SEISMIC UPGRADING OF HAZARDOUS STRUCTURES*

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ABSTRACT

A critical revision of the philosophies, strategies and technologies used in Mexico in the up grading of hazardous buildings (mainly concrete framed and steel framed), potentially subjected to seismic events is performed. Particular emphasis is given to the discussion of upgrade and retrofit of buildings with the ADAS (Added Damping and Stiffness) system.

RESUMEN

Se hace una revisión crítica de las filosofías, estrategias y tecnología utilizadas en México para la rehabilitación y mejoramiento de edificios que potencialmente estarán sujetos a sismos. Los edificios considerados son los diseñados a base de muros de concreto y acero. Se hace énfasis en los edificios que utilizan el sistema ADAS.

INTRODUCTION

A commonly accepted definition of a seismically hazardous building, is "a building located in a region of seismic risk, which offers real potential for life loss or life threatening injury".

We can also consider a hazardous building any building which its structural framing is inadequately resistant to earthquake forces, either due to its change of use, to its change of categorization according to newer Codes, or due to degradation by subsequent earthquake damages.

In the present work we will refer only to some particular type of buildings, such as concrete framed, steel framed building (with or without unreinforced masonry walls), and we will be disregarding other type of construction. Likewise, we will not cover in the following discussion the risks originated by poorly anchored parapets and appendages or with inadequately anchored exterior cladding and glazing, nor theaters and auditoriums having long-span roof structures.

Thus, those buildings, both with concrete or steel framing, which after having been designed according to old codes and for a certain use, have been found to be inadequate for a different use or unsatisfactory to conform a more stringent building Code, may be considered hazardous. This particular type of buidings would otherwise not necessarily be considered hazardous or unsafe in other situation.

The importance to upgrade hazardous structures is directly related with:

a) Inminent risk of life threatening to ist occupants or adjacent building's occupants.
b) Degree and importance of previous earthquake damage.

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c) Importance of the occupancy of the building.
d) Possibilities of affecting adjacent properties.
e) Code changes which can be considered as mandatory and retroactive.

Other considerations may also imply the necessity of upgrading hazardous structures which are:

f) Possibilities of increasing the income from rentals of the building after renovation and upgrading, at a convenient cost/benefit ratio.
g) Advantages derived from offering an improved image of a seismically safe building.
h) Economic incentives or reducing tha insurance costs after retrofitting, obtaining federal tax benefits, investment tax credits and accelerated repair cost recovery.
i) Special benefits derived fron the expense of rehabilitation and/or retrofitting certified historic structures, listed in the National Register or located in a registered historic district and certified to have historic significance.

The last argument being found of prime importance in the particular case of Mexico city, since the Local Authorities have been estimulating the rehabilitation of a vast historic district with private funds, derived from the "fictitious Sale" of additional nonexisting land area, which will allow the investor to build the required area in compliance with the requirements of the Building Code. Thus, if a certain developer has planned to build a property with a total construction area which exceeds that permitted by the Code, then he has to negotiate with the Government Authorities, what is called "a change of potentiality", which in essence is the fictitious "purchase" from the Government, of that amount of land which is added to the real area of the existing property, that would allow him to meet the Code demands in building the desired total construction area.

Philosophies, Strategies and Technologies used in Mexico in the Upgrading of Hazardous Building.

Several schemes have been commonly used in Mexico City to retrofit structures. Each scheme shows advantages compared to others, depending on the particular situation of the existing structures.

The following discussion concerns the retrofitting of earthquake damaged structures as well as the upgrading of existing structures.

A) Jacketing of reinforced concrete framed buildings.

One of the solutions for rehabilitation of concrete framed building is the jacketing of its structural members (columns and/or beams).

The term jacketing has been known as the addition of a reinforcement surrounding a member which is aimed to enhance its strength and ductility.

Several types of "jackets" area common:

1.- Structural steel members at the element's corners (normally structural angles) tied around the columns and/or beams by welded tie-plates. The oversized external dimension of the member is filled with new concrete adhering to the original concrete of the member.

Little experimental evidence on the performance of this type of rehabilitation exists and some guidelines for the design of this scheme are desirable for the professional practice.

One of the main unknowns is the effective bond between the new and old concrete of the members, as well as the ductility of the rehabilitated joint. The work done by Sergio Alcocer and James O. Jirsa at the University of Texas, has provided valuable information on this technique yet to be complemented by further testing and verification.

The constructibility of this type of rehabilitation is still one of the major problems, since it involves local demolition, temporary shoring of members, drilling through slabs, beams and columns and tight fitting of the jacketing elements, all of which has inherent difficulties of execution. Figure 1 shows typical arrangements of this of jacketing.

2.- Steel reinforcing bars placed either isolated or in bundles at the corners of the columns and beams.

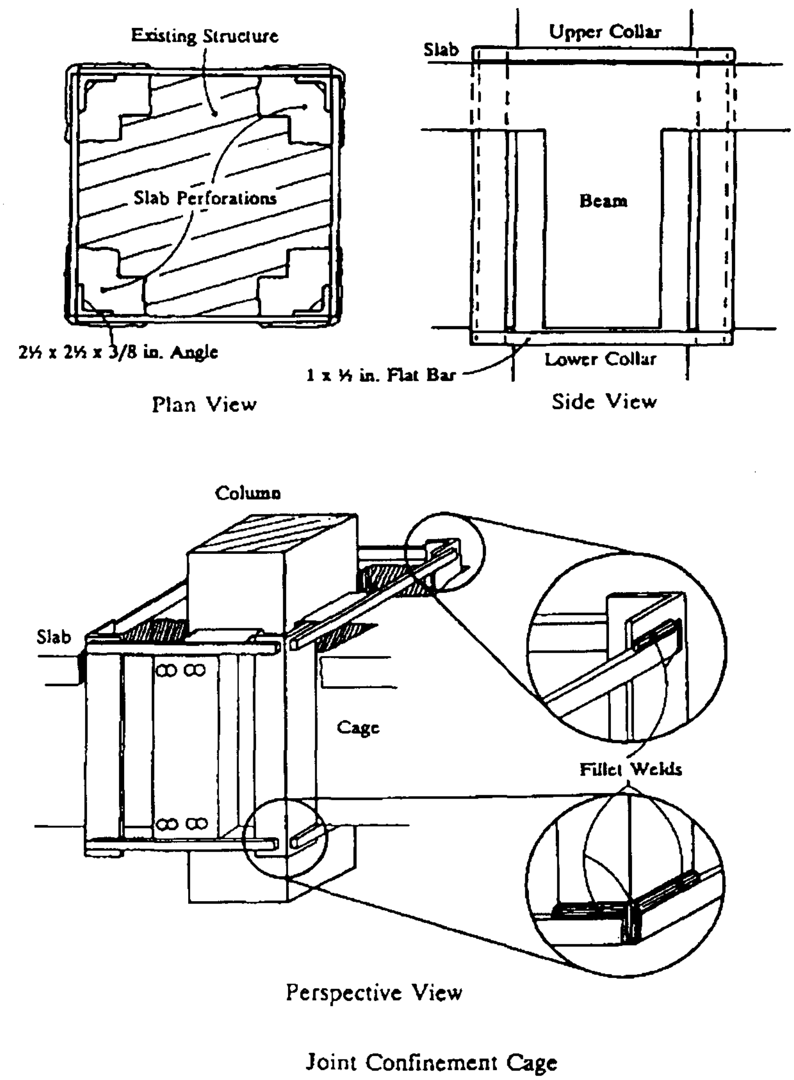

Fig. 1 Typical arrangements of jacketing

This type of jacketing incorporates a steel cage made out of vertical reinforcing steel bars and horizontal tie bars to provide confinement. Such a cage is embedded in concrete, so as to surround the column or beam increasing its original size. (figures 2 and 3).

As in the case of the structural steel sections used for jacketing, serious problems of execution are normally observed in the placing of bars and cages. The concrete pouring demands special care and it is of common practice to use plastisizers (fluidifyiers) additives to increase the slump to about 8-9" (20 to 22 cm) in order to avoid porosities and defects on the new concrete surrounding.

This type of structural rehabilitation also lacks of specific design guidelines. Although Alcocer and Jirsa have accomplished interesting experimentation, soon to appear in a widely known technical publication, there should be a serious commitment on technical agencies and research institutions to recommend a uniform design practice.

The observation of the behavior of structures with this type of retrofitting after strong earthquakes should also provide valuable recommendations for future implementations and designs.

B) Shear wall reinforcement

The rehabilitation of structures by the addition of shear walls in rew locations and/or strengthening of existing shear wall has also been considered as a very common practice to strengthen. And upgrading existing hazardous structures.

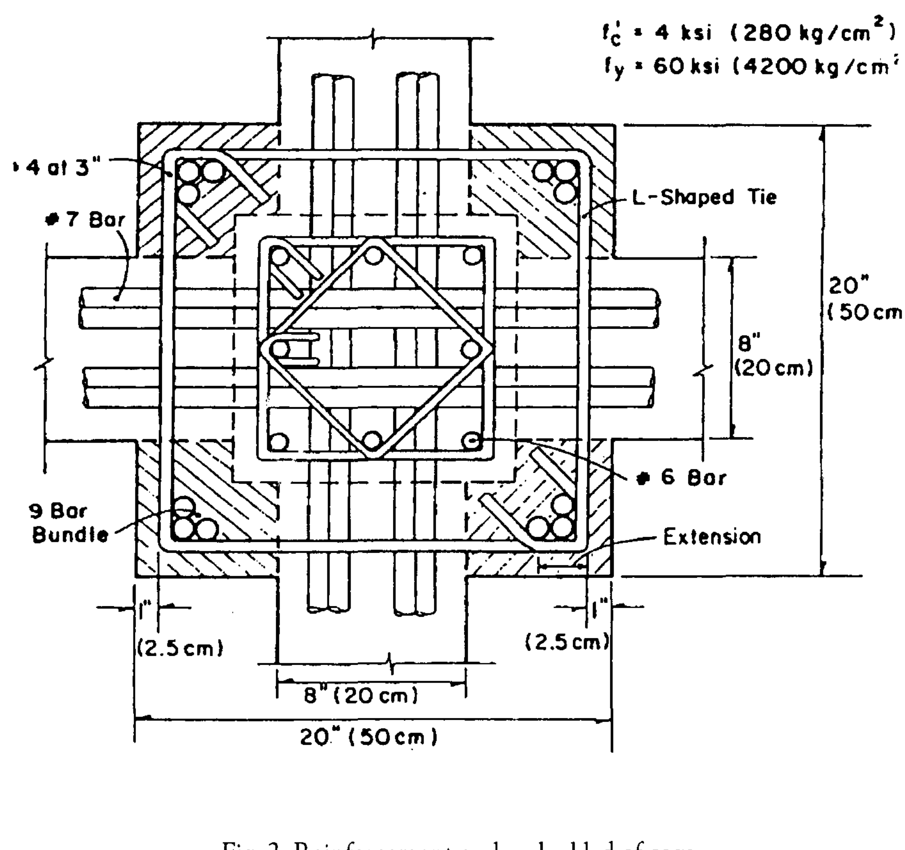

Fig. 2 Reinforcement and embedded of cage

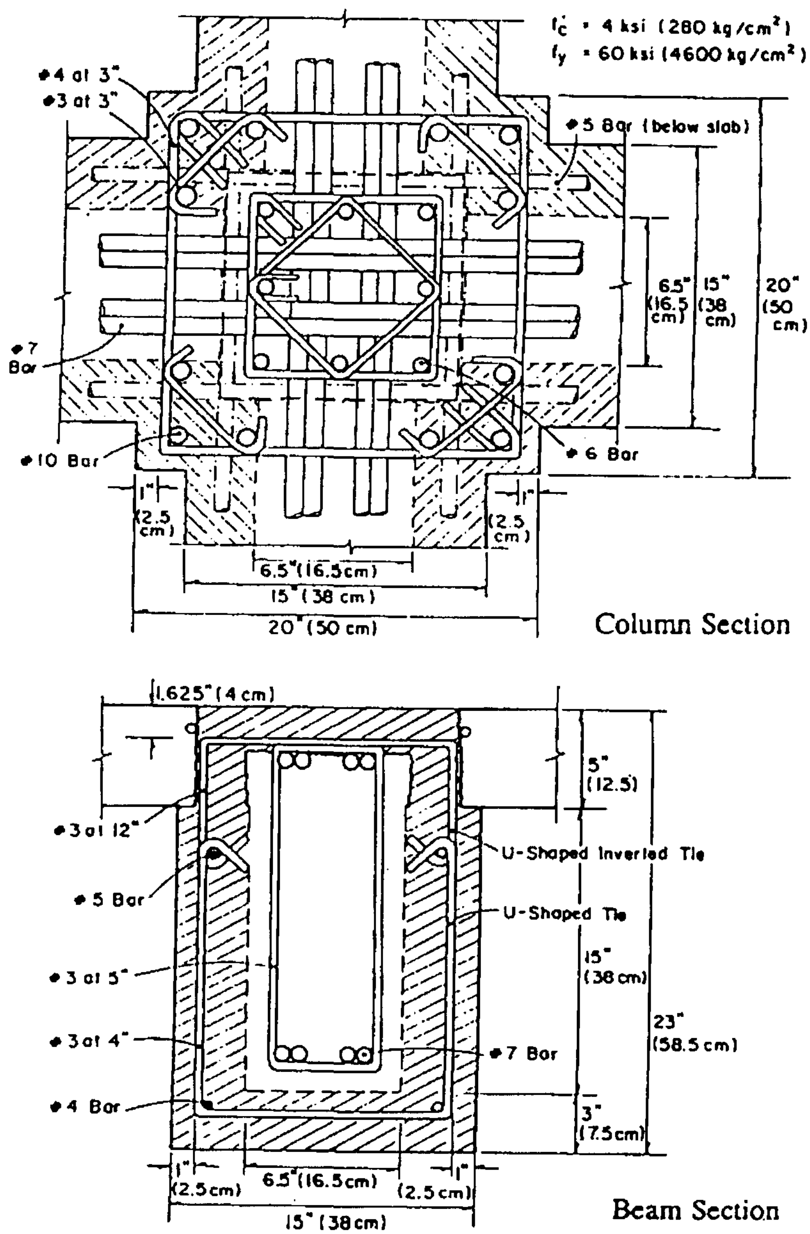

Fig. 3 Reinforcement details

The physical implementation of this type of reinforcement is also complicated since it involves the removal of superficial concrete on the sides of the boundary elements, and difficult placing and anchoring of the steel reinforcement (figure 4).

An offset for this type of rehabilitation is the enormous amount of weight added to the building, and the sometimes excessive loading conditions imposed to the existing building's foundation which in most cases requires special strengthening, typically in difficult soil conditions.

However, this retrofitting practice has gained popularity due to its reliability and apparent economy.

An alternative practice to enhance the strength of existing masonry walls consists in adding shot concrete to the external faces of the wall, which is reinforced with wire mesh "nailed" to the wall and partially embedded in the surrounding structural member of the wall (figures 5 and 6).

Some recommendations have been developed by the research done at the Universidad Metropolitana in Mexico and the Institute of Engineering at the University of Mexico. The National Center of Disaster Prevention in Mexico (CENAPRED) is also coordinating research on this type of reinforcement.

C) Rehabilitation through steel bracing

This particular scheme has been favored in the retrofitting and upgrading of structures for the past years, and has proven to substantially improve the seismic behavior of structures. Del Valle, Rioboo and Rodriguez-Cuevas have pioneered designs with this type of structure rehabilitation.

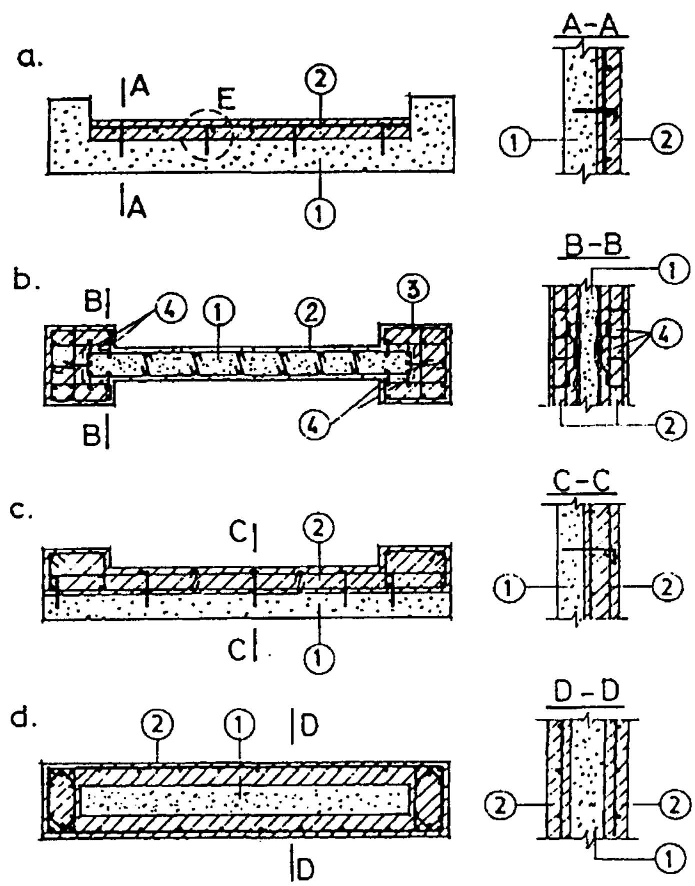

Fig. 4 Physical implementation of reinforcement

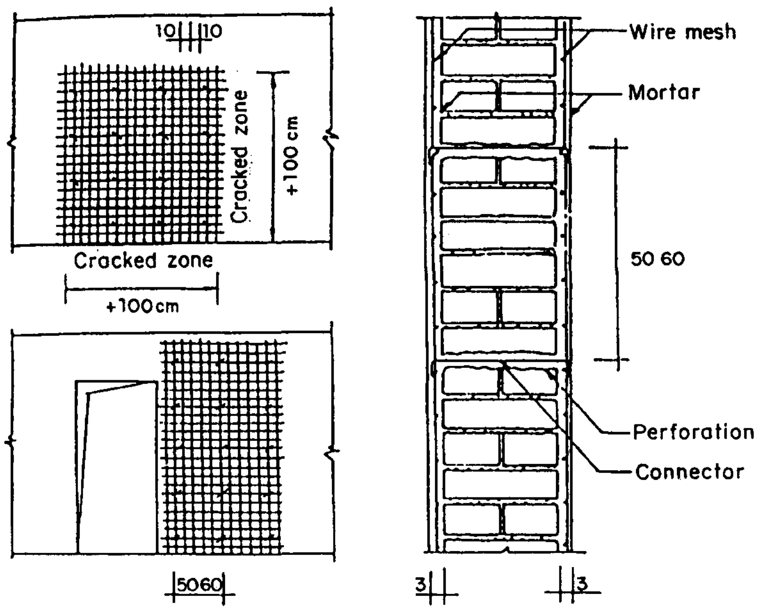

Fig. 5 Alternative to enhance strength

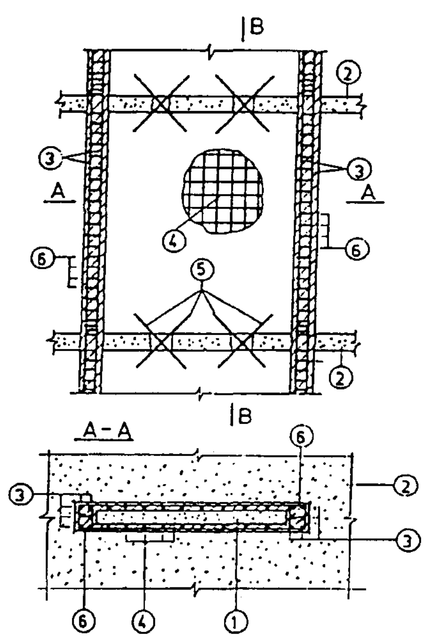

Fig. 6 Alternative to enhance strength

The prime difficulty exists on the connection of braces to the existing structure, which demands tailor made elements for every single position as well as heavy field weldments normally very expensive.

Another issue of consideration es that in many instances buildings are being straightened to a full vertical position at the same time that the braces are being located into its position, originating some overstresses that are difficult to evaluate in the already built braces.

Little is known however, on the ductility of this system and therefore, some extensive experimentation should enlighten this issue and procure design guidelines for a reliable rotrofit.

D) Combination of diagonal bracing and shear wall

Few cases have been applied incorporating this type of structural rehabilitation in Mexico City. However, there is one building with irregular shape located on Reforma Avenue in Mexico City, which features heavy diagonal braces and strong shear wall on its exterior. This building suffered earthquake damage and it was considered convenient to reduce the number of stories as a combined measure with the reinforcement previously mentioned.

It has not been possible to investigate on the conditions which originated this type of heavy reinforcement which has demanded substantial strengthening of the building's foundation, all of which make questionable its economic justification.

E) Upgrade and retrofit of buildings with energy dissipation devices

This novel type of reinforcement has been incorporated in three major buildings in Mexico City: one of them in the process of rehabilitation and two more already implemented.

The ADAS (Added Damping and Stiffness) elements have been incorporated in specific locations at the vertex chevron bracings, underneath the floor beams.

Our experience on this type of retrofit has been quite stimulating. On one side it has given us the opportunity to understand better the energy dissipation phenomena on a building during an earthquake motion, providing us with better sources of knowledge in the way in which those forces are absorbed by the structure and transmitted to the foundation of the building along the duration of the earthquake.

The analysis of building systems incorporates elements, such as the ADAS whose nonlinear behavior, offers serious complexities; in particular when they are structurally analyzed within the time domain. The time-history dynamic analysis of tridimensional building systems with non-linear elements constitutes an absolute challenge to the engineering profession and the demands to thorough understanding of this phenomenon.

The normally available tools to the common Structural Engineer are quite sophisticated but still somewhat rudimentary. The DRAIN-2D computer program offers possibilities to analyze plain frame systems only. However, when trying to interpret the tridimensional behavior of the structural components we face the problem of having different forces and displacements for a certain particular member in the same step in time, as reported from the analysis on the orthogonal directions.

Thus, if a certain column of a building is analyzed as a part of orthogonal frames which contain such a column, it is very difficult to obtain the bi-axial behaviour of that particular column at the same interval of time and more difficult yet to evaluate the maximum-minimum force combination along the earthquake duration.

Special emphasis is to be made in the fact that the input energy Ei of a building without ADAS devices is larger than the input energy of the same building with ADAS by virtue of the energy which is dissipated by the added damping attained. Furthermore, it comes clear that the larger source of energy dissipation of a certain building system comes from the ductile behavior of the frame, being the other source of energy dissipation the elastic strain energy Ee and the kinetic energy Ek. However, it is known that the ductile behavior is in most cases related to some concrete cracking and degradation, wich also means damage.

Thus, it is desirable to dissipate the energy with certain controlled yielding elements independent from the original structure in order to provide large amounts of hysteretic energy dissipation at the time that structural members behave within its elastic range. Typically, all earthquake damaged structures do not guarantee further ductile behavior.

Although we recognize that this situation is very difficult to balance we can attain this possibility in almost a whole structural system, with some exceptions of members (normally beams) yielding plastically under extreme loading conditions.

Edward Wilson has recently produced a very effective tool to analyze building system with non-linear elements both in the elastic and dynamic mode, through his computer program denominated SADSAP, stil unreleased for professional use (Static And Dynamic Structural Analysis Programs).

Through its use we have been able to study tridimensional building systems with ADAS elements, previously analized with simpler non-linear computer programs. The result of its application has been highly estimulating and has enabled us to improve our understading of the global non-linear dynamic behavior of the structure during an earthquake.

We are in the process of instrumenting buildings where the ADAS devices have already been installed in order to calibrate our analysis and tchnological effort.

We must emphasize that this type of structure retrofitting and rehabilitation also involves substantial physical difficulties of the installation of the braces and the devices. However, it permits a larger degree of prefabrication as well as the installation of these devices during the occupation of the building, situation which is highly advantageous.

Figures 7 and 8, show the input energy-versus the dissipated energy through the ADAS elements in two directions. It is noted that the building without an ADAS retrofitting system has greater input energy that the building with ADAS, being the difference the increased damping provided by the ADAS.

Figures 9 to 13, typify useful plots of the SADSAP program.

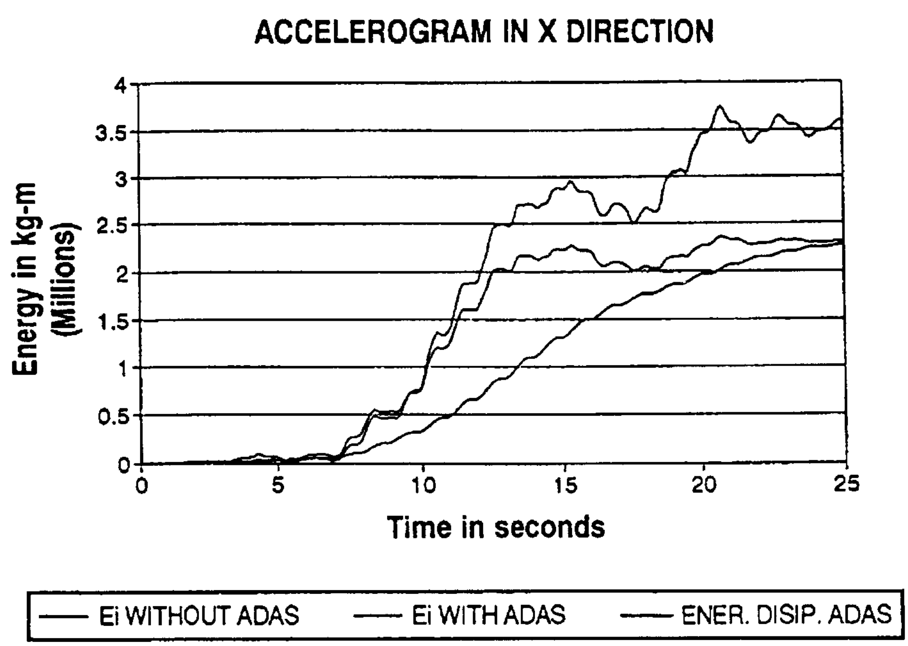

Fig. 7 Energy comparation

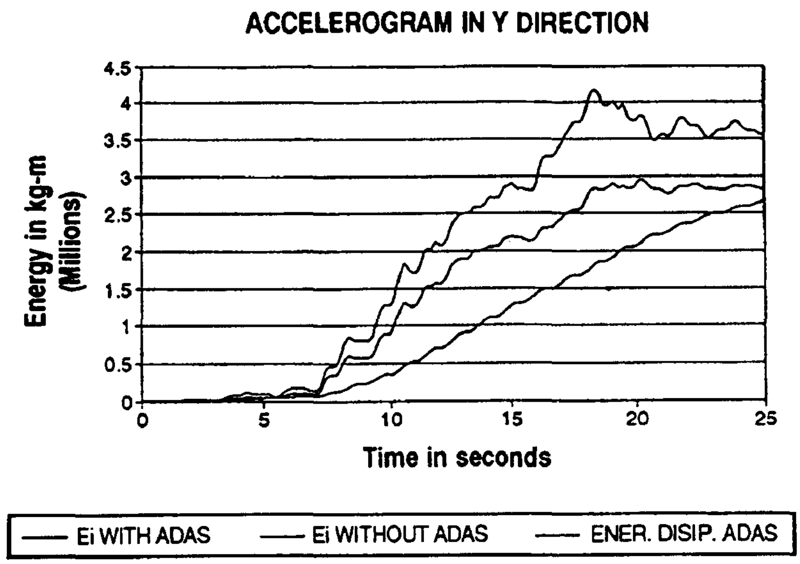

Fig. 8 Energy comparation

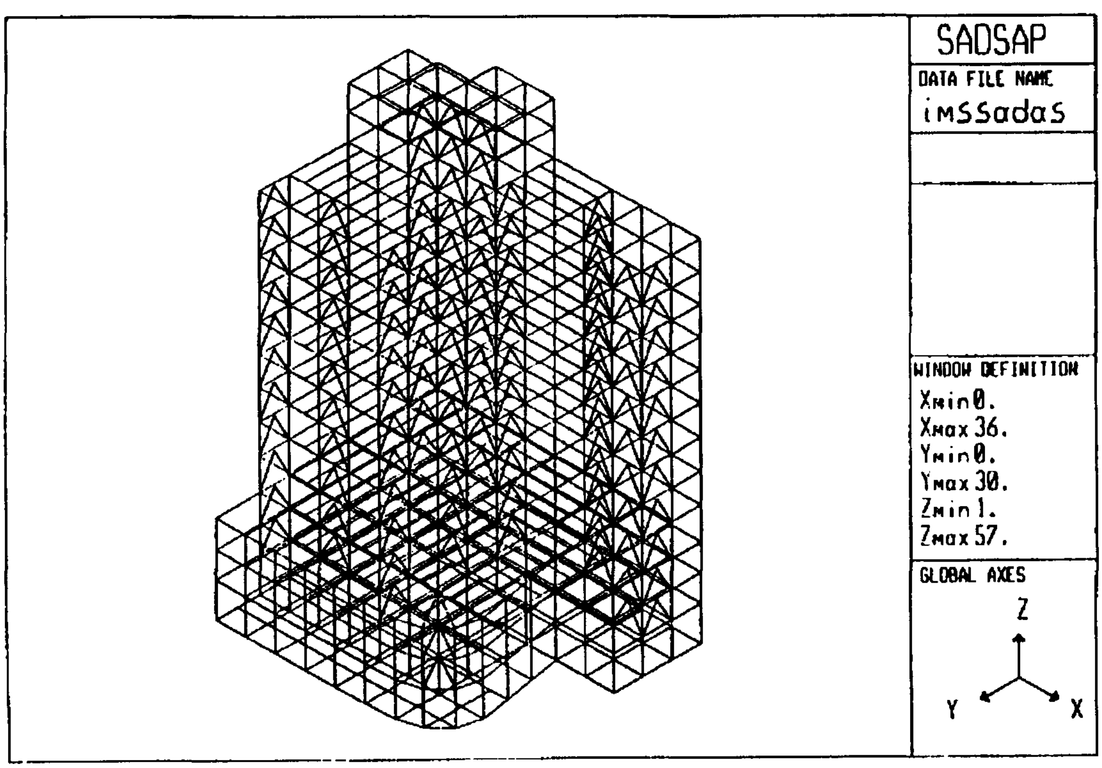

Fig. 9 SADSAP program

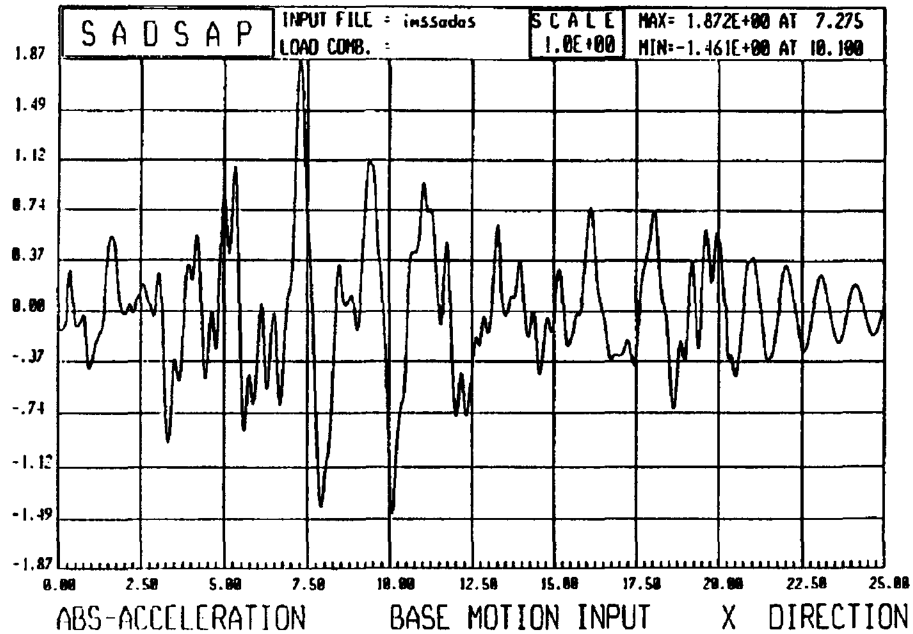

Fig. 10 SADSAP program

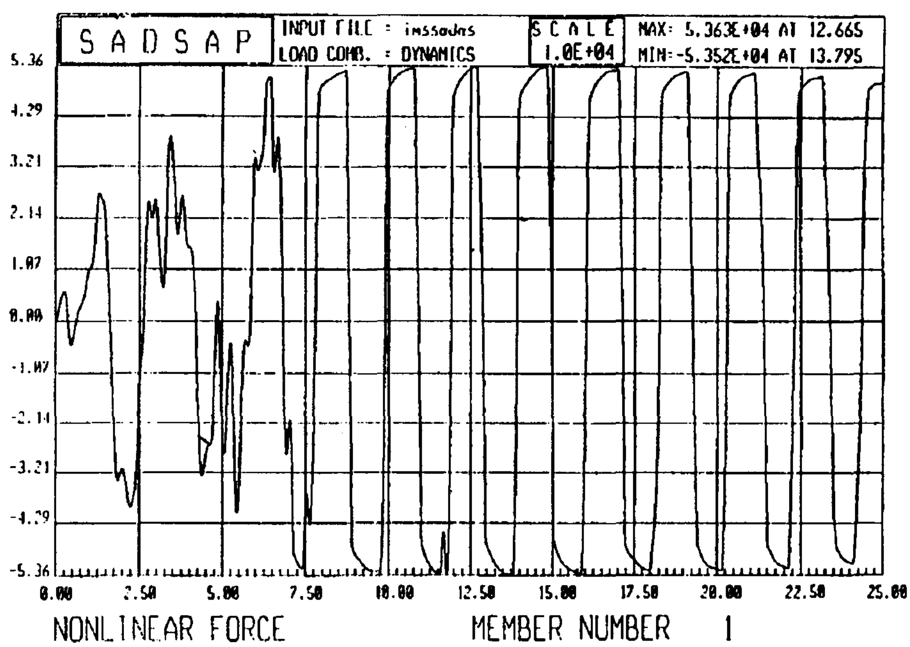

Fig. 11 SADSAP program

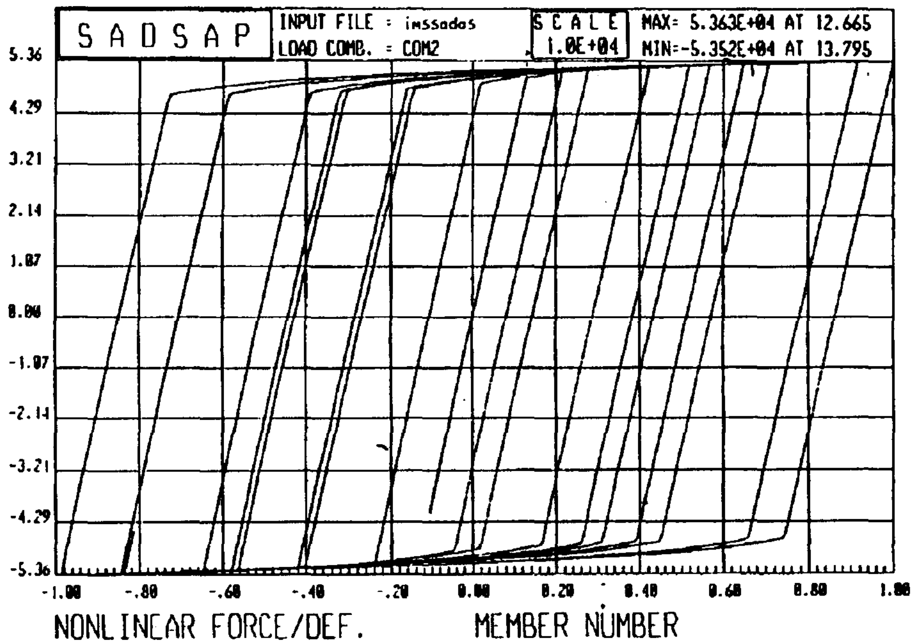

Fig. 12 SADSAP program

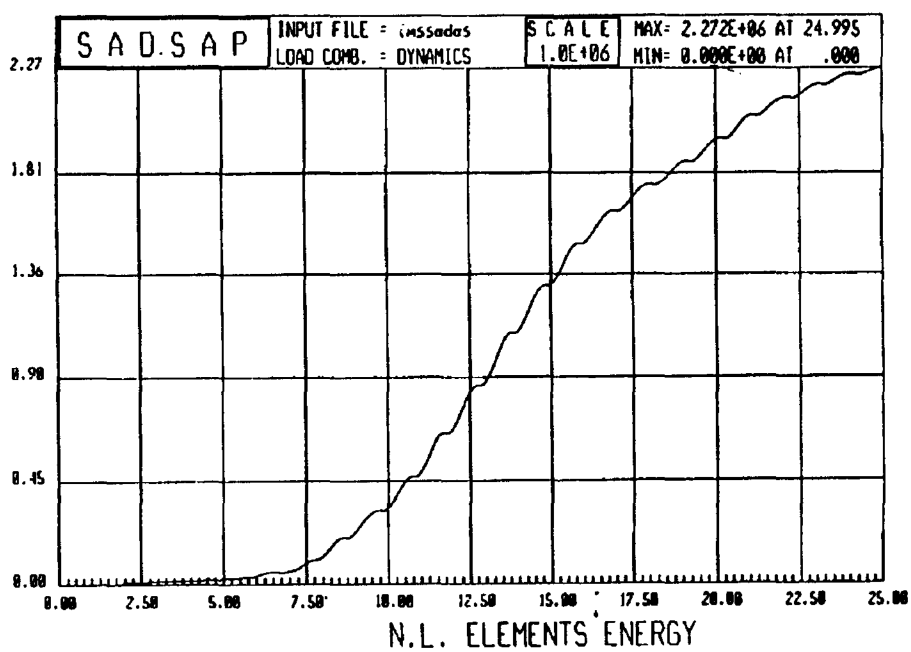

Fig. 13 SADSAP program