The 'Bell-Building': A new type of earthquake resistant structure

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ABSTRACT: This paper presents an alternative structural concept for multistory buildings, especially when an open first floor is required. The improved seismic performance makes possible the construction of such a building even in environments where strong earthquakes have to be taken into consideration. Due to the boundary conditions of different structural components, the bell will practically remain in vertical position, even during an earthquake. Because the "Bell Building" structure remains in elastic range under all loading combinations, including strong earthquakes, the self-centering will never be a problem.

1 INTRODUCTION

The search for appropriate earthquake resistant structures has been underway since buildings have been damaged in earthquakes.

The progress in this field of activity was quite slow, from masonry construction in 1900 to steel and reinforced concrete framing in the 1920's, to welded steel frame assemblies in the 1950's, to ductile concrete frames in the 1970's, to eccentric braced steel frames in the 1980's. We are now beginning to design and build with new concepts using isolation and passive energy dissipation devices.

These new concepts are very useful, especially in the design of buildings whose fundamental frequency of vibration is in the range of frequencies where earthquake energy is strongest. By means of adequate isolation and passive energy dissipation devices, the frequency of the structure can be significantly altered. This clearly results in a significant response reduction for most sites.

Such a structure as a whole is more flexible than a typical one. For this reason it should be emphasized that softening a structure can mean an invitation to higher or lower inertia forces, depending on its relation to the frequency content of the ground motion. It is self-evident that long-period ground motions, defined herein as motions with periods of more than one second, can therefore be an important issue in the design and performance of structures incorporating isolation and/or energy dissipation.

The goal of current codes is to prevent structural collapse and loss of lives.

Isolation, respectively base-isolation, and passive energy dissipation devices are intended to provide a level of structural performance that goes well beyond the normal code requirements. In this case, however, it should be kept in mind that new systems generate new problems. Whenever a new type of structure has to be designed and an earthquake hazard must be taken into account, it should never be forgotten that each earthquake provides many surprises in structural performance which are not easily reconciled with existing theories of behavior. Accordingly, the design of structures incorporating isolation and/or passive energy dissipation systems is a complex mat-

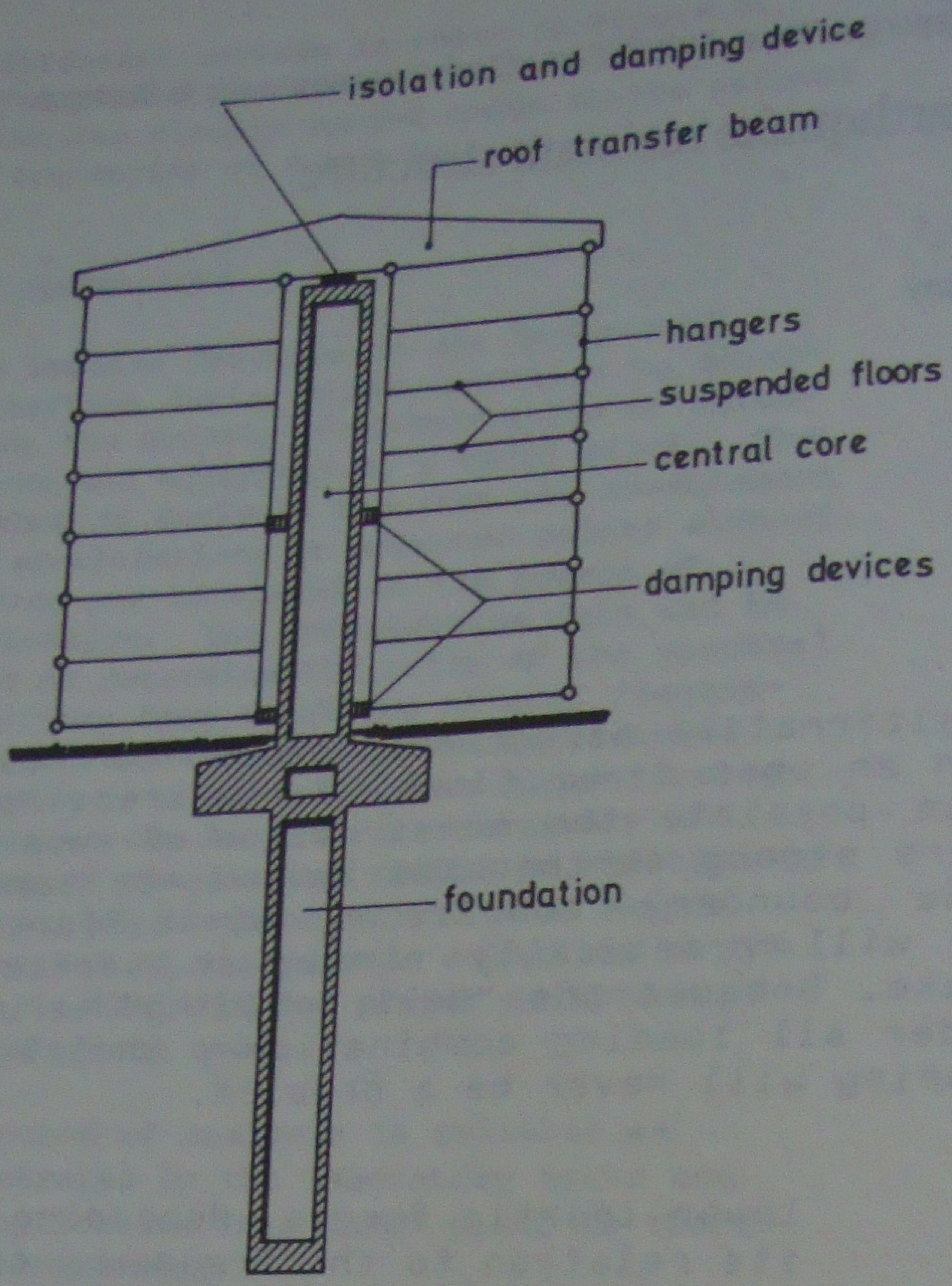

Fig. 1 Schematic cross-section of the "Bell Building".

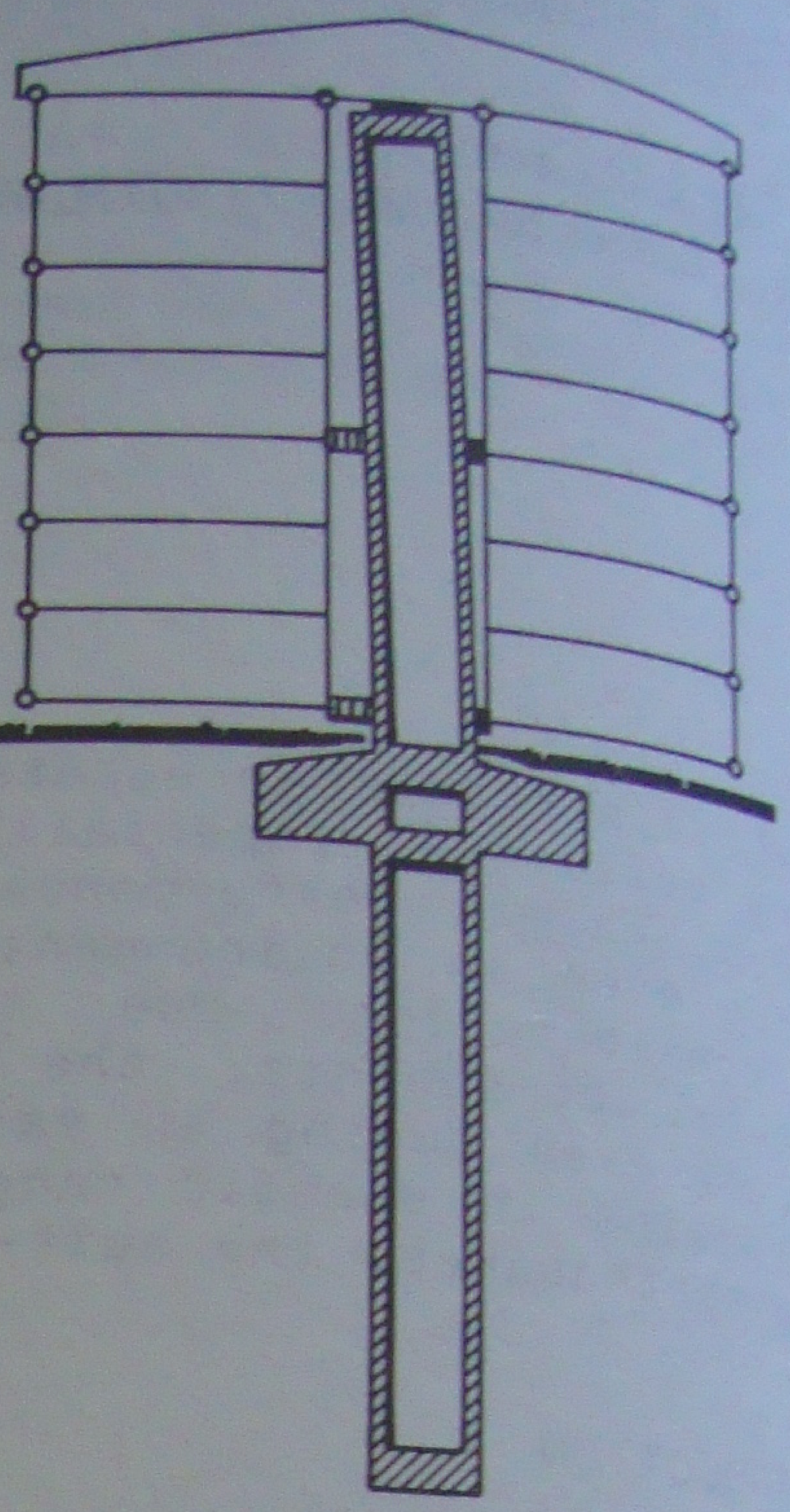

Fig. 2 Distorted geometry of the "Bell Building" under earthquake loading combination.

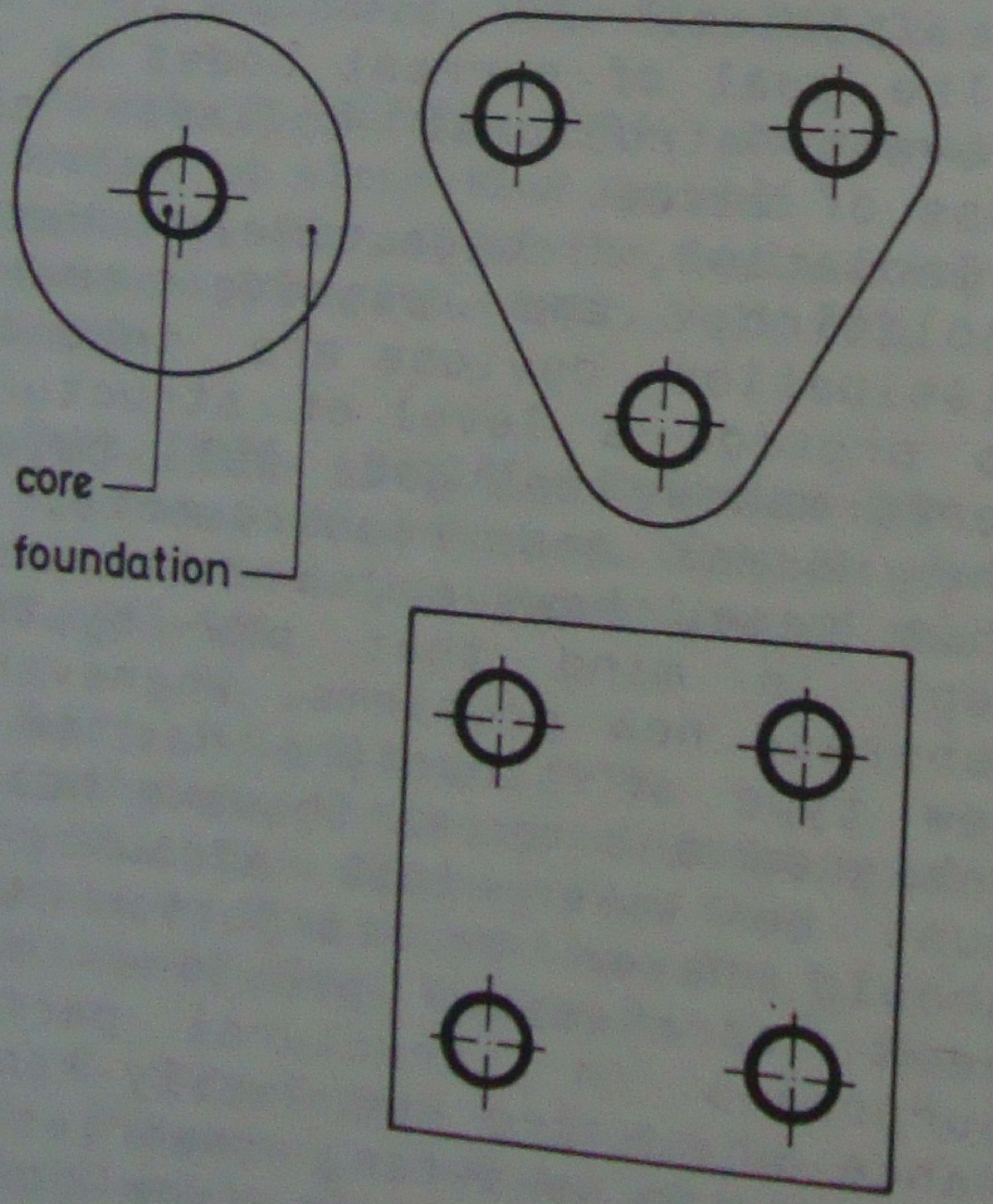

Fig. 3 Possible arrangement of the cores in a "Bell-Building".

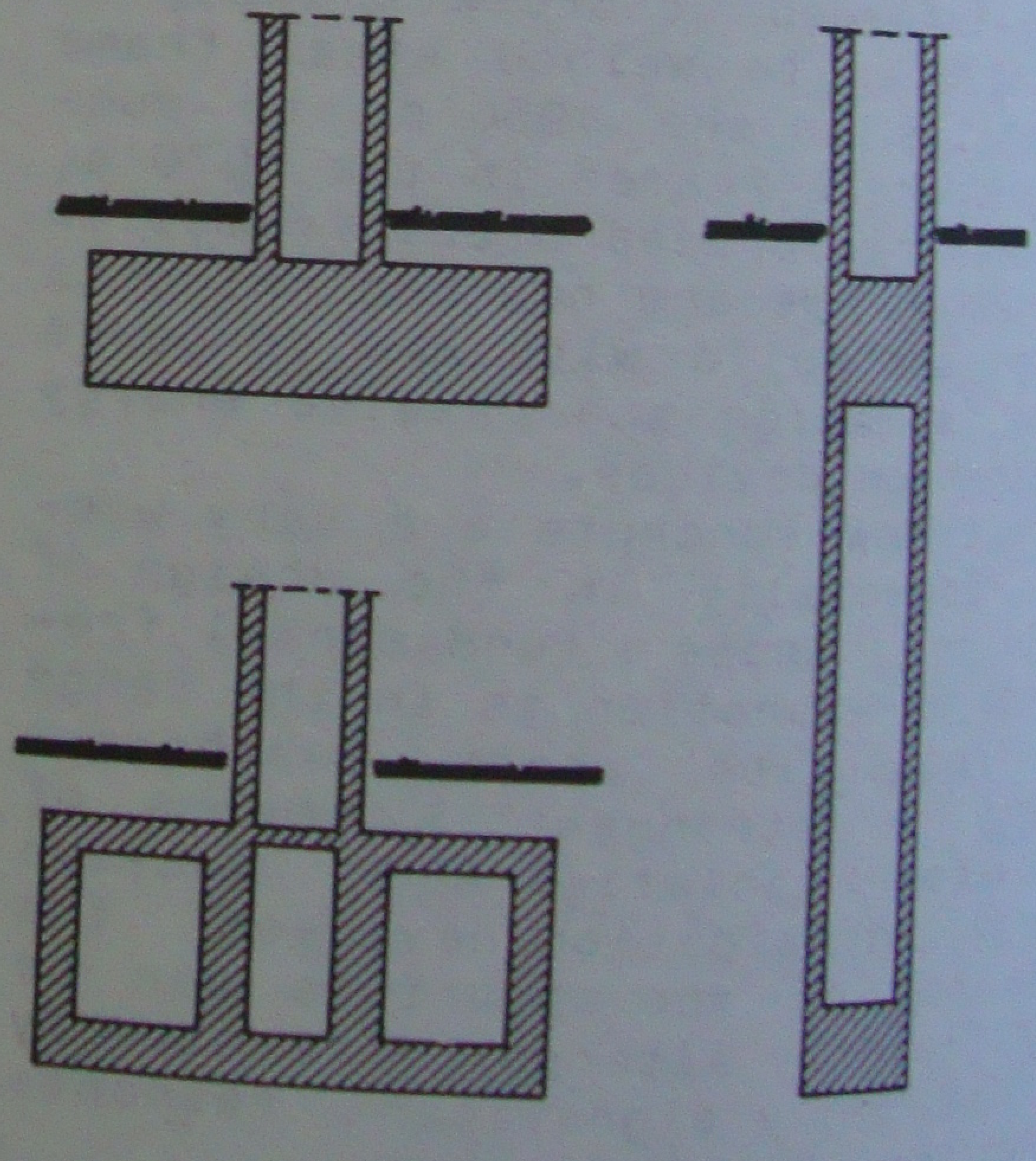

Fig. 4 Different types of foundations for a "Bell-Building".

ter requiring complex design and analysis techniques, including the use of computers and sophisticated software. It is this complexity that is at the root of research on, and practice of, earthquake engineering.

2 THE BELL BUILDING

2.1 General considerations

Particularly in the earthquake engineering field of activity, design professions are likely to agree to innovations that do not represent a large departure from current practice. This suggests that the most readily accepted innovative systems will be those that improve the properties and performances of a typical structure. The "Bell Building" is a typical structure, but with improved seismic performance.

Before describing the above-mentioned structure, it is advisable to review the past and thus to account for the reasons which have prompted the study of the "Bell Building".

In the past as in the present, the discrepancy between the nature of the buildings that engineers study and those which architects design and build may be clearly noticed. The engineer conceives a building in engineering terms, and the architect, on the other hand, sees engineering profession as a means of achieving buildings which have arisen from different criteria, such as, originality, uniqueness, image, etc.

For this reason, perhaps, the "soft first story" concept continues to be taken into consideration, even if its seismic performances are by far not the best.

The aesthetic attraction of the "floating box" with its open first floor is very real to architects and urban designers interested in plazas that link the building to the street. The high first floor is very useful when large spaces - such as banking floors - have to be provided at ground floor level. Therefore, it seems assured that the "floating box" will be with us in the foreseeable future.

According to the above-mentioned considerations, the following questions need an explicit answer: Is it possible to erect in a seismic environment a reliable and economical building having an open first floor with no restriction concerning the floor's height or inner distribution, which concurrently avoids the poor seismic performance of the first soft story? Is it possible to reconcile the otherwise conflicting aims of architects and engineers? Yes, it is.

The building satisfying the above-mentioned requirements is the "Bell Building".

2.2 General description

The structural components of such a building are (fig. 1):

- The foundation which can be of different types depending on the soil report recommendations (fig. 4).
- The central core, or cores, bearing the loads of the bell.
- The "Bell", consisting of floors plus vertical structural and non-structural components, which transfer the loads at the top of the core by means of special isolation and damping devices.
- Springs and damping devices placed between the different floors and the core, with the aim of controlling the relative displacements between the floors and the core.

The allowable relative displacements between the core and the floors depend on a lot of parameters and are generally specified in the "technical requirements of performance" drawn-up by the owner and its consultant or in the earthquake regulations of the country where the structure has to be built.

The allowable relative displacements between the floors and the core as well as the data concerning the ground motion are of essential importance for the dimensioning of the springs, isolation, and damping devices.

2.3 Behavior and performances

Under normal operating loads, i.e. vertical loads, wind forces or minor earthquakes, the behavior of the "Bell Building" is similar to that of a normal suspended structure without isolation and damping devices. Certainly, all these devices placed in a "Bell Building" must have adequate constants so that the normal operating loads may be carried without excessive displacements or unpleasant oscillations.

Under the loading combination of vertical loads and inertia forces due to a strong ground motion (fig. 2), the core will deflect but the bell will remain practically vertical. The special springs and damping devices placed between the floors and the core avoid any excessive relative displacements between the two structural components as well as unpleasant oscillations.

Because all vertical loads of the suspended floors are transferred at the top of the core, i.e. above the "bell's" center of gravity, a stable state of equilibrium is always ensured. The stiffness of the core, constant from top to bottom, the concentration of the vertical loads at the top of the core, and the isolation and dampening devices placed between the core and the bell will reduce the accelerations in the structure and the inertia forces to the advantage of the occupants and the contents of the building. The period of the fundamental mode may be increased well beyond 2 sec., making this type of structure suitable for most sites.

The proposed structure may be partially or fully isolated, depending on the direction and intensity of the earthquake acceleration. The new structural concept not only allows the building to remain elastic during a strong earthquake, but spares the non-structural elements from extensive distress. Since the non-structural components in a typical multistory structure account for about 50% - 80% of the building's cost, a positive means of preventing distress in such elements during strong earthquakes would represent significant savings in the repair and replacement costs which would otherwise be required.

Since the proposed building will remain elastic during a strong earthquake, the self-centering of the structure will occur automatically.

The proposed building can also be achieved as a base isolated suspended structure, if the safety against overturning and the self-centering after an earthquake is not a problem, and the maintenance, inspection, and replacement of base isolation devices may be performed economically.

3 CONCLUSIONS

The "Bell Building" provides an alternative structural concept for multistory buildings, especially when an open first floor is desired.

The proposed concept allows the construction of the open first floor even if a strong ground motion has to be taken into account, removing the poor seismic performance of the soft first story concept.

The new alternative is also an attempt to reconcile the otherwise conflicting aims of architects and engineers, and to change the open first floor structural concept from a liability to an asset.

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