text{ cm}}{1.5 \text{ cm}} = 2.6$$

4. CONCLUSIONS

This analysis, even being very simplified, allows the following conclusions:

1) Ductility developed by the structure during this earthquake, not very high, means that the structure remained still far from its ultimate resistant capability.

2) A more detailed analysis, taking into account masonry walls as earthquake resistant elements, would give an even smaller value of ductility ratio.

3) Quantities and disposition of steel reinforcing, specially of those for shear, indicate that structure should develop a ductility considerable larger than the value obtained in this study.

4) Previous considerations justify in a satisfactory way the absence of damages in the structure and limited damages observed in masonry walls.

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DAMAGE TO BRIDGES DURING THE NORTH CAUCASUS EARTHQUAKES

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In the USSR damages of bridges were observed during the earthquakes of 1970 and 1975 in the North Caucasus region (Daghestan).

The earthquake of 1970 with magnitudo M = 6.6 and focal depth H = 13 Km spreaded over an area of about 600 Km^2 with intensity 8 (MSK scale). It was accompanied by rockfalls and landslides along river banks and steep mountain slopes. The volume of landslides in some places exceeded 1 million m^3, the extent of the breaches reached several hundred meters [1, 2]. Some of the stone buildings in the settlements, located on the epicentral area, were collapsed (fig. 1). The quake of 1975 had intensity 7. It caused heavy damages to rubble buildings (fig. 2).

In 1970 most of girder and arch railway bridges, constructed in 1914 (fig. 3), suffered moderate damages such as deep cracks in wing walls of abutments (fig. 4), ice-breakers (fig. 5), bridge seats and concrete arches. Among massive structures the least damages were received by simple-span bridges with reinforced concrete slab superstructures, anchored in the abutment masonry.

As a rule the damages of stone and concrete bridges in 1970 didn't create dangerous conditions for service of the structures. The quake of 1975 caused the development of the initial cracks and considerable decrease of the bearing capacity of these structures. In some cases stone and concrete bridges needed reinforcing.

In 1975 reinforced concrete frame highway overcrossings were subjected to ground shaking with intensity 7 and received unimportant cracks in the joints and end columns. These damages didn't effect the bearing capacity of the frame bridges.

The analysis of the seismic and soil conditions as well as bridge structures and their damages during the quakes of 1970 and 1975 confirms the provision of the USSR design specifications [3], that requires the girder bridge piers and the arch bridges should be prevalently designed of reinforced concrete and their foundations, as a rule, should be based on the hard ground.

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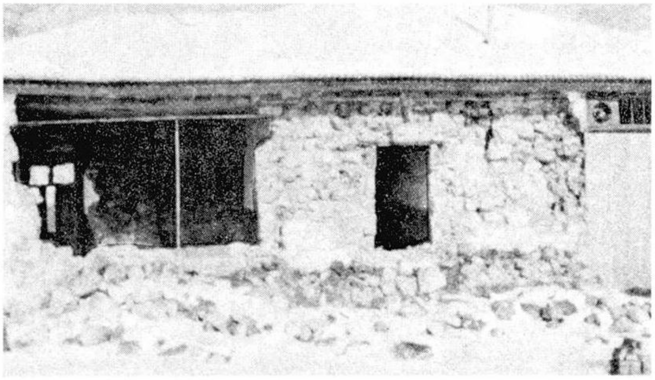
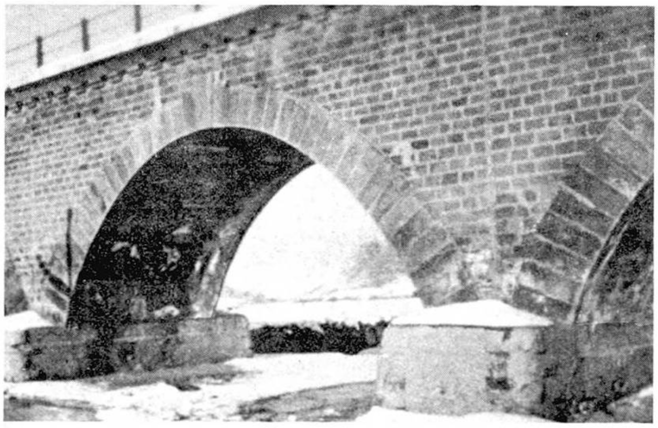
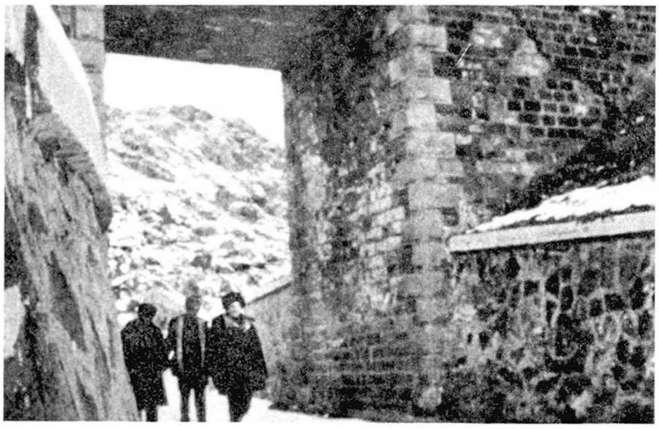
[2] The Daghestan Earthquake of May 14, 1970. In. "Earthquakes in the USSR", Moscow, "Nauka", 1973, pp. 28-49. Authors: N.W. Shebalin, W.N. Krestnikov, D.N. Rustanovitch etc.

[3] Construction in Seismic Regions. Design Specifications. SNiP 11-A. 12-69^{x}. Moscow, Strojizdat, 1977, pp. 53.







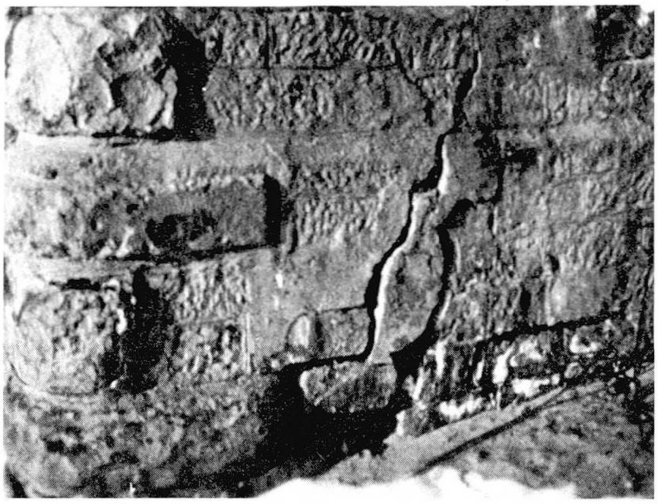


Fig. 1	Fig. 2
Fig. 3	Fig. 4
Fig. 5	

A FIRST GEOTECHNICAL ASSESSMENT OF THE RECENT PATTI EARTHQUAKE (SICILY)

UNE PREMIERE EVALUATION GEOTECHNIQUE DU RECENT TREMBLEMENT DE TERRE A PATTI (SICILE)

EINE GEOTEKNISCHE SCHÄTZUNG VON DEN UNLÄNGSTLICHEN ERDBEBENS BEI PATTI (SIZILIEN)

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Abstract

On Saturday 15th April 1978, at about half an hour after midnight, a 5.4 magnitude earthquake occurred near Patti, making 312 houses uninhabitable and 712 people homeless.

On the basis of instrumental data the maximum ground acceleration at Patti was 0.14g, according to the attenuation law for Eastern Sicily established by Costa and Maugeri.

Old masonry houses collapsed and small landslides, induced by the earthquake, were noted. The new concrete building built on fissured clay were apparently damaged on the buffer walls only.

Resumé

Samedi, le 15 avril, envers minuit et demi, un tremblement de terre, de la magnitude de 5.4, s'est produit près de Patti, avec le résultat que 312 maisons etaient rendues inhabitables et 712 personnes n'avaient plus une maison à eux.

Sur la base des informations instrumentelles, la plus grande accéleration de sol a Patti a été 0.14g, selon la loi d'atténuation pour la Sicile orientale établie par Costa e Maugeri.

Les vieilles maisons en pierre se sont ecroulées et de petits éboulements, produits par le tremblement de terre, ont étés remarqués. Il parait que les nouveaux bâtiments en beton, construits sur l'argille fissurée, ont reçu des dégâts seulement sur les murs de résistance.

Zusammenfassung

Am Samstag, 15 April , ungefähr eine halbe Stunde nach Mittenachts, ist ein Erdbeben, von der Magnitude 5.4, in der Nähe von Patti geschiehen , dass 312 Haüser unbewohnbar und 712 leute heimatlos gemacht hat.

Auf der Basis des instrumentalisches Angaben, die höchste Bodenbeschleunigung war 0.14g, der Verdünnungs Regel für Ost Sizilien, von Costa und Maugeri fortgesetzt, gemäss.

Alte Steinhaüser sind zusammengefallen, und kleine Erdrutsche, vom Erdbebens verangelassen, waren bemerkt. Die Gebaüdeschäden den neuen Beton gebaüden, auf gespalteten Ton gebaut, waren anscheiend nur an den Stossmauern.

I. DESCRIPTION OF THE EARTHQUAKE

On Saturday 15th April 1978, at about half past midnight (local time), a 5.5 magnitude earthquake occurred in the Aeolian Islands between Lipari and Vulcano, opposite Marina di Patti, a small coastal township in the Commune of Patti (fig. 1).

The main shock was followed by a series of shocks; the largest, having a magnitude between 4.0 and 4.2, occurred on 16th (3 shocks) and 24th April (Istituto di Geofisica dell'Università di Messina , 1978). All the epicentres were located in the sea opposite Patti at a depth ranging between 15 km and 18 km.

Six people were indirectly killed by the earthquake: five of them , in the cities of Messina, Palermo, Patti, Gioiosa Marea and Sant'Angelo di Brolo, died of heart failure, while the sixth was killed in Palermo by a car as he fled from his home.

The worst damaged city was Patti, with 312 houses rendered uninhabitable and 712 people made homeless. Next came Castroreale and the Aeolian Islands where the church with its bell tower suffered severe damage. Also on Lipari 200 people were made homeless.

Landslides, induced by the earthquake, occurred at Capo Calavà and the February 78 landslide at Naso moved again during the earthquake.

The instrumental data now available consists of seismographs recorded at the University of Catania and a seismoscope amplitude recorded at the "Osservàtorio" of the Collegio Pennisi at Acireale. The strong motion instruments at the University of Messina did not record any signals because they were not sufficiently sensitive.

2. ENGINEERING CHARACTERISTICS

The earthquakes appeared to be of tectonic origin and several faults are present in the region, as sketched schematically in fig. 2. It is interesting to note the presence of a fault passing by Mt Etna . through Patti till it reaches the Island of Vulcano, which probably was active during the earthquake.

Recently this kind of fault evidence was confirmed and studied again by means of satellite observation. This tectonic instability could be related to the rock formations which give off carbon dioxide fumes as noted in the recent work on the building of tunnels for the Messina-Palermo autostrada, not far from Patti.

The main shock was preceded by a small shock a few minutes before. Its record is incomplete because the seismograph at Catania University went off the scale (fig. 3) as did the one at Messina University.

As appears clear from fig. 3 the main shock was very quickly followed by an induced sussultory earthquake.

Even the seismoscope record at the Collegio Pennisi is incomplete because the pen went off the scale.

By way of comparison, the record with the same historical seismoscope (called Vicentini) of a 4.3 magnitude earthquake which occurred on 28th March 1962 at 3km from the Acireale station (Costa, 1977) is represented in fig. 5.

This station also recorded two other significant earthquakes before 15th April 1978. The first on 23rd February was of the 5th degree on the M.M. scale and the second, on 11th March 1978, was of the 3d degree of intensity on the M.M. scale.

Owing to the present lack of ENEL strong motion records at Patti , the following formulae were applied to the evaluation of the earthquake enginnering characteristics: acceleration, velocity and displacement:

$$a = 5000 \; e^{0.8M} \; (R + 25)^{-2}$$

$$v_1 = 15 \; e^{M} \; (R + 0.17 \; e^{0.59M})^{-1.7} \qquad \text{Valid if } R > 20 \text{ Km}$$

$$v_{11} = 15 \; e^{M} \; (R + 0.17 \; e^{0.59M})^{-2} \qquad \text{Valid if } R < 20 \text{ Km}$$

$$d = \left(1 + \frac{1}{R^2}\right) \frac{v^2}{a}$$

These formulae, derived from Esteva (1969), with the same exponential structure of the attenuation law proposed by Merz and Cornell (1973), were established by Costa and Maugeri (1978) for Eastern Sicily and are valid for $M \leq 6$.

The calculation leads to the following results:

a max = 0.14g v max = 9.88 cm/sec d max = 0.71 cm

The value quoted for the displacement at Acireale was 0.08 cm which was favourable when compared to the approximately 0.30 noted by the seismic station. One can expect a better correspondence between the calculating acceleration and the one measured at Patti by the ENEL instruments. This recorded value is still a metter of calculation by ENEL; from a first assessment it ranges around 0.16g (Capozza, 1978).

3. GEOTECHNICAL CONSIDERATIONS

The worst damaged houses in Patti were those founded on sandstone, built of masonry and rarely cemented, in the old centre of the town.

On that site the sandstone formation assumes a hill configuration, which could produce an amplification on maximum ground acceleration (Maugeri, 1976), which can explain, together with the poor construction quality, the severe destruction of some houses.

In fig. 6 the damage suffered by one wing of Patti Cathedral is visible and in fig. 7, the damage at the corner of the main nave is evident.

The new concrete buildings in Patti, shown in fig. 8, are built on fissured clay and were apparently damaged on the buffer walls only, mainly at the lower levels.

Liquefaction phenomena noted in the marshy area to the left of the town in the gulf of Olivieri could not be confirmed because their traces were quickly cancelled by human activity (fig.9). In any case limited liquefaction would be favoured by a water level near to the surface and by the regular and constant grain size of the sand of the site, and this phenomena cannot be generalised to the alluvium site.

A landslide, consisting in a rock mass failure, was observed at Capo Calavà, whose location is on the left of the Patti gulf. The slope was high and formed of very jointed and altered rock, which has been consolidated in the past by spritz beton and anchorages.

Because of the earthquakes the rock failure was accelerated and a series of blocks, from 10 to 60 cm in diameter fell down into the road. As is clear from fig. 10 the entire cliff is at present in a dangerous limit equilibrium.

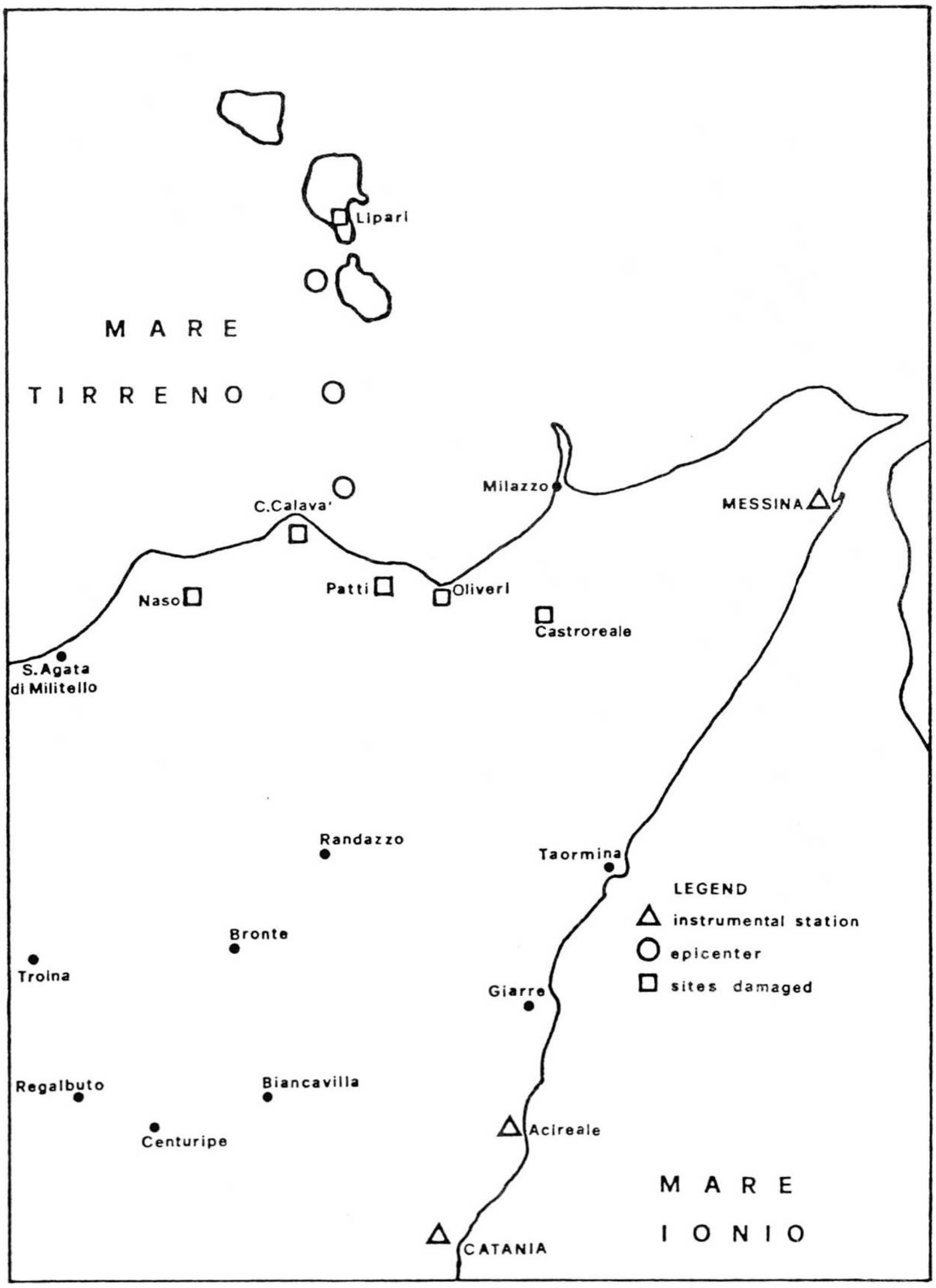

Fig. 1 : Patti Earthquake, April 15, 1978.

Fig. 2 : Sketch of fault probabily related to earthquake

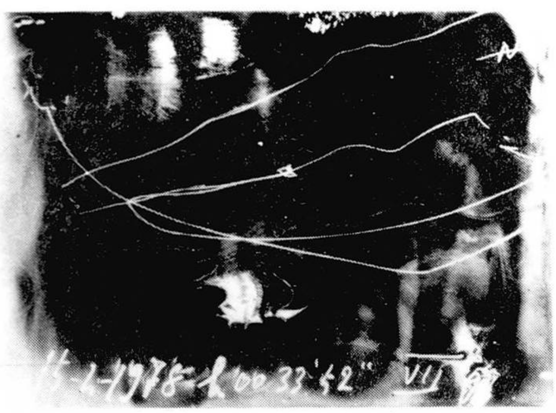

Fig. 4: Seismoscope record at Collegio Pennisi of Patti earthquake.

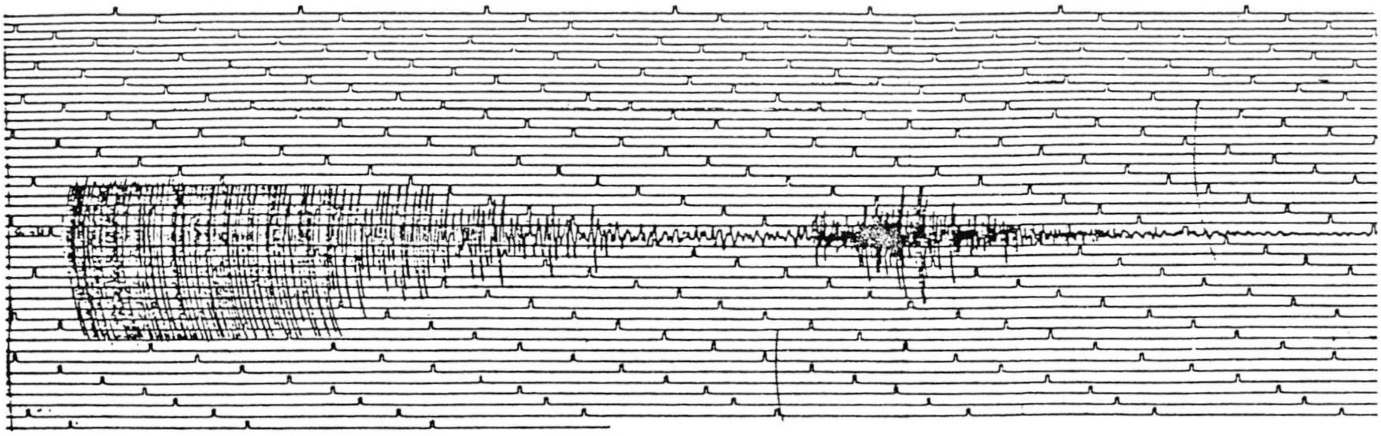

Fig. 3: The Patti earthquake recorded at the University of Catania.

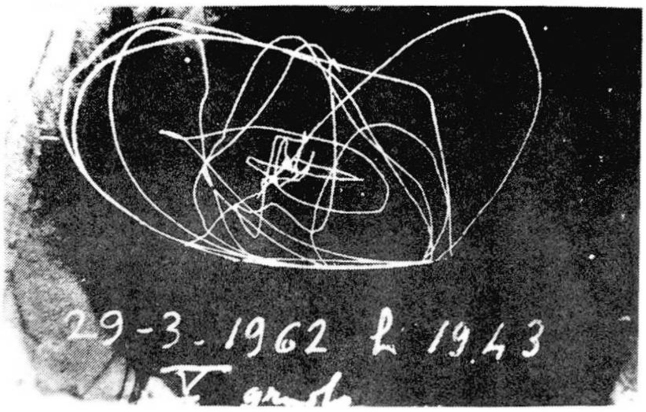

Fig. 5: Seismoscope record of a 4.3 magnitude earthquake.

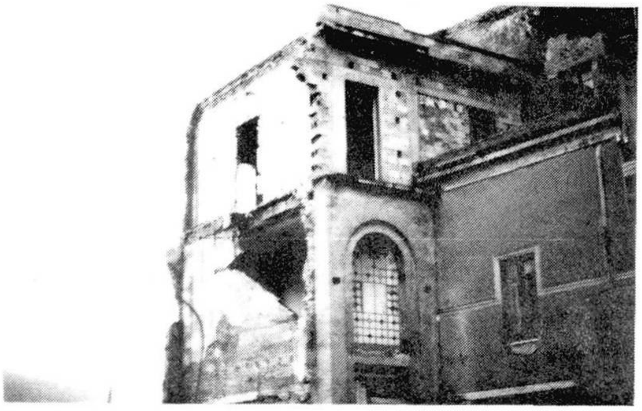

Fig. 6: Patti Cathedral: the left wing.

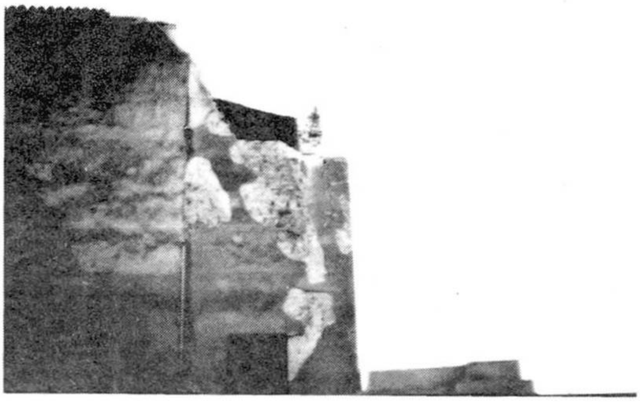

Fig. 7: Patti Cathedral: the corner of the main nave.

Fig. 8: Concrete buildings at Patti virtuolly undamaged.

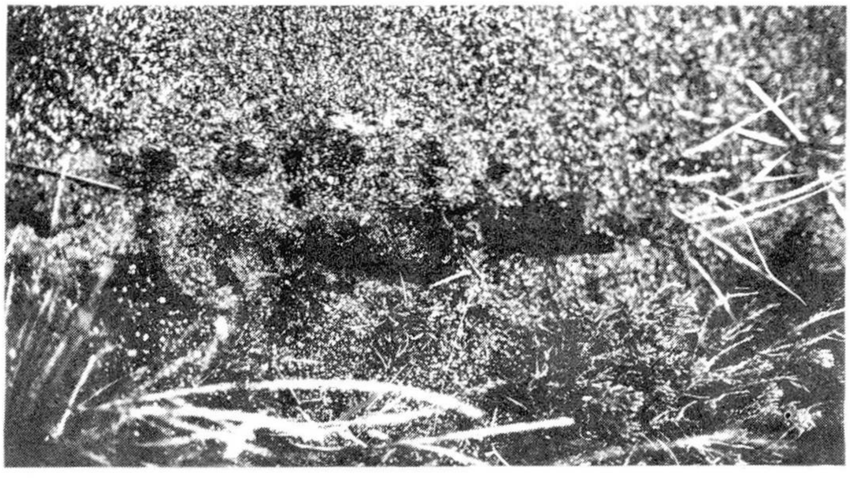

Fig. 9: Dubious traces of liquefaction.

Fig. 10: Rock fall at Capo Calavà.

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