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Maintenance and Flexibility of Use of Multistory Buildings

Entretien et souplesse de l'utilisation des bâtiments à étages

Instandhaltung und Flexibilität der Nutzung von Stockwerkbauten

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1. Introduction

Adaptation to change in use of a building is directly related to functional changes during the life of a building and as such, to the integration of design criteria for multi-functional use. This particular report is developed with respect to high-rise steel and composite structural systems and incorporates some design considerations for multi-functional occupancy and flexibility for structural changes. It is obvious that in order to evolve a suitable structural system which incorporates some of the criteria for change in usage, one must necessarily explore the architectural requirements for the different types of space. Some of the inter-dependent architectural-structural criteria are examined briefly. In any planned, functional change, the inevitable question relates to economy in terms of first cost versus return on the investment. Some types of high-rise structural systems which inherently offer flexibility without inducing significant structural premiums are also examined.

2. Design Parameters That Affect Flexibility

The types of occupancies that could be reasonably grouped or that could coexist in a multi-function building consist of offices, apartments, hotel, car park, commercial and public spaces. Some of the planning and loading constraints are discussed for each occupancy only insofar as they affect structural planning of these systems.

a. Offices

It is desirable that multi-tenant office spaces be prime space which will fetch prime rental. Generally, prime space could be defined by the distance between the exterior glass line to the core of the building. A distance of 35 to 45 ft. is generally accepted in the United States as being most desirable for office planning. Deeper spaces will effect space quality in that some interior spaces without access to windows will fetch lower rental. For office buildings in urban centers where large corporate offices are likely to be located, a blend of different floor shapes and areas are desirable. The floor-to-floor height in the office building is controlled by the ceiling height from the floor as well as the depth of the floor-ceiling sandwich space. Ceiling heights vary from 8.5 ft. to 9.0 ft. and the sandwich space from 3 ft. to 4 ft. for a floor-to-floor height range of 11.5 ft. to 13.0 ft. A false ceiling is generally provided to cover all mechanical and electrical distribution systems. Electric power distribution to offices is provided either in a cellular floor metal deck or in the floor-ceiling sandwich space and punched through where outlets are needed. The superposed floor live loading generally ranges from 50 to 80 psf with a 20 psf allowance for the partition loading. Heating and ventilation systems are centralized and located on isolated mechanical levels.

b. Apartments and Hotels

Apartment and hotel spaces are more strongly controlled by the requirement of depth from the exterior glass line to the core or corridor. Apartments or rooms located totally inside without window space for viewing appear to be generally unacceptable. The depth for efficient planning ranges from 25 ft. to 35 ft. The floor-to-ceiling height is about 8 ft. and in most instances, a flat surface such as that of a concrete flat plate structure is desired which could be merely plastered and used as a finished ceiling. In most instances, individualized air conditioning and heating units are provided for each apartment which eliminate the need for a false ceiling. A floor live loading of 40 psf is used in apartment and room spaces. The partition loading is higher and ranges from 20 to 40 psf depending on the type of partition materials. Most hotels are planned with ancillary spaces suitable for restaurants, assembly rooms, meeting rooms, ballrooms, health club, swimming pool, etc.

c. Commercial Spaces

Commercial spaces consist of shops, stores, restaurants and similar kinds of occupancies. A higher ceiling height from 9 ft. to 11 ft. is generally desired. The superposed live load requirement ranges from 100 to 125 psf. Proximity to the windows is not generally required.

d. Parking Spaces

Parking spaces are controlled by size and orientation of the parking slot, vehicular circulation lanes, inter-floor ramping and entrance and exiting from the facility. The floor loading is about 50 psf and the clearance or head room from the floor to the structure is 7 ft. to 8 ft.

3. Structural Design For Flexibility

Because of the varied requirements of different occupancies, it would be ideal if changes in occupancies could be predetermined and, therefore, incorporated during the preliminary design stages. For instance, if a high-rise structure is to be planned so that it would initially be an office building which would later be converted in part or totally to an apartment building, the following initial criteria could be used. The building volume would be evolved in such a way as to keep the distance from the glass line to the core suitable for both occupancies. Typical office and apartment layouts would be tested so that reasonable space efficiency is obtained for both. Elevator capacities would be based on office population and the larger floor-to-floor height required for the office would be used for all floors. The higher superposed live and partition loading would be used in the design of the floor system. The type of floor framing would be selected in such a way that vertical shafts for plumbing services could be provided in the slab for future apartments.

A more typical situation is encountered when changes in occupancies cannot be established during the design phase. What structural systems and subsystems are available which afford some degree of flexibility for changes and remodeling? The following is a brief discussion relative to various structural systems and subsystems.

a. Floor Loading

The superposed design loading (live load) affects flexibility directly. These loads are specified by codes and standards for various occupancies and represent the minimum load capacity required. An average value of 50 psf is typically used for office occupancy. It is left to the design engineer to evaluate if the desired degree of flexibility could be satisfied by the code specified live load or if it should be increased. The minimum live loading covers a normal office with desks, chairs, other normal office equipment and people loading. It is not uncommon for modern offices to have libraries, computerized data processing equipment, and floor-to-ceiling file cabinets for papers, which will need additional loading capacities. This could be accomplished by several different methods.

(i) A floor strip of a certain width at the ends of the span of the floor beams could be designated for heavier occupancies such as libraries, computerized equipment, storage and so on. This would only require shear capacities of beam connections increased without substantially increasing the bending moment requirement.

(ii) A higher live loading can be assumed for the design of the floor elements while a minimum live load could be used for column design. This is based on the premise that a localized higher load affects the floor framing directly while the increase in column load is negligible, because it carries the load from several floors. The advantage of this dual load criteria is that only the floor elements need be designed for higher loading.

(iii) A higher live loading assumed for the design of both columns and floor framing elements would obviously increase the load capacity for the full office space in lieu of just localized areas. It should be remembered that the proportion of the live load to the total load is of the order of 30 to 40 percent and that a 30 percent increase in live load would only have a 10 to 15 percent increase of the total load. A 30 percent increase in live load would obviously increase the floor capability quite significantly.

In terms of increasing overall flexibility, an 80 psf live load for instance, would not only offer complete flexibility for office occupancy, but this loading would also be suitable for commercial, classrooms and assembly rooms, etc. Obviously, the cost premium for such capability would be quite justifiable in multi-purpose, megastructures which will have to be designed for maximum flexibility.

b. Floor Framing Systems

Floor framing refers to all horizontal beam and slab elements which transfer applied gravity loads to columns or vertical compression elements. The degree of flexibility and the extent to which a floor system can be remodeled are directly related to the type of framing as well as to their structural material.

Some of the issues of flexibility have to do with the removal of components, reinforcing for higher capacity and the ability to provide shafts and penetrations through the floor system. The economic feasibility of remodeling to a large extent, depends on the ease with which this could be accomplished or to the labor cost of remodeling.

In general, maximum flexibility for changes is obtained by:

(i) Floor elements which are connected to the supporting structure by bolting or by a seated connection, thus facilitating their easy removal.

(ii) Floor systems which consist of widely spaced beam elements which support relatively thin slabs whereby shafts and openings between floors can be provided in the slabs without remodeling the beam elements.

(iii) Beam elements which are capable of being reinforced to increase their load carrying capacity.

Fig. 1 shows some of the typical floor systems. Concrete framing systems where the concrete is poured in-situ monolithically with vertical supporting elements offer the least flexibility. Examples of this type are the flat slab, flat plate, one-way joist and the waffle joist or two-way joist systems. Additional load carrying capacities are not easily obtainable in these systems by adding concrete to an existing system. Therefore, consideration should be given to designing for a larger live load initially.

In the joist system, joists should be spaced as far apart as possible so that floor penetrations and shafts could be provided in the slab areas.

The extreme rigidity of the poured-in-place concrete floor system can be improved upon by precast systems. Two versions are shown in Fig. 1. The precast beam, if connected to the supporting system by a seated connection, could be easily dismantled and replaced. The slab could be either on a corrugated deck or precast planks, thus facilitating their removal if required.

Structural steel framings offer maximum flexibility for remodeling. Steel beams are generally connected to supporting members either by bolting or by a seated connection which could be removed. Steel beams could be spaced farther apart and the slab (reinforced concrete or metal deck) could be cut between beams. If additional loading capacity is needed, bending resistance of the beam could be increased by adding steel plates to the top and bottom flanges. Further, subframings between beams could be provided by welding secondary beams to existing main beams.

c. <u>Overall Structural Systems</u>

A required characteristic of a high-rise building is its resistance to lateral load of wind and earthquake. As the building height increases, the structural system is increasingly dominated by lateral load design. Several structural systems in concrete and in steel have been evolved over the years which offer varying degrees of flexibility in terms of adaptation to changes. The following is a brief review.

Frame buildings rely on the bending resistance of beams and columns arranged in a planar Vierendeel truss form in two directions for their lateral load resistance as shown in Fig. 2 (A). The beam elements on the frame lines are attached to columns by means of rigid or semi-rigid moment connections and as such, cannot be removed or relocated. Flexibility toward changes and modifications will, therefore, have to be constrained to within a bay area. If the frame building is conceived in a concrete flat plate or joist system, the available flexibility is further reduced since the slab over at least 50 percent of the width of the bay is used as a frame beam and cannot therefore be modified.

Shear wall building systems either partially or fully rely on the concrete walls usually provided around the building core for their lateral resistance. The floor system is generally designed only for gravity load. If proper selection of the floor system is made, this will allow some flexibility in removal or remodeling of the floor at isolated locations. For instance, structural steel framing for the floor outside of the shear wall can be used which would increase the amount of flexibility available. Systems of this type have been quite popularly used in the United States and in Europe.

Exterior tubular systems use the facade framing to develop an equivalent cantilever structure and offer maximum potential for adaptation to change. This is because the interior of the building is free of any lateral load resistance as long as some requirements of the floor diaphragm are met for the development of the overall cantilever system. One obvious advantage is that the interior can be adjusted to meet the requirements of multiple occupancy as well. The 100 story John Hancock Building in Chicago uses a diagonalized exterior with interior steel framing. This arrangement was extremely conducive to meet the requirements of commercial, parking, offices, apartments and television transmission facilities, all in one building. Fig. 3 shows a cross-section through the building. The floor beam spacings for various apartment groups were different since the beams were required to correspond to partition locations. The taper is generated to satisfy the minimum depth requirements of the apartments as contrasted to that of offices.

The advantages of planning flexibility offered by steel framing could be combined with structural rigidity of a reinforced exterior concrete tube for lateral loads, to evolve a type of composite system, where concrete and steel can be used to their maximum advantage. This was the basis of design of the 52 story One Shell Square Building in New Orleans. The building under construction is shown in Fig. 4 which reveals the closely spaced columns and deep spandrel beams of the exterior tube of reinforced concrete. The floor system consists of steel beams spanning between exterior composite columns of the concrete tube and interior steel columns. The floor slab consists of concrete topping on metal deck.

Fig. 2D shows a bundled tubular system formed out of four smaller size tubes or cells. In addition to offering the advantages of a tubular system previously stated, the bundled form is also suitable for modularion of floor area. Different floor shapes and sizes could be evolved by termination of different tubes at different heights to suit various functional needs.

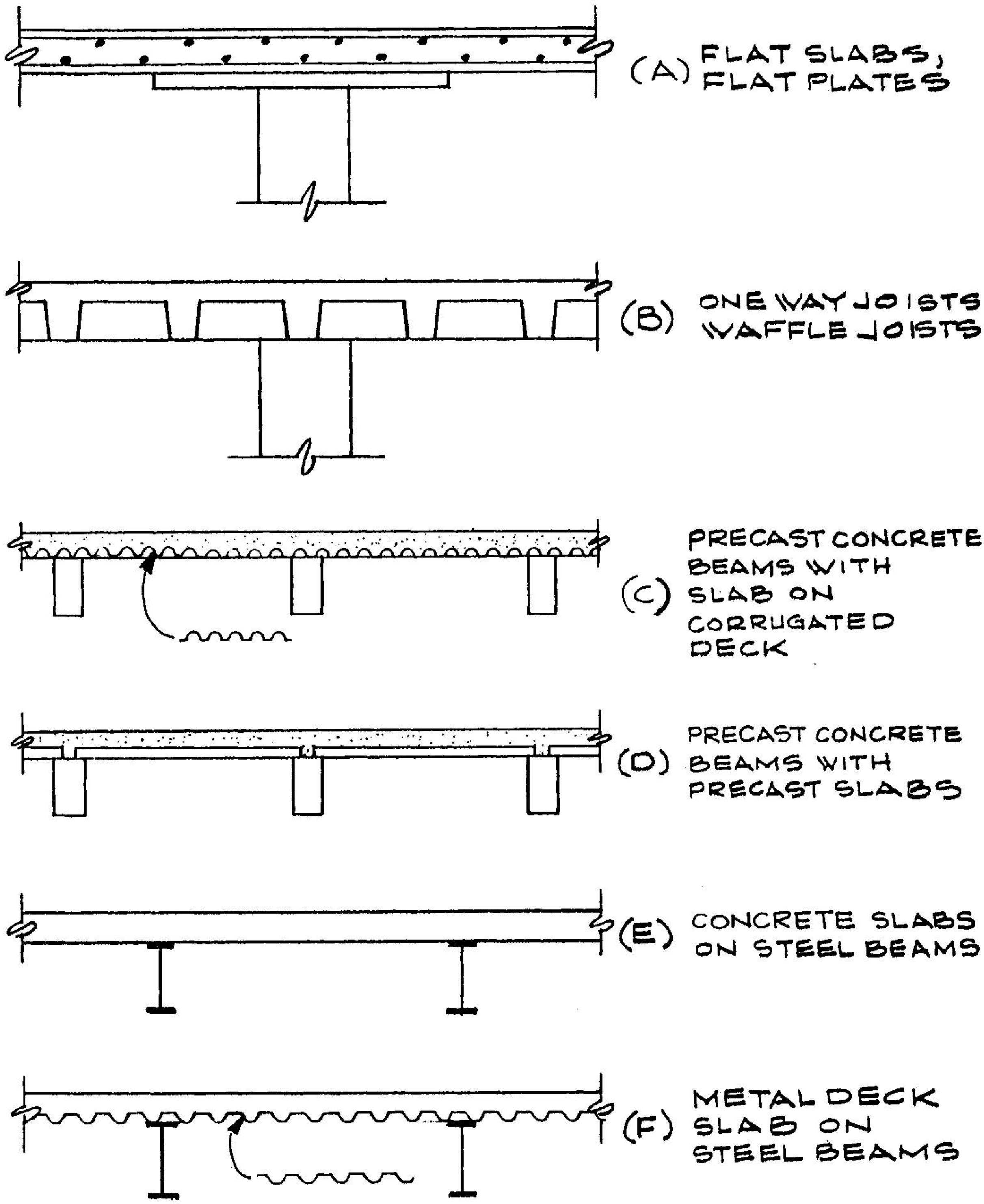

FIG. 1 FLOOR FRAMING SYSTEMS

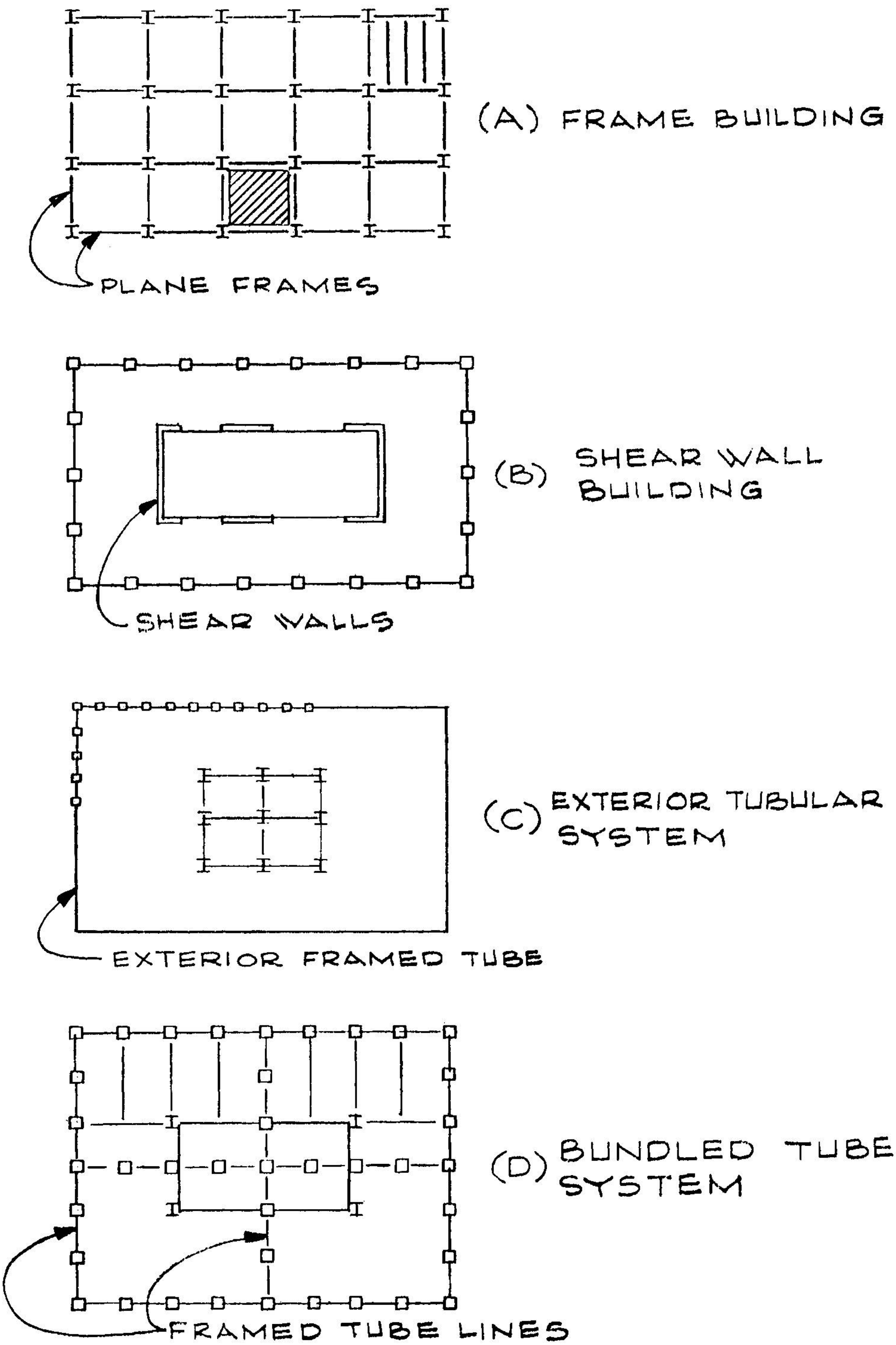

FIG. 2
STRUCTURAL SYSTEMS

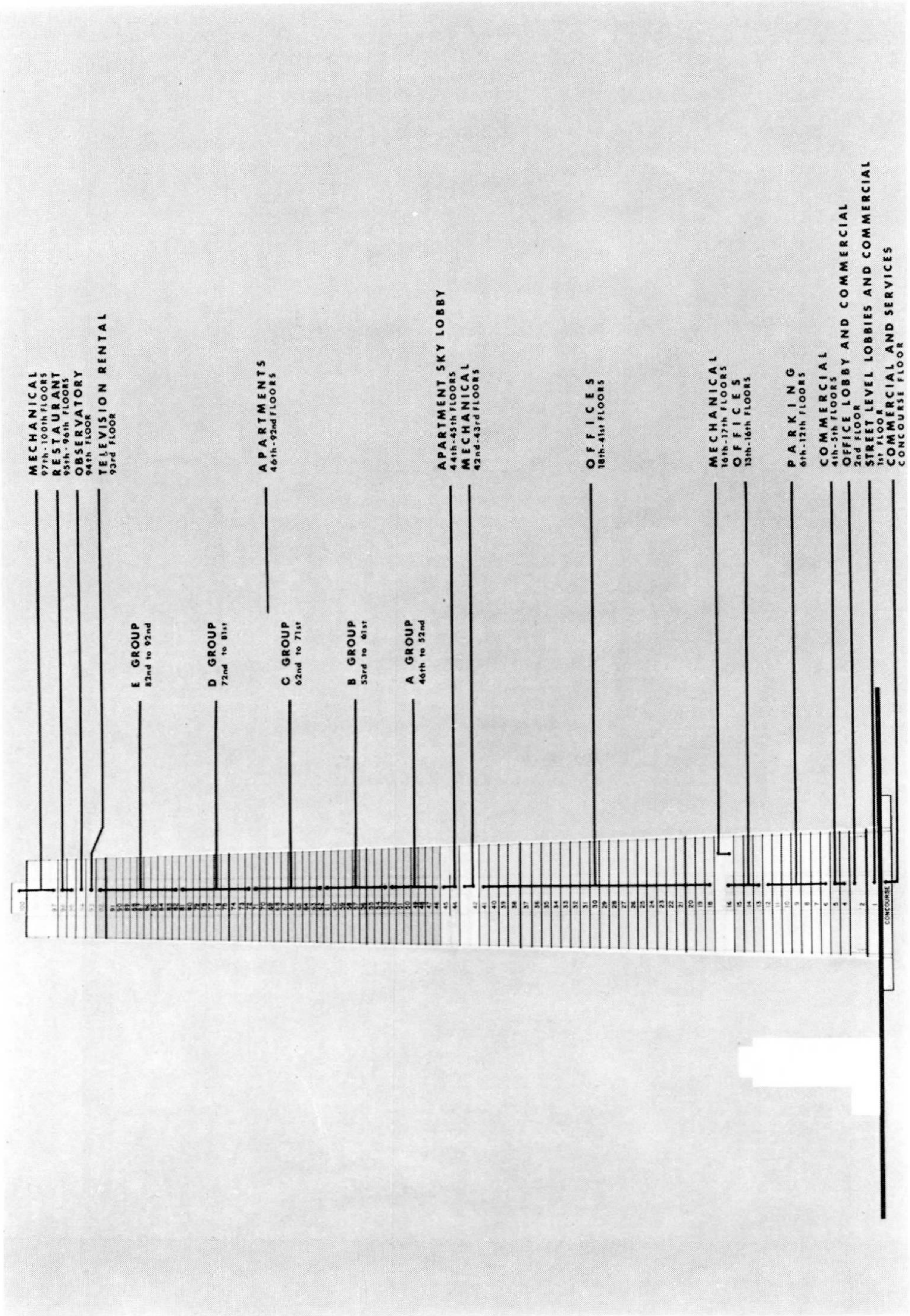

FIG. 3 MULTIPLE FUNCTION OF JOHN HANCOCK CENTER, CHICAGO

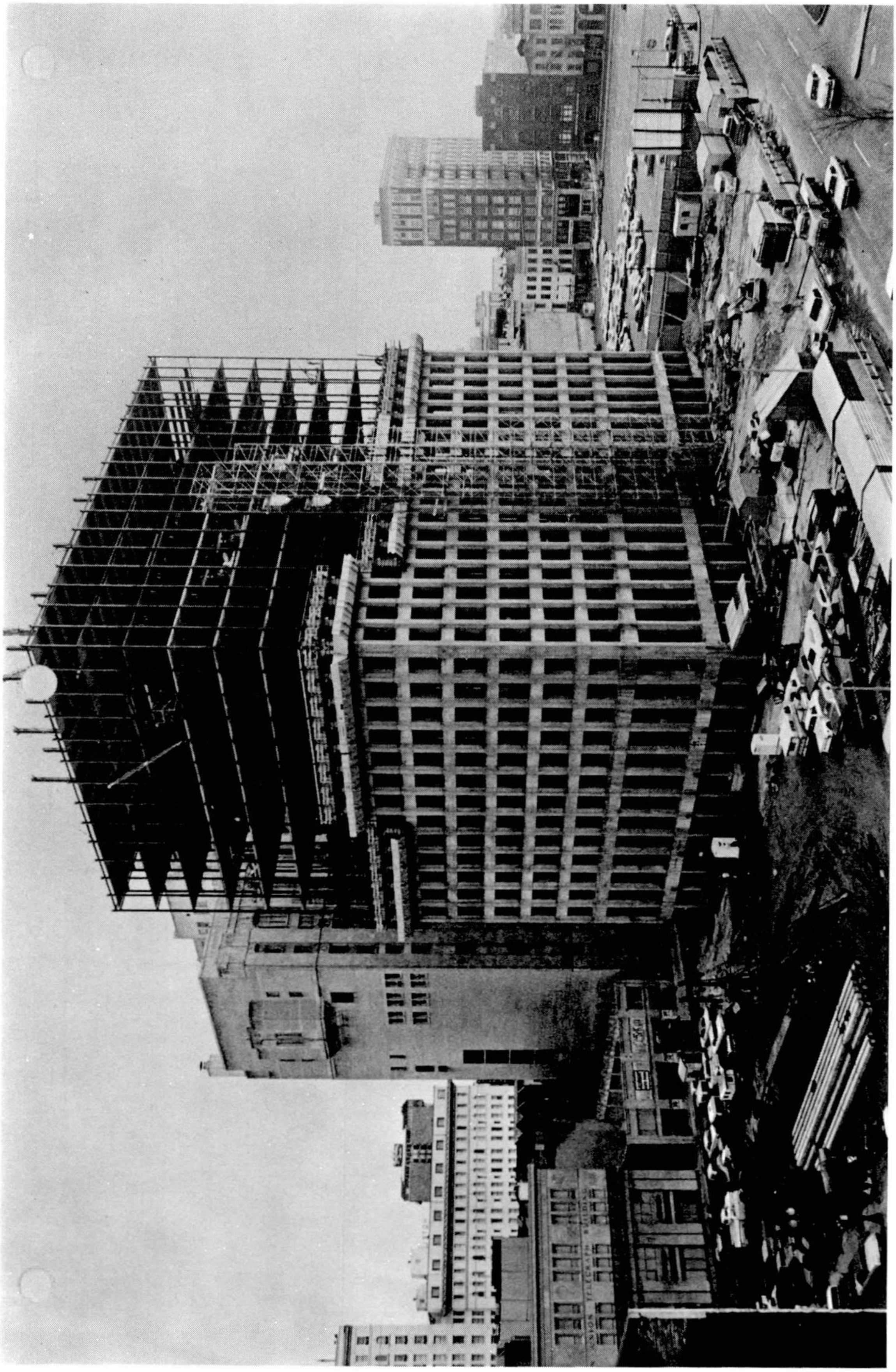

FIG. 4 COMPOSITE SYSTEM WITH EXTERIOR CONCRETE TUBE

SUMMARY

This report presents some general considerations for the design of the floor systems and overall systems which offer some flexibility toward multiple occupancy and for adaptation to changes in occupancy, as applied to high-rise steel and composite structures. Flexibility considerations will play a major role in future megastructures which must necessarily involve multiple functions. It is obvious that total flexibility will not become a reality until modularization and standardization concepts are used for all building components so that they are truly replaceable and interchangeable.

RESUME

Ce rapport présente quelques considérations générales sur le système de planchers et le système global d'une construction devant offrir une certaine souplesse d'utilisation et d'adaptation, telles qu'ils sont appliqués dans les maisons hautes en acier ou en construction mixte. Les considérations relatives à la souplesse d'utilisation joueront un rôle déterminant dans les futures mégastructures devant remplir nécessairement plusieurs fonctions. Il est évident qu'une souplesse totale ne deviendra réalité que lorsque le concept d'éléments modulaires et normalisés sera employé pour tous les composants du bâtiment, permettant alors réellement un remplacement ou un changement.

ZUSAMMENFASSUNG

Der Bericht vermittelt einige allgemeine Ueberlegungen zum Entwurf von Stockwerksystemen sowie von allgemein anwendbaren Systemen eines Bauwerks, das eine gewisse Flexibilität in der Nutzungsdauer aufweisen muss und sich den wechselnden Anforderungen anpasst, wie dies bei Stahl- und Verbundhochhäusern der Fall ist. Die Ueberlegungen hinsichtlich Flexibilität werden in den zukünftigen Hochhäusern eine grössere Rolle spielen, die notwendigerweise mehrere Funktionen zu erfüllen haben. Es ist offensichtlich, dass vollkommene Flexibilität erst dann erreicht ist, wenn das Konzept der Baukasten- und Normungselemente für alle Bauteile angewendet wird, damit diese auch tatsächlich ersetzt und untereinander ausgetauscht werden können.

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