

ENGINEERING ASPECTS OF EARTHQUAKES IN RUMANIA  
IN THE LIGHT OF MODERN INVESTIGATIONS

by

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I, IMPORTANCE AND ROLE OF ENGINEERING SEISMOLOGY

Among the natural calamities striking mankind earthquakes are the most dreadful because of the huge damages they provoke. In a few seconds, important losses of human lives and enormous material damages are recorded.

History mentions numerous earthquakes which deeply impressed human remembrance.

For instance the earthquake in Lisbon (nov.1,1755) caused over 30,000 dead and a great destruction of the town. The earthquake in Tokio and Yokohama is reported to have caused the death, of more than 100,000 people and destroyed more than 125,000 buildings through quake shock and 450,000 by fire. The Assam quake (Jan.12,1897) is considered until now as having shown the greatest intensity and area of destruction ever recorded in the world, whilst the San Francisco quake of 1906 showed, for the first time, the disastrous effect of earthquake shocks on the modern building systems and the importance of fire as a consequence of quakes on big and crowded towns.

Considering the great losses of life and damages caused by quakes it is easy to see why mankind tried to find means to suppress or at least to reduce the disastrous effects of earthquakes.

We must stress that the great number of dead is due mainly to the failure of buildings.

Therefore the problem of buildings resisting to earthquakes is of a particular importance and actuality, so much the more, as the overcrowding of towns increases the danger for the inhabitants.

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The first protection measures against quake damages were based on elementary observations and had no scientific support.

They were restricted to different requires referring usually to the building material employed and to the type of constructions

At a certain moment, wooden buildings were in great favour, on account of their resistance to shocks and to their light weight. But soon they proved dangerous on account of fire which always follows earthquakes.

The first work concerning designing of quake resistant buildings are due to the French engineer Lescasse, who published in 1877 in Paris a book, "Etude sur les constructions japonaises et sur les constructions en général au point de vue des tremblements de terre et description d'un système destiné à donner une grande sécurité aux constructions en maçonnerie". This study was based on the effects of earthquakes in Japan.

Later on, John Milne published in Transactions of the Seismological Society of Japan, Tokyo, 1880, a paper: "The earthquake in Japan of February 22, 1880" and two years afterwards "Construction in earthquake countries (ibidem, vol. XIV).

Of a wide practical importance were the studies of F. Omori published at the end of the XIX century in Japan. These studies have opened the way to scientific preoccupations in the field of antiseismic structures. The elaboration of Omori's "static method" means an important technical improvement in this direction.

The greatest difficulty the investigators met with, was the appreciation of the mechanical elements characterizing the seismic motion, which were strictly necessary to pass to the designing of constructions.

Along with the progress of science and the development of new designing methods of structures on one side, and the using of steel and reinforced concrete for structures frames on the other side, the problem of earthquake resisting structures could receive a scientific basis.

The investigations carried out in Japan (F. Omori) have known a great soaring after the earthquake in San Francisco (1906) when the modern structure system on resistant frames has shown its qualities in a strong earthquake.

Later on, when the record of the characteristics of seismic wave by means of modern instruments was made possible, the premisses of investigations closer to the real

phenomenon were created. Nevertheless, we shall mention that true engineering seismology is of recent date, as a consequence of the sustained efforts of a great number of engineers and scientists in the world.

The first world conference on engineering seismology, which discussed the problem of the destroying action of earthquakes on structures took place in San Francisco in 1956. In the same year, in Moscow, were presented the works of a conference with similar character.

The impulse given by these important scientific manifestations determined all earthquake visited countries to pay to the engineering seismology greater attention, using the most recent discoveries and investigation possibilities offered by science and its application.

Owing to the organization of the II<sup>nd</sup> world Conference on Engineering Seismology in Japan, the country with valuable contributions for the creation of a new science on engineering seismology, it seems that the exchange of opinions and informations on international level receives a permanent character. This fact is gratifying to those who work at the delicate mission to diminish or even to suppress the disastrous effects of earthquakes.

## II. ENGINEERING ANALYSIS OF THE EARTHQUAKE IN RUMANIA OF NOVEMBER 10, 1940

Rumania, generally, has not been considered as an intense seismic country, although during centuries a series of earthquakes have been mentioned as having produced important damages. Nevertheless, it cannot be spoken of catastrophes like those in Portugal, Japan, America, India, a.s.o.

We can mention for its intensity, the earthquake in 1445 which has committed ravages and the shock of which was felt strongly enough even in Moscow.

The earthquake in 1472 among other damages destroyed the Church of the Neamtu Monastery, renowned art monument of our country and the earthquake in 1683, which caused the collapsing of the Suceava fortress towers, the ancient chief city of Moldavia.

We also mention the earthquake which in 1738 damaged the lordly palast of Bucharest, and the earthquake in 1802, which caused the collapse of the "Coltea Tower" a remarkable building in Bucharest at that time.

Due to the fact that in Bucharest and in other towns of the country, there were no important constructions, the damages produced even by the strong earthquakes caused no important destructions.

More strongly have been felt the effects of the earthquakes in our century, which is characterized by an important soaring in constructions.

Important earthquakes recorded in this century are those in 1912, 1916, 1929 and 1938, but without great evidence of distress.

The earthquake which deeply impressed the inhabitants of Rumania was that of November 10, 1940. Because of this earthquake Rumania has been considered since among the countries with pronounced seismicity.

The damages produced on constructions situated in various regions of the country and the extensive region subjected to earthquake arose among the engineers a well-sustained activity for analysing the causes of damages and destructions and for the design of antiseismic structures.

Several earthquakes centers have been identified till now, but the most important which has produced also the earthquake of November 10, 1940 is situated in the Vrancea Mountains. This center is defined by the geographic coordinates  $45.9^{\circ}$ , northern latitude and  $26.5^{\circ}$  eastern longitude, being situated at the depth of nearly 150 km (fig.1). Because of this depth, its effects are felt on a large zone.

Measurements regarding the characteristics of the seismic waves were not performed because the instruments of the Institute of Seismology in Bucharest were put out of order at the first shocks of the earthquake.

The intensity of this earthquake was stated by means of the seismic scale Mercalli-Cancani-Sieberg.

The medium degree of earthquake was 8 and it affected nearly 80,000 km<sup>2</sup>. In Bucharest it was estimated at 8-9 degree, and within the epicentral region and other isolated points, at degree 10. According to Gutenberg-Richter scale, this earthquake had the magnitude 7, being of class B. The Carpathian Chain protected, in a certain measure, the Transylvanian Plateau, and the northern, north-western and south-western regions of the country (fig.2).

In order to state the earthquake intensity and to establish the isoseistics, nearly 5000 reports from various parts of the country were used, being corroborated afterwards with other personal investigations performed by seismologic researchers.

We mention that in the epicentral region some villages were totally destroyed and in Panciu and Focșani, towns in the neighbourhood of the epicenter, extremely great da-

damages were noticed. All the destroyed or damaged buildings showed a very weak execution and a defective engineering conception.

The most heavy accidents of the earthquake of Nov. 10, 1940 took place in Bucharest. Here one of the tallest civil buildings (the Carlton building) of very recent construction date, having two undergrounds and 11 stories on a reinforced concrete structure collapsed completely burying under its ruins almost all the lodgers of the building, i. d. over 100 persons. With regard to the amplitude of this disaster, it seems that in the history of the concrete constructions, this accident represents one of the greatest destructions.

The great number of dead was also due to the fact that the accident took place in the night, at 4 o'clock in the morning, local hour.

In Bucharest other buildings of reinforced concrete were also damaged, as well as smaller brick-buildings. We must point out that reinforced concrete as resistant material for tall constructions was introduced in Bucharest only after 1910. In general, these structures were calculated only for vertical loads and very few were verified for wind action. Generally they were stiffened with brick walls, which offered a lateral rigidity sufficient for wind stresses.

No assurance whatever of these constructions against earthquake had been taken into account, the intense earthquakes having occurred tenths of years before, when no constructions of such height or importance existed in the town.

The most important discussions which followed the earthquake of Nov. 10, 1940 were caused by the collapse of the Carlton building. The real causes of the collapse could not be established on account of the complete destruction of the reinforced concrete resistant frame followed by a big fire, but some assumptions could be made as is shown later.

It is interesting to note that opposite the Carlton building was another building, 6 stories high, having only concrete floors and load-bearing brick masonry. This building resisted in very good conditions, although the soil conditions were the same and the absence of a resistant skeleton rendered it more sensible to earthquake shocks. Other buildings of the neighbourhood too, as tall as the Carlton building suffered only very slight damages.

An examination from the engineering side of all the various damages and especially of the causes that produced the failure of the Carlton building, was performed by

Prof. Eng. Aurel A. Beles, member of the R.P.R. Academy, in the two papers published immediately after the quake /1/, /2/ are exposed in a detailed manner the causes of the damages and the destruction of different structures in Bucharest.

In connection with the complete collapse of the Carlton building, the essential cause was the conception on which the design of the reinforced concrete frame had been based. As there were shops at the ground-floor, in order to get as big shop-windows as possible, some of the columns were reduced to transversal reinforced concrete walls only 22 cm in width, but 200 m in length.

After clearing away the ruins of the building in the cellar of the building, one of these concrete columns was found intact. It seems that by the earthquake shock, the column was cut at its base and on account of insufficient connection of the reinforcement the column was removed on the reinforced plate, perforated it and fell in the cellar, drawing the whole building after it.

The Column having the heating element still attached can be seen in the figure (fig. 3 - 7).

Consequently, the failure of the Carlton building may be attributed to the shear caused by the seismic shock which produced the section of columns and afterwards the complete failure of the building. To the complete destruction also contributed the imperfect mode of transmitting the loads to the foundation due to the lack of continuity of all the columns.

Generally, for structures resting on a concrete skeleton, it was stated a series of faults due to some execution defects. For instance, there were found columns whose reinforcement bars were bound in unfitted places (fig. 8, 9) other columns with too thin and too distanced ties (fig. 10, 11), some with non-corresponding structural joints, and insufficient reinforcement or with a diameter (fig. 12, 13) too small - at same columns - relative to the importance of forces they had to support. On that account, many local yields have been recorded, which caused only local ruptures without collapse.

In case of structures consisting of load-bearing masonry, important faults were recorded in those constructions where the mortar was insufficiently hardened or where the vertical brick joints were not filled. These were the causes that a series of modern buildings although tied with concrete floors showed strong degradations of the masonry (fig. 14, 15). The presence of wooden floors producing by the supports of the beams a discontinuity in the masonry,

caused the rupture of walls, In general, the apparition of the classical X-shaped ruptures as a consequence of strong shear forces was noticed (fig. 16 - 19).

We mention the fact that structures with a concrete skeleton suffered more as compared to structures with load-bearing masonry and concrete floors. A satisfactory behaviour showed the common old buildings of the last century when concrete was not yet introduced in Rumania, but which had sufficient ties and a good strong masonry.

Another cause which brought destruction in many structure was the torsional effect. This was due to the difference between the center of rigidity and the center of mass (fig. 20). This produced the rupture of the small columns which were supporting the vault covering the amphitheater of the University in Bucharest. It is interesting to note that the rupture was stronger on the orthogonal directions of principal shear stresses (fig. 20 - 22).

With regard to the influence of foundation soils, there were made numerous interesting - even contradictory - statements.

Bucharest is situated on a slightly undulated plain, traversed by the Dimbovitza river, whose main bed has 300-400 metres breadth. The soil on the sides of the river has the characteristic features of loess and loess-clay layers. These strata are resting on a layer formed of gravel and sand, of great thickness. The bed of the river presents alluvial deposits consisting of fine sands with intercalations of mud and organic material. Therefore, the banks of the Dimbovitza river are considered as having a weak foundation soil, with an allowable resistance of 1 - 1.50 kg/sq.cm. The higher region of the plain shows a more consolidated soil, with an allowable resistance of 2 to 3.00 kg/sq.cm.

Nevertheless, we shall mention that among the structures situated within the Dimbovitza zone, only very few were damaged by the earthquake, and the damages were of slight importance. Even the churches - of a sufficiently old age - and generally sensible of earthquakes within this region behaved satisfactorily. On the contrary, most of the damages and destructions were noticed exactly in the region outward the Dimbovitza banks, where the foundation soil, as mentioned, is much better. The level of the ground-water in the Dimbovitza zone ranges from nearly 2 m depth in this region, whilst in the upper region it is met at a depth of 5 to 10 metres.

### III. THE ANTISEISMIC COMPUTATION METHODS

The earthquake in Rumania of November 10, 1940 imposed a total revision of the conception concerning structure designs when considering the destroying action of seismic motion.

In the first period after the earthquake, the principles of the Italian building laws for seismic regions were adopted, but the issued instructions for antiseismic building founded on these principles had no obligatory character.

After the war, on account of the great soaring concerning industrialization of the country and the increase of the construction of dwelling houses, the problem of antiseismic protection got the due importance. Therefore investigations were carried out to find the right method of computation and best measures of construction for designing quake resisting buildings.

We must admit that the mechanic phenomenon of the seismic shock not being satisfactorily studied, it cannot be introduced in the mathematical form necessary for designing of buildings and structures.

Indeed from mechanical standpoint, an earthquake can be reduced to a very complicated and irregular space motion of the earth crust. The seismic motion shows displacements with amplitudes, velocities and accelerations variable in direction and time. Even if all these elements could be registered on a special spot, as for instance at a seismic observatory, it is doubtful whether the registered values could be generalized for a whole region, in which the nature of soils, the stratigraphy, the underground water level might be quite different.

If the ground motion is known, the response of the foundation cannot be easily established and so much the more the motion of the building. The proper oscillations of the building have themselves an influence on the displacements of the foundation, so that it is very difficult to get a right idea of the stresses developed in the building. One must not forget that apart from the general movement of the building, each element of construction, walls, columns, girders, beams a.s.o. has its own vibration which can be the cause of great load stresses and can be a cause of destruction.

All this movements transmission forms what is called in new seismic terms "the interaction between structure and foundation ground".

On account of all these interactions the real pheno-

menon cannot be fixed in a precise mathematical form, and the necessity of simplification and approximation appears imperiously. In this form, the registration of the mechanical elements of the earthquake shocks was the first necessity. Recently new strong motion seismographs can furnish the necessary data as a basis for determining the earthquake intensity, but as these instruments are very expensive and cannot be installed in all seismic regions, other means of estimating the earthquake intensity are necessary.

The methods of estimating the earthquake intensity equivalent to its destructive force may be divided into two distinct groups, namely: subjective methods and methods based on the records of the real phenomenon (Richter-Gutenberg's magnitude, Housner's spectrum intensity a.s.o.).

The subjective methods use seismic scales which catalogue the earthquakes into several degrees (based on the impression of witnesses, the damage degree of structures a.s.o.) to each of them corresponding a conventional acceleration. The best known seismic scale is the modified Mercalli scale.

The magnitude and the spectrum analysis are based on records and they express the absorption energy of seismic waves. Contrary to the seismic scales, this mode of calculation of the seismic intensity takes no account of the subjective data about psychological expressions, damage of structures, whose behaviour depends on a series of factors which are not strictly depending on earthquake intensity, as for instance: inadequate designing and computation, improper materials, faults of execution, hidden defects etc.

As regards the calculation of building for seismic loads, two methods are known: the static method and the dynamic method. The static method neglects the elastic characteristics of structure considering - along the vertical - a linear variation of the seismic coefficient given by the Mercalli scale for the considered region.

The dynamic method considers the static-dynamic properties of the structure, by means of a seismic coefficient which varies along the height and depends on the elastic characteristics of the building. The earthquake characteristics may be estimated either by means of a seismic scale (see Soviet prescriptions) or by the seismic spectrum (see American recommendations). For the appreciation of the seismic forces, dynamic elements are used, but these forces, however, are considered in the end as static forces.

The dynamic method has been developed throughout the last years by the American, the Japanese and the Soviet schools.

The American school studies the dynamic response of elastic structures reducing the latter to an equivalent system with a single mass. The influences of seismic disturbances are introduced in form of a seismic spectrum whose variation is based on a corresponding calculation of the accelerations recorded during real earthquakes. The seismic forces of each story are determined by means of the fundamental shear force, the value of which is computed on the basis of the system with a single mass.

The Japanese code of 1955 estimates the seismic forces taking into account the elastic characteristics of structures, the type and degree of damping, the nature of foundation soil, and the seismicity degree of the region within which the structure is located.

The Soviet school considers structures as elastic systems with  $n$  degrees of freedom corresponding to the number of floors, and the seismic influence is assimilated by an analytical expression of the motion impressed on the foundation in form of a convergent series of trigonometric functions. The seismic force is computed directly for the level of each story, the intensity of earthquake being expressed by coefficients according to the Mercalli-scale.

While the American recommendations consider a linear variation of the first normal vibration mode, the Soviet prescriptions distribute the loads along the height of the structure on the basis of the real accelerations of an elastic equivalent system.

Contrary to the American recommendations the Soviet prescriptions allow the calculation of seismic forces also in the case of superior vibration modes.

The application of the Soviet computation formula for seismic forces seems to be more rigorous from mathematic standpoint, while the American formula is practically simpler and more direct. It seems also that the earthquake effects by means of spectrum analysis approach the reality better than the assimilation of the motion produced by the seismic wave.

Although these methods are not yet perfect, they do represent an immense progress on the way of introducing dynamic methods into the design practice.

For both methods a still more difficult problem consists in precisising the physical characteristics of structures and chiefly of the proper vibration periods, the seismic coefficients are depending on. There are some procedures to determine the periods but they don't respond completely to the

real physical phenomenon. Even "the exact computation methods" are only informative because the existing schemes introduce a series of simplifying computation hypothesis.

#### IV. CONCLUSIONS

It is very well known that the antiseismic design of buildings influences seriously the cost of many buildings. Now, when the economic problem is in the first rank all over the world, the choice of computation methods for anti-seismic design approaching the most the reality is an utmost important problem. In this sense, the modern dynamic methods seem to be, at the present hour, best corresponding to the present needs.

In Rumania efforts were made to find the best means for antiseismic design of construction and in 1957 the project for a standard for the computation of seismic forces was elaborated. This standard is based on the dynamic methods and takes into account the soil characteristics, the interaction with the foundation, the elastic properties of the construction, the coefficient of seismicity of the region and the mass distribution along the height. On account of the lack of seismic records, the intensity of seismic motion is characterized by means of the Mercalli-Cancani-Sieberg scale.

But we must emphasize that, whatever the method used for antiseismic computation, on account of the simplifications and approximations and the uncertainty referring to mechanical effect as well as the elastic properties of the materials used in constructions, the method of computation and designing presents neither total accuracy nor complete certitude.

The recent earthquakes, among which that in Mexico City of July 28, 1957, showed structures which, though complying with the modern computation prescriptions, presented more serious damages than structures which had not been designed according to the antiseismic prescriptions.

We think that the extremely complex phenomenon which accompanies an earthquake has not yet been sufficiently well studied in the investigations carried out so far.

We therefore consider that it would be extremely necessary to have more ample and various informations and to know the experiences of the different parts of the world, which would contribute to a judicious solution of this problem.

Surely the first and the present Conference on engineering seismicity brings many new and very interesting views,

but it would be most profitable if a continuity could be created in the general studies of this delicate problem.

We suggest therefore the foundation of a permanent institution of international character called : "International Association for Engineering Seismology" having following objects in view :

a) The elaboration of an international intensity scale of the Mercalli type with the necessary instructions, which would allow a better and a more uniform estimation of the earthquakes intensity.

b) On the basis of this scale, the formulation of a universal questionnaire about the earthquake effects, in order to state the earthquake intensity on a more uniform basis.

c) To develop and set up a simple and cheap strong motion earthquake recorder - as for instance the Wilmot survey type - which should be installed in various observation points in high seismic regions.

d) To collect and centralize all informations, data, records and photographs about effects, damages and other characteristic elements of the earthquake.

e) To publish the important results obtained by the above mentioned means about different earthquakes as well as theoretical and practical studies of importance, regarding engineering seismology.

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Engineering Aspects of Earthquakes in Rumania

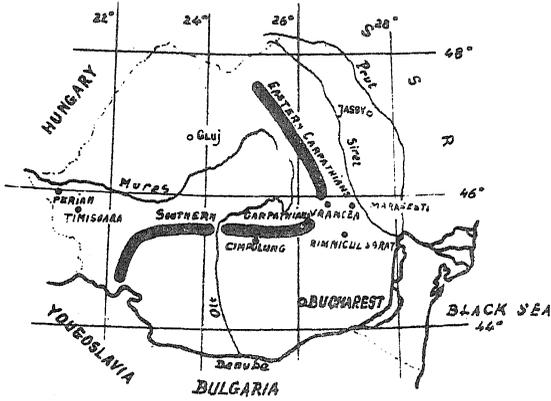


Fig. 1 Centers of seismicity

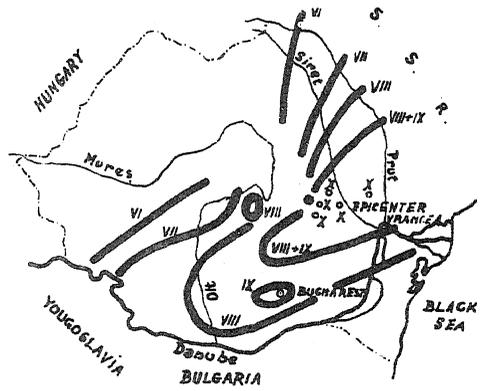


Fig. 2 Isoseismics of Rumania



Fig. 3 Building Carlton

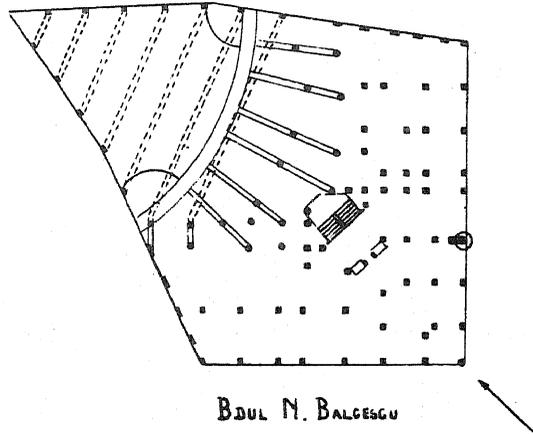


Fig. 4 Columns at the ground floor

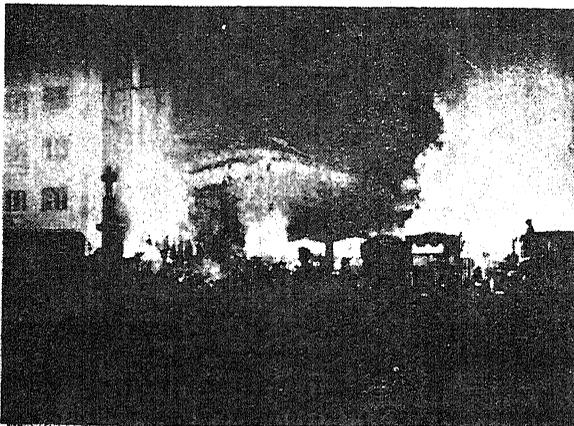


Fig. 5 Building Carlton in fire

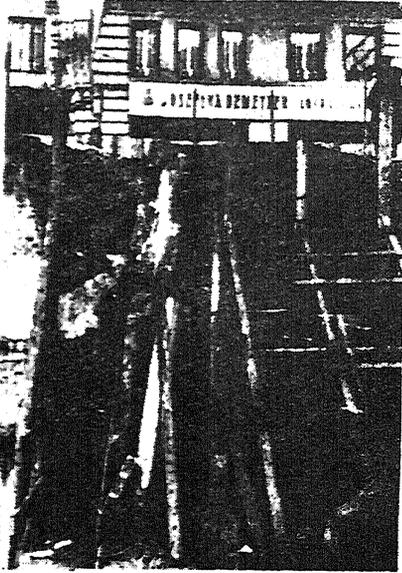


Fig. 6 Building Carlton  
The column that collapsed

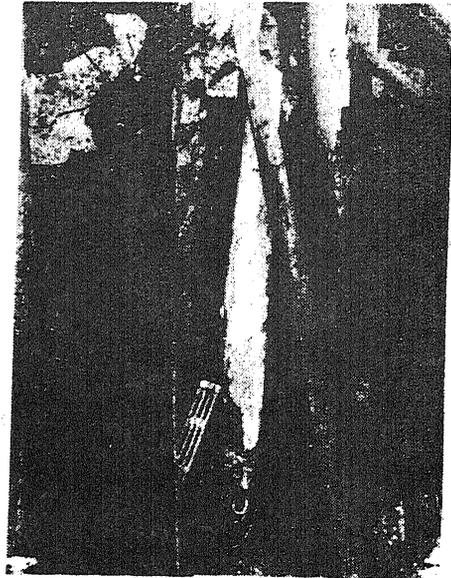


Fig. 7 Building Carlton  
Detail of the collapsed  
column

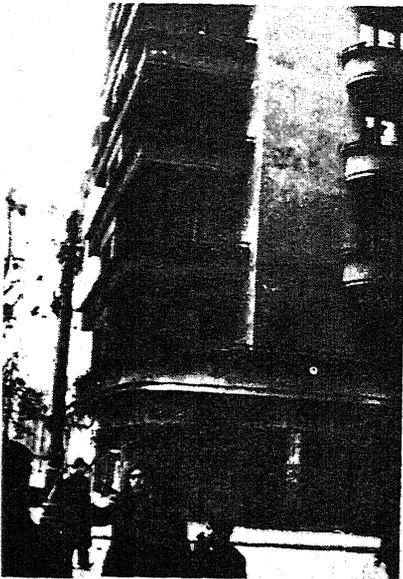


Fig. 8 Column with non corresponding bars

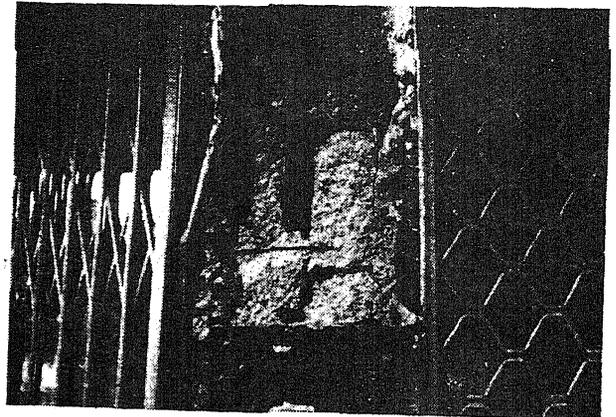


Fig. 9 Details for Fig. 8

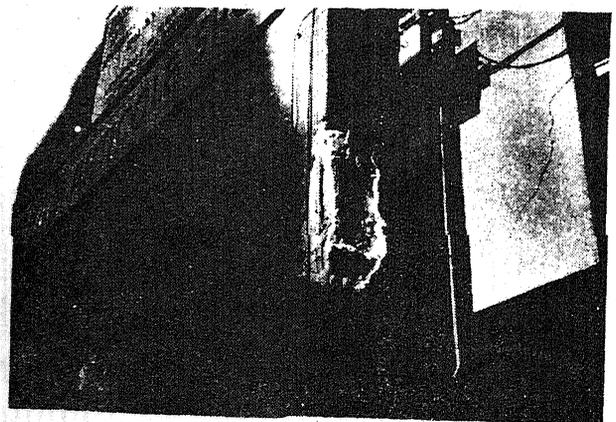


Fig. 10 Too distanced ties

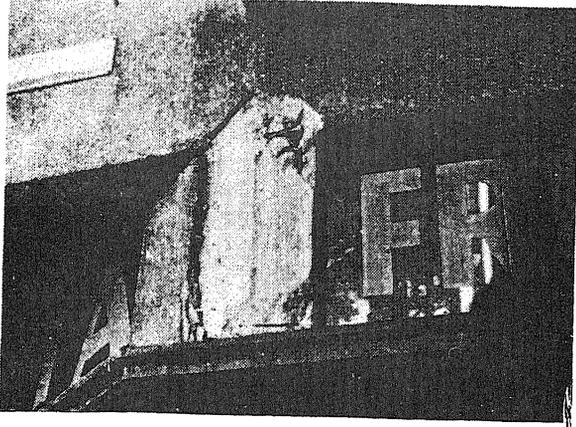


Fig. 11 Non corresponding structural joints

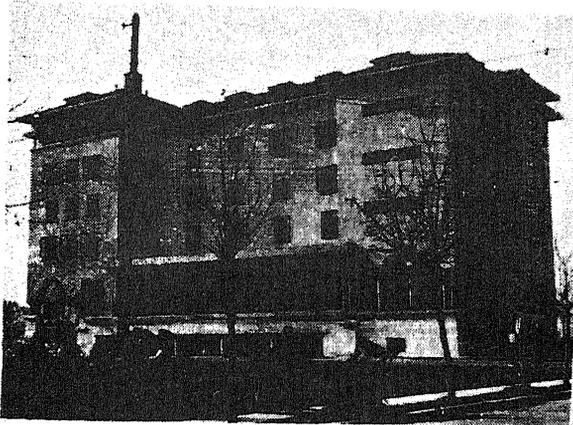


Fig. 12 Non corresponding columns



Fig. 13 Details of columns Fig. 12

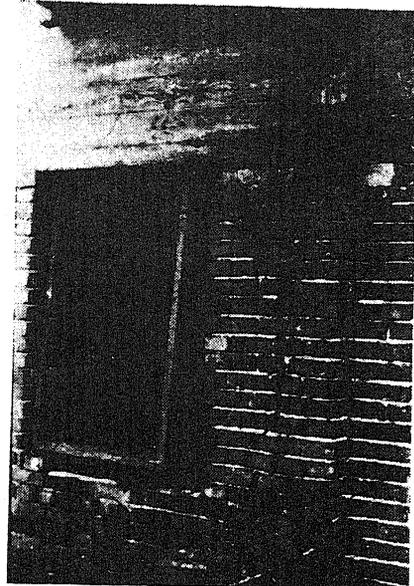


Fig. 14 Non corresponding masonry

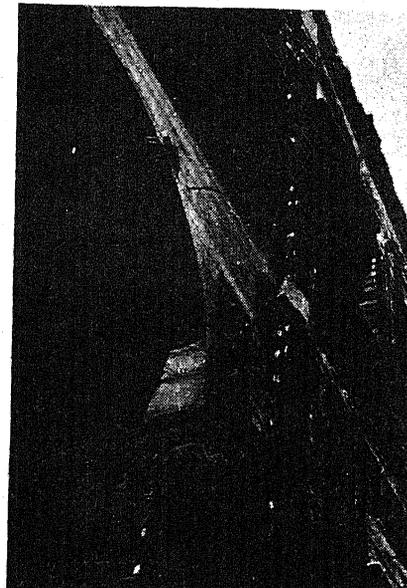


Fig. 15 Non corresponding masonry

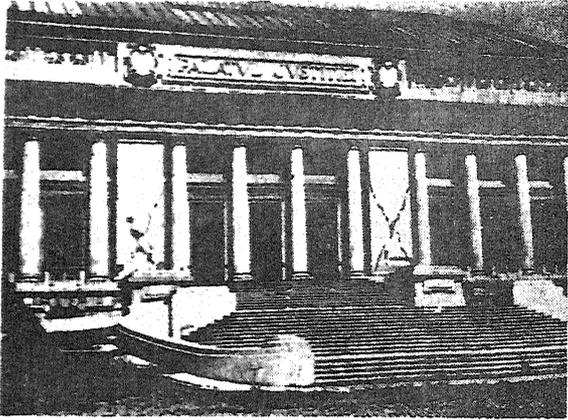


Fig. 16 X-shaped ruptures

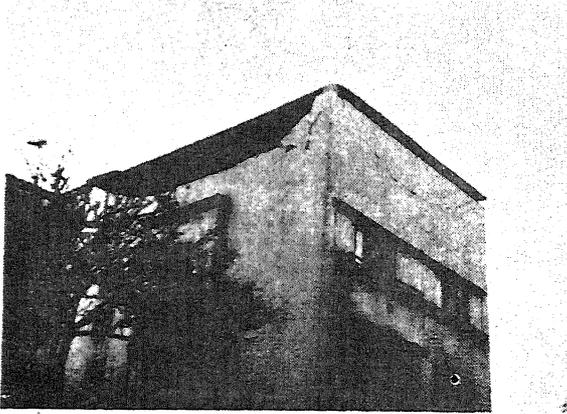


Fig. 17 Non corresponding walls  
Lack of ties

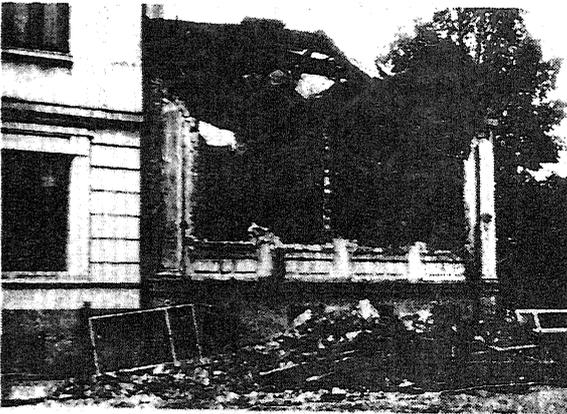


Fig. 18 Non corresponding gable

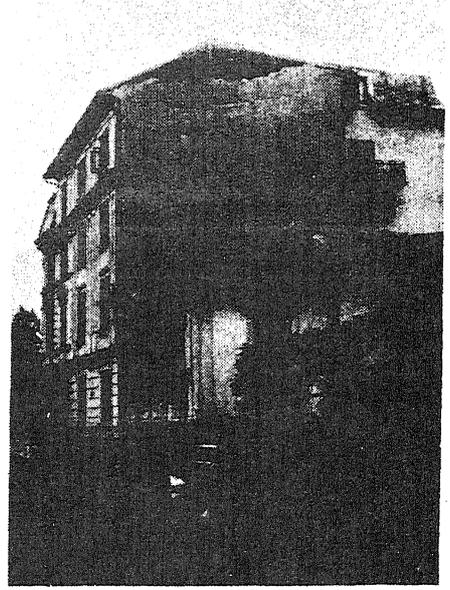


Fig. 19 Effects of gable Fig. 18

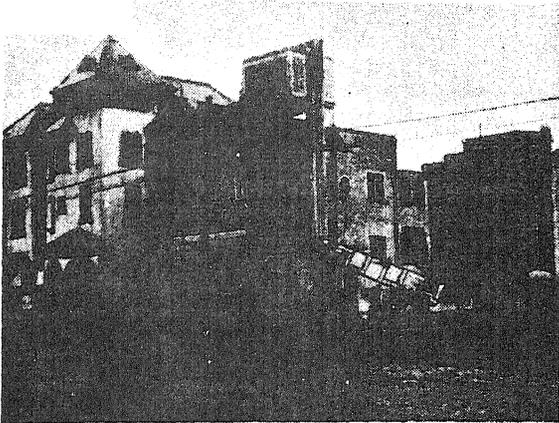


Fig. 20 Torsional effect

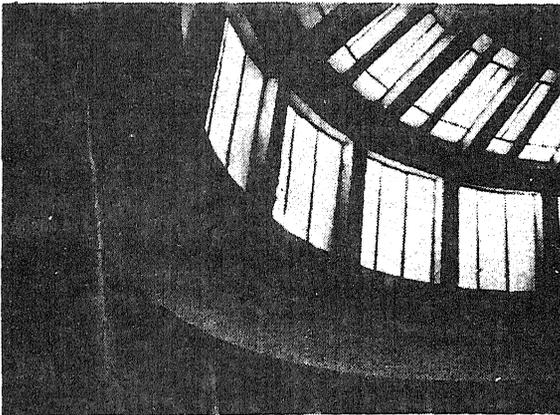


Fig. 21 University of Bucharest  
Rupture of the cupota columns

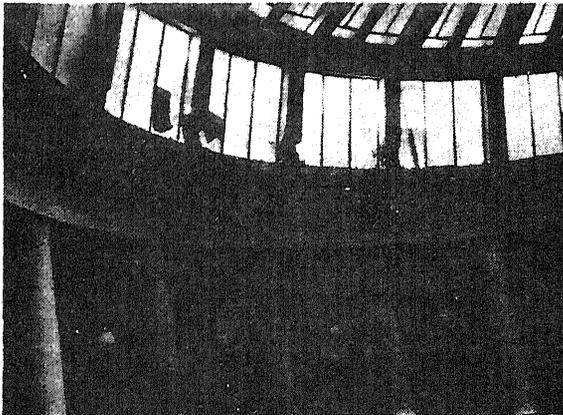


Fig. 22 University of Bucharest  
Details of the columns of  
the cupota