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Institute of Earthquake Engineering and Engineering Seismology
University "Kiril and Metodij" – Skopje

SEISMIC RISK ASSESSMENT AND MEASURES FOR REDUCTION OF EARTHQUAKE CONSEQUENCES IN URBAN REGIONS

By

Predrag GAVRILOVIĆ, Dr. Sc., Professor
Zoran MILUTINOVIĆ, M. Sc., Assistant Professor

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ABSTRACT

The increasing urbanization and the enormous growth of urban regions accompanied by a high concentration of population is greatly influencing the level of seismic risk although there are no any basic changes in the seismic hazard the considered region is exposed to.

Regarding to these considerations, this paper is presenting an integrated model for assessment of the seismic risk, generally based on seismological and instrumental data, regional and local studies as well as damage data and experiences obtained from past earthquakes that can be transmitted in the region under consideration.

Correct engineering estimation of the seismic risk level a given region is exposed to, enables the engineers, urban planners, public policy makers and administrators to elaborate in advance proper safety plans for an immediate rehabilitation and investigation of the affected region or to elaborate a seismic protection plans in order to mitigate the possible consequences.
The paper is also discussing in general the pre-earthquake and post-earthquake measures and activities that should be undertaken by the society in order to decrease the vulnerability and mitigate the seismic risk. Also, basic criteria for design of earthquake resistant structures are presented in order to underline the engineering approachfor reducing the overall vulnerability level of new developments. The Appendix to this paper summarizes the earthquake damage and usability classification of buildings developed and later employed during the Montenegro, Yugoslavia earthquake of April 15, 1979.

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INTRODUCTION

Under the conditions of permanently existing seismic danger, the increasing urbanisation and the enormous growth accompanied with high concentration of population it is greatly increased the seismic risk in cities. Such an increase of the seismic risk without any basic changes of the seismic hazard potential itself requires performance of studies of the seismic risk associated with urban regions (urban seismic risk) rather than seismic risk on isolated structures. The output of these studies should include appropriate estimators to represent the vulnerability of groups of existing types of structural systems used in modern housing or new developments, as well as in convenience of design regulations and codes according to which their design has been performed, policy of urban and regional planning, for the purpose of developing a uniform pre-disaster assessment tools for effective mitigation programmes and uniform post-disaster assessment tools including rehabilitation and revitalisation of economic and social activities, etc..., creating the rational and consistent framework in which decisions can and should be made.

The year by year developments of earthquake engineering have enabled the countries exposed to high seismic hazard to decrease overall vulnerability of populated regions by relocating highly vulnerable structural systems according to new policies in urban planning or by replacing conventional types of structural systems with modern ones designed and constructed according to newly developed seismic regulations and codes. However, there still exist a large number of so called 'traditional' types of structures and structural systems designed by taking into consideration only the effects of the gravitational loads. This makes the overall process of improvement too slow and any moderate to severe earthquake attack will continue to bring high seismic disaster expressed in terms of damaged or lost structures and lifeline systems, losses of human lives, other direct and indirect losses with long and short contraversal effect terms on the regional economy. Therefore the principal goal of engineers, urban planners, public policy makers and administrators is to consider rationalities for earthquake safety programmes in order to protect a region subjected to earthquakes, or to enable immediate and effective rehabilitation and revitalisation of industry, economic and social activities in the stricken region.

1. SEISMIC RISK ASSESSMENT

Following the definitions proposed by UNESCO (1976, 1977 and 1979) the seismic hazard is defined as a probability that the seismic intensity I will exceeded in a period of T years, where under the term seismic intensity any qualitatively or quantitatively defined parameter related to earthquake magnitude M as a measure of seismic phenomena, can be employed. The hazard parameter I may be modified Mervally intensity (MM), response spectra (RS), peak ground acceleration (PGA) or any other parameter of engineering segnificance; and for the region of interest it is a function of seismicity (i.e. probability of earthquake occurrence $P[M]$) and attenuation $P[I/M]$ (i.e. loss of seismic energy from earthquake source to the site under consideration), mathematically formulated as:

$$\text{SEISMIC HAZARD} = P\,[I] = \int P\,[I/M]\;P\,[M]\;dM$$

The vulnerability $P\,[D]$ is defines as probability or degree of loss to a given element at risk, or set of such elements under a specified level of seismic intensity and can be generally formulated as:

$$\text{VULNERABILITY} = P\,[D] = \int P\,[D\,/\,I]\;P\,[I]\;dI$$

However, information on vulnerability of various elements at risk are less potential and less reliable than the information that is usually available on the seismic hazard itself, since various categories of data are required, related not only to the degree of economic and social disorganisation that may take place. Therefore there is still a need for collecting, assembling and publishing of information, as much as possible, on damage to various elements at risk that have occurred in past earthquakes.

Finally, seismic risk is a qualification of vulnerability of given elements at risk, or set of such elements. It is a probability of loss $P\,[\text{loss}]$ and is formulated as:

$$\text{SEISMIC RISK} = P\,[\text{LOSS}] = \int P\,[\text{LOSS}/D]\;P\,[D]\;dD$$

where P {loss} is the value term which can be widely understood. It is a qualification of consequences of natural phenomena, or a qualification of the capital investments to be involved in advance in order to mitigate the total penalty caused by seismic disaster.

An integral model for assessing the expected seismic risk of considered region shoul involve the following basic steps:

- evaluation of seismic hazard;
- identification of elements at risk;
- derivation of the appropriate vulnerability functions for given elements at risk, describing interrelation between the specific loss and seismic hazard;
- evaluation of the specific seismic risk per element at risk and its participation factor in the existing volume of properties; and
- evaluation of the total seismic risk for the considered region.

Out of the three factors determinig the seismic risk: the value of the elements at risk, their vulnerability i.e. their specific loss potential and the seismic hazard, only the first two are under the human control and they can be therefore controlled by the pre-disater risk management, risk mitigation programmes or pre-disaster prevention programmes. Although it is possible to control efficiently the value of elements at risk by relocating a seismic-exposure-sensitive elements at risk to regions of lower seismicity, it is still necessary to provide economically justified practical measures for protection of the rest of elements at risk, which, due to favourable natural conditions, have to be located in the regions with higher seismicity. For the later case, depending on the level of the economic development of the considered region or the entire country, a level of acceptable risk should be estimated and defined through the level of expected vulnerability.

Considering an earthquake as a sudden phenomenon occurring [illegible] which can cause [illegible] economic loss to an area stricken by it, it is necessary to [illegible] the exposed vulnerable elements at risk, or in other words, to define [illegible] model of the considered region.

A direct loss model, Fig. 1.1, usually refers to physical damage expressed in terms of human casualties and injuries, damage to local infrastructure (road and river systems as well as water and gas supply, etc.), residential and other types of building structures or any other property or material goods owned by the state or enterprises lost or damaged during or immediately after an earthquake event.

Besides the physical damage and functional disorder caused by its appearance there are also categories of indirect effects of earthquakes which can be generally classified into economic and social damage, Fig. 1.2. Stagnation of industrial activities, decreasing of industrial production, regional revenue and extra expenditures for immediate rehabilitation of the stricken area, are classes of typical indirect economical losses. Interruption of transportation, water and electric power supply systems, decrease in civil and information services as well as unfavourable reputation of the damaged areas can be considered as classes of typical social damage.

To estimate correctly the type of possible disaster as well as the level of capital investment that should be placed in advance for mitigation of earthquake consequences or payed as penalty by the whole society due to earthquake occurrence, it is necessary to formulate a long term effects model of earthquake losses. It can be efficiently done, Fig. 1.3, by complying the direct loss (Fig. 1.1) and indirect effects (Fig. 1.2) models through interrelation and a time-series estimation of economic effects induced by direct losses and considering, as well, an adjusting mechanism between the unaccelerated supply of productivity due to earthquake-induced damage and the accelerated demand of investment for repair and reconstruction of the stricken region.

The achievement of the stated goals - development of earthquake loss model including various elements at risk and finally, assessment of seismic risk for a considered region are strictly dependent on data for damage from past earthquakes. Particular attention and emphasis should also be payed to derivation of vulnerability functions (relation between the specific loss and the seismic intensity descriptor) since they are the most sensitive step of any procedure for seismic risk assessment.

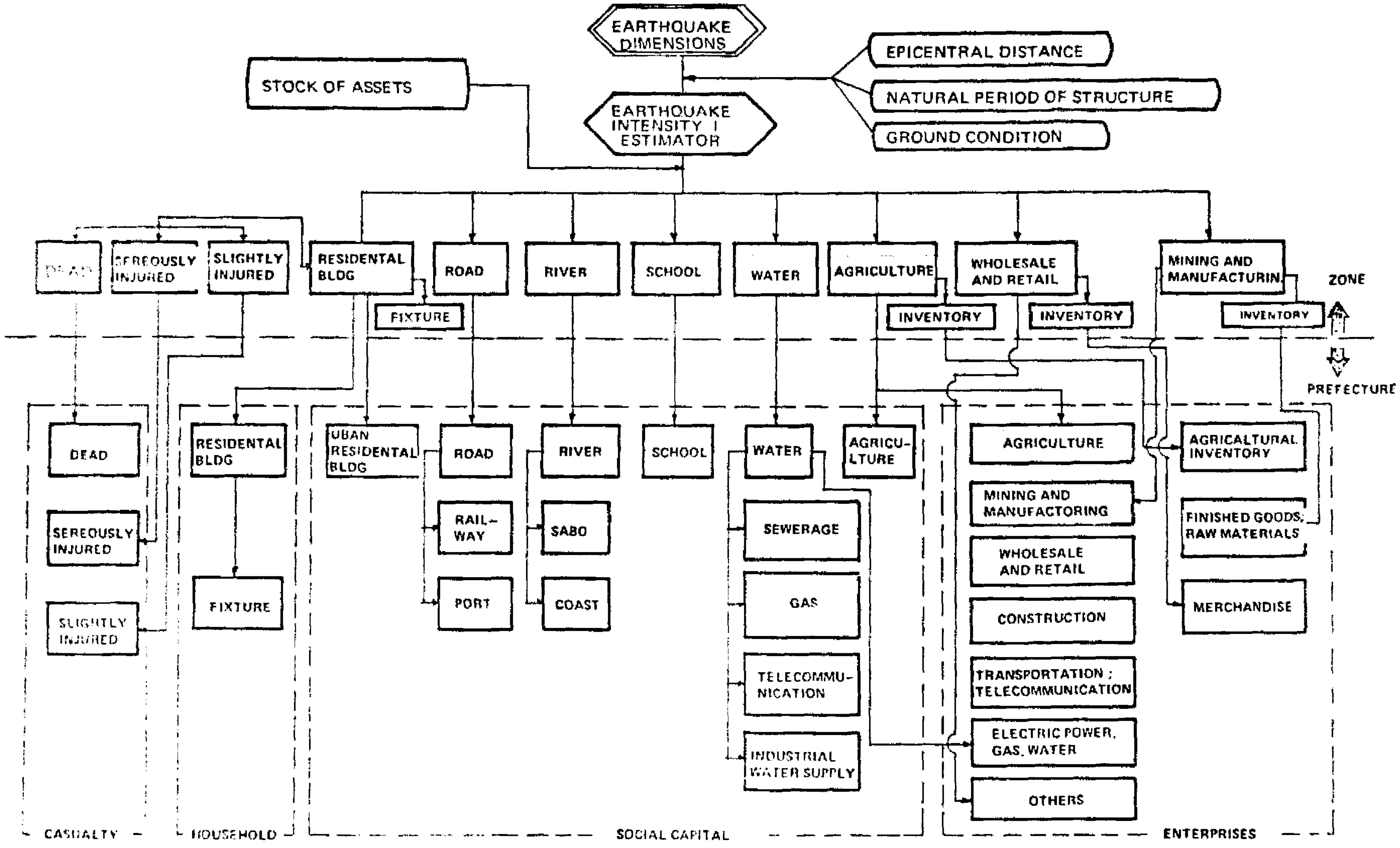

Fig. 1.1. Direct Loss Estimation

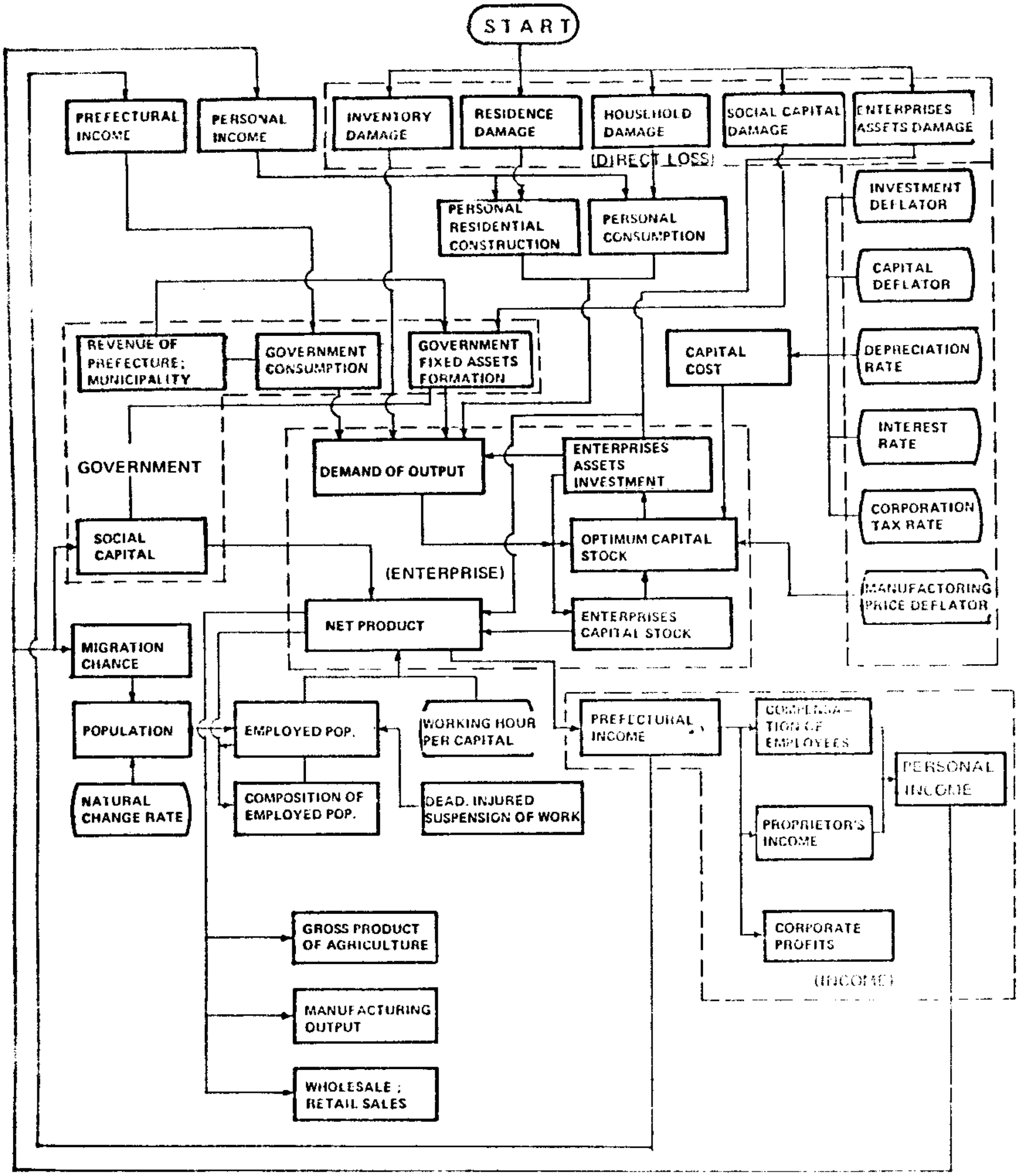

Fig. 12. Indirect Effect Model

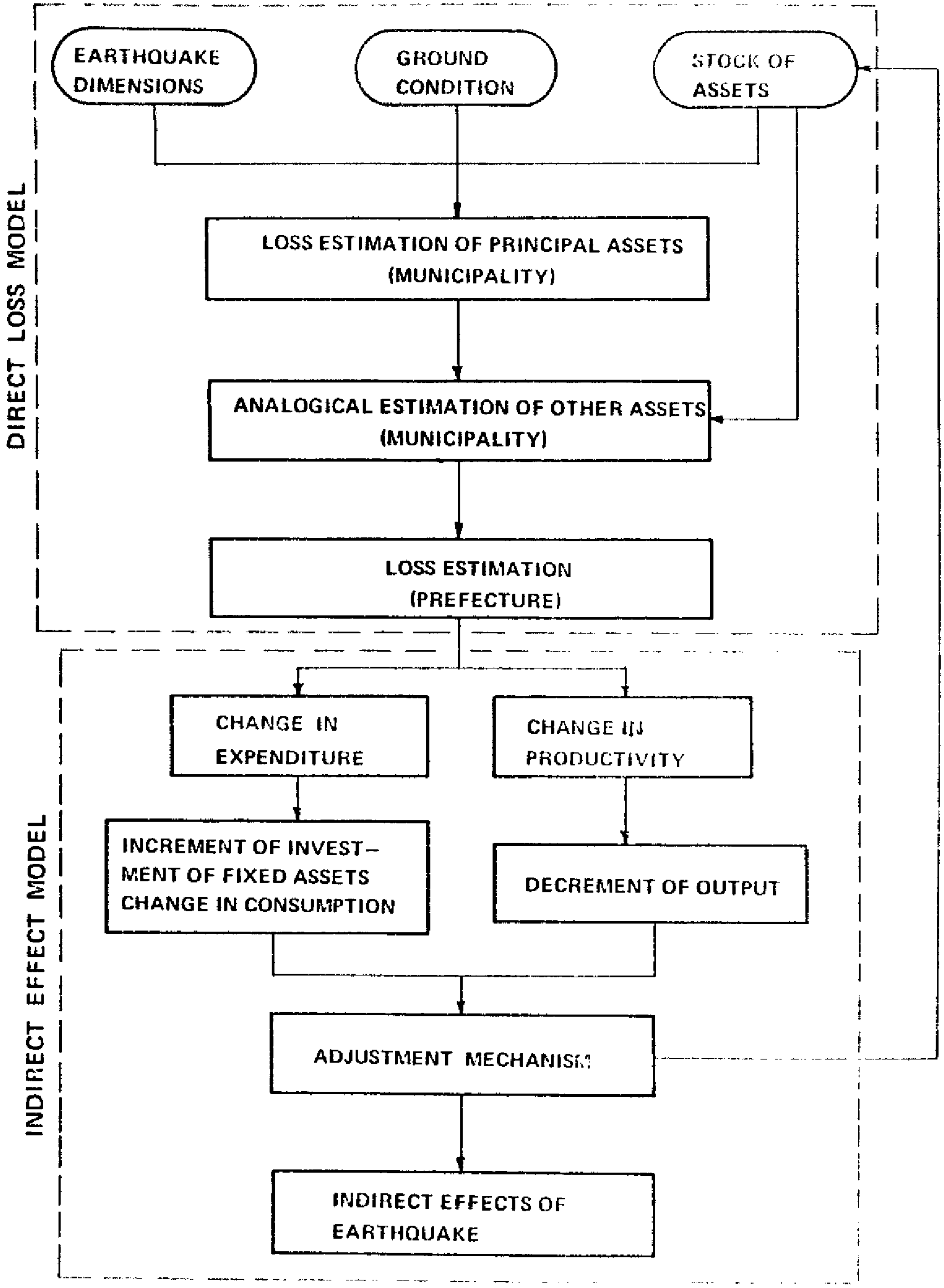

Fig. 1.3. Structures of Direct Loss Model and Indirect Effect Model

2. MEASURES FOR REDUCTION OF EARTHQUAKE CONSEQUENCES AND MITIGATION OF SEISMIC RISK

Due to recent catastrophic earthquakes in the Mediterranean region, a large number of residential buildings, schools, hospitals and other public, administrative and industrial buildings, as well as other facilities of local and regional infrastructure have been severely damaged. The largest number of the damaged buildings are in the state that their use is not permissible before adequate repair and strengthening of the basic structural system, nonstructural elements and installations. In order to assure appropriate safety and normal functioning of the damaged buildings, it will be important to recognize that these buildings will be exposed in future to a large number of small and moderate earthquakes and with significant probability to catastrophic earthquakes with large magnitudes, similar to those in the past. In order to meet the requirements for economic development and aseismic design, systematic scientific and applied research should be carried out for the purpose of seismic risk evaluation, definition of economically justified and technically consistent design criteria, and improvement of structural systems, capable to withstand the expected earthquake effects.

However, the experience gained from past earthquakes has shown that similar measures can be undertaken in advance in regions with high seismic hazard potential in order to mitigate the possible earthquake consequences. For this reason, it will be essential that in the stage of master, physical and urban planning of these regions incorporate safety criteria, which are based on determined and economically justified levels of acceptable seismic risk assuring that estimated damageability levels permit safe and undisturbed use of engineered structures, facilities, life lines and other structures of vital importance, thus providing an acceptable seismic protection against the expected disaster.

For the purpose of reduction of earthquake consequences and mitigation of seismic risk, pre- and post-earthquake measures as well as short- and long term studies and actions should be organized by the governement authorities and professionals. The basic steps of these studies and actions will be summarized briefly in the following:

2.1. Pre - Earthquake Measures and Activities

Earthquake protection is well recognized and implemented with improvement of seismic zoning maps, strong-motion instrumentation networks, seismic microzoning studies of urban areas and sites of important projects as well as improvement of seismic design and construction code and regulations. These improvements are mainly associated with new structures which are much smaller in volume than the existing nonaseismic structures. It will be not realistic to assume that economic potential of the Mediterranean countries in the visible period of time will create conditions for significant reduction of seismic risk on existing nonaseismic buildings, structures and utilities. Therefore, for earthquake-prone regions, it is necessary to organize continuous and prolongated observations to obtain realistic data that will be needed for elaboration of pre-disaster civil protection plans, rehabilitation and revitalization plans, considering the existing stock of exposed material goods. On the other hand, the obtained data should be implemented for decreasing of over-all vulnerability towards exposed material goods by improving and strengthening the existing stock of buildings as well as by improving the design procedures and quality of construction of new developments. All these information should be incorporated in elaboration of master, physical and urban plans of earthquake hazard exposed regions.

Pre-earthquake measures that should be undertaken in seismically active regions includ:

- Studies on seismicity of the region considering instrumental and historical data of occurred earthquakes;
- Elaboration of a neotectonic map with evaluation of dynamic neotectonic processes;
- Elaboration of a seismotectonic map for the region;
- Elaboration of seismic hazard maps of the region for different acceptable levels of seismic risk for planning, design and construction;
- Physical planning of seismic regions based on damage evaluation and vulnerability studies.

- Evaluation of expected vulnerability and acceptable seismic risk level with requirements of counter-measures for protection;
- Elaboration of Code, instructions and manuals for aseismic design and construction of different types of structures, retrofitting of existing structures and other specific general requirements;
- Elaboration of seismic microzoning maps for significant urban areas;
- Studies for planning, design and construction of structures of vital importance;
- Elaboration of laws and regulations for counter-measures against large-scale earthquakes;
- Development and installation of strong motion network;
- Improvement of the network of seismological stations with telemetered and computerized systems for rapid collection and analysis of earthquake data.

All these pre-earthquake studies and activities in seismically active regions should be performed in order to:

- Improve scientific basis for physical and urban planning and general planning for reduction of earthquake consequences and mitigation of seismic risk;
- Obtain appropriate information on the magnitude of the disaster in terms of number of usable, damaged and dangerous buildings for the purpose of immediate protection of human lives, housing of the people and performance of the basic life activities in the affected region.
- Provide data for planning and organization of civil defence system and elaboration of plans of resque operation after earthquake disasters, training of staff, and organization of supplies.
- Assure data base for uniform estimation of economic losses for developemnt of appropriate rehabilitation programmes and efficient assistance in reconstruction and development of regions expected to be affected.

2.2. Post - Earthquake Measures and Activities

In earthquake prone regions a uniform post-earthquake assessment tools should be used to achieve both, scientific and practical goals through co-ordinated efforts of the civil protection centers and the teams of engineers-specialists. Depending on the size of disaster, a post-earthquake measure that should be undertaken includes: (1) emergency measures for an immediate protection of population and other material goods placed in jeopardy by the seismic activity as well as rehabilitation of serviceability of vital life line systems, (2) short trem measures that have to be undertaken for obtaining more practical and also transferable data that can be of potential use for development of revitalization and long-term rehabilitation programs, and (3) long-term measures that should provide enough large volume of data to be used in development of seismic safety and seismic risk mitigation programs.

Emergency measures that have to be carried out immediately after a disastrous earthquake takes place can be summarized as follows:

- Establishment of centers which will carry out emergency protection measures in each city, village and institution;
- Extinguishing of fires in the first stages by voluntary people and fire-protection by professional staff;
- Emergency rescuing of people
- Evacuation from densly populated and dangerous places
- Establishment of centers for food supply and organization of other emergency activities;
- Organization of temporary housing, medical centers, schools and other public utilities based on the immediate needs;
- Removal of ruins, demolishing and clearing out of structures or parts of buildings apt to failure being a direct or indirect danger for the population.

The following are the short term studies and activities for reduction of earthquake consequences:

- Classification of buildings, structures, local and regional infrastructure according to the usability and level of damage using uniform methodology for damage classification.
- Planning of temporary housing, organization of medical centers, supplies, schools and other public activities.
- Studies of earthquake effects and damage distribution.
- Seismic activity studies with existing and temporary installed seismic stations and immediate installation of strong motion accelerographs and seismoscopes for recording of stronger aftershocks.
- Seismic records data collection and analysis for the purpose of elaboration of seismic design criteria for repair and strengthening of damaged buildings and structures.
- Elaboration of requirements and instructions for repair and strengthening of damaged buildings and structures.
- Reconsideration of physical and urban plans with mapping of spatial distribution of earthquake effects.
- Estimation of earthquake damage value, planning of financial and legal actions for reduction of earthquake consequences.
- Urban planning for construction of new settlements for housing, bedical centers, schools and other public utilities based on the immediate needs, existing usable buildings and future urban development.
- Execution of repair and strengthening of damaged buildings and demolition of heavily damaged buildings, with parallel elaboration of site investigations and designs for repair and strengthening.

It should be noted that postearthquake damage evaluation should be organized with implementation of a systematic methodology and rapid procedure in order to establish basic information for the local and national governmental authorities for decision making and undertaking of economically justified and technically consistent measures for reduction of earthquake consequences in uniform manner for the entire region. Based on the uniform methodology and procedure as presented in the appendix to this paper, more practical and transferable data can be developed that are of potential use in the Mediterranean region as well as other seismically active regions in the world.

Principal elements for establishment of uniform methodology and procedure for post-earthquake damage evaluation such as: damage and usability classification of earthquake damaged buildings, procedure and organization of data collection, earthquake damage data analysis and organization of data bank, estimation of economic losses, human fatalities and injuries, as presented in the appendix, are developed and implemented during the studies performed on the effects of Montenegro, Yugoslavia earthquake of April 15, 1979.

Long term measures and activities in earthquake affected regions basically do not differ from pre-earthquake measures described under item 2.1, but basically all data and results obtained from short-term activities, particularly the data on damage distribution and classification as well as observed vulnerability of various structural types and other engineered facilities should be consistently implemented for decreasing of the seismic risk in the case of repeated seismic activity that normally should be expected.

3. BASIC CONCEPT, CRITERIA AND APPROACH FOR EARTHQUAKE RESISTANT DESIGN

The general problems involved in predecting seismic responses of a building are symbolically defined and schematically illustrated in Fig. 1. The structural engineers are concerned with predicting the response (symbolically indicated as a X_4 in Fig. 1) due to the shaking (vibration) of its foundation (X_3 in Fig. 1). As shown in Fig. 1, $X_4 = X_3 . D$, where D is dynamic factor, $X_2 = X_1 . A$ is amplified seismic wave of the bedrock X_1, which accounts for the local soil effect influence, thus $X_1 = f_1(R_1, M_1)$ is seismic ground motion in function of earthquake magnitude, source distance and depth, as well as type of fault and earthquake origin. Although it is a simplified presentation it can be clearly seen the necessary approach for definition of the seismic parameters as input data for prediction of structural response to strong earthquake effects, such as :

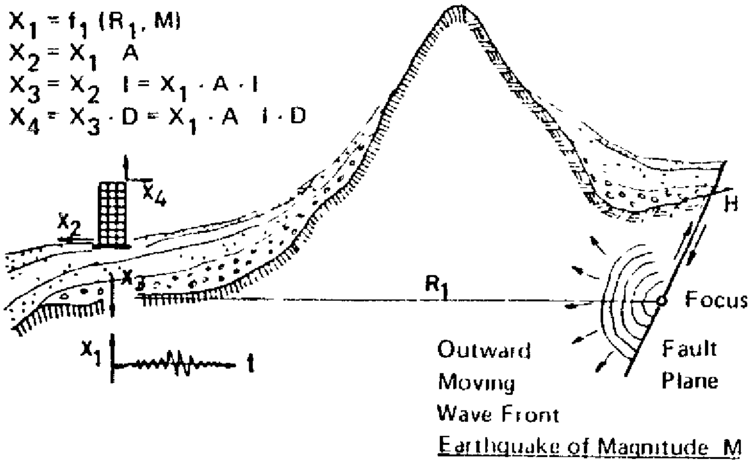

Fig. 1. Factors involved in predicting seismic response

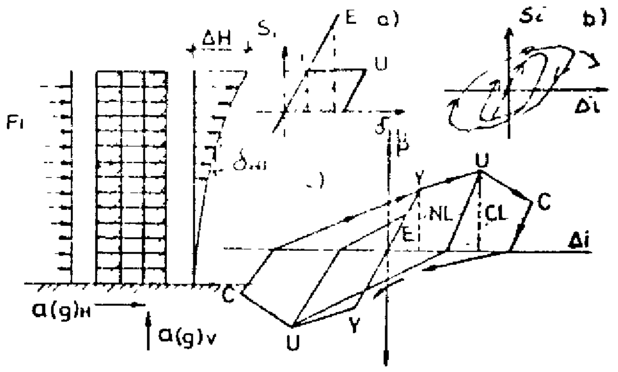

Fig 2 Earthquake response of structure

(i) Regional investigations, which based on the geotechnical structure of the region, define active and potential faults, then a study of the earthquake phenomenon, strong ground motions in the epicentral zone, particularly, in order to predict their intensity, frequency and amplitude content and recurrence period. This could be achieved by collecting strong ground motion data for the purpose and the establishment of a strong motion recording network is required and suggested.

(ii) Studies for evaluation of seismic risk and earthquake design parameters based on the seismic history and regional seismo-tectonic investigation as well as strong ground motion records obtained on bedrock and different types of soil deposits.

(iii) Study of local soil conditions on the basis of geophysical and geotechnical investigations in order to predict amplification and modification of ground motion through soil deposits to the level of foundation or surface layer of soil.

In other words, definition of the seismic parameters for design of earthquake resistant structures can be summarized in determination of expected level of seismic effects on the site (with the acceptable seismic risk level) determined through the maximum acceleration amplitude, frequency content of the earthquake effect as functions of acceleration versus time, velocity versus time and displacement versus time, i.e., spectra of corresponding effects for different values of damping for three levels of seismic intensity :

Level 1 - for an expected earthquake effect of a return period of 50 - 100 years (slight and moderate earthquakes); Level 2 - for an expected earthquake effect and a return period of 200 years (strong earthquakes); and Level 3 - for a maximum probable earthquake effect (catastrophic earthquakes). Such defined parameters represent the basis for determining the individual criteria as well as stability criteria.

The basic concept in the design of aseismic structures is expressed through the expected seismic effect level and the structural response, i.e., structural behaviour during the earthquake defined according to the force and deformation characteristics correlated with the damage level is presented and it means:

(1) For expected earthquakes of Level 1 the structure should be designed to reach elastic range (Fig. 3a) without any damage to the basic structural system and minimum damage to nonstructural elements (partition walls, front wall element, ètc). No interventions are required after the earthquake.

(2) For expected earthquakes of Level 2 the structure behaves beyond the elastic range and reaches nonlinear range, which means that it suffers moderate damage to structural elements (beams, columns and R.C. walls)

(Fig. 3b) and considerable damage to nonstructural elements (partition walls). The structure experiences stiffness deterioration, but damages are repairable and the structure can be used.

(3) For expected maximum or catastrophic earthquakes of Level 3 the structural behaviour is characterized by severe deformations to the structural elements (Fig. 3c-Cl range) but no structural collpse, with heavy damage and partial failure to the secondary infill elements.

Such an approach enables a rational design of earthquake resistant structures which ensures the required safety level, defined by the structural seismic stability criteria expressed through the load carrying and deformability structural characteristics, such as ductility, relative story drift, velocity and acceleration at each characteristic level of the structure elevation, structural ability for energy absorption and dissipation during the seismic effect. The accomplishment of this approach for development of design criteria and seismic stability criteria of any structure is not acceptable at the present level, however, it is inevitable as the basis for elaboration of design and construction Code and for the design of vital structures, typified structures and structures produced in large series (industrialized construction) of large urban units, settlements, new towns and elaboration of microzoning maps of large towns. Such elaborated design parameters for certain regions, for simple structures should be translated to the level of the knowledge of the design engineers through definition of the equivalent seismic forces acting as horizontal forces at the storey levels based on the dynamic structural characteristics and the seismic parameters as a basis for proportioning structural elements to sustain the effect of the equivalent moments, shear and axial forces.

The usual process for structural design is determined through the structural response to ground motion in terms of transmision of the seismic ground vibrations to the structure and this is the most frequently considered acpect especially when seismic design provisions in building Code are followed. However, structures can be damaged due to other earthquake effects: fault displacement, strong ground vibration (shaking), compaction and liquefaction of the soil foundation, landslides, tsunami and other phenomena triggered by some of the above effects, and [illegible] [illegible]. The previous statements show the complex character of the problem and that a classical design concept with determination of gravity and other loads including seismic loads through equivalent seismic forces has been exceeded from the aspect of the required safety level, protection of human lives and material properties. The modern contept should provide an integral approach based on scientific knowledge, natural and economic conditions of the region or the country. Let us return to the problem of structural behaviour prediction during the earthquake, which means that each seismic motion is a random type of vibration, and that the response is defined by the force-displacement relationship (Fig. 2) of earh floor taking into consideration the relative storey displacement δ Hi and the equivalent force S_i variable with the time factor which yields in a cyclic or histeretic structural behaviour (Fig. 2b). Here, it should be emphasized that structural design for critical loads to work in elastic range (Fig. 2a) is not rational and economically justified (this principle is applicable only to very important structures, whose instability can cause considerable consequences: nuclear power plants, dams, etc.) which means that the structure works in linear range up to a certain load level and then it passes to nonlinear range of behaviour (Fig. 2c) up to ultimate bearing capacity, after which collaps occurs which still does not mean falling down of the structure.

It is obvious that such an approach cannot be ensured by Code provisions, since the basic concept of all codes in the world is based on determination of the equivalent seismic forces according to the structural dynamic characteristics and the prescribed spectral curves for definition of the shear force level, which means static consideration of the dynamic structural effects, which requires that by adopting the adequate design procedure and selection of the appropriate materials favourable structural behaviour under dynamic effects is provided. It is only that through nonlinear dynamic response analysis for different frequency contents of the earthquake acceleration and the expected level of the maximum peak ground acceleration a realistic structural response can be predicted with an adequate understanding and modelling fo the mechanical and deformability characteristics of the structure. However, considering the fact that dynamic response analysis of seismic effects is still in the domain of scientific institutions and investigators (due to its complex character and the need for powerful computer systems and special software) applying the results by those and other studies, especially of the cyclic behaviour

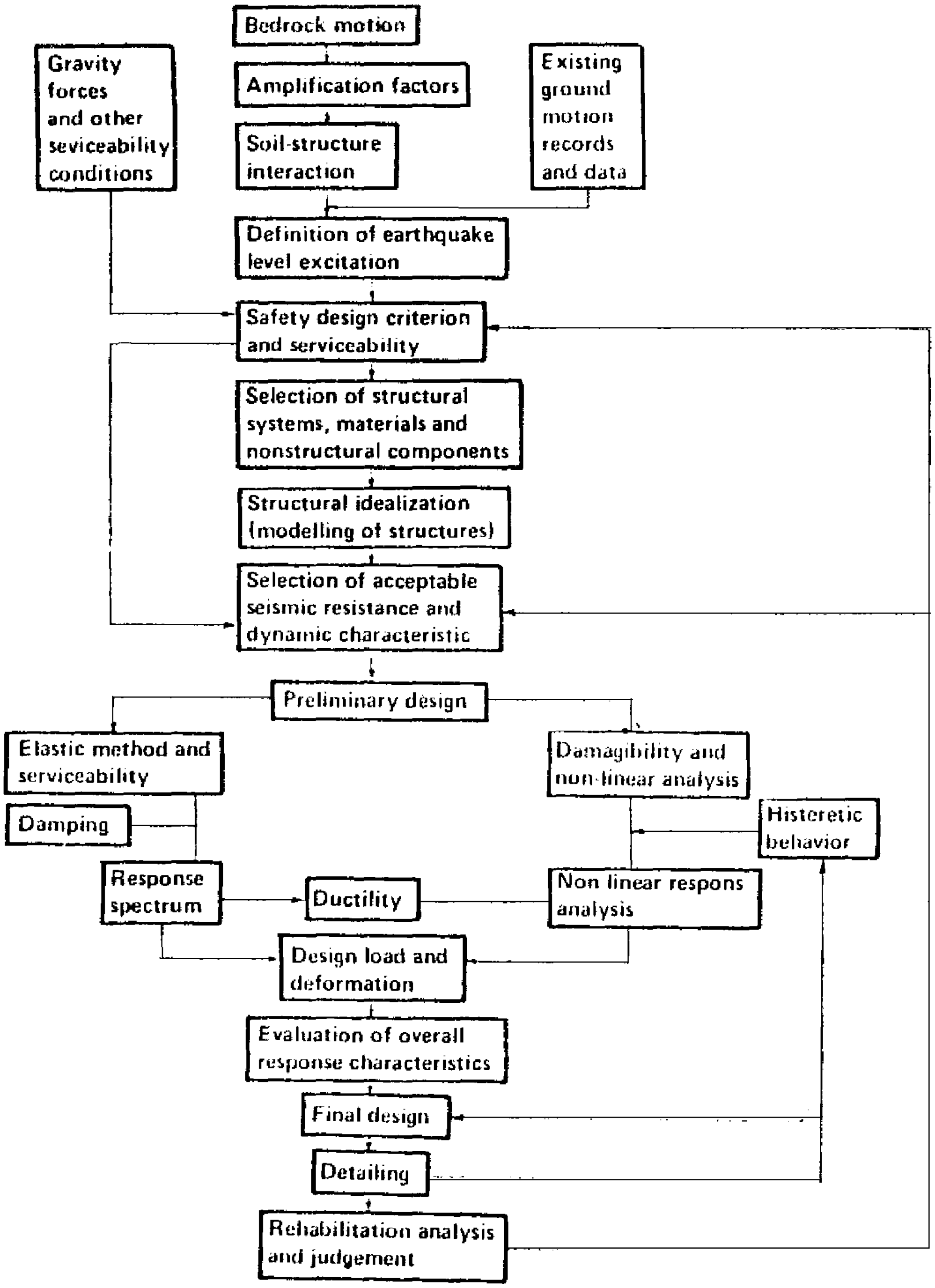

Fig. 3 Flowchart : procedure of seismic resistance design

of elements, components and structures, presented in Fig. 3 is the flow diagram of the general aspects and approach for seismic resistant design.

From the aspect of the actual structural behaviour it has been concluded, based on experimental and analytical studies as well as analysis of earthquake damaged structures, that it is very important to respect the basic design principles, such as: regular bases, avoiding non-regular heights, proper mass distribution, avoiding possible torsional effects, design of details which will follow design failure mechanisms, avoiding brittle failure and failure of frame joints, construction of rigid and resistant foundations, proper control of execution quality.

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