EARTHQUAKE OF MARCH 4, 1977 IN ROMANIA — DAMAGE AND STRENGTHENING OF STRUCTURES

Mihail Ifrim

SYNOPSIS

This paper contains a series of observations and conclusions about the effects of the strong earthquake in Romania on March 4, 1977. Presented are the main causes which have contributed to the disastrous effects of this earthquake, and a short description of the earthquake damage and behaviour of buildings. The paper concludes with some viewpoints on the evaluation and strengthening of structures that were damaged by this strong earthquake, based on the long personal experience of the author and on the observations of the effects of the recent seismic shock.

RESUME

Cette communication décrit les raisons principales qui ont contribué aux dégats ainsi que l'effet catastrophique sur les bâtiments lors du tremblement de terre du 4 mars 1977 en Roumanie. Les points de vue de l'auteur sont aussi présentés quant aux réparations et au renforcement des structures endommagées par ce violent séisme.

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1. INTRODUCTION. EARTHQUAKE CHARACTERISTICS

The strong earthquake that occurred in Romania on March 4, 1977 has had unusual violence and a geographic distribution of intensities very different from other previous seismic motions. The epicentre was located in Vrancea zone (the Carpathian arc) and the event has influenced a large area of Romanian territory, especially the south of the country.

The earthquake caused loss of life (about 1570 people) and material losses (US $ two billion) concentrated mainly in Bucharest (the capital of Romania) and in Craivoa, as well as in the adjoining industrial zones.

The recent earthquake at Vrancea had the following characteristic parameters: coordinates: 45° 34 N and 26° 30 E, depth of 109 km, Richter magnitude M = 7,2 and time 19.22.15 G.M.T. It was estimated that the intensity on the MSK Scale was between VI and IX.

One complete instrumental recording of the shock of March 4, 1977 has been obtained on a SMAC-B accelerograph at the Building Research Institute in Bucharest (Fig. 1). Due to the specific mechanism of generation of this earthquake, certain predominant low frequencies can be observed, that is 1,5 Hz for the E-W component and 0,65 Hz for the N-S component. The peak accelerations are: 1,6 m/s^2 for the E-W component and 2,1 m/s^2 for the N-S component.

The behaviour of structures during the earthquake of March 4, 1977 demonstrated the relationship among magnitude of earthquake, eipcentral distance and effective intensity in certain zones. In this respect it was observed that a focusing tendency of seismic waves occurred in some areas.

On the basis of completed research at the Centre of Earth Physics and Seismology of Bucharest concerning the distribution of intensity, the macroseismic intensity map in fig. 2 was derived. This map shows a non-symmetrical and irregular distribution of intensity of the earthquake; in the epicentral area the intensity of the earthquake was less than at some greater distances.

Thus, the focal mechanism of the earthquake, the effects of local geological conditions, and the dynamic filtering effect of upper layers played an important role and have contributed to the production of long predominant periods. The spectral contents of seismic motion demonstrated that long predominant periods were present, particularly on the alluvial layers in the south of Romania (including Bucharest). In those areas the effects of earthquake were more disastrous.

It should be pointed out that the Vrancea zone also generated a strong earthquake on November 10, 1940, with a Richter magnitude M = 7,4 and a different spectral composition from the one of March 4, 1977.

The most important damage and collapses occurred in Bucharest, a city of two million people, especially in reinforced concrete multi-storey buildings.

2. BEHAVIOUR OF STRUCTURES

2.1 Influence of Spectral Motion Characteristics on Structural Safety

An analysis of the behaviour of structures subjected to the strong seismic motion of March 4, 1977, regardless of whether or not they incorporated seismic resistance in concept and design, has contributed to the elucidation of some fundamental scientific and technical aspects. Further, the effects of the recent earthquake in Romania have provided valuable lessons in seismic engineering.

Most of the buildings in Bucharest are built of reinforced concrete having different types of structural systems, and of load-bearing masonry (of up to four storeys).

During the earthquake of March 4, 1977, structures built before 1940 and those which were not aseismically designed have been most severely damaged, some even collapsed.

The causes and effects of the earthquake damage could be traced mainly to the concepts which formed the basis for the initial design of the structures. The old construction built before 1940 consists of structures conceived and designed only from the point of view of gravity loads having only nominal safety against horizontal loads (random aseismic protection). The recent construction (erected after 1940) has structures conceived and designed from the seismic point of view in accordance with the current official code regulations.

The structures not designed against earthquake have had the most severe damage. Among these, 27 apartment buildings have collapsed in Bucharest (20 being multi-storey buildings of reinforced concrete construction). Generally, the up-to-date construction exhibited good behaviour. Only three cases of collapse of the new reinforced concrete buildings were reported in Bucharest.

One of the most important causes which contributed to the disaster of March 4, 1977 was the high intensity of the earthquake. In many areas, the effective level of seismic intensity has substantially exceeded the design seismic intensity as stipulated in the code regulations. Furthermore, the specific source mechanism of this earthquake has produced a motion that is characterized by unexpectedly long predominant periods. The absolute acceleration response spectra for seismic shock recorded in Bucharest, shown in Fig. 3, as well as in the south of the country, have shapes very different from those that were in code regulations before the earthquake. The comparison among normalized spectra of absolute accelerations is shown in Fig. 4a. In Fig. 4b is shown the variation of dynamic factor (design spectrum) stipulated in Romanian design requirements before and after the March 4, 1977 earthquake.

The above remarks demonstrate that there was a discrepancy between the real response of structures during the earthquake and the response stipulated by design. In particular, the safety level of flexible structures was smaller than that of rigid ones.

If the high intensity of seismic motion is taken into consideration, along with the above observations (without taking into account other causes), it is sufficient to explain the majority of failures observed in the tall buildings in Bucharest.

2.2 Influence of Concept and Design

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

From the survey carried out after the earthquake of March 4, 1977 until the present, the author has concerned himself with this phenomenon. A short synthesis regarding some fundamental aspects of earthquake engineering has been presented at the "Seminar on Constructions in Seismic Zones," organized by IABSE-ISMES, Bergamo - Udine (Italy, 1978). This paper will present more information about aspects concerning concept and design. As the rehabilitation of construction after an earthquake is of immediate importance, certain points of view about the repair and strengthening of structures will be advanced.

The concepts of structural dynamics of the three-dimensional members and ensemble subjected to seismic motion is very complicated and could therefore not be encompassed, as is sometimes claimed, only by sort of an "engineer's common sense." This simplistic way to view problems of a most complex dynamical concept has led to confusion. The dynamic concept of structural members, also taking into account the contribution of nonbearing members, demands a thorough study of each individual detail and structural element, up to the entire structural ensemble. The effects of earthquakes that occurred during recent years, including the one on March 4, 1977 in Romania, have shown that neglecting the dynamic concept of design and construction of a building may lead to local damage or total collapse of some urban blocks of flats.

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

-- remarkable lack of geometric symmetry and geometric 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 non-uniform depth and having different destinations and functions, disproportionate partitions, heavy cantilevers, eccentrically placed stairwells, juts and recesses, accidental configuration within the project of the buildings, heavy finishing, etc.);

-- dynamically unreasonable proportions in the distribution of structural and non-structural masses (overloads on upper floors; overloading due to the conversion of apartment blocks into office buildings; penthouses; heavy roofs, etc.);

-- marked discontinuities in the distribution and variation of stiffness in structural members in both horizontal and vertical planes, which did not ensure general three-dimensional interaction (discontinuity of structural elements; undersized beams and columns; absence of horizontal diaphragm effect; high ground floors; columns with different axial forces; stair and elevator walls superficially designed within the structure as a whole, etc.);

-- unfavourable post-elastic behaviour of structures of reinforced concrete (frames and shear walls) due to low ductility and poor dissipation of energy through damping.

The above-mentioned errors may lead directly to detrimental effects, particularly in buildings whose design was based upon a gravitational concept.

The above deficiencies are further detailed as follows: eccentricity between the mass centre and the centre of rigidity, resulting in a torsional effect, particularly on L-, U- and V-shaped structures; great lateral drifts of flexible framed structures which, as was found, have evidently affected the vertical structural elements and the non-structural partition walls; concentration of strong motions and overstrain at the ground floor level and in the lower storeys; increased horizontal displacements in flexible structures especially in those with open ground floors; the non-uniform stresses in vertical elements (columns and wall piers); the tendency to dislodge members or even of units which, as compared to the whole structure, were either very flexible or very stiff; different stress levels in the structures, leading to failures in places of high seismic vulnerability.

From the dynamic point of view, the presence of such errors of concept and design of a structure when subjected to lateral forces may lead to some inertial, elastic, energy and tension concentrators. This constitutes vulnerable and unsatisfactory behaviour, and may result in disastrous effects during strong seismic motions.

Besides these global findings resulting from errors existing within the general dynamics concept, the survey of earthquake effects revealed also serious errors of concept and the superficial study of some details of structural design such as: the narrow spaces of separation between buildings; the high percentage of openings at the first floor storeys, particularly in load-bearing masonry, with floors of different structural types and differently loaded (made of timber, metal girders with small arches, reinforced concrete) and without ties to vertical load-carrying elements; local disproportions between the stiffness of columns and beams, thus lacking the plane or space frame effect; eccentric beam-column connections for transfer of deformation energy between horizontal and vertical load-carrying elements; inadequate longitudinal and transverse reinforcement of columns, beams, shear walls, lintels, and joints resulting in uncertain ductility factors during post-elastic deformations and the appearance of plastic hinges; inadequate safety factors for shear forces in vertical load-resisting elements; the wrong use of X-braced frame systems; excessive stress in vertical elements that led to fracture, crushing, and buckling of the reinforcement; corrosion of reinforcing bars, unsuitable reinforcement, large distances between stirrups, insufficient concrete cover.

With some exceptions, one may say that the behaviour of recent construction, designed and built on the basis of seismic resistance, was quite good, especially when one takes into account the fact that in Bucharest the intensity of the seismic activity of March 4, 1977 has far exceeded the safety level stipulated by the design and by the official design code regulations.

3. SURVEY OF EARTHQUAKE DAMAGE

In Bucharest many different types of structural systems are employed for blocks of flats or buildings used for other purposes.

The majority of the structures built before 1940 (no anti-seismic design) are made of load-bearing masonry walls and reinforced concrete frames with masonry infills. Generally, the modern multistorey buildings erected recently (seismically protected) employ reinforced concrete frames, reinforced concrete shear walls and precast reinforced concrete panels to resist the loads.

An analysis of the effects produced by the earthquake on March 4, 1977, has shown that the new construction demonstrated quite good behaviour compared with the older one, considering all the above-mentioned unfavourable causes. However, three new buildings have collapsed partially or totally.

The author did not consider it necessary to describe in detail all damage produced, because the effects of strong earthquakes on different types of structures are well known from experience in other parts of the world.

The survey of earthquake damage based on direct observations was very important in establishing the causes that lead to errors relative to the seismic safety level, design concepts, calculations and implementation. With this in mind, particularly with reference to the effects produced by the earthquake in Romania, it is thought to be more important to note the proportion and frequency of certain typical damage.

In this way the investigations when corroborated with the previously described causes provide supplementary data related to building codes for future design and construction as well as the repair and strengthening of the damaged structures.

Among typical effects produced by the earthquake are the following:

- the damage and sometimes collapse of corner buildings;

- severe damage localized at the open ground floor and confined to lower storeys;

- major damage in the structural and non-structural members of flexible construction with large horizontal relative displacements;

- characteristic diagonal cracks in columns of reinforced concrete frames, in piers of reinforced concrete shear walls, in load-bearing masonry walls, and in infilled masonry;

- cracks and failures in structural members (columns, beams, slabs, lintels of reinforced concrete shear walls, joint connections, etc.);

- degradation processes (concrete crushing, scaling, expulsion, pulverization, destruction, dislocation and buckling of reinforcement bars).

Some representative examples are shown in the enclosed photographs.

4. REPAIR AND STRENGTHENING OF STRUCTURES

Of the main aspects which are characteristic of the "construction - seismic action - damage - reconstruction" cycle, the author has chosen here only those that concern the evaluation of the degree of damage, the principles concerning the strengthening process, and the way to test the efficiency of the reconstruction work.

In many cases, the evaluation of the "degree of damage" of structures damaged by a destructive earthquake permits certain remedial work which provides the structures with added capacity to resist lateral and gravitational actions.

The repair of deteriorated construction represents a most laborious and difficult job, more complicated than the designing of new construction. In defining certain remedial solutions it is necessary to have extensive technical knowledge and highly qualified professional experience.

Essentially, in estimating the "degree of damage" and in specifying the remedial solution, the inertial, dissipative, elastic and resistant characteristics which govern the behaviour of structures during strong seismic motions should be analysed.

The dynamic concept of the strengthening plan should take into account future violent earthquakes, particularly when dealing with initially seismically unsafe construction. It is obvious that the strengthening solutions chosen on the basis of strict technical criteria should be based on economic and comparative investigations.

Some conclusions are subsequently presented, derived from the personal experience of the author, in strengthening and restoring of certain Bucharest buildings following the violent earthquake in Romania on March 4, 1977.

4.1 Causes which Affect the "Degree of Damage" in Structures

The analysis of the degree of damage in structures following a violent seismic motion should be done according to the initial design concept employed. Thus, construction which is to be surveyed will generally be classified as:

A. Structures conceived and designed only from the gravitational point of view, having an undefined level of safety against horizontal motions.

B. Structures conceived and designed from the aseismic point of view, in accordance with the current official code of regulations.

In any damage survey the above-mentioned criterion is a fundamental one and should be correlated to the structural type which will be different for each individual building. It is obvious that each investigated object represents a "particular case" capable of revealing important--sometimes spectacular--differences of the seismic effect. These are sometimes difficult to explain or interpret.

The evaluation of damage, according to the safety level to lateral actions and the structural type, as well as the identification of these by direct observations, instrumental measurements and numerical analysis, provides basic information for the formulation of remedial solutions.

Arising from the statistical evaluation of effects produced by intense earthquakes, damage may be generally classified as:

a) Minor damage; insignificant from the point of view of the load-resistant capacity of structures. In this case, strengthening as such is not necessary, only repair of the non-structural elements.

b) Moderate damage; limited to certain vertical and horizontal load-resistant elements, generally located at the ground floor, or even at the first and second floors. The strengthening steps will be of limited extent, and will concern only locally or partially damaged structural elements so as to restore or improve the safety level against lateral forces.

c) Severe damage; may involve important parts of the structural system, extending in both the horizontal and vertical plane. The reconstruction process will have a rather general character consisting of the recovery of the structure as a whole, from both the stiffness and the load resistance point of view. In this situation it is necessary to improve the degree of safety against lateral actions, thus reducing the potential risk in case of a possible future violent seismic shock.

d) Major damage; may involve most of the load-resisting members, leading to the necessity of extensive, complex and expensive reconstruction. In such cases it is advisable to demolish and rebuild.

While estimating the efficiency of the strengthening process, one should take into account the fundamental relation between the complexity of the technical measures to be implemented and the necessary economic effort.

There are several main aspects which may influence the "degree of damage" of a structure, as verified by numerical or random analysis to seismic motion. They will not be enumerated because of lack of space, but they depend on seismic intensity, local conditions of soil, effective structural characteristics, quality of materials, etc. Of special importance is the vulnerability and sensitivity of the structural system to lateral actions. This may contribute to an increase in damaging effects in structures.

4.2 Principles Concerning the Strengthening Process of Structures

Theoretically speaking, the concept of the strengthening solution for construction deteriorated by a strong earthquake consists of reconstituting the dynamic structural behaviour through the recovery of inertial, dissipative, and elastic characteristics, as well as in the repair of force resistance and ductile capacity of damaged members. The general principles which should be taken into account in designing the remedial solutions of deteriorated structures are:

A. The recovery of inertial characteristics, by avoiding local overloads, by removing heavy architectural elements, by building uniform partition walls made of light materials, by eliminating the storage of heavy materials, mostly at the upper floors, by retaining the intended occupancy of buildings, etc.

B. The recovery of dissipative characteristics, by employing materials and devices with energy dissipative properties, by providing the reinforced concrete frame structures with load-bearing or partition walls having energy absorbing characteristics, by filling some of the non-functional openings of reinforced concrete diaphragm structures with deformable materials, by lowering the ground water level.

C. The recovery of elastic characteristics, by the accurate proportioning of the stiffness of damaged members (beams, columns, diaphragms, joints, connections, structural parts) or even of the entire structure through local or more extensive changes. Further considerations are the proportioning or the variation of relative stiffness between floors (mostly at the ground floor and lower storeys), the limitation of lateral displacement, and the alignment of the position of torsional centres with the mass centres.

D. The recovery of force resistance and ductile capacity, by judicious design of the damaged elements and by employing the proper materials, in accordance with the stipulated safety factor.

Some detailed steps to be taken with respect to the remedial design that stem directly from the above-mentioned general principles could thus be enumerated:

-- The identification of all damage and deterioration occurring in the structural and non-structural members and analysis and interpretation of these from a static and a dynamic point of view.

-- The evaluation of the distribution of deteriorated members within the entire structural ensemble (both in the horizontal and vertical planes), the distribution and location of these for a clear definition of the areas more vulnerable to lateral actions.

-- The determination of physical and mechanical properties of the foundation soil, the location of the ground water level, the development of the soil-structure interaction phenomenon, the influence of neighbouring construction, the orientation relative to the predominant direction of the seismic action, so that the influence of local foundation conditions on the structure during an earthquake can be established.

-- The complete survey of the entire structure, the geometrical reconstitution of all structural members and the identification of reinforcement (when the original plans are missing) and not limiting the survey only to the visible members deteriorated by the earthquake.

-- The instrumental analysis of the quality of materials, the identification of the amount of reinforcement as well as its location, the experimental testing of the dynamic characteristics of the structure, before and after the remedial work.

-- The establishment, by structural analysis, of the real strength of the structure to lateral action before the earthquake, as damaged after the shock, and as finally strengthened.

-- The adaptation of remedial solutions to each individual structure, as well as to the specific type of damage within the elements themselves.

-- The strengthening of structural members by providing the entire structure with adequate static and dynamic resistance to gravitational loads and to future seismic motions that might result in limiting lateral displacements.

-- The complete exclusion of all current trends to take exclusively empirical (and inadequate) steps in matters of strengthening.

-- The introduction of additional vertical and horizontal structural members, closing non-functional gaps and reducing excessive local loadings.

-- The correction by strengthening works of structurally inappropriate design concepts in an attempt to avoid the development of the dangerous phenomenon of dynamic torsion.

-- The need to provide the strengthened elements with ductility to correspond to that of the rest of non-strengthened elements, paying particular attention to the ductility of joints so as to allow the transfer of the deformation energy among the structural elements under elastic or post-elastic stress.

-- The need to ensure both local and spatial interaction between the strengthened elements and the rest of the structure by providing continuity between the structural elements in the superstructure and the foundation.

-- The implementation of simple techniques in the strengthening procedure and the use of high quality materials.

-- The economics of the reconstruction relative to the replacement value of the respective building.

It must be emphasized that the design solutions should focus on the deteriorated structure, and not on the type of strengthening per se.

4.3 Testing Criteria of the Efficiency of the Reconstruction Process

A. By means of numerical analysis, the response of the initially designed structure could be compared to the response of the strengthened structure using in both situations the same seismic motion that produced the damage. Taking into account the actual characteristics of deteriorated elements, one can analyse the resistance of the deteriorated structure to horizontal action.

These analytic tests may provide important information about the safety level of strengthened structures to future seismic shock. In most cases, the remedial solution should improve the safety to lateral actions relative to that provided by the initial design.

B. By means of experimental measurements one can determine in situ the natural characteristics of vibrations of the damaged structure and finally of the refurbished structure. These kinds of investigations are based on the recording of the response of the structure to microseismic activity and to human excitation, or to the free vibration produced by transient actions of short duration.

If the dynamic characteristics of the structure are known prior to the damage caused by the earthquake, the conclusions will be more reliable.

The experimental data permit the verification of the probable behaviour of the strengthened structure to a future strong earthquake. Thus one may obtain important information on the natural period of translation and rotation, on the mode shape of vibration, on the critical damping ratio, on the variation of lateral stiffness, on the position of stiffness centres (torsion), on the main directions of vibrations, etc.

Generally, the efficiency coefficient of strengthening may be expressed as

$$E.C.S. = \left(T_D / T_S\right)^2 > 1$$

where T_D and T_S are the fundamental periods of vibration of the structure as deteriorated by the earthquake (T_D) and as strengthened (T_S).

This can be used to characterize numerically the degree of strengthening of a given structure. Starting from the initial status of the structure (before the earthquake) and the damaged states (after the earthquake), variation bounds for E.C.S. could be determined. This coefficient thus characterizes approximately the global stiffness of the strengthened structure.

Visual observations and instrumental analyses of destructive effects produced by the earthquake of March 4, 1977 demonstrated the important dynamic function of all constitutive elements of a certain structure, improperly called "structural and non-structural." In the dynamic concept of design all elements contribute to the behaviour of a structure subjected to seismic actions. In such cases the notion of "non-structural element" must be excluded. In many specific situations a careful and accurate treatment of so-called "non-structural elements" could have avoided or limited serious damage.

The accurate design and implementation of strengthening is, as in the case of a new building, a matter of great professional and social responsibility.

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The pictures show some of the remedial solutions, designed and applied by the author, for some of the Bucharest buildings of reinforced concrete, load-bearing masonry or both, damaged by the strong earthquake of March 4, 1977.

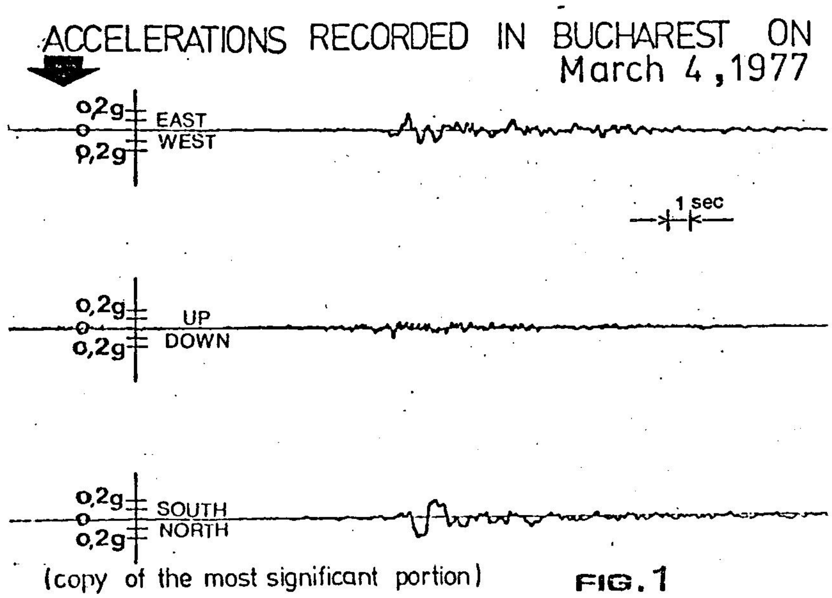


FIG. 1

Fig. 1 Accelerations recorded in Bucharest on March 4, 1977

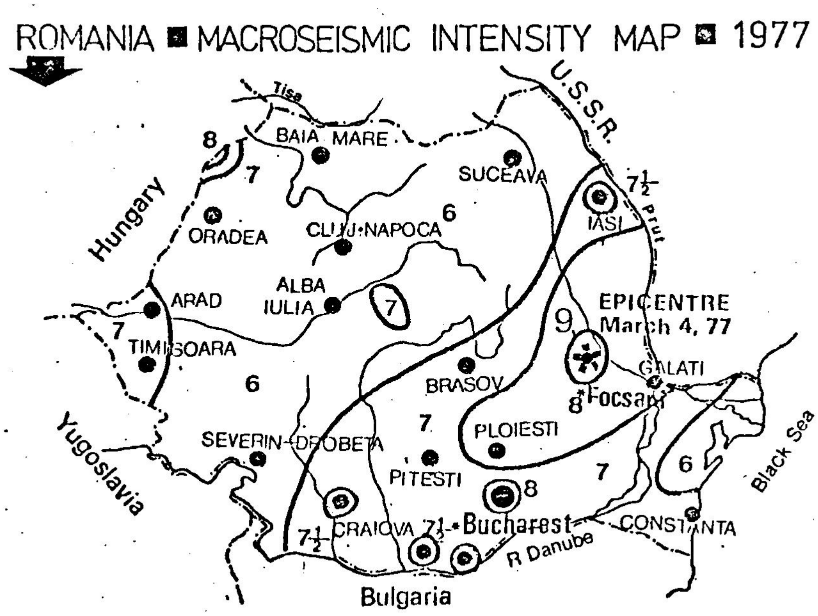


FIG. 2

Fig. 2 Romania - Macroseismic Intensity Map - 1977

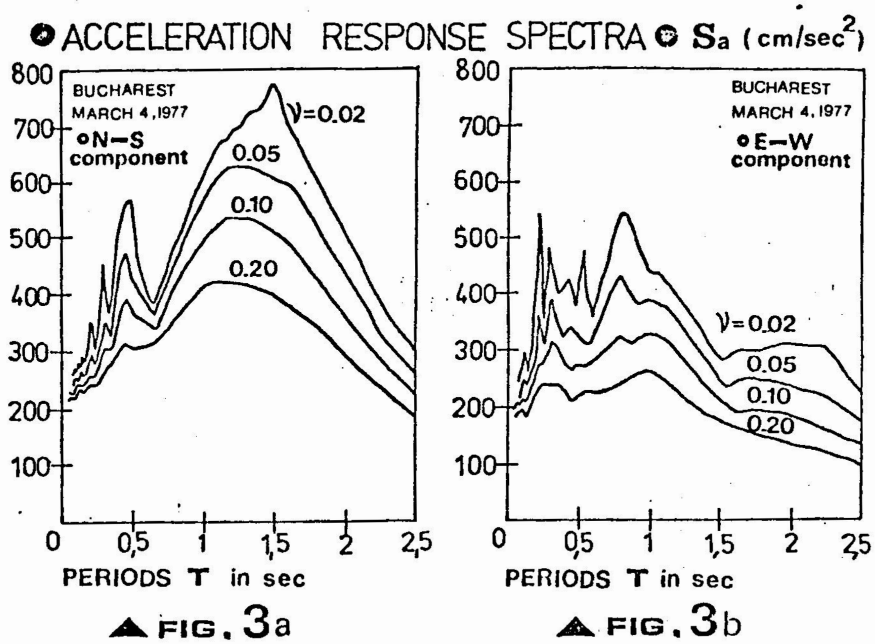


Fig. 3a,b Acceleration response spectra

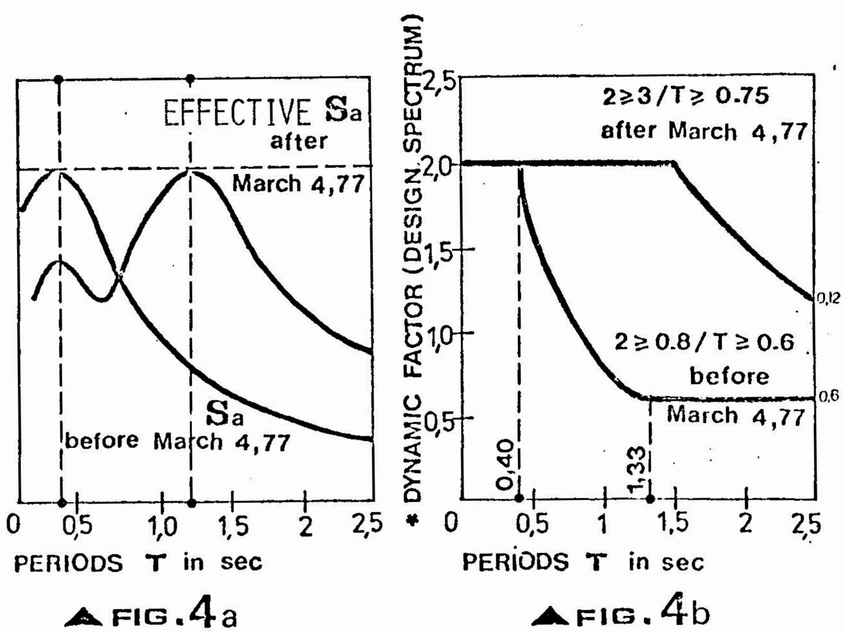


Fig. 4a Mean Spectra Fig. 4b Design Spectra

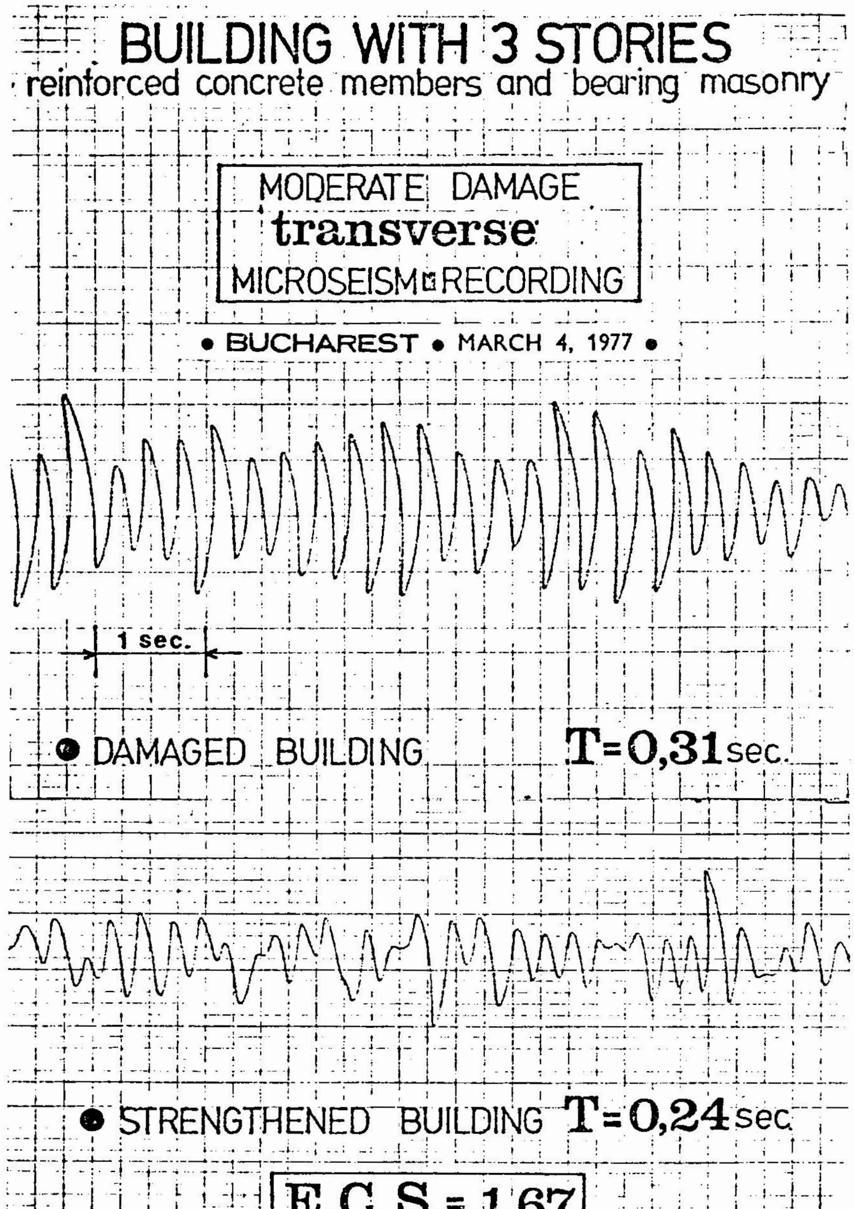
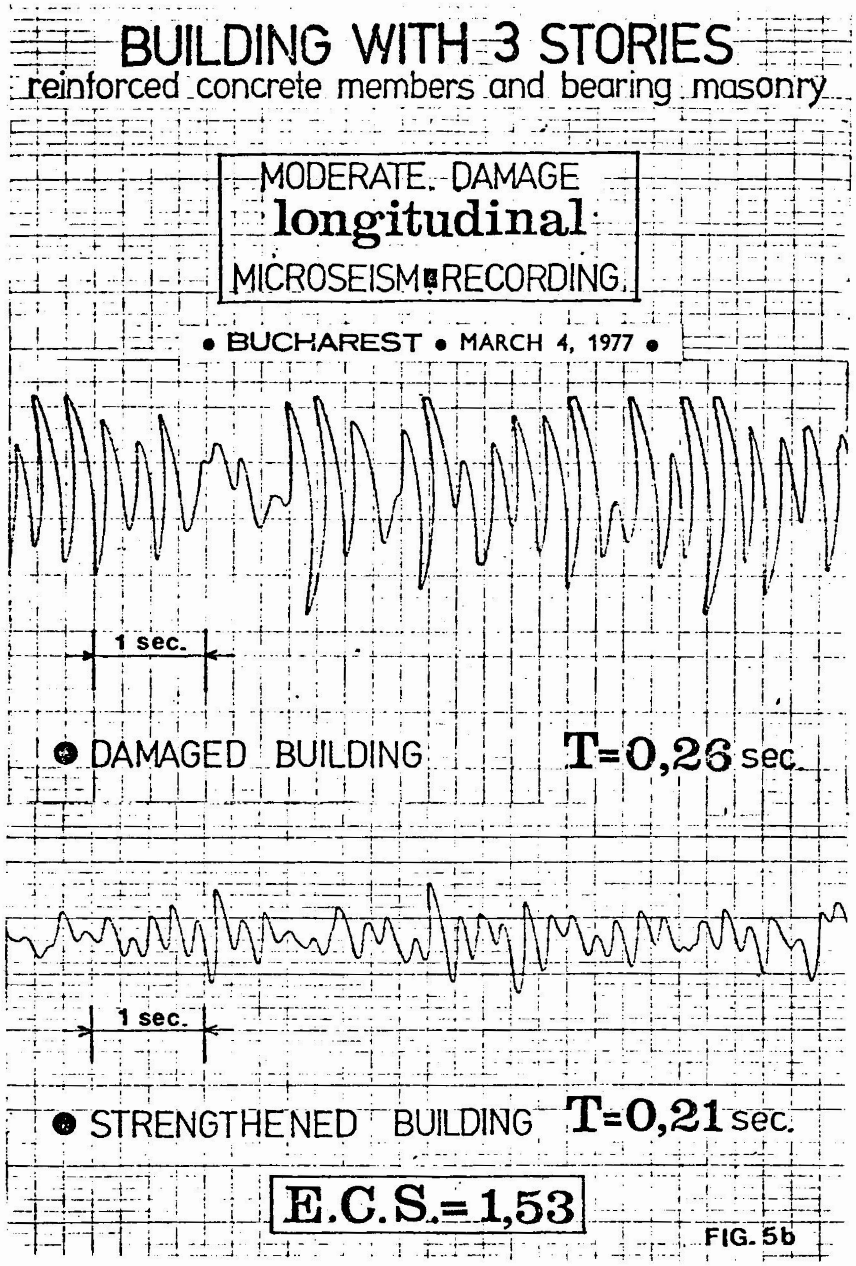


FIG. 5a

Fig. 5a,b Microseismic recordings obtained before and after the strengthening of a three-storey building with a mixed structural system (load-bearing masonry, widely spaced columns, beams and slabs of reinforced concrete). Efficiency coefficient of strengthening (E.C.S.) demonstrated the moderate damage to the building, as well as the effective strengthening on both directions



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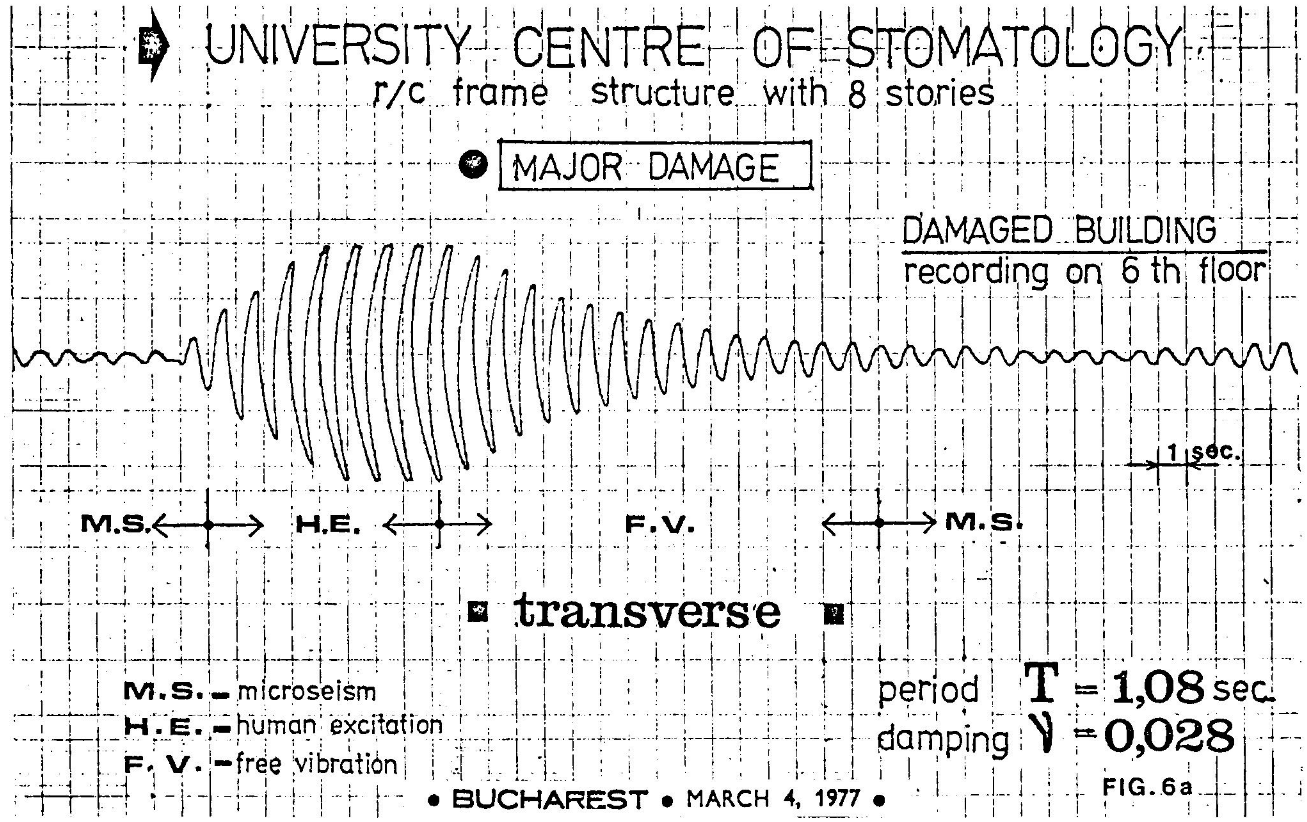


Fig. 6a,b,c,d Recordings obtained on the 6th floor of a reinforced concrete frame building. The values of E.C.S. show the major damage level of the structure, as well as the strengthening in both directions

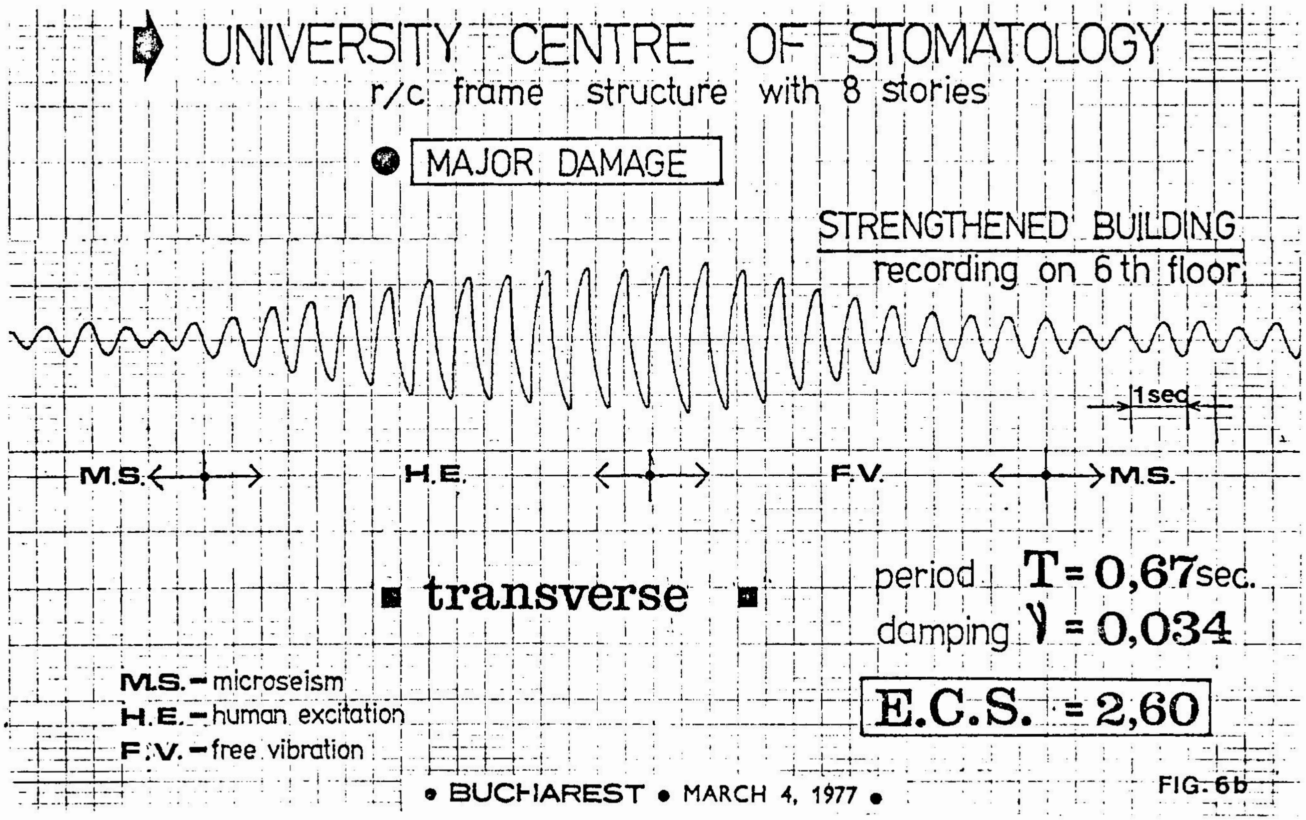
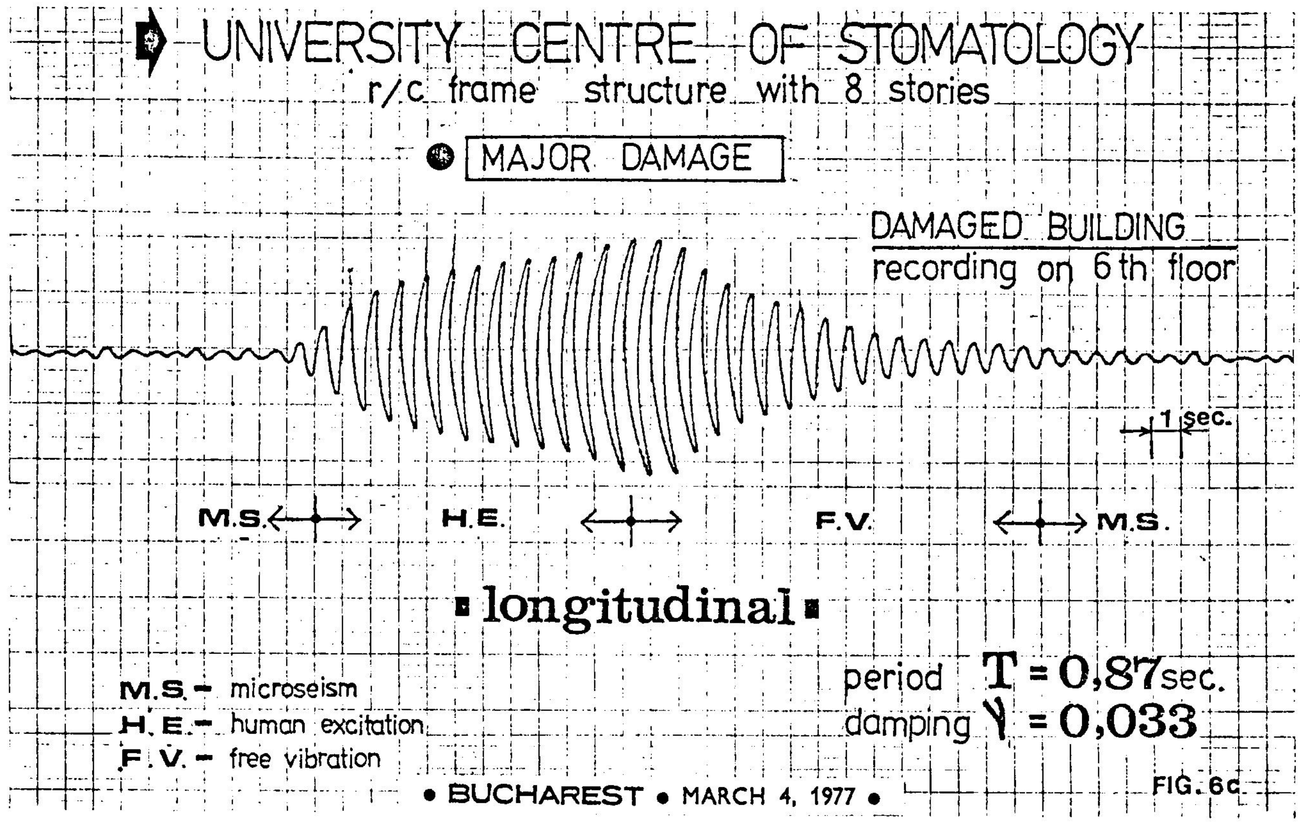


FIG. 6b

Fig. 6a,b,c,d Recordings obtained on the 6th floor of a reinforced concrete frame building. The values of E.C.S. show the major damage level of the structure, as well as the strengthening in both directions.



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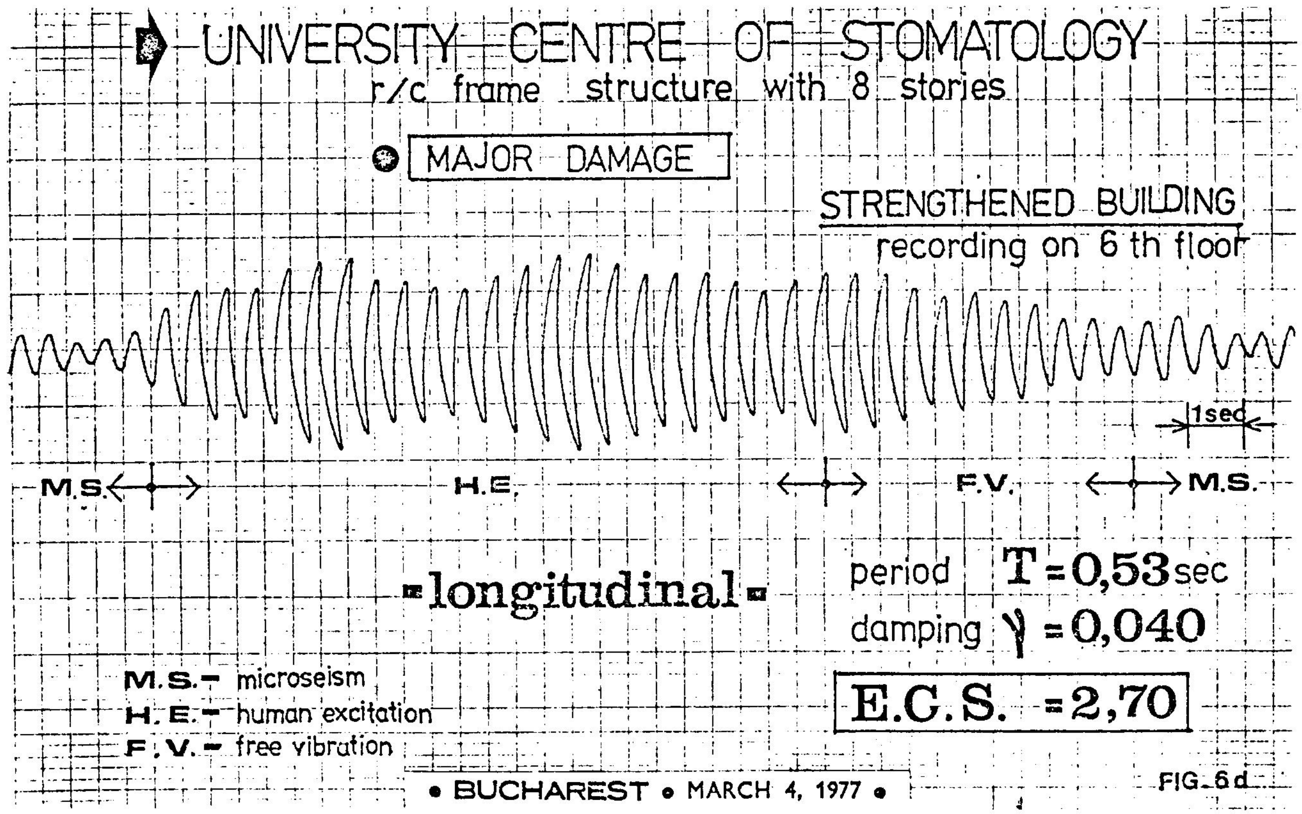

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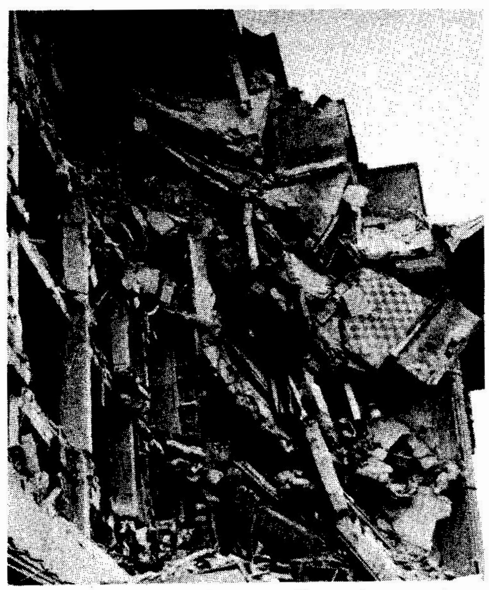
1 • BUCHAREST • MARCH 4, 1977 •

Partial collapse of a 10 storey apartment building of reinforced concrete frames (erected before 1940)



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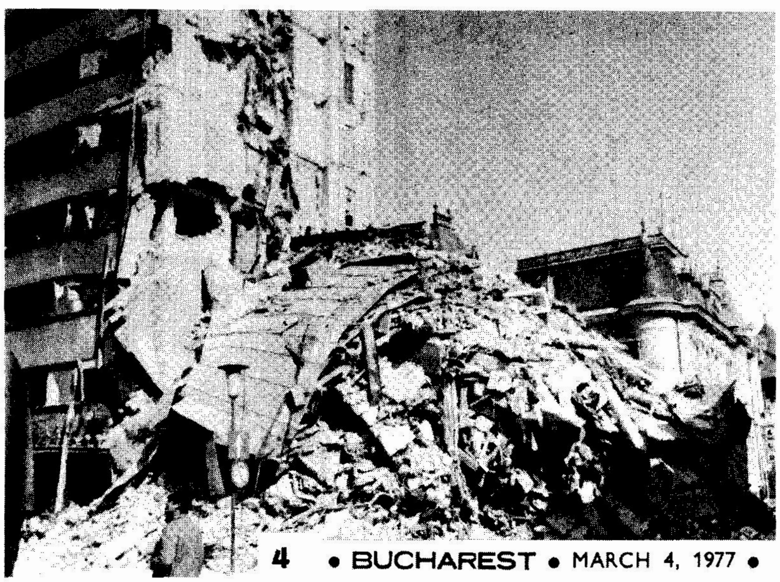
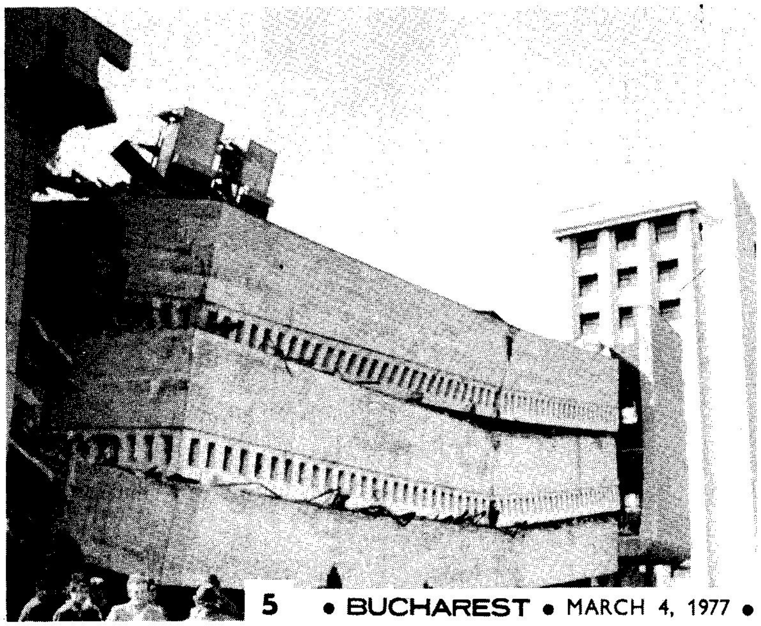
Detail of a partial collapse of an 8 storey building with reinforced concrete frames (erected before 1940)

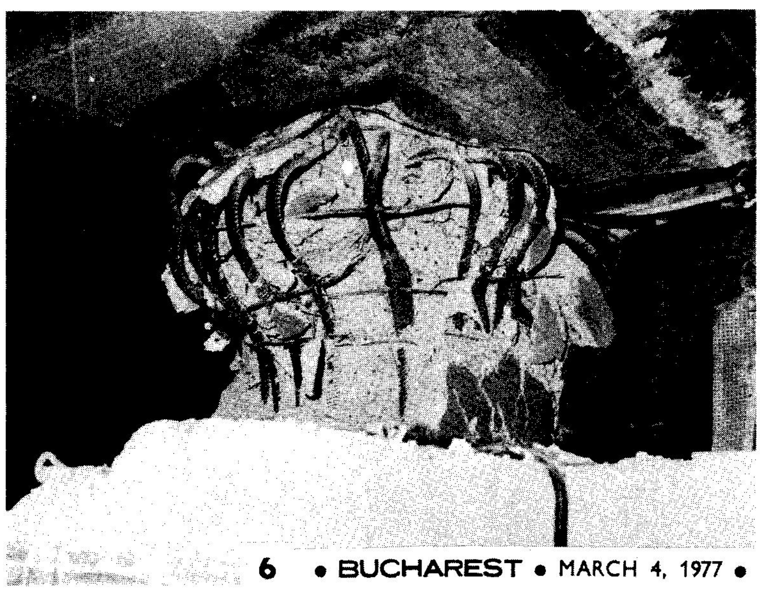
Collapsed block of flats with soft ground floor (erected before 1940)



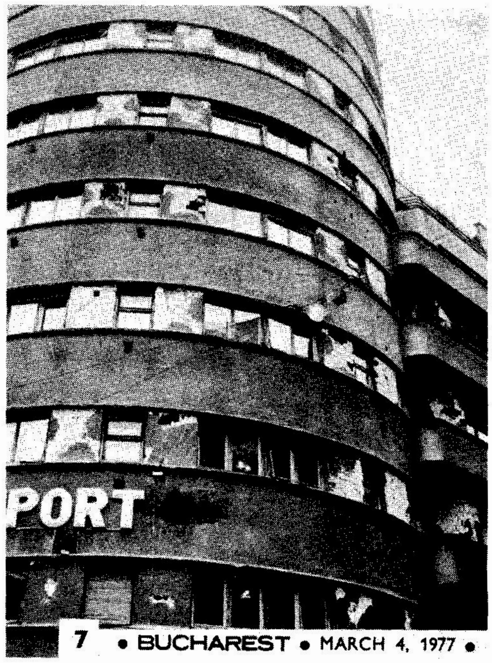
Complete collapse and wreckage of the multi-storey apartment building with reinforced concrete frames (erected before 1940)



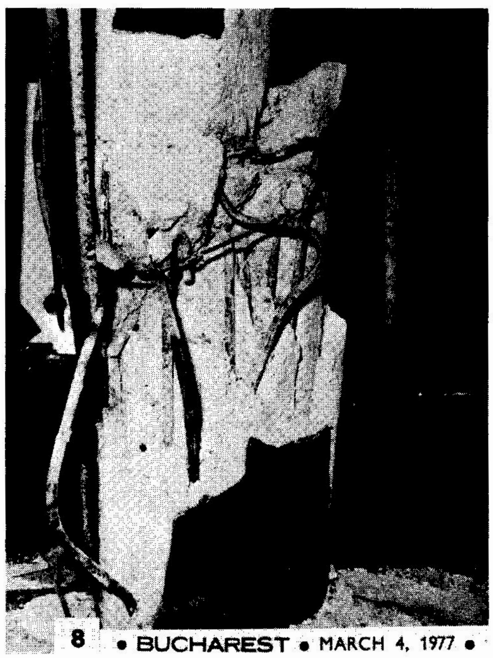
Collapsed Computer Centre designed according to code requirements



Failure at the top of the first storey (Computer Centre)



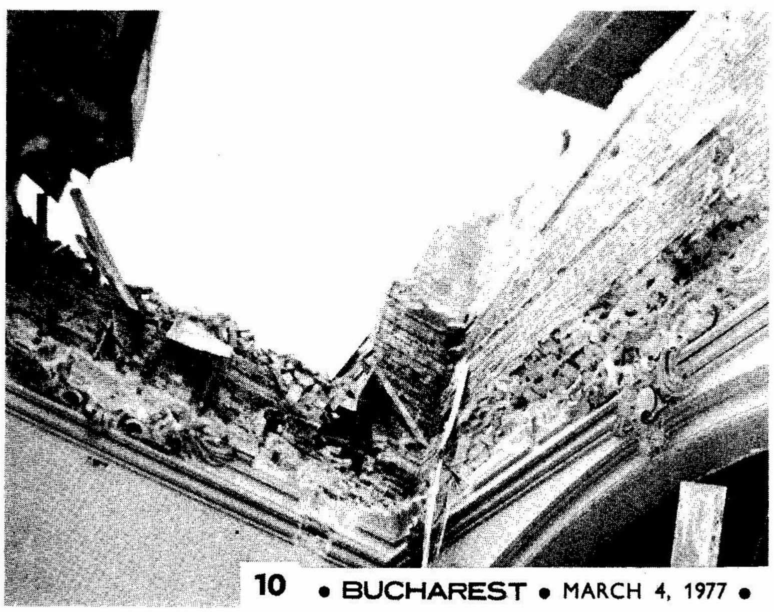
Cracking in exterior infill masonry walls of a reinforced concrete structure, erected before 1940



Fracture of interior first storey column

9 • BUCHAREST • MARCH 4, 1977 •

Partial collapse of old brick wall building which was not designed to resist earthquake



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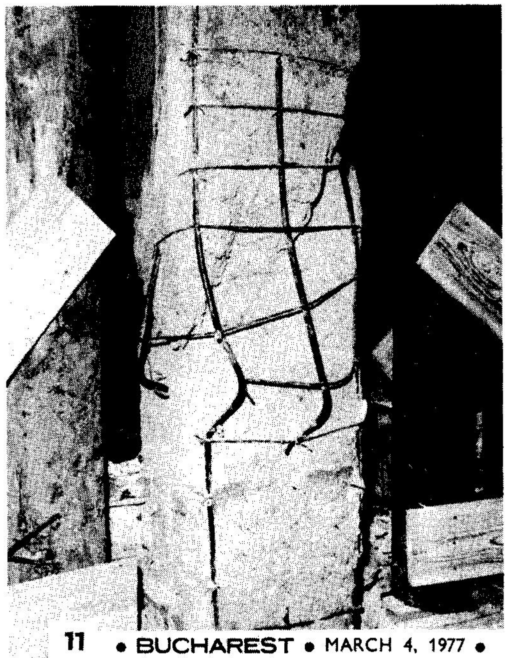
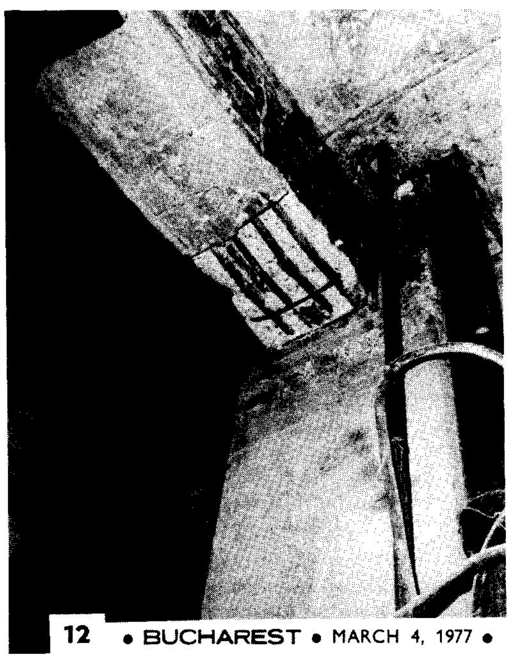
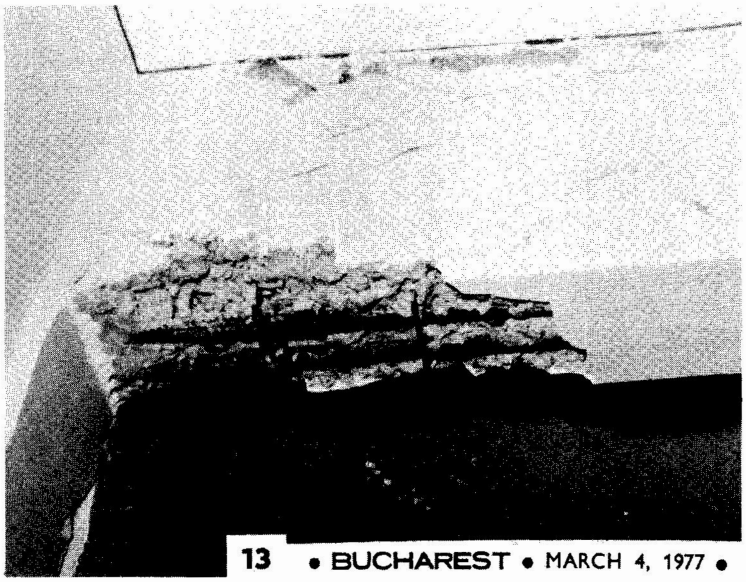
Interior close-up view of the building in photo 9 with partial damage



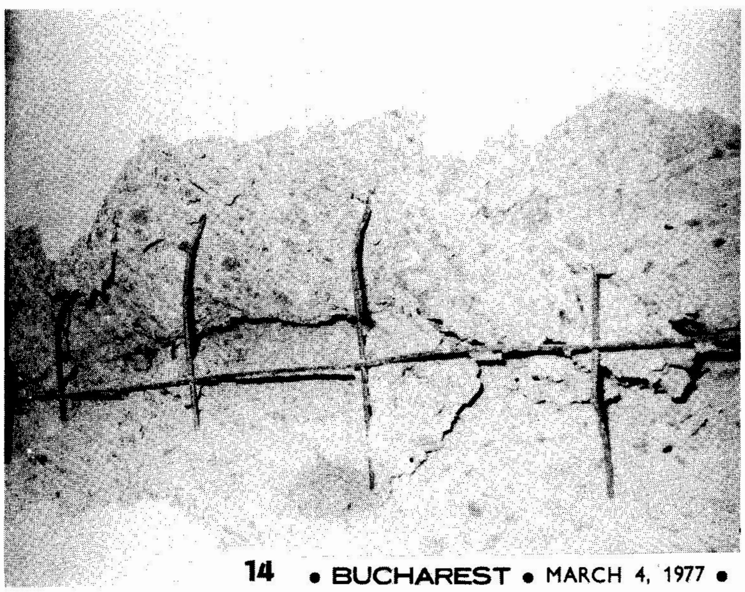
Shear failure in ground floor column



Deterioration of transverse beam at the support

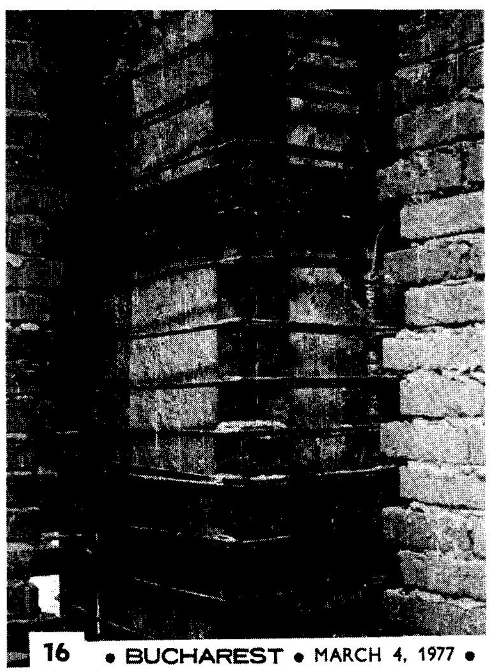


Fractured lintel of reinforced concrete shear wall building

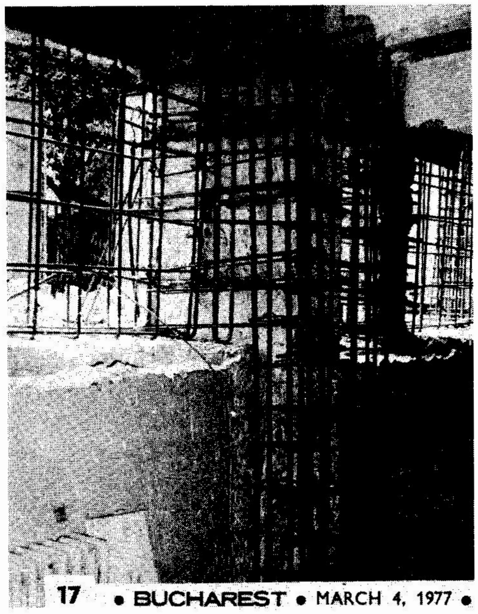


Cracked reinforced concrete shear walls

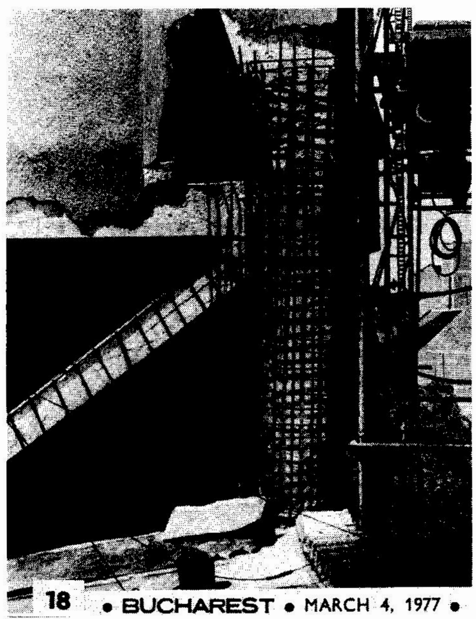
Strengthening of a column and adjoining masonry with reinforcing bars



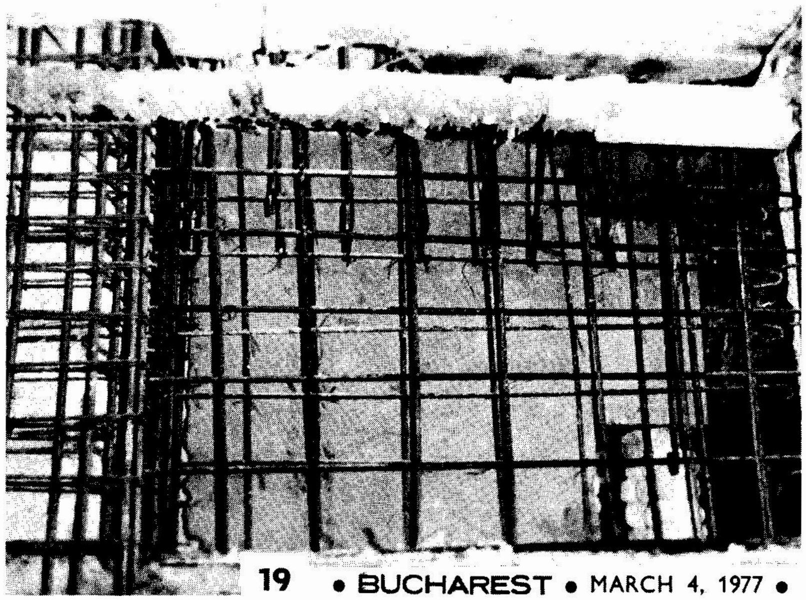
Strengthening of a column



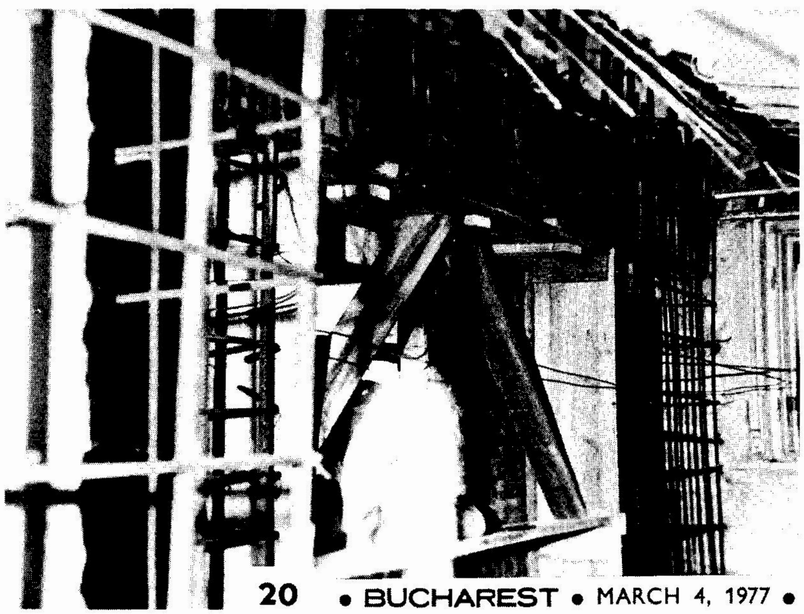
Strengthening of a column and closing of windows in basement of multi-storey building



Partial strengthening in the 3rd storey of an older building



Improvement of resistant capacity to lateral forces of a building not designed to resist earthquake by introduction of reinforced concrete shear walls



Strengthening of a reinforced concrete frame