SOFT FIRST STORIES: TRUTHS AND MYTHS

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SUMMARY

In conceiving building configurations the engineer and architect are working from fundamentally different criteria. The soft first story is an example of a design concept with proven poor seismic performance which, because it meets certain aesthetic and planning criteria, will continue to be used.

Four characteristics which create a soft first story are discussed, and three characteristics are described which superficially appear to be soft first stories but are not. Some ways of reconciling architectural and engineering aims are outlined, and the use of the deliberate soft first story is noted to reduce, in a controlled way, the forces on building superstructure.

INTRODUCTION

There exists a chronic discrepancy between the nature of the buildings that engineering researchers study and those which architects design and build. The engineer conceives a building in engineering terms, and finds it hard to understand alternative reasons for the origin of building configuration. The architect, on the other hand, sees engineering as a means to achieving building conceptions which generally have arisen from a different set of criteria. These criteria respond to requirements of originality, uniqueness, and image that are derived more from cultural fashions than physics. It is important to recognize that, in doing this, the architect is performing his rightful service in the eyes of his clients, and that this situation is unlikely to change.

For this reason the "soft first story" concept - now commonly recognized as a type of building configuration with a known history of poor performance - continues to be relevant. The soft story represented, perhaps, a pioneer aberration - in the eyes of engineers - by architects who took an otherwise rational, ideal, regular and symmetrical form and arbitrarily introduced a significant and dangerous discontinuity. The aesthetic and programmatic reasons for this discontinuity have never really been understood by engineers. The aesthetic attraction of the "floating" box is very real to architects, the open first floor is very real to urban designers interested in plazas that link the building to the street, and the high first floor is a useful programmatic tool when large spaces - such as banking floors - must be provided at ground floor level.

So, it is reasonable to assume that the soft first story will be with us in the foreseeable future, in building designs which are responding to aesthetic, urban design, or programmatic requirements. In addition, contained within the newer images now becoming popular, are forms which may, or may not,

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be soft first stories, depending on the detailed way - structurally or architecturally - they are handled. Finally, we have a large inventory of soft first story buildings, built primarily in the 1950s and 1960s, which are a cause for concern as we investigate the possible hazards of existing buildings.

However, although the soft first story problem has moved from that of being understood by researchers to becoming familiar to practicing engineers, and even being recognized by some architects and members of the public, in following this progression its definition has become blurred. As a result, many designs which are not soft first stories are wrongly identified as such, because of superficial characteristics: conversely, some designs which are soft first stories are not recognized as such because their characteristics are not immediately apparent. The result is bringing confusion and ill-informed judgments, where clarity and precision are needed - and are not difficult to exercise.

SOFT FIRST STORY CHARACTERISTICS

The essential characteristic of a soft first story consists of a discontinuity - of strength and stiffness - which occurs at the second floor column connection. This discontinuity is caused because lesser strength, or increased flexibility, in the first floor vertical structure result in extreme deflections in the first floor which, in turn, result in a concentration of forces at the second floor connection. If all floors are approximately equal in strength and stiffness, the entire building deflection under earthquake loads is distributed approximately equally at each floor. If the first floor is significantly less strong or more flexible, a large portion of the total building deflections tends to concentrate in that floor, with consequent concentration of stresses at the second floor connections (Figure 1). Although the columns or the joint may be strengthened in the attempt to resist this condition, the fundamental fault lies in the configuration of the buildings rather than the structure, so that measures taken to strengthen the columns or joints are not dealing with the fundamental cause of the problem.

In more detail, the soft first story problem results from four basic conditions. These are:

1. A first floor structure significantly higher than upper floors, resulting in less stiffness and more deflection in the first floor relative to the upper floors. The condition becomes worse as the relative height of the first floor increases, the number of floors above the first increases, and the stiffness of the upper floors increase (Figure 2).

2. An abrupt change of stiffness at the second floor (though the floor heights remain approximately equal). This is caused primarily by material choice: the use, for example, of heavy pre-cast concrete or masonry elements, above an open frame structure. This condition may often occur as the result of remodeling of older commercial buildings, in order to introduce storefronts or hotel lobbies (Figure 3).

3. The use of a discontinuous shear wall, in which shear forces are resisted by walls which, generally for programmatic reasons, do not continue

to the foundations but stop at second floor level. Olive View Hospital, San Fernando, and the Imperial County Services Building, El Centro, are classic examples of this condition (Figures 4 and 5).

4. Discontinuous load paths, created by a change of vertical and horizontal structure at the second floor to provide a more open first floor. This is often done for programmatic reasons, in order to reduce the number of columns at first (or basement) floors: to permit large spaces or provide for car parking (Figure 6).

The above characteristics, individually or in combination (high first story combined with discontinuous shear walls, for example represents a particularly bad concept) are readily identifiable. However, depending on combinations of materials and or design detail a building may appear to have the above characteristics but may, in fact, not do so. It may then be wrongly identified as a soft first story building.

WRONG IDENTIFICATION OF SOFT FIRST STORIES

Not All Open First Floors Are Soft First Stories

As noted above, an open (or partially open) first floor is often a desirable urban planning concept. Does this inevitably mean a soft first story? Since the issue is not openness, per se, but a significant difference in strength and stiffness between first and upper floors, correct use of materials can provide an open first floor of the same stiffness as those above so that the building structure is essentially regular. The key is to ensure that the materials of the superstructure - particularly the exterior skin - are kept light so that their removal at the first floor does not significantly change the dynamic characteristics of that floor. Such a beneficial situation would occur if the superstructure is constructed as a light aluminum and glass curtain wall or, if opaque wall is required, the use of metal studs with stucco or a proprietary metal faced insulated panel (Figure 7).

A Soft Appearing Perimeter Does Not Necessarily Indicate a Soft Lateral Resistance System

In engineering terms we are concerned with the characteristics of the entire lateral resistance system, not solely its external appearance. If the lateral resistance system is primarily dependent on the use of the core (of a high-rise office building, for example) perimeter columns may be tall and slender in appearance, but there is no soft story. In a building with a central core it is not difficult, if the core dimensions are sufficient, to ensure that the stiffness of even a tall first floor core is adequate to ensure no structural discontinuity at the second floor (Figure 8).

Paradoxically, this beneficial condition is much easier to achieve in a relatively slender high-rise building than in a low- or medium-rise structure. This is because in a slender high-rise tower a much larger percentage of the floor area is occupied by elevators, stairs, and ducts. These fixed elements can easily form the basis for a stiff cantilever shear wall or braced lateral resistance system such that perimeter columns will receive little lateral load. Conversely, a low building of larger floor area will use relatively little area for stairs and elevators: staircases will be distributed in a more random pattern which will tend to introduce torsion if these are designed as stiff, lateral resistant elements. If, in such a building, an open or tall first floor is designed and a rational shear wall system is prohibited, the design of the lateral resistance system is much more of a problem (Figure 9). The use of stiffened columns, or even a superbay concept, as described below, would be a feasible solution.

Not All Discontinuous Walls Are Shear Walls

A large wall that stops short of the first floor is only creating a soft first story if it is, in fact, a major element in the lateral resistance system, or if its mass is such that, if not designed as part of the lateral resistance systems, it would significantly affect it. The latter case may occur with the use of a heavy pre-cast wall that, though not considered as part of lateral force system, will seriously modify the characteristics of the frame to which, it is attached. However, in today's construction, large opaque walls are often constructed as steel studs faced by stucco or brick tile. These are relatively light in weight and look more massive than they are. Though the effect of such walls on dynamic response is not negligible they provide a high degree of ductility (albeit at the cost of much broken cement plaster and tile) that may be beneficial to the integrity of the main structure (Figure 10).

RECONCILING ARCHITECTURAL AND ENGINEERING AIMS

Given that the appearance of a soft first story may continue to be desirable for a variety of architectural reasons, what safe and economical ways are there of providing for it in a seismic environment? Some of them have been touched on above, but the following summary indicates some structural concepts, or even subterfuges, that may be useful in reconciling the otherwise conflicting aims of architect and engineer.

As noted above, if the appearance, insulation and acoustic value of a large opaque wall is designed in a location that could create a soft first story:

1. Ensure that such a wall is not part of the lateral resistance system.

2. Reduce the mass of the wall by the use of light-weight materials and hollow construction (which is easier to insulate).

3. If, for other reasons (such as the need for mass in a passive solar climate modification system) then ensure the wall is detached from the structure in such a way that the superstructure is free to deflect to a comparable degree to that of the first floor.

If a high first floor, with no walls, is desired, either:

1. Introduce bracing that stiffens the columns up to a level comparable with the superstructure.

2. Design the main structure as a superbay in which the lateral force system is dynamically regular and architectural variation introduced by lighter nonstructural elements (Figure 12).

If the architect insists on such material and design constraints that a major discontinuous shear wall design is the only solution, refuse to do it. The liabilities involved in using a proven dangerous concept are too great.

THE DELIBERATE SOFT FIRST STORY

The fundamental problem of the soft first story - that it is subjected to significantly more deflection than the other stories - also leads to the possibility of its use in significantly reducing the forces on the superstructure of the building. The problem is how to do this in a controlled way: the potential rewards lie primarily in greatly reduced nonstructural damage. There is also the possibility of reduced first costs if the additional cost of introducing the beneficial discontinuity can be more than counterbalanced by reduction in the cost of superstructure that can be designed for less deflection and less, or no ductility. This, in turn, makes possible the use of economical pre-cast or simple concrete structures.

A recent building in New Zealand shows that this possibility is now a reality. Union House in Auckland is a 12-story private office building on the harbor. It is built on reclaimed land, which necessitated that it be built on piles some 30 to 40 feet long, which reach down to bedrock. Each pile is designed in such a way - with weakened sections at the top and bottom - so that it will allow the superstructure to move laterally (Figure 13). It acts as a flexible "first story." But the top of this story approximates ground level, and here are installed "energy dissipators" that prevent the superstructure from moving too far, and dissipate the energy of ground motion before it enters the building proper (Figure 14). In the event of severe ground motion its energy will bend the steel bars in the energy dissipators. After the earthquake these may each be replaced.

The superstructure, from first floor up, is an economically braced, nonductile concrete frame, requiring no internal shear walls. The exterior cross-bracing, of steel plates encased in concrete, is both efficient and elegant. The entire building structure is isolated from the surrounding ground down to bedrock. Columns run in tubes, allowing for relative movement between the columns and the adjoining ground.

CONCLUSION

Engineers must accept the fact that the appearance of the soft first story will remain a desirable architectural characteristic for the foreseeable future. However, there are a number of ways in which the architectural effect can be achieved without detriment to the structural integrity of the building. Recent advances in materials research and energy dissipation concepts are changing the soft first story from a liability to an asset.

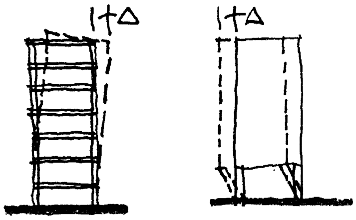

Figure 1. soft story deflection

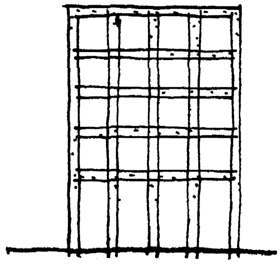

Figure 2. soft first story: tall columns

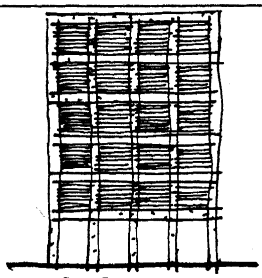

Figure 3. soft first story: abrupt change of stiffness

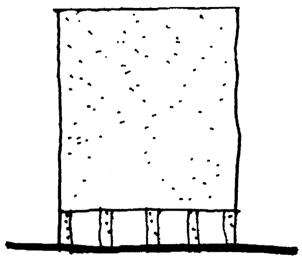

Figure 4. soft first story: discontinuous shear walls

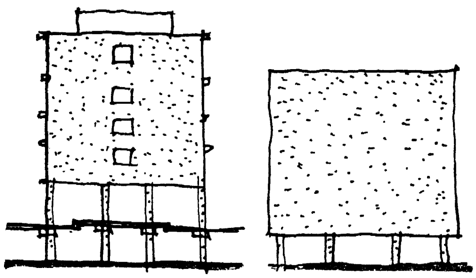

Figure 5. Olive View Hospital (L) ICS Building (R)

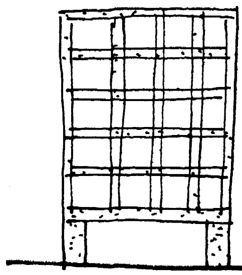

Figure 6. soft first story: discontinuous load path

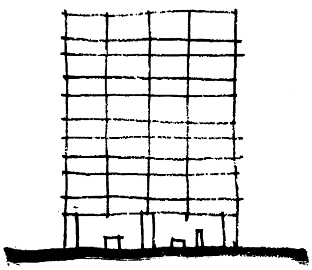

Figure 7. open first floor, but no soft story

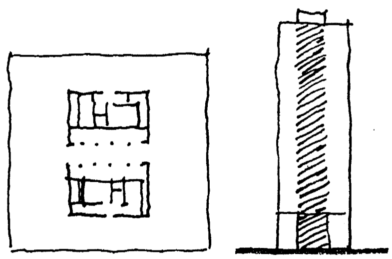

Figure 8. lateral resistance in large core: no soft story

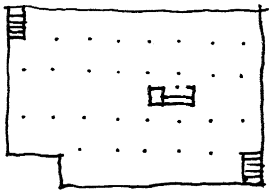

Figure 9. low-rise building: small circulation cores

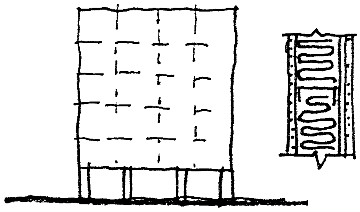

Figure 10. opaque light-weight wall prevents discontinuities

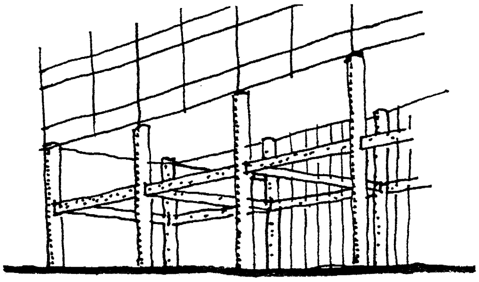

Figure 11. stiffening of high first floor columns

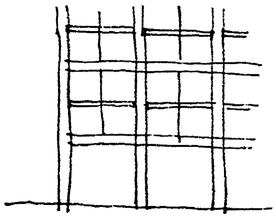

Figure 12. superbays

Union House: base isolation

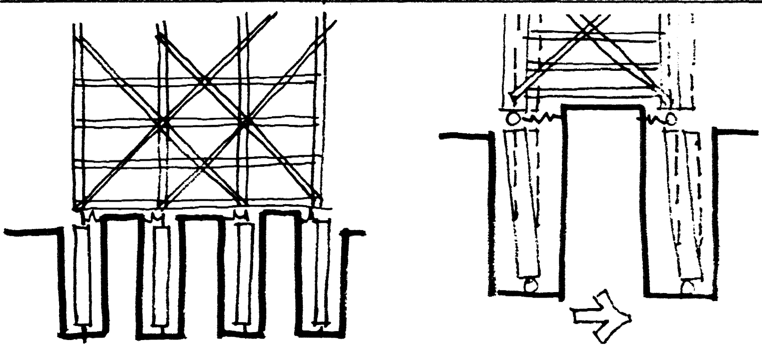

Figure 13.

Union House: energy dissipators

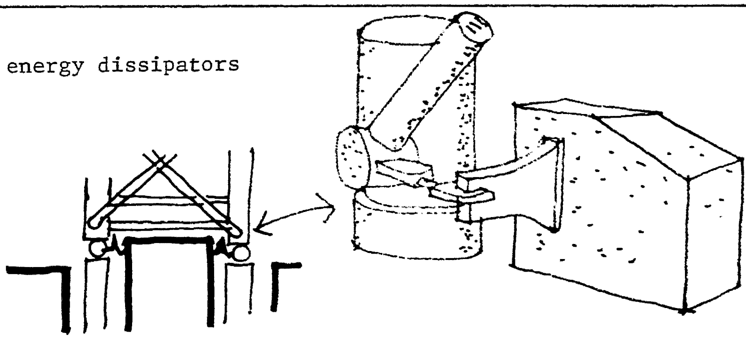

Figure 14.