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Autor: Ifrim, Mihail

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SOME FUNDAMENTAL ASPECTS OF EARTHQUAKE ENGINEERING

by MIHAIL IFRIM, Professor, Ph.D., Civ.Eng.,
Head of Department of Theoretical and Applied Mechanics
Faculty of Civil Engineering
Bucharest, Romania

SUMMARY

The work includes a series of observations on the effects of recent strong earthquakes and on some measures which become essential in earthquake engineering, and includes aspects related to: concept and design, seismic code of regulations, soil influence, numerical analysis, construction, research and professional education.

QUELQUES ASPECTS FONDAMENTAUX DU GENIE PARASEISMIQUE

RESUME

Le travail contient quelques observations sur les effets des recents et forts tremblements de terre et sur quelques mesures qui s'imposent dans le génie paraséismique, portant aussi sur des aspects concernant la conception et le projet, le code des normatifs paraséismiques, l'influence du sol, l'analyse numérique, la construction, la recherche et l'enseignement professionel.

EINIGE GRUNDANSICHTEN ÜBER DAS ERDBEBEN-ENGINEERING

Die Arbeit enthält eine Reihe von Beobachtungen über die Wirkungen des schweren Erdbebens, das vor einiger Zeit statt fand; sie enthält weiter die notwendigen zutreffenden Massnahmen und verschiedene Aspekte und Ansichten, betreffs: Auffassung und Projektieren, Normierung bei dem Erdbebenschutzbauen, Einfluss des Bodens, Numerische Untersuchung, Bauwesen, Forschung und Fachschulung.

From the theoretical, experimental and practical point of view as well as from that of the researchers and professionals, earthquake engineering has made during the last twenty years a great progress. This was directly reflected by the concept and design of structures of all kinds in seismic areas.

In spite of these, the strong earthquakes which have shaken such urban centres as Mexico-City (1957), Agadir (1960), Skopje (1963), Anchorage (1964), Niigata (1964), Caracas (1967), Tokachi-Oki (1968), San Fernando (1971) and recently Bucharest (March 4, 1977), had most destructive effects.

The analysis of structures behavior at strong seismic motions, regardless of the fact that they were or not build on a lateral actions safe concept and design basis, provides particularly important qualitative and quantitative informations which may help in the elucidation of some fundamental scientific aspects and in the improvement of the design process.

The examination and interpretation of effects produced by earthquakes upon structural and nonstructural elements as well as upon the extrapolation of these, should be done with utmost discernment and precaution since each building represents a particular case having a specific dynamic behavior.

The identification of these effects within certain "degrees of damage" in order to define a local scale of seismic intensity of risk represents a most difficult task, sometimes with misleading results.

The age of the buildings is of ultimate importance in the estimation of the degree of damage because of the phenomena to which they were subjected in time. For instance: the alteration or the degradation of physico-mechanical properties of materials used in the initial construction; the creep of concrete; soil layers settlement of the foundation; vibrations due to intense and steady traffic; accidental shocks such as moderate earthquakes, blast effects, strong winds a. s. o.; periodical changes of the buildings functions or destination; defficient maintenance of the resistant structure, etc.

The generally satisfactory behavior of structures built closer to the date of a strong earthquake has been clearly demonstrated even when the seismic motion exceeded the seismic design intensity. This was also valid for the event of March 4, 1977 (a Richter magnitude of 7.2).

The process of structural decay is permanent and unavoidable because Nature can not preserve in time all that man and technology was able to achieve at a certain stage of civilization.

The behavior of different types of structures to violent earthquakes recently produced in the world - including that of March 4, 1977 in Romania - was affected by the following main factors: concept and design, the seismic code of regulations, the soil influence, the numerical analysis, the construction, the research and the professional education.

1. CONCEPT AND DESIGN

The concept of structural dynamics of the three dimensional member and ensemble in relation to the seismic motion is larger and could therefore not be defined, as it is sometimes claimed, only by sort of an "engineer's commonsense". This simplistic way of belittling a most complex dynamical concept has often led to confusions. The dynamic concept of structural members taking also into account the share of nonbearing structures, assumes a thorough study of each individual detail and structural element, up to the entire structural ensemble. The effects of earthquakes produced during the last years have shown how the breach of the dynamical concept of design and construction of a building may lead to local partial or total damages of some urban blocks of flats.

The survey of the damaged buildings revealed the following deficiencies related to the dynamical concept of structures as a whole:

- remarkable geometric dissymmetries and geometrical discrepancies in the distribution of structural and rigid elements as well as in the arrangement of partition walls, both vertically and horizontally, due to a dynamically inadequate architectural design (spaces placed at nonuniform depths and having different destinations and functions, disproportionate compartments, heavy cantilevers, eccentrically placed stairwells, juts and recesses, accidental configuration within the project of the buildings, heavy finishings, a.s.o.);
- dynamically unreasonable disproportions in the distribution of structural and non-structural masses (dead overloads of upper floors; overloadings due to the turning of apartment blocks into office buildings; penthouses; heavy roofs; a.s.o.);
- marked discontinuities in the distribution and variation of stiffness in structural members in both horizontal and vertical planes, not ensuring the general three dimansional interactions (the discontinuity of structural elements; the undersized beams and columns; the absence of horizontal disc effect, high ground floors; columns with different axial forces; stair and elevator wells superficially designed within the structure as a whole, a.s.o.).

The presence of such errors of concept and design of a structure to lateral forces may lead, from the dynamical point of view, to the appearance of some inertial, elastic, energetic and tensional concentrators, all of which constitute a vulnerable and unsatisfactory behavior, which may result in disastrous effects during strong seismic motions.

In fact, the above-mentioned errors may lead to direct detrimental implications, mostly in the buildings whose design was based upon a gravitational concept. One may thus mention: the eccentricity between the mass center and the rigidity center, resulting in a tortional effect; the great lateral drifts of flexible framed structures which as found out, have evidently acted upon the vertical structural elements and upon the nonstructural partition walls; the concentration of strong motions at the ground floor level and at that of the lower stories; the nonuniform stresses in resistant vertical elements (columns and wall piers); the tendency to dislodging of members or even of units which, as compared to the whole structure, were greatly flexible or stiff; the different degrees of stress upon the structure, leading to failures in places of high seismic vulnerability.

Besides these global findings resulting from errors existing within the general dynamics concept, the survey of earthquake effects revealed also the serious errors of the conception and the superficial study of some details of structural composition, such as: the narrow spaces of separation between buildings, the high percentage of openings at the first floor stories, particularly in the bearing masonry, with floors of different types of structures and differently loaded (made of timber, metalic girders with small arches, reinforced concrete) with no boundary wall bonds; indirect transmissions of overloads to vertical resistant elements; local disproportions between the stiffness of columns and that of beams lacking the plane or space frame effect, eccentric beam-column connections; the undersize of corner or marginal columns; the presence of a single longitudinal diaphragm in linear structures; the eccentric position of free masonry walls within the openings of frames; the superficial design of the beam-column connections in order to ensure the deformation energy transfer between horizontal and vertical resistant elements; an inadequate longitudinal and transversal reinforcement of columns, beams, shear walls, lintels and joints with random ductility factors that may lead to postelastic deformations and to the appearance of plastic hinges; minimum safety coefficients to shear forces in resistant vertical elements, the wrong use of X-braced frames system; excessive stress in vertical elements that led to fractures, to crushing and buckling of the reinforcement.

Except for some instances, one my say that the behavior of recent constructions, build on the basis of a seismic safe concept and design, under satisfactory conditions, was quite good more so when one takes into account the fact that the intensity of the seismic activity of March 4, 1977 has by far exceeded in Bucharest the safety level stipulated by the design and by the official design code regulations.

2. SEISMIC CODE REGULATIONS

The survey of the effects of the recent strong seismic motions on humans and animals, on the seismic waves propagating medium and on constructions of different types and age, all have led to the conclusion that the current code regulations in this respect will have to be fundamentally reconsidered.

Future studies on seismic zoning and microzoning of the country, a work of high complexity and risponsability, will have to be correlated to those of geophysics, geology, geotechnics, hydrology and seismic engineering. In order to develop such maps new and modern investigation criteria are required for these must take into consideration potential strong earthquakes which might have quite different generating mechanisms and spectral compositions, and which in the future might take place at shorter time periods.

As to the seismic code regulations, the records received in Bucharest, the processing and preliminary interpretation of these have shown that the current quantitative regulations, particularly those regarding the variation of the design spectra, do not correspond to the actual findings.

The theory of response spectra accepted by almost all countries subjected to high seismic risk, was found inadequate for the description of the effect produced by an earthquake upon the resistant elements of a structure. Thus, the present seismic design of a structure on the basis of spectral theory does not include the cumulative energetic process due to the cyclic phenomenon, specific of the seismic motion, and the duration of this. This cumulative process is most important and its effects are much more disastrous going beyond the safety measure of providing materials and structures specifically resistant to the peak values of stress and strain. The future codes of regulations will have to take into account all these aspects as well as the necessity to ensure the safety of buildings in at least two next strong earthquakes. It also becomesnecessary to ensure the compulsory obligation of the dynamical approach of the conception, design and building of aseismic structures.

3. SOIL INFLUENCE

Due to the multitude of its specific phenomena, the soil has always been a determinant factor of the effects produced by the seismic motion upon structures. The major problems are related to some specific aspects of the soil, namely: the influence of characteristics of the seismic wave propagation medium under specific geological and lithological conditions; the influence of local geotechnical and dynamical properties related to the site and location; the presence of underground waters; the configuration of the local relief, stratigraphy and the depth of the bedrock; the focusing of seismic waves, the amplification, attenuation or dispersion of these; the possible faulting, landslips, variation of velocities, a.s.o.

The 1977 earthquake produced in Romania has evidenced a particular way of propagation and amplification of seismic waves, in different directions and in areas quite far from the epicentral zone. Also, a marked focusing of seismic waves was found in strongly urban concentrations. The indentification of the bedrock as well as of the nature of the intermediary stratigraphy and of the structure of rocks will help to a quantification and qualitative estimation of the share which the superficial layers may have had in amplifying or attenuating the seismic response of structures. It is most important that the structural design engineer should know well the physical, mechanical and dynamical properties of superficial layers (inclusively the predominant periods) of a certain site, since all of these provide valuable informations on the specific foundation conditions, the potential limitation or even avoidance of amplification, nonuniform settlement and liquefaction phenomena, being thus capable to assume an expected size of the interaction phenomenon between the soil and the structure it bears.

The variety of effects found in and around Bucharest after the March 4, 1977 earthquake have clearly pointed out to the significance of the site characteristics, the knowledge of which involves thorough studies in the field of structural geology, geotechnics, geophysics, seismology, a.s.o., in order to evidence potential tendencies to collapse, landslipping, faulting and alteration of the underground water mirror. At the same time, one of the requirements is the estimation from these points of view of the seismic risk as correlated to the micro- and macrozoning mapping of the country.

The specific features of Romania's March 4, 1977 earthquake , namely the kynetical and spectral ones, have evidenced high predominant periods in the superficial layers, a fact which has led to the amplification of the seismic response of the tall, more flexible, buildings. Although the mirror of underground waters had no important share in tall buildings the interaction phenomenon appeared as a marked rocking of the buildings, leading to ground dislodgings, slight remanent slopes, collisions within the separation gaps as well as to the visible openings of these. No significant foundation damages were found, mostly in those with continuous or raft foundations, a fact which proves the satisfactory design of the Bucharest buildings infrastructure.

4. THE NUMERICAL ANALYSIS

The specific effects found in the resistant structural elements of buildings damaged by the recent earthquakes have evidenced a series of deficiencies regarding the estimation by the numerical analysis - currently used in design - of the stress and strain condition. Also, the reinforced concrete dimensioning methods provided by the official code regulations are inadequate for the short-duration, cyclic and time-cumulative action, specific of the seismic motion.

The design schemes, patterns and hypotheses, stipulated by current code regulations, do not virtually reflect the actual behavior of structures during an earthquake. A reconsideration is required of the design and of the seismic reliance of structures by the approach of a dynamic theory-based analysis and by taking into account the three-dimensional interaction under the conditions of a non-linear behavior and of a post-elastic behavior. Particular attention will have to be paid to the structures local and general design of stiffness, as well as to the ductilities of resistant elements such as to avoid detrimental phenomena brought about by the general torsion and to limitate as much as possible the relative displacements between floors, particularly at the ground floor and lower stories.

It has also been found that current design methods used for the dimensioning of reinforced concrete structures do not adequately ensure the resistance of vertical elements to axial forces and shear stress.

5. CONSTRUCTION

The engineer who designs an aseismic building, conceives and designs a"conventional building" to which he assigns a priori certain properties and characteristics. The seismic safety initially assumed will be seriously altered unless the provisions stipulated by the project are not strictly observed during the process of construction.

The international reports on detrimental effects of earthquakes on some buildings aseismically conceived and designed have evidenced serious deficiencies of building materials and quality of execution.

Reality has unfortunately confirmed that deficiencies of concept and execution in aseismic buildings have led to effects much more serious than some errors of design.

6. RESEARCH

Theoretical investigations carried up to now did not lead to a unitary and general concept of a physical and mathematical model able to reflect in a complex way the ultimate forces which governs the behavior of a structure - regardless of its type and destination - to a strong earthquake.

Scientists concentrate since a long time on the finding of such a model able to allow for a structural analysis and synthesis, and it should further remain a matter of concern. Natural experience offered by real earthquakes has shown in many instances that the real behavior of some buildings refuted the analysis model of design.

Probabilistic analysis, which at the present is particularly centred on the random character of the seismic motion and of the structural parameters, will further be able to elucidate many of the present incertitudes.

Experimental research still can not adequately account for the dynamic properties of materials, for the postelastic behavior of structures, for their behavior to strong cumulative and cyclic motions, for the phenomena of hysteretic damping a.s.o. At the same time, laboratory as well as full scale research work will have to be extended in order to study experimentally the behavior of certain types of elements, units and structures to simulated seismic motions.

The time evolution of physical and mechanical characteristics of materials should be better known as well as the process of ageing and decay which they are subjected to. This will allow for a probabilistic estimation of time-dependent variability of structural characteristics as well as of the expected response to strong shocks acting within predeterminated return periods.

7. PROFESSIONAL EDUCATION

Taking into account the marked seismic activity in many parts of the world, the area it involves, the size and the destructive periodical effects, one can not conceive a structure without the need of highly qualified professionals to design and construct it.

The design and construction of an aseismic structure represents a technical masterpiece with deep social and economic implications.

Thus, the professional education should start at the universitary level and furthered periodically by post-graduate training, having a technical and practical caharacter and providing updating in the field of seismic engineering.

Particular aspects should be particularly studied by fundamental and experimental investigations and by testing models at a laboratory as well as at a full scale level.

In many countries of the seismic-risk areas the lack of qualified professionals in seismic engineering had negative effects, regarding mainly the aseismic design of structures, the interpretation of destructive effects, the aftershock restoring and reinforcement of structures.

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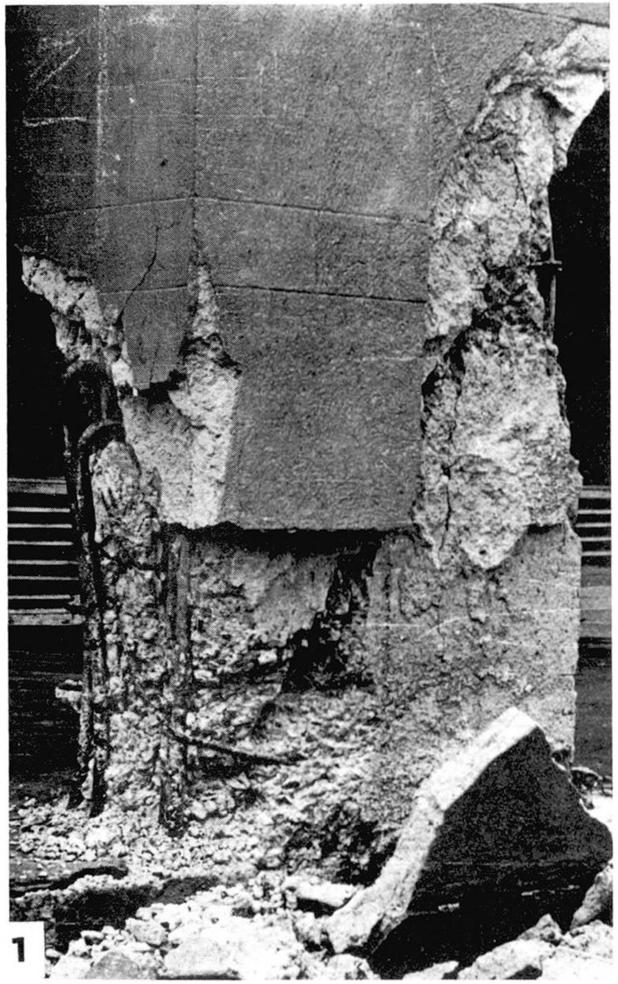
It is only by a permanent and concentrate co-operation of all researchers and engineers from seismic-risk countries that seismic engineering may make such progress as to eliminate, as much as possible, fear and incertitude.

CAPTION S

Photo 1, 2 - Column failure in a building with flexible ground-floor
Photo 3 - Column failure due to discontinuities of stiffness
Photo 4,5,6 - Column failure due to strong axial and shear forces
Photo 7 - Important failure in column due to the absence of stirrups
Photo 8,9,10 - Failure in a non-shear designed column
Photo 11 - Dislocation of a beam-column joint
Photo 12, 13- Local damage at the extremity of a shear wall due to strong compression
Photo 14, 15- Partial collopse of nonseismic designed buildings (built in the '30's)
Photo 16, 17- Span of separation between buildings after the earthquake
Photo 18, 19- Dislocation of frontispiece with great inertial effect in a monumental building
Photo 20 - Damage in masonry walls of a structure in concrete frames (build in the '30's)
Photo 21, 22- Typical crack in bearing walls (build in the '30's)
Photo 23 - Rocking effect due to soil-structure interaction.



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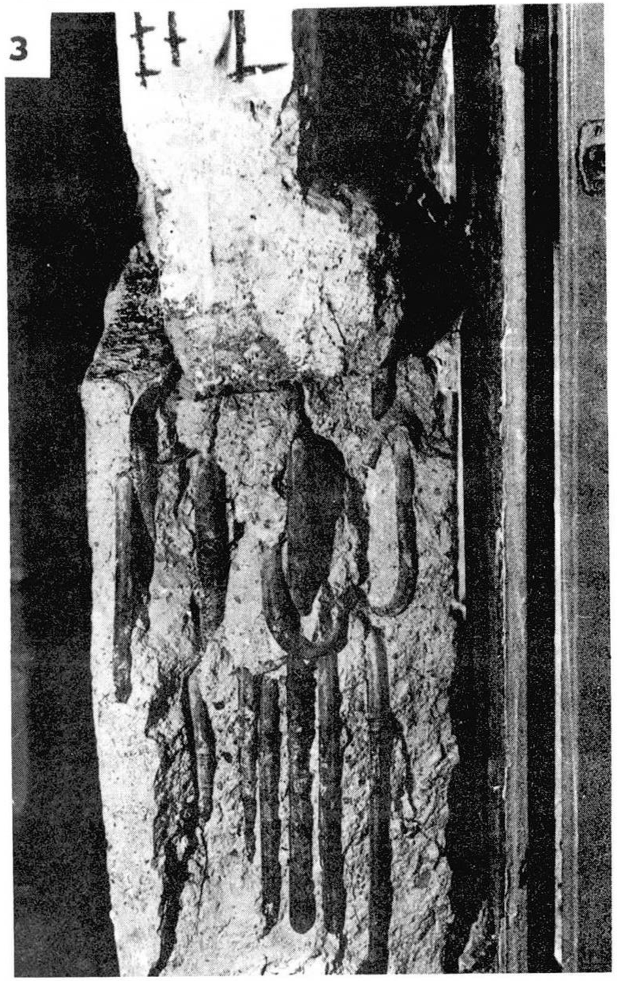

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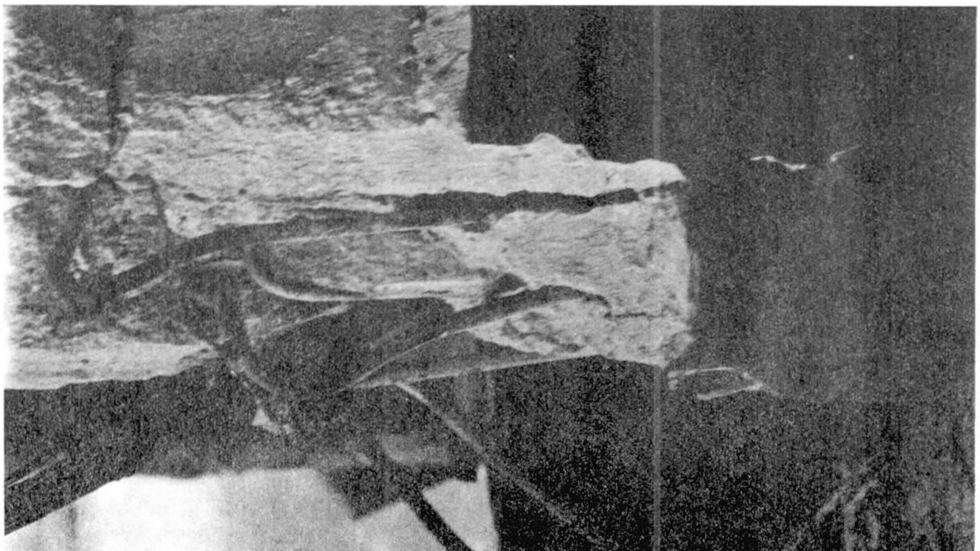

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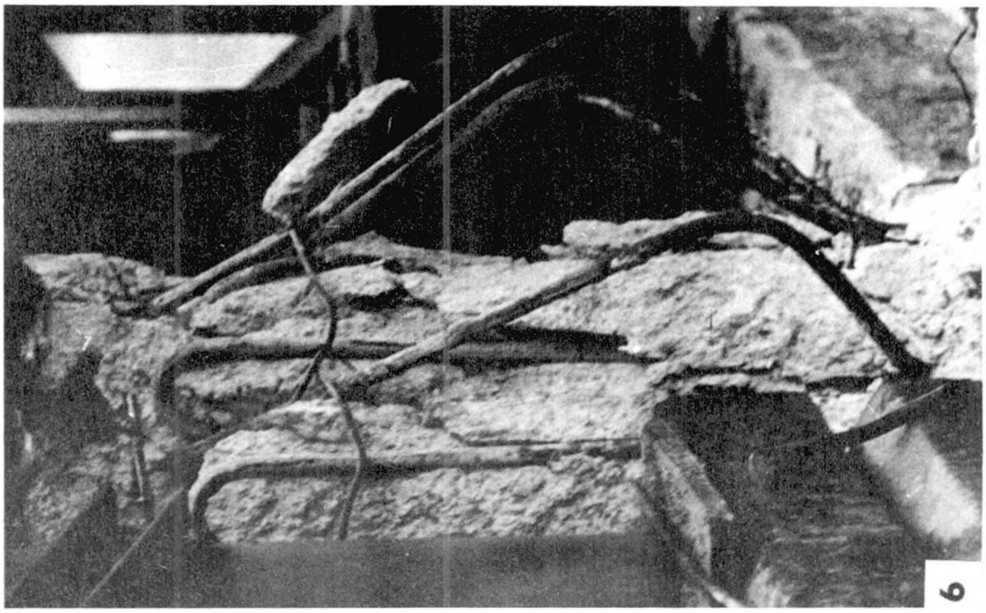

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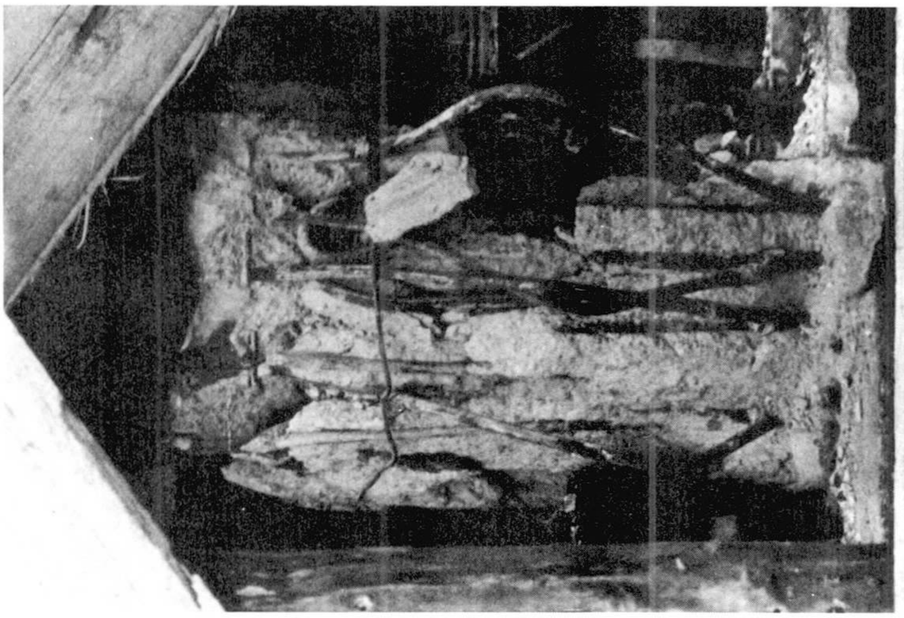

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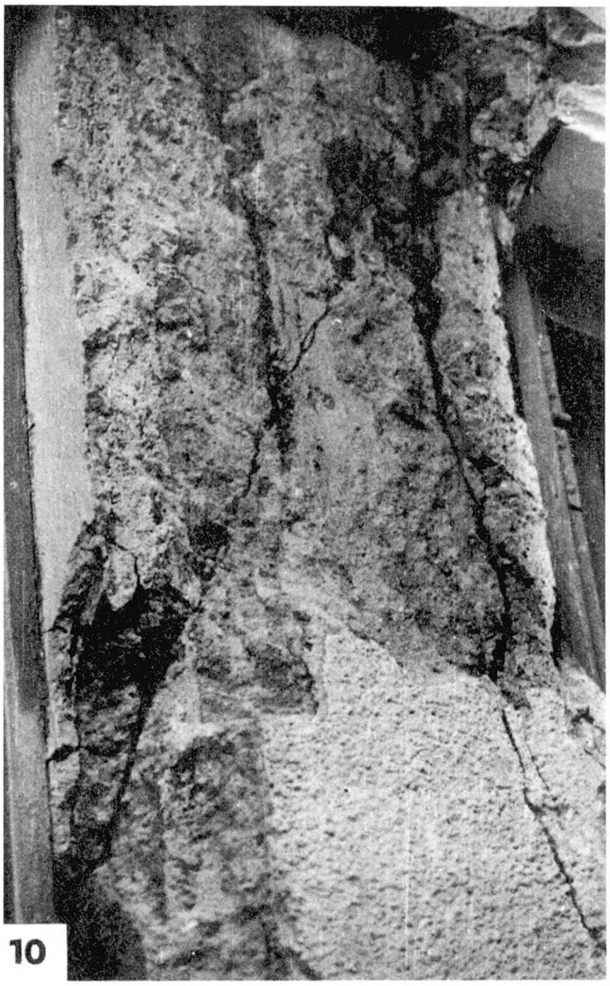

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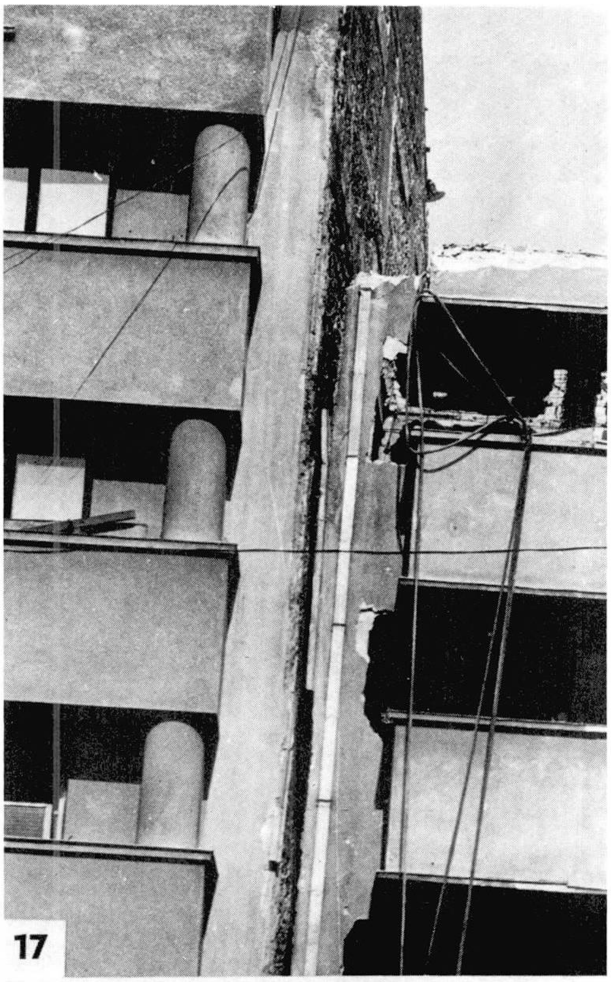

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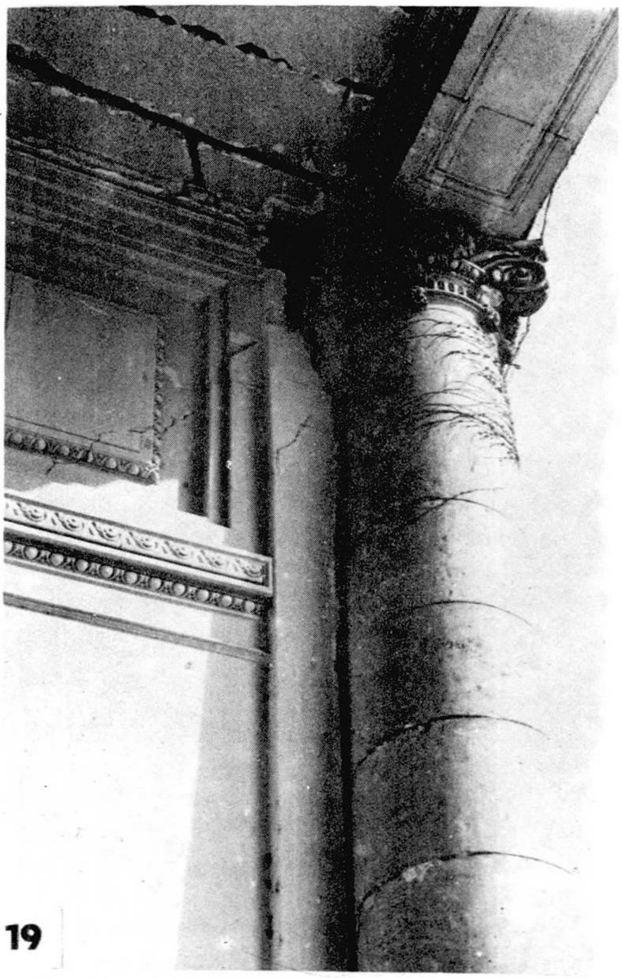

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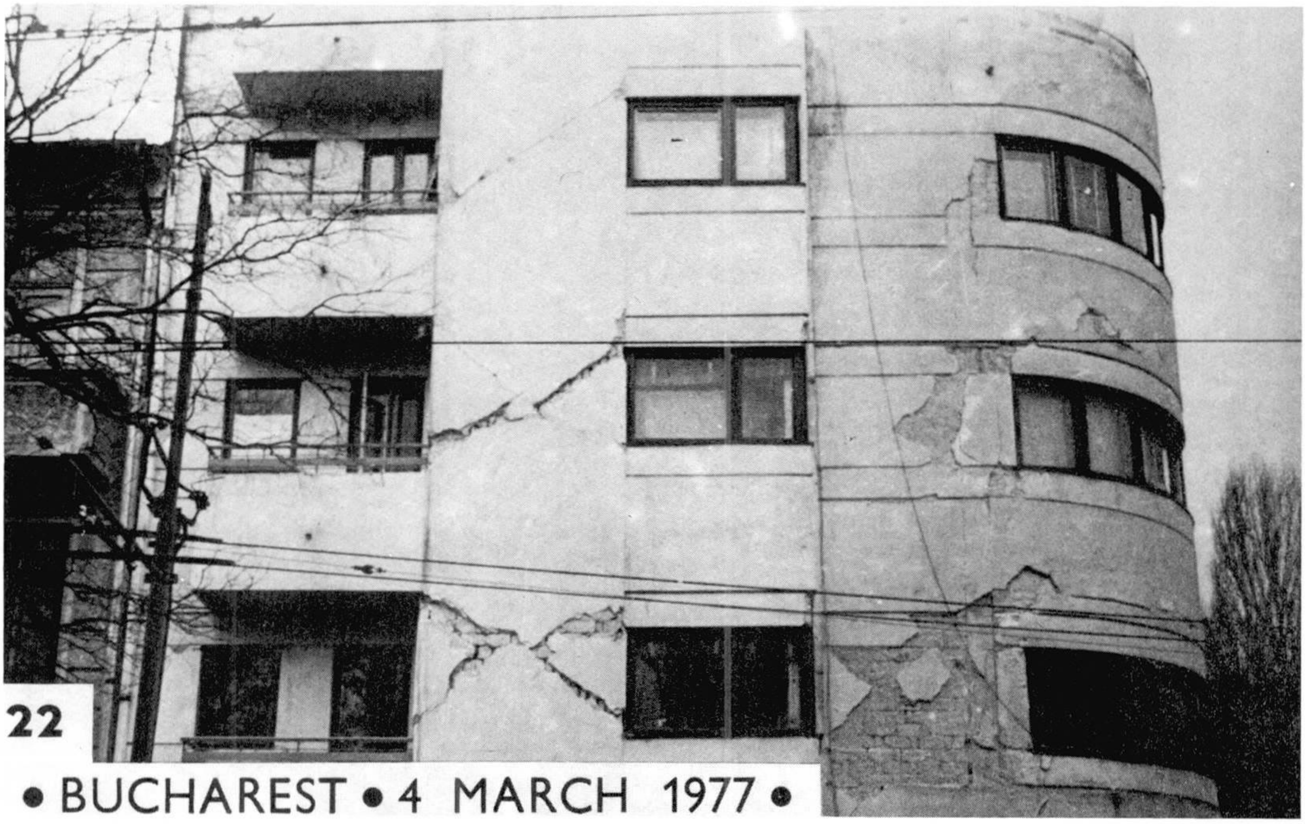

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