STRENGTHENING CONCEPT AFTER ROMANIAN STRONG EARTHQUAKE OF MARCH 4, 1977

by

MIHAIL IFRIM[I]

SYNOPSIS

The paper offers some viewpoint on the survey and strengthening of structures damaged by strong earthquake in Romania on March 4, 1977.

The conclusion were based on the long personal experience of the autor and on the lessons drawn from seismic shocks produced in the last years.

1. INTRODUCTION

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 recent earthquake at Vrancea had the following characteristic parameters: coordinates: 45^{o} 34 N and 26^{o} 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.

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.

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

The development of degraded process of structural stiffness is conditioneted both of intensity of earthquake and the shape of response spectra (fig.1). In this situation, the local soil conditions interfere being characterized mainly by predominant period (T_o). That was the reason becouse of the building code requirements was changed in Romania, so it is shown in the particular situation from fig.2.

I. Professor, Ph.D., Civ.Eng.Head of Department of Theoretical and Applied Mechanics. Faculty of Civil Engineering. Bd.Lacul Tei no.124, 72302 Bucharest, ROMANIA.

2. 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.

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.

2.1. 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.

2.2. 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 inadequated) 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.

3. TESTING CRITERIA OF THE EFFICIENCY OF THE RECONSTRUCTION PROCESS

Theoretical and experimental investigations have the purpose of estimation of the stiffness of degraded structures as well as determination of main dynamic characteristics of structures in the damage state. Based on the quantitative and qualitative obtainable data it can draw up the strengthening solutions taking into account a certain level of seismic safety (pre-established).

A. By means of numerical analysis, 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 free vibration produced by transient actions of short duration.

Generally, the efficiency coefficient of strengthening may be expressed as

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

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.

CAPTIONS

Fig.1. The interdependence between the shape of acceleration spectra, stiffnes-degrading of structures and the variation of the action intensity, during of the earthquake.

Fig.2. The correction of total lateral force coefficients (base-shear coefficients) after. Romanian earthquake of March 4, 1977) for Bucharest area.

Fig.3. The strengthening of a 7 stories building in Bucharest (r/c frame structure) having moderate stiffness-degrading. Efficiency coefficient of strengthening obtained E.C.S. = 1,63.

Fig.4. The strengthening of a 13 stories building in Bucharest (r/c frame structure) having moderate stiffness-degrading. After the strengthening it has resulted E.C.S. = 2,19.

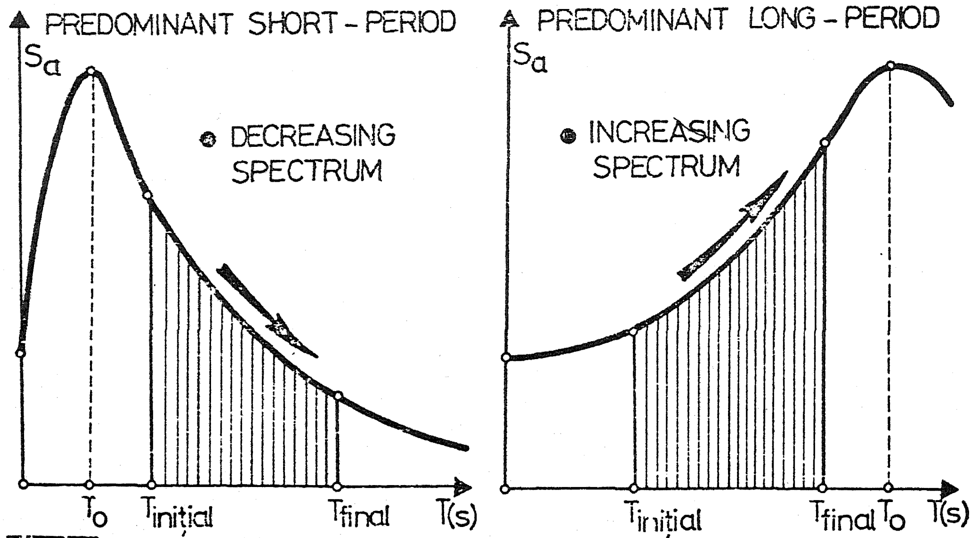

Fig.1 STIFFNES - DEGRADING STRUCTURES

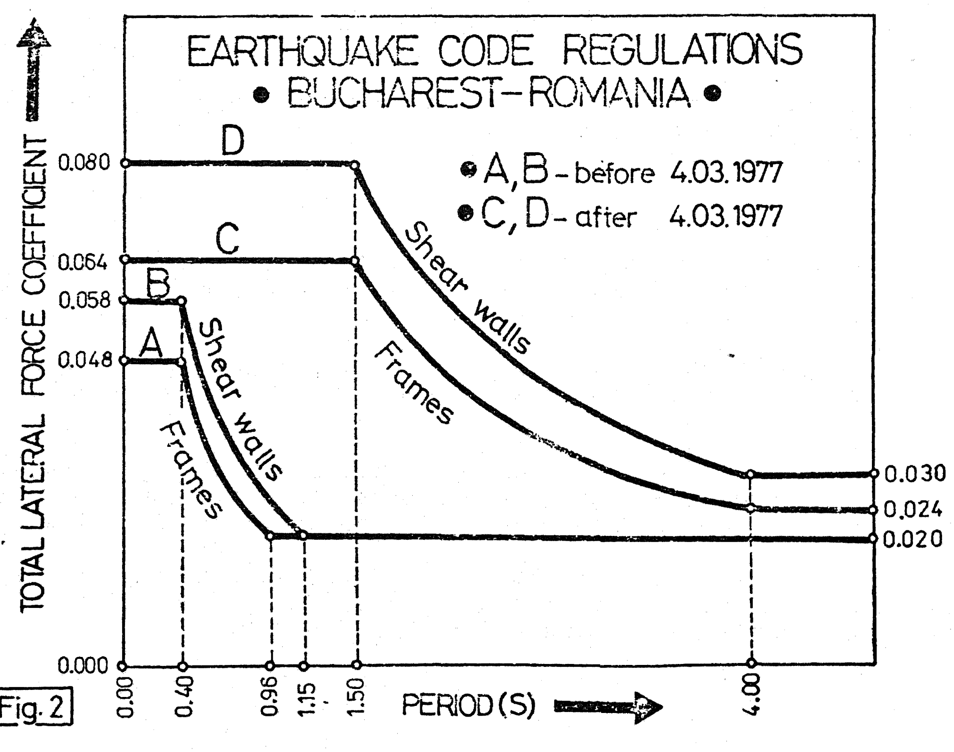

Fig. 2

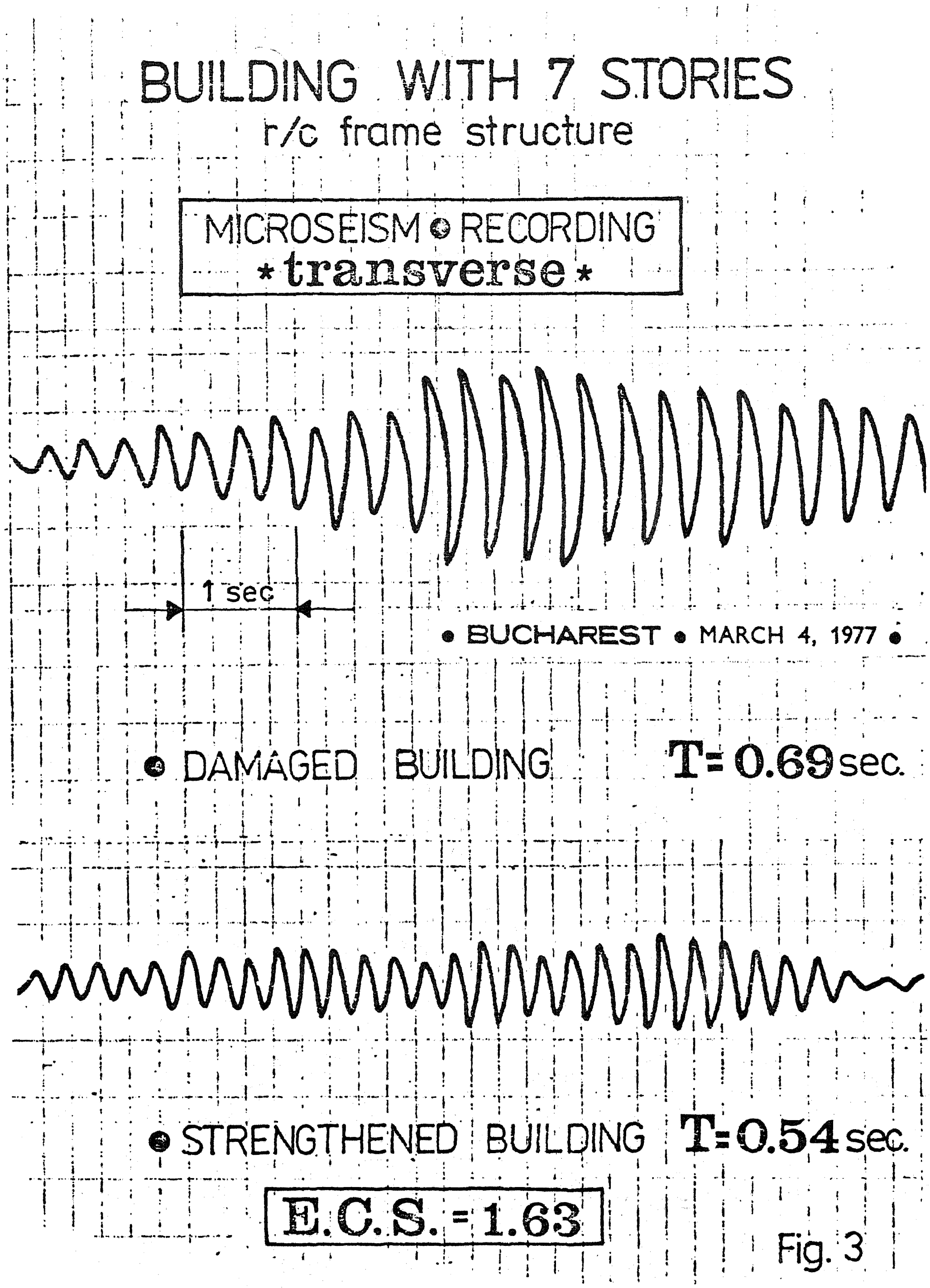
BUILDING WITH 7 STORIES
r/c frame structure
MICROSEISM RECORDING
transverse
1 sec
BUCHAREST MARCH 4, 1977
DAMAGED BUILDING T= 0.69 sec.
STRENGTHENED BUILDING T=0.54 sec.
E.C.S. = 1.63

Fig. 3

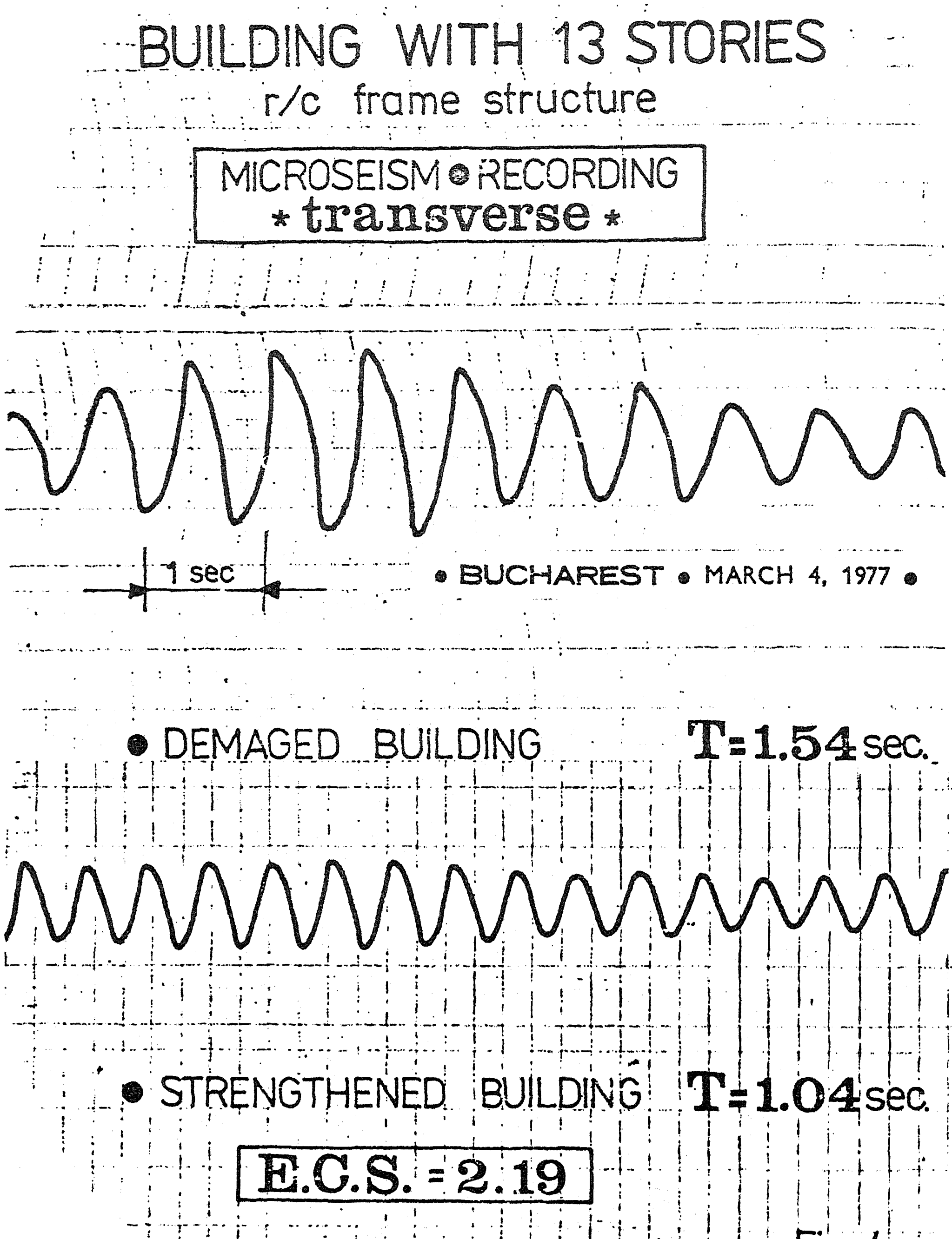
BUILDING WITH 13 STORIES
r/c frame structure
MICROSEISM RECORDING
* transverse *
1 sec
• BUCHAREST • MARCH 4, 1977 •
• DEMAGED BUILDING
T=1.54 sec.
• STRENGTHENED BUILDING
T=1.04 sec.
E.C.S. = 2.19

Fig. 4