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PRECAST CONSTRUCTION OF TALL BUILDINGS UTILIZING THE TENSION-STRUCTURE PRINCIPLE

by

Rudolph Szilard, Dr.-Ing, P.E.* & Philip C. French**

INTRODUCTION

The acute housing shortage in the United States cannot be solved without a thorough industrialization of the construction industry.

Conceivably, a rational approach to the problem might be an extensive use of conventional construction techniques and materials, combined with new structural concepts.

These new concepts can also employ familiar construction methods which hopefully would help overcome the strong reluctance of the construction industry to accept industrialization. In most metropolitan areas of this country, the cost of land is becoming exceedingly expensive, so much so, that it becomes almost mandatory to erect tall apartment complexes for satisfying the low cost housing needs.

In this paper, an innovative systems approach to tall building construction is introduced, utilizing mass prefabrication of large concrete elements, combined with the structural advantages of contemporary tensile structures.

ARCHITECTURAL CONSIDERATIONS

Figure 1 shows the perspective view of such a highrise (from 10 to 20 storeys) apartment complex. The building has a central corridor, off which one, two and three bedroom apartments are located (Figure 2).

Utilities such as plumbing and electrical fittings, together with door frames, may be cast into the concrete tee panels, which are an integral part of the structural system.

The exterior face of the building could conceivably utilize architectural precast wall panels.

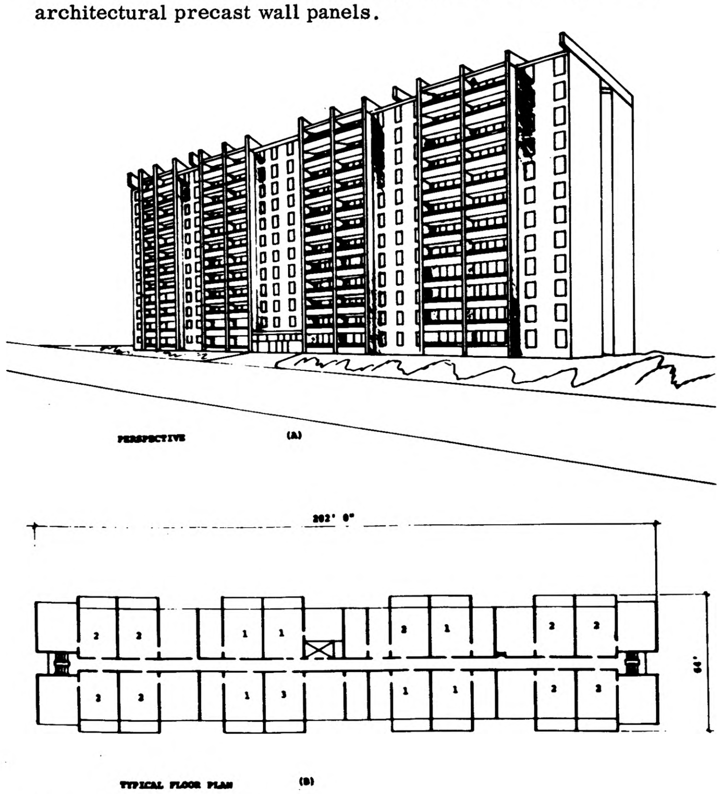

Fig. 1. Architectural Layout

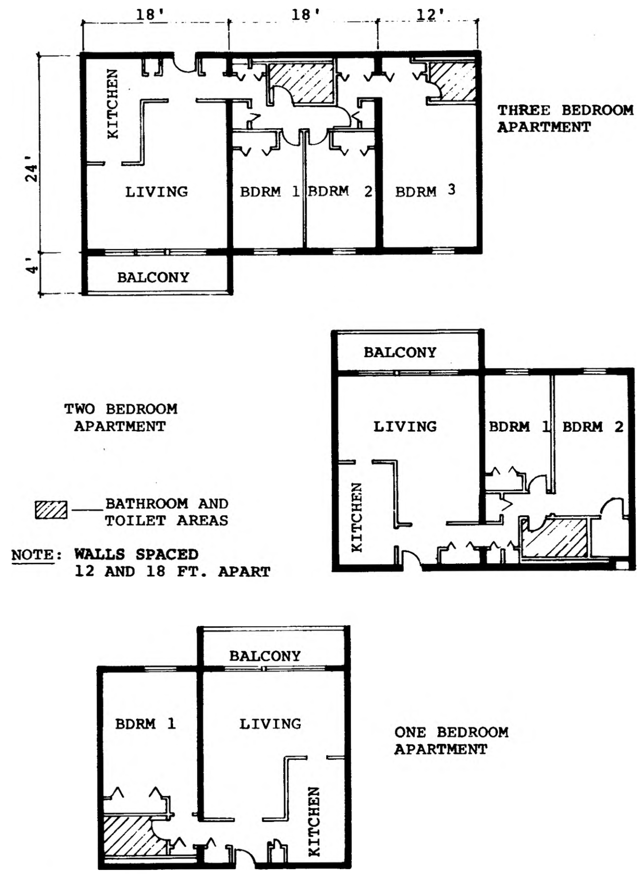

Fig. 2. Apartment Layout

THE STRUCTURAL SYSTEM

Basically, the structure comprises of a cast-in-place central core, from which precast tee panels are suspended (Figure 3). Precast in-fill panels bridge the gap between the load-carrying tee members. Vertical and horizontal prestressing not only tie the precast elements to the core, but create a monolithic structure with extremely high earthquake and wind resistance characteristics.

The precast tees carry the dead loads (with the exception of internal partitions - 10 p.s.f.). These loads are transferred by means of horizontal prestressing to the central core as indicated in Figure 4A. The shear force between the core and the precast tees is carried by the concrete, by virtue of the frictional resistance caused by the pre-compression, together with shear keys provided in the stem of the tee section.

In this way, the wall and floor elements for each level are suspended from the core.

The superimposed loads (live and partition loads) are transmitted directly through the stem of the precast tees which act as bearing walls, once the dry packing and welding has taken place.

The main purpose of the vertical prestressing is to achieve a monolithic structural action for wind and earthquake resistance. The high-strength alloy rods for the vertical post-tensioning run from the foundation up to the roof grillage beams, (possibly precast). When the structure is under the influence of lateral loads, it acts basically as a cantilevered deep beam. The resulting,

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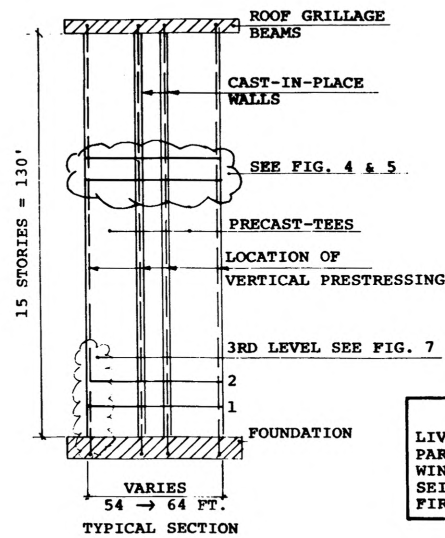

TABLE 1 -

DESIGN CRITERIA	
LIVE LOAD	= 40 P.S.F.
PARTITIONS	= 10 P.S.F.
WIND	= 30 P.S.F.
SEISMIC	- ZONE 3
FIRE RATING	- 2 HRS.

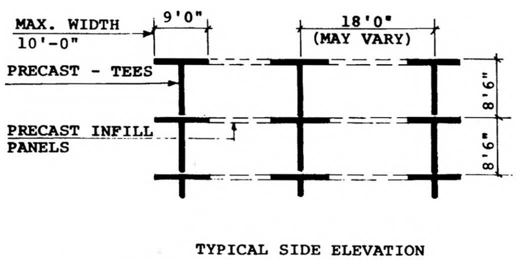

Fig. 3. Structural System

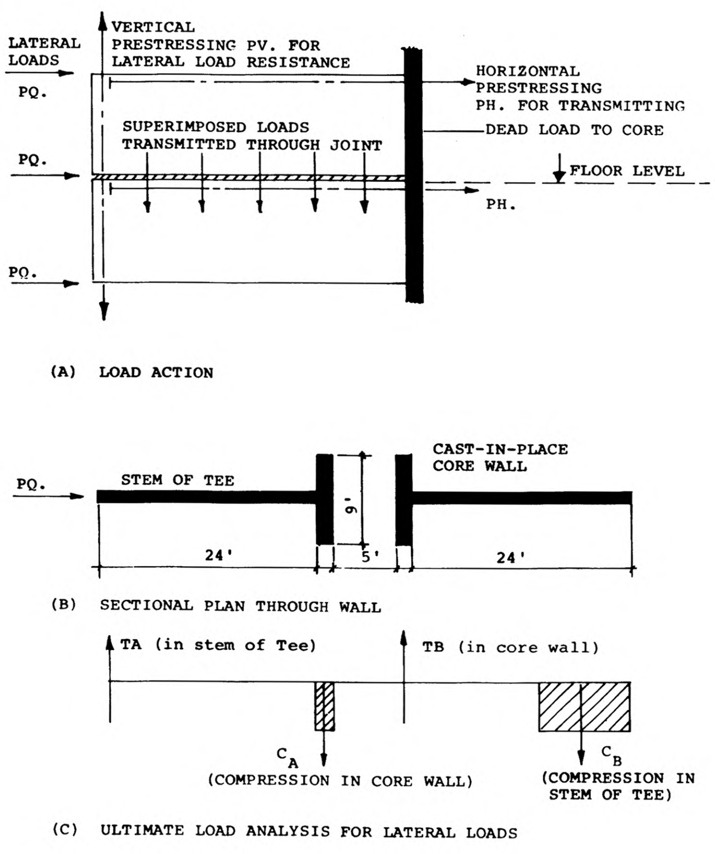

Fig. 4. Structural System

relatively low stress can be estimated by a simple ultimate load design procedure.[1] The horizontal shear forces are transmitted from one level to another by means of welded shear connectors. See Figure 5B on connection details.

STRUCTURAL MATERIALS

All precast elements are made from lightweight concrete (120 lbs. per cu. ft.) with a strength of 5000 p.s.i. at 28 days. Cast-in-place concrete is to be regular weight (150 lbs. per cu. ft.) utilizing a strength of 4000 p.s.i. in the foundation and 6000 p.s.i. in the core walls at 28 days. The high-strength alloy prestressing bars should have a minimum ultimate strength of 160,000 p.s.i. Although for structural reasons bonded post-tensioning offers certain advantages, for cost-saving purposes, unbonded bars connecting the tees to the core may be provided, assuming adequate protection is made against corrosion, e.g. bars may be greased and wrapped or hot-dipped galvanised.

INDUSTRIALIZED PRODUCTION

Types of products to be made are tee panels, infill floor panels, corridor soffit planks and exterior wall panels. All precast elements, other than the exterior wall panels, are to be factory-produced on a long line basis with steam curing permitting an efficient use of the precasting beds. A partial prestressing (pre-tensioning) of all elements would be desirable, not only for handling purposes, but also to eliminate any cracking due to shrinkage. All surfaces, provided that special textured effects are not prescribed by the architect, should be smooth and ready for painting or floor covering. The outside surface of the exterior wall panels may have a variety of finishes to enhance the appearance of the building. As mentioned earlier, conduits, (piping and wiring), door and window frames may be cast into the elements during their manufacture.

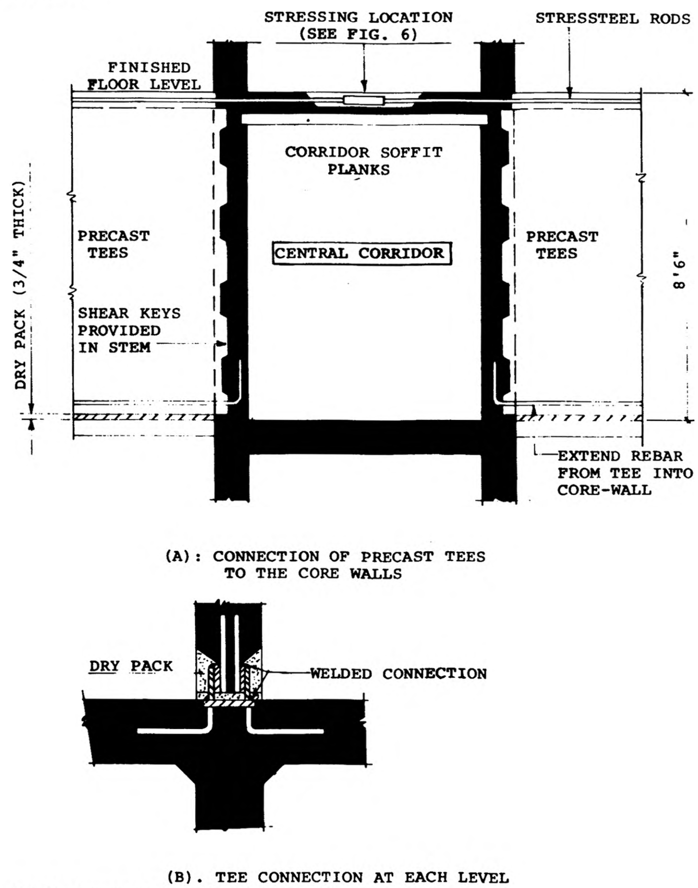

Fig. 5. Connection Details

[1] At the moment the proposed structure is being more rigorously analysed by a computerized matrix displacement method.

In this way, high standardisation can be attained, while the labour force, especially at the construction site, can be kept to a minimum. The majority of the precast manufacturers in the U.S. are capable of producing the above-mentioned components, without any major additions or alterations to their existing plant facilities.

FIELD CONSTRUCTION AND ERECTION

The preparation of the building site is done in a conventional way. The foundation slab is cast in the usual manner with care being taken to locate correctly the threaded anchor plates needed for the vertical prestressing. Local stress concentration in the vicinity of the anchorage should be considered in the final design.

Initially, it had been the intent to construct the central core up to a height of three or four levels prior to suspending the precast elements. However, it became apparent that the connection details between the precast elements and the central core would cause a number of problems, such as

1. Stabilising the tees during erection,
2. Caulking of joints between the cast-in-place concrete and the precast elements.
3. The high degree of workmanship required in ensuring the proper vertical and horizontal alignment of the core wall.
4. The necessity to maintain extreme accuracy in the production of the precast elements.

Hence another construction technique was sought which would overcome these drawbacks, yet maintain the overall structural concept.[2] The construction and erection may then be summarised as follows.

The central core wall forms are set up, with cut outs provided to receive the stem of the precast tee panels. All prefabricated elements are erected, other than the exterior wall panels, prior to the pouring of the central core. As indicated in the Structural Materials Section, a high strength concrete (F'c = 6000 p.s.i.) has been used for the core, enabling the post-tensioning of the precast tee elements to the core to take place after the concrete has achieved a strength of 3000 p.s.i. (approximately two to three days). See Figure 5A. The exterior wall panels may be erected prior to post-tensioning.

Stress-steel tensioning tongs (Figure 6) permit the stressing operation to be executed within the corridor. The top and bottom of the tees are welded together as indicated in Figure 5B to transmit horizontal shear. Combined with "dry-pack" under the wall sections, this ensures transmittal of the superimposed loads down through the structure (stem of tee becomes a load-bearing element).

In order to ensure that the dead load of the structure is transmitted to the core wall and not down through the stem of the precast tees, "Freyssinet Flat Jacks" may be used during the erection sequence. After the tees have been post-tensioned to the wall, the jacks may be deflated and removed.

At every third floor level, vertical prestressing is applied as indicated in Figure 7, ensuring structural stability during erection.

PRELIMINARY RESULTS

A 15 storey building approximately 130 ft. high and varying in width from 54 ft. to 64 ft. was roughly analysed. The results, based upon design criteria given in Table 1, are as follows:

1. Core Wall - 10 in. thick - lightly prestressed vertically in close proximity to the stem of the precast tee panels.
2. Precast Infill Panels - 5 in. thick. These panels are approximately 9 ft. wide by 24 to 28 ft. long, and are considered as simply supported members spanning in the short direction. Maximum weight per panel = 6.25 tons.
3. Precast Tee Panels - A preliminary flange and stem thickness of 5 in. appears to be satisfactory. However, such problems as deflection and torsion should be investigated in a final design. The tee panels are 9 ft. wide, 8 ft. 6 in. deep and 24 to 28 ft. long. Maximum weight per panel = 11 tons.

[2] Various connection details are being considered in order that the initial construction technique outlined above may be used.

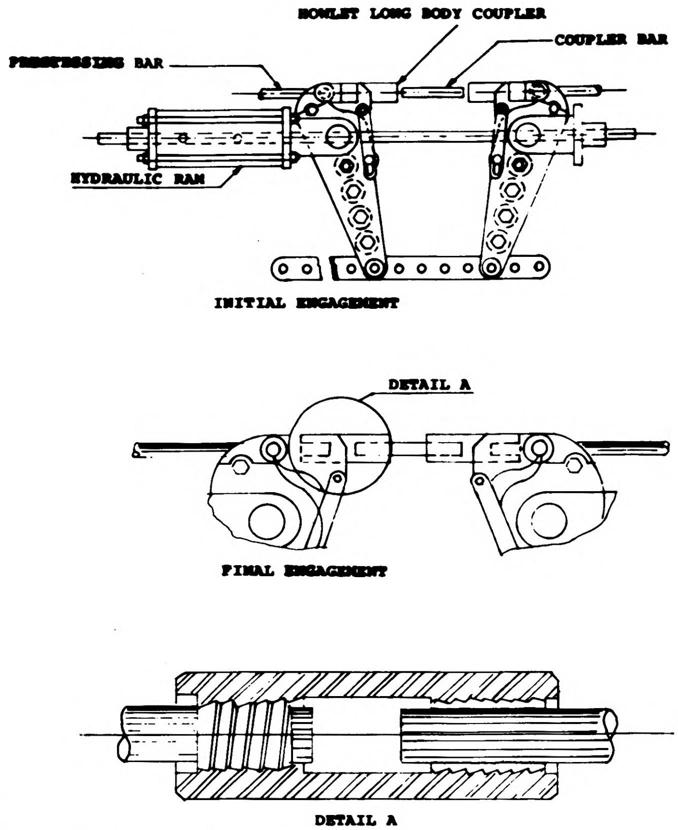

Fig. 6. Stressteel Tensioning Tongs

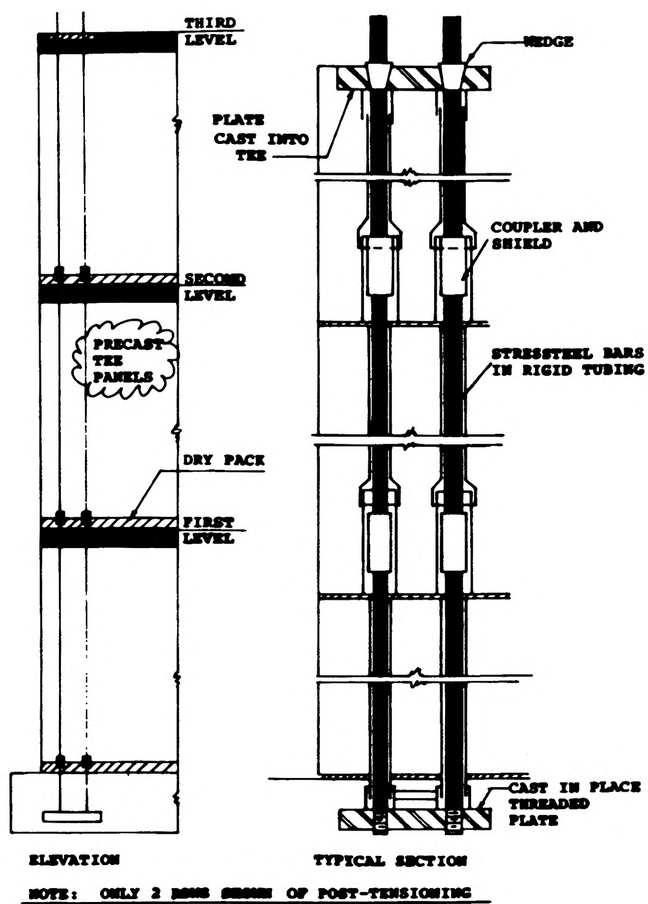

Fig. 7. Connection Details of Vertical Post-Tensioning

4. Prestressing -
   (a) Horizontal - based upon ultimate load capacity, a 1 1/8 in. dia. 160 k.s.i. Stressteel bar, is sufficient to suspend each tee from the core wall.
   (b) Vertical - as indicated in Figure 4C, the maximum amount of prestressing required is equivalent to four 1 in. dia. Stressteel bars placed in the outer edges of the precast panels.

CONCLUSION

The proposed new construction for tall apartment complexes attempts to eliminate perhaps the two most important obstacles to the industrialized production of low-cost housing, namely:
(a) The hesitation of the construction industry to use unfamiliar systems.
(b) The present undesirable restrictive building code requirements.

New concepts invariably have a multitude of known and unknown drawbacks, including the reluctance of the architects, engineers and contractors to be innovative. However, it is felt in this case that the advantages outweigh the disadvantages, for example:

1. For dead-load, the structure acts as an "X-mas tree" i.e. a tension structure, while the live loads are carried by the wall section of the precast tees. This division of load reduces the overall weight of the building by 10 to 20% when compared to conventionally reinforced concrete structures.
2. An extremely high earthquake and wind force resistant structure, due to the vertical prestressing.
3. Mass fabrication techniques in the manufacture of the precast elements in which utilities are incorporated.
4. Permits versatility for architectural design.
5. Fast erection, with a considerable reduction of on-site labour.
6. Utilization of presently available prestressing plants.

No attempt has been made to cover three of the most important functional requirements of multi-storey dwellings, namely thermal insulation, sound insulation and structural fire requirements. All three should be thoroughly investigated prior to the final design of the structural elements.

However, the main purpose of this paper is to illustrate that the construction of low-cost apartment complexes is feasible utilizing the tension structure principle.