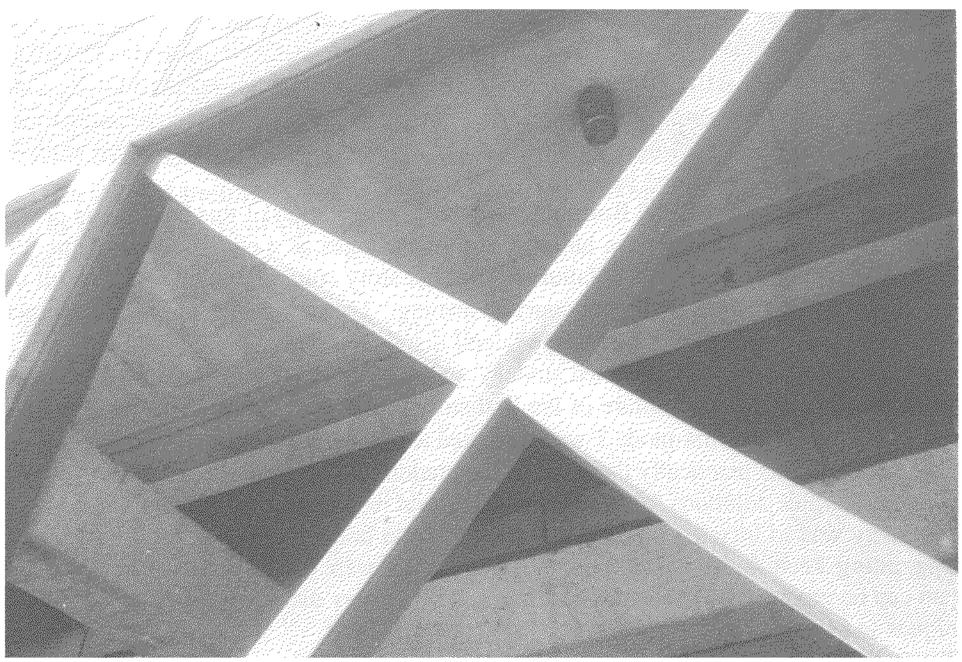
(1) Overview of building: the steel braces were used for lateral stiffening of the original RC building



(2) Closeup of the buckled braces

Fig 47 (d) During the 1989 Loma Prieta EQ, buckling of the braces that had been used to upgrade a RC building in San Francisco

Fig. 47 PHOTOS SHOWING PERFORMANCE OF UPGRADED STRUCTURES IN RECENT EQs desirable to limit deformation, particularly tangential interstory drift. Furthermore, in selecting the upgrading strategy, careful consideration should be given to the entire soil-foundation-superstructure-and-nonstructural-components system, and not just to the superstructure. Evaluation of the adequacy of the foundation is an essential step in the selection of the most appropriate strategy.

Selection of an Appropriate Upgrading Technique and Final Design. After the selection of the proper strategy, schemes by which it can be implemented must be developed and analyzed. The final implementation scheme must not only consider the technical aspects and the total cost of upgrading, but must also minimize disturbance to the function of the building during upgrading The latter consideration necessitates upgrading strategies which either (1) involve construction activity only on the external faces of the building, or (2) require only minimal reconstruction work inside the building. Generally, the final upgrading strategy is a compromise among the following: the optimal technical strategy, the strategy that demands the smallest construction costs, and the strategy with minimum disturbance to the occupants.

The ideal approach for selecting an efficient upgrading program is, after selecting an efficient upgrading strategy and technique, to conduct the design and estimate the cost for upgrading the existing facility according to one of three alternatives regarding desired future performance: (1) the upgraded structure will realize all of the objectives of the presently accepted philosophy of EQRD for new buildings; (2) under the maximum credible EQGM, the upgraded building will be not only safe but operational as well; or (3) the structure will not suffer any damage, even under safety EQGMs. The advantages and costs of each of these different design goals should be explained to the client, and he or she should decide what is affordable.

The final design of the upgrading scheme must include both detailed analyses of the building's performance under all significant EQGM levels, and complete details and procedures of the field work, because some of the selected upgrading techniques may be unfamiliar to construction workers. Many more field changes are generally required for upgrading work on existing facilities than for construction work on new facilities. Construction activity must be closely monitored to ensure that the upgrading details and the intent of the retrofitting strategy are followed. Thorough inspection is an integral part of any upgrading project.

APPLICATION OF THE PROPOSED ENERGY APPROACH STRATEGIES AND GUIDELINES TO THE UPGRADING OF EXISTING BUILDINGS. The lecturer and his research associates have conducted a series of detailed studies on the seismic upgrading of existing structures, applying the concepts, approaches, strategies and guidelines proposed above [41-45]. A brief summary of the main observations made in an extensive study of one building, the CPM building, is presented below.

Seismic Upgrading of the CPM Building. A detailed description of this building is presented in Refs. 42 and 43. The photos of Fig. 48 illustrate the building and its damages as a consequence of the 1985 Mexico EQ. The main reason for the damage was a shear failure of the first story column, which was a result of the addition of a spandrel beam that supported an overhanging concrete awning. The remaining severe damage was a result of the pounding of adjacent units as a result of their large lateral displacements.

(a) **Upgrading Strategy.** The selected strategy was to remove the concrete awning and spandrel beam in order to eliminate the danger of shear failure of the first story columns; and to change the dynamic characteristics of the facility to shorten its T (the first-mode T was estimated as 2.1 seconds) in order to reduce lateral displacement, and particularly because T was practically the same as the predominant period of the EQGMs predicted for the site. After considering all possible solutions for decreasing the lateral response of the building, it was concluded that the most efficient strategy was to increase the lateral stiffness with a bracing system.

(b) Upgrading Technique. The different techniques that were considered for the selected strategy of using a bracing system can be grouped as (1) **elastic solutions** and (2) **energy dissipation solutions**. A detailed discussion of these techniques is presented in Ref. [41].

(1) Elastic Solutions. The following schemes were considered: **diagonal cross-bracing; chevron bracing; a one-diagonal-brace system**; and **high-strength post-tensioned steel rods or cables used as diagonal bracing**. Attempts to keep all of these bracing systems in their elastic ranges resulted in very expensive solutions, except for the post-tensioned rods scheme.

(2) Energy Dissipation Solutions. Attempts were made to allow the above bracing systems to yield or buckle (or both), thereby dissipating part of the E_I through E_H. However, the yielding or buckling of the above conventional bracing systems was considered not to be an efficient and reliable technique. Thus, it was decided to add energy dissipation devices to the bracing systems. The following solutions were studied: **friction-damped diagonal cross-bracing; chevron bracing with friction-slip devices; diagonal bracing with friction-slip devices;** and **added damping and stiffness elements.**