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Design and construction features of a 37-story precast reinforced concrete moment frame building in Tokyo

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ABSTRACT

This paper describes design and construction features of a high-rise apartment building project in downtown Tokyo, Japan constructed during 1990. Not only is the building the tallest reinforced concrete building in this high seismic risk region, it was constructed using precast concrete frame "cruciform" elements fabricated at the jobsite. All connections use the "emulation design" approach for precast concrete to assure monolithic concrete performance of the structure.

Details of site fabrication of the cruciform elements are discussed, permitting lower ratio of labor required compared to that for formed cast-in-place structures.

Assembly of the erected elements is described. This includes column-to-column and column-to-beam connections, as well as the use of half-thickness factory-manufactured floor and balcony slabs, all of which are tied together with a cast-in-place concrete topping pour. One floor was structurally completed every six days, and other trades could begin work on the floors immediately below.

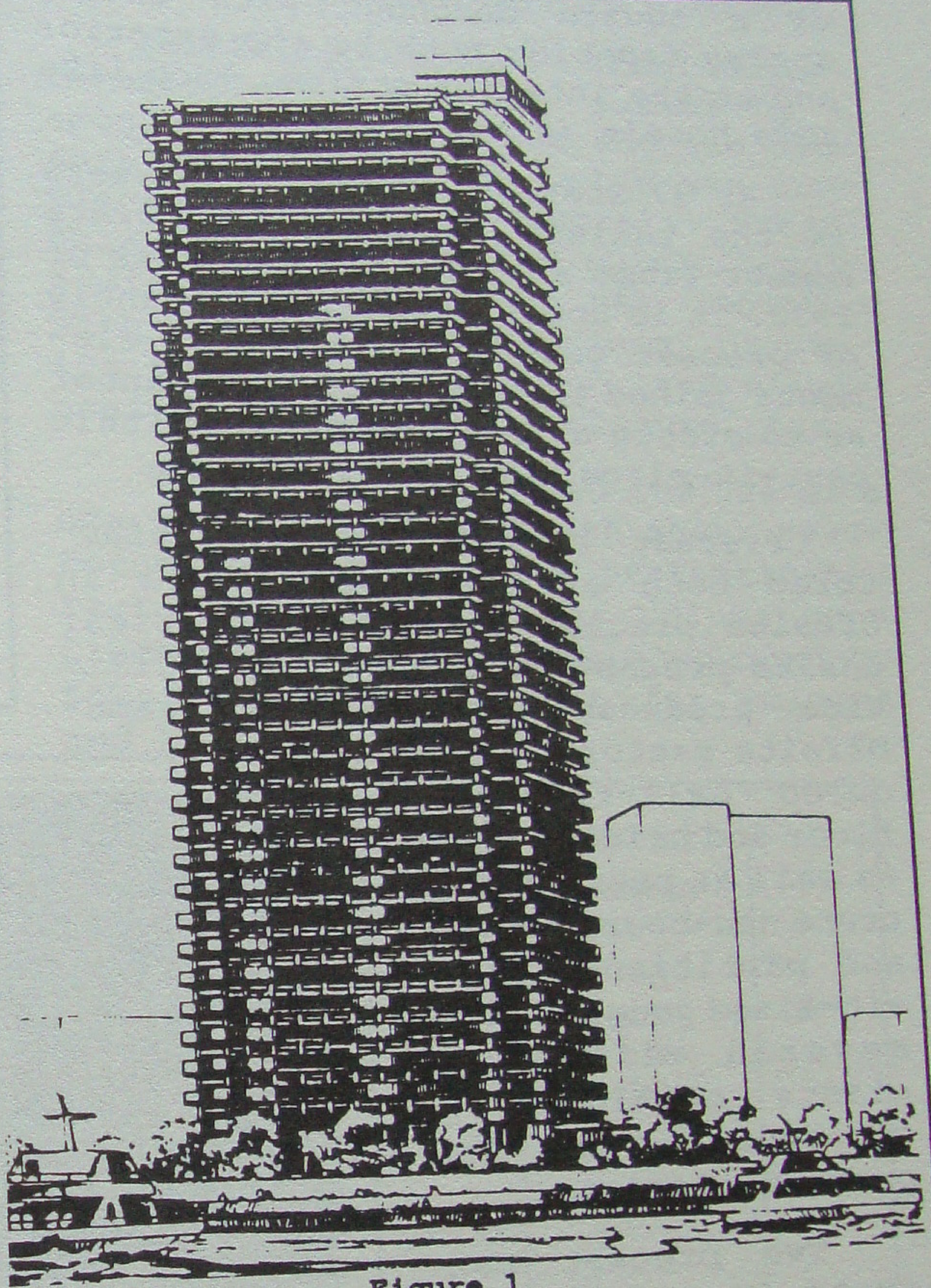

Figure 1
Artist's view of completed
Ohkawabata River City 21 residential center.

GENERAL

The project, called Ohkawabata River City 21, is a residential center of mid- to high-rise buildings located on an attractive peninsula in the Sumida River near downtown Tokyo. (Fig. 1)

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It was as constructed by a joint venture of the Taisei, Shimizu and Ohbayashigumi corporations. Taisei prepared the detailed designs. The site area is 87,400 square feet (8,740 sq. m) and the building footprint is 15,272 sq. ft. (1,527 sq m). The building extends 32 feet (10m) underground to provide for parking and building support. The building extends 37 floors or 348 (106m) feet above grade. It was built in the form of a square doughnut with living spaces fronting both to the exterior and to the interior atrium, much like some hotels in North America.

At 37 stories, Ohkawabata Towers is the tallest reinforced concrete moment frame structure in Japan as of 1990. It is constructed predominantly of precast concrete structural elements joined together in such a manner as to create an equivalent monolithic cast-in-place concrete building.

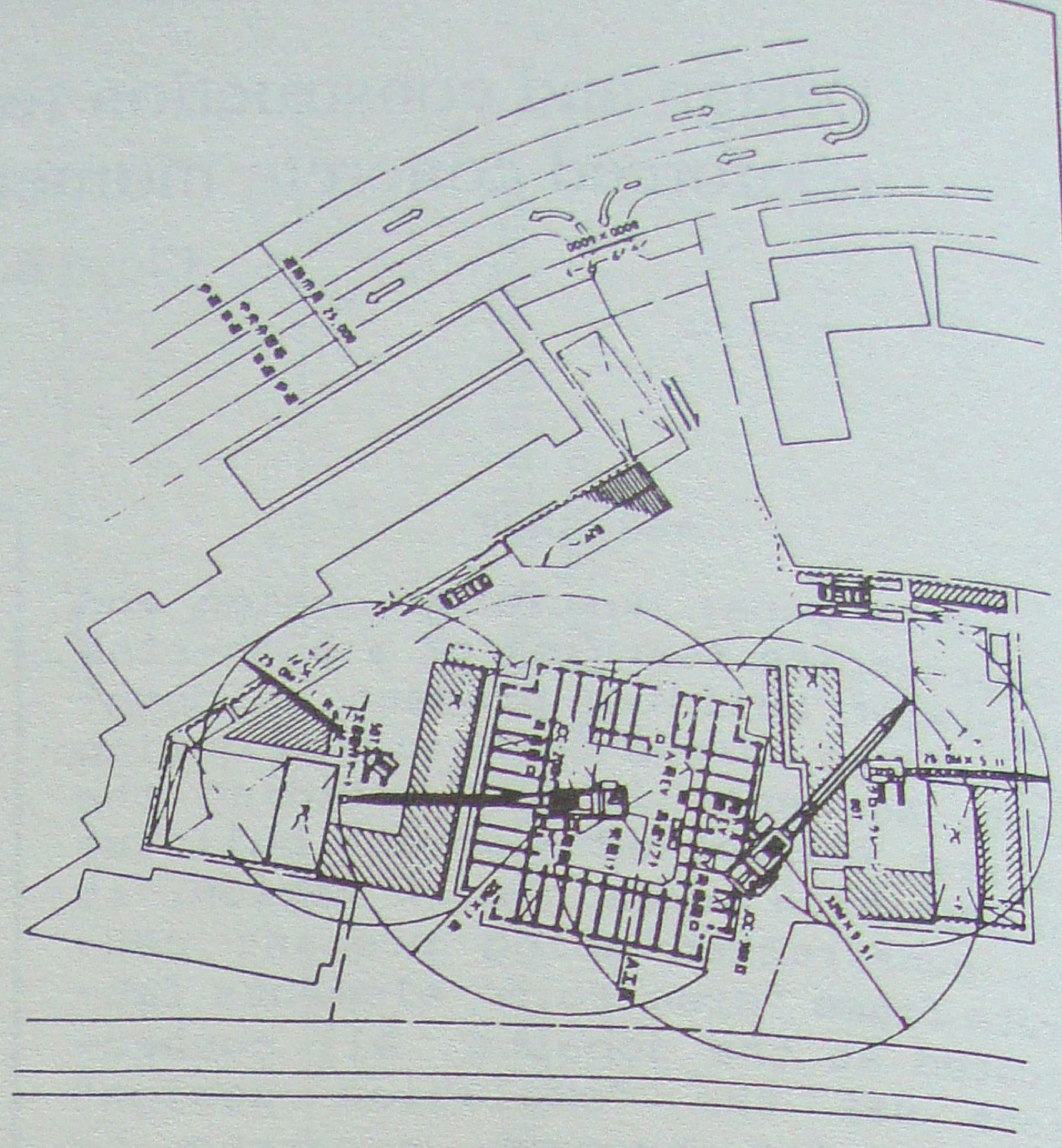


Figure 2
Two temporary precast concrete structural manufacturing plants were established at the base of the building, one on each side within the reach of a tower crane.

Precast elements were manufactured both at the jobsite and in offsite precast concrete factories. Onsite precast manufacturing facilities produced columns and beams. Offsite factories produced half-thickness floor and balcony slabs as well as precast concrete non-bearing walls and partitions. Transit-mixed concrete from several different plants provided the concrete for the site precast elements.

Two precast concrete manufacturing facilities for the frame members were established directly at the base of the building, one on each side. (Figs. 2 and 3)

Conventional cast-in-place concrete topping was placed over the precast floor and balcony elements to provide a diaphragm. Simultaneously, open-

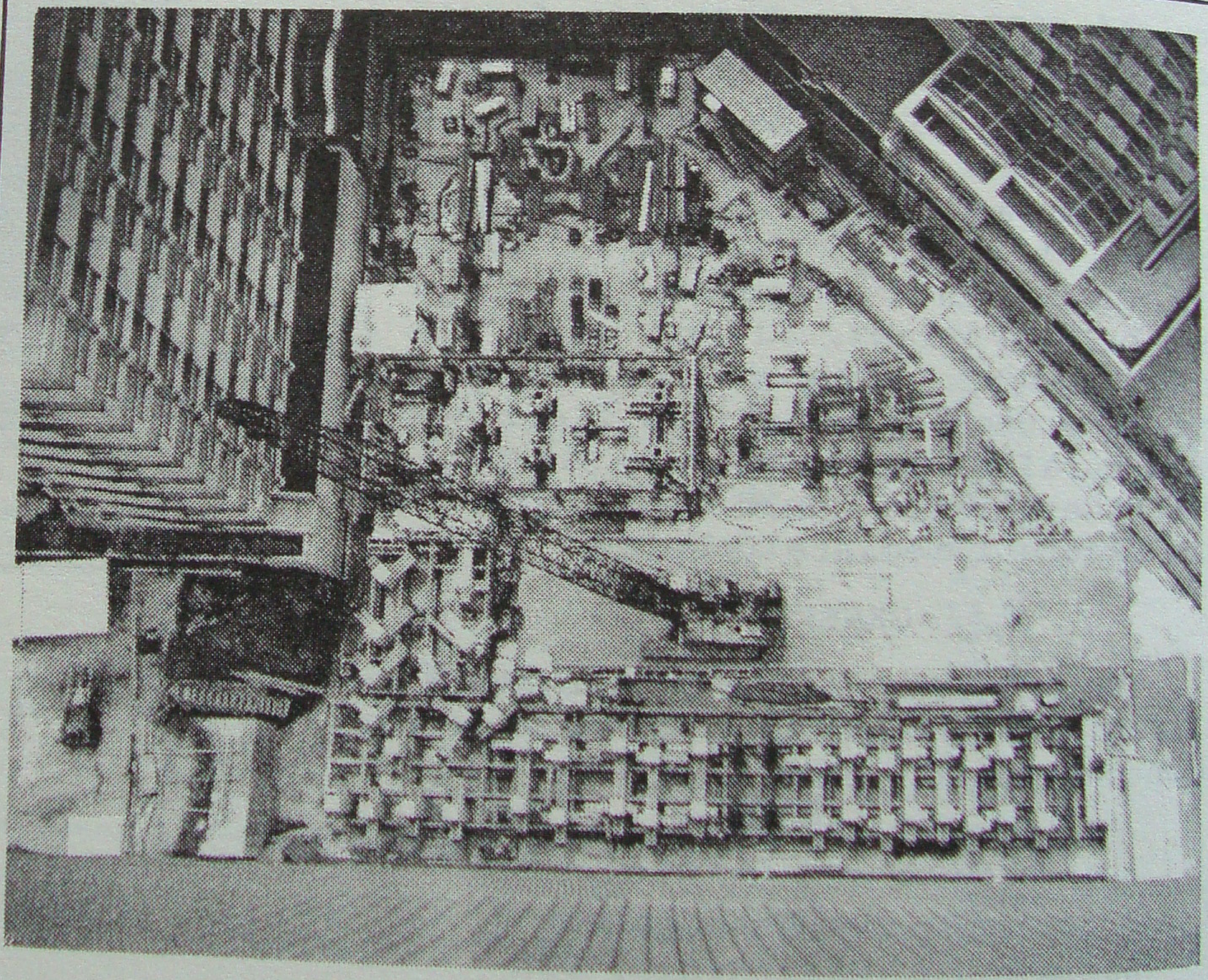


Figure 3
Aerial view of one of two precast concrete plants established on-site at the the base of the building.

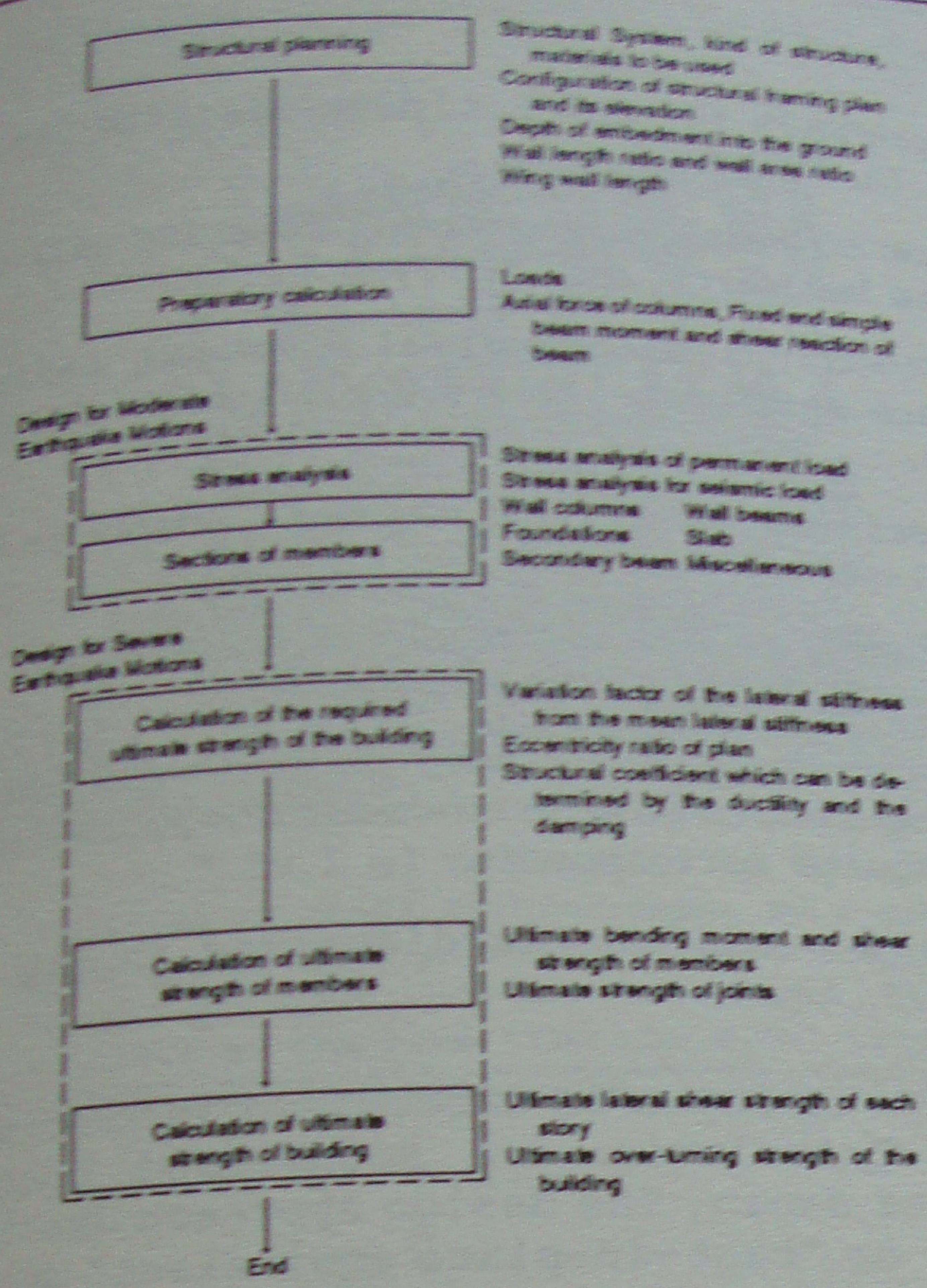


Figure 4

Flow chart of Japanese Aseismic Design Method.

ings between beam ends were filled with concrete of the same specification as that of the floor topping.

The basic element used in construction of the frame was a three-dimensional beam-column "cruciform tree" connected at locations away from the high moment region. During the early stages of erection, in the lower portion of the building, structural steel sections were embedded in the precast concrete cruciform elements.

Initially, column longitudinal reinforcing steel was joined by a special welding process and the closure area around the welds was completed with poured concrete. Subsequently, welding of the column longitudinal reinforcement was replaced with mechanical connections, providing a "blind connection", and eliminating the need for a closure pour.

Innovations included the use of a new type of high strength shear reinforcement in the form of prefabricated rectangular spirals for column confinement and a newly developed robot to fabricate reinforcement for columns and beams.

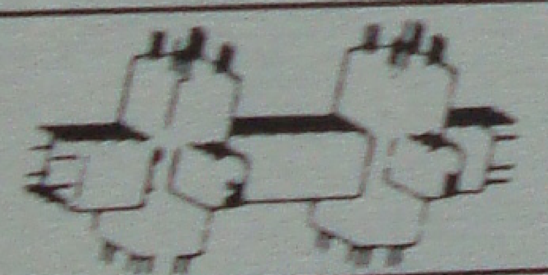
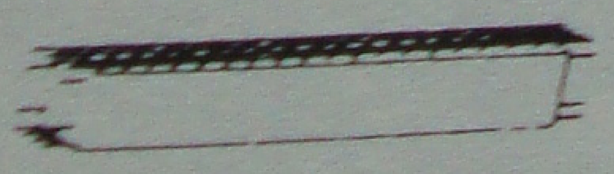
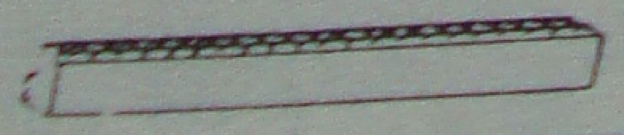
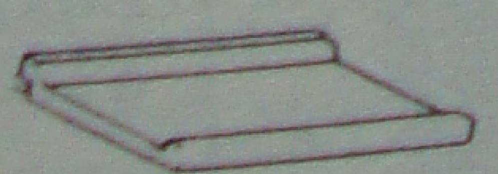
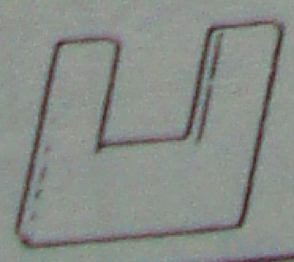
Items	Shape or thickness	Units	Maximum weight per unit (tons)	Cast at:
Column-Beams		24	11.9	PC factory in the job site
Columns		32	6.4	
Girder		8	5.4	
Small Beams		28	3.3	Outside precaster
Omunea Planks	Thickness 55 (2.25")	84	1.1	Outside precaster
Precast Balcony		56	3.4	
Exterior Precast Walls		30	2.7	

Figure 5

Types and numbers of precast concrete elements per floor

Seismic Considerations

The Japanese ASEISMIC DESIGN METHOD approach for the building described herein establishes the following base criteria (Ref. 1):

"(1) To prevent damage to the building from moderate earthquakes (about 100 gal) which will occur often during the service life of the building, and

(2) To prevent collapse of the building, although it may be partially damaged, and secure the safety of human life in the event of a severe earthquake (300-400 gal) which will occur rarely during the service life of the building.

On the basis of these basic criteria the aseismic safety is confirmed in definite terms by performing successively the following two stages of design:

(1) First Stage (Primary design, elastic design, allowable stress calculation) Perform elastic design against seismic energy corresponding to 0.2G.

(2) Second Stage (Secondary design, plastic design, ultimate strength calculation) Secure the ultimate strength and ductility required to be able to absorb the seismic energy acting on the building in the event of an earthquake corresponding to 1.0G."

The Japanese New Aseismic Design Method procedure is diagramed in Fig. 4.

Emulation Design

Design of reinforced concrete structures in Japan is determined in accordance with the "AIJ Standard for Structural Calculation of Reinforced Concrete Structures" of the Architectural Institute of Japan. The design approach described below is called "Emulation Design."(Ref. 2) or "cast-in-place equivalent" design.

The Ohkawabata building was designed as if it was an ordinary moment-resisting frame which would be configured for aseismic response according to the AIJ criteria noted above. Had it been cast in-situ, the columns, the beams and floor slabs would have been formed and poured in the conventional manner. Using the concept of emulation design, the building was divided into discrete elements which could be fabricated separately and later joined to create an equivalent monolithic structure. These basic elements are shown in Fig. 5.

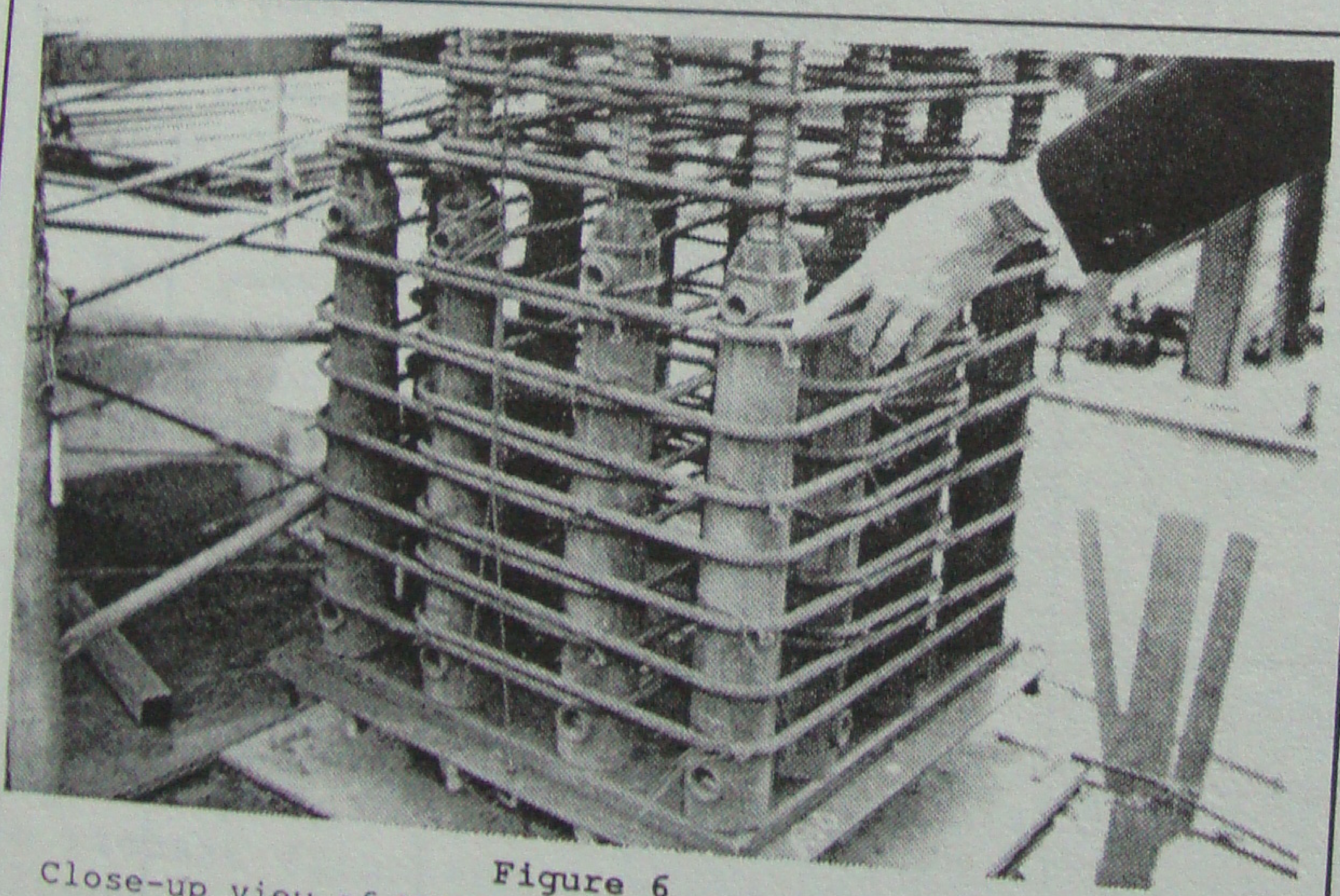


Figure 6
Close-up view of NMBSS mechanical connections. Each is accurately located by means of a special sleeve setting device installed in the base of the column form.

Connections

Connections of reinforcing bars in conventional reinforced concrete may be accomplished by one of three recognized methods: by lapping, by welding, or by use of mechanical connections. Any of these methods may also be used to join precast concrete structural members. All are recognized by the ACI building code, and by regional building code bodies.

Conventional lapped splices may be used quite effectively in emulation splicing of precast concrete beams when there is sufficient room for them, but they

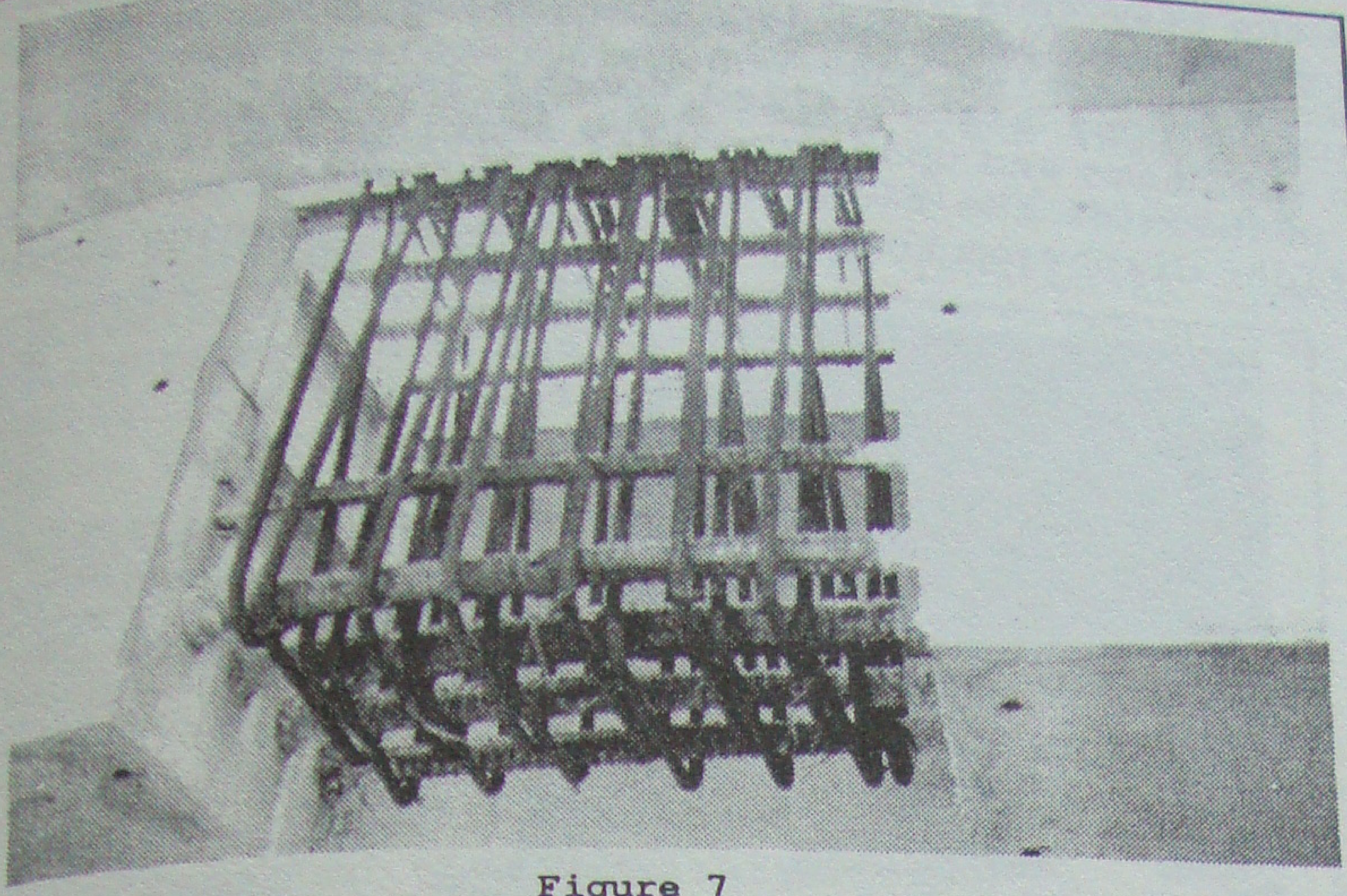


Figure 7
Splicing of steel reinforcement by a special enclosed inert-gas welding process has been completed. The space between the beam ends was formed and filled with fresh concrete at the same time the floor topping is poured.

are economically and practically of little advantage in splicing precast concrete columns.

Welded splices may also be employed for the same application as indicated above for the lapped splices, and within the same limitations. In the building described here, a special enclosed butt-welding process was used to insure ductility in the bar splices. This will be discussed later.

A third alternative for making rebars continuous is use of mechanical connections.

Design Concept

Initially, precast concrete column elements were connected by butt-welding the reinforcing bars in a relatively large space provided between the column ends which was located midway between floors. This space later was filled with poured concrete. As the building progressed, it was decided to eliminate the more expensive, difficult and time-consuming closure pour and to instead connect the column reinforcing bars with grout-filled mechanical connections called NMB Splice Sleeves (NMBSS). (Fig. 6).

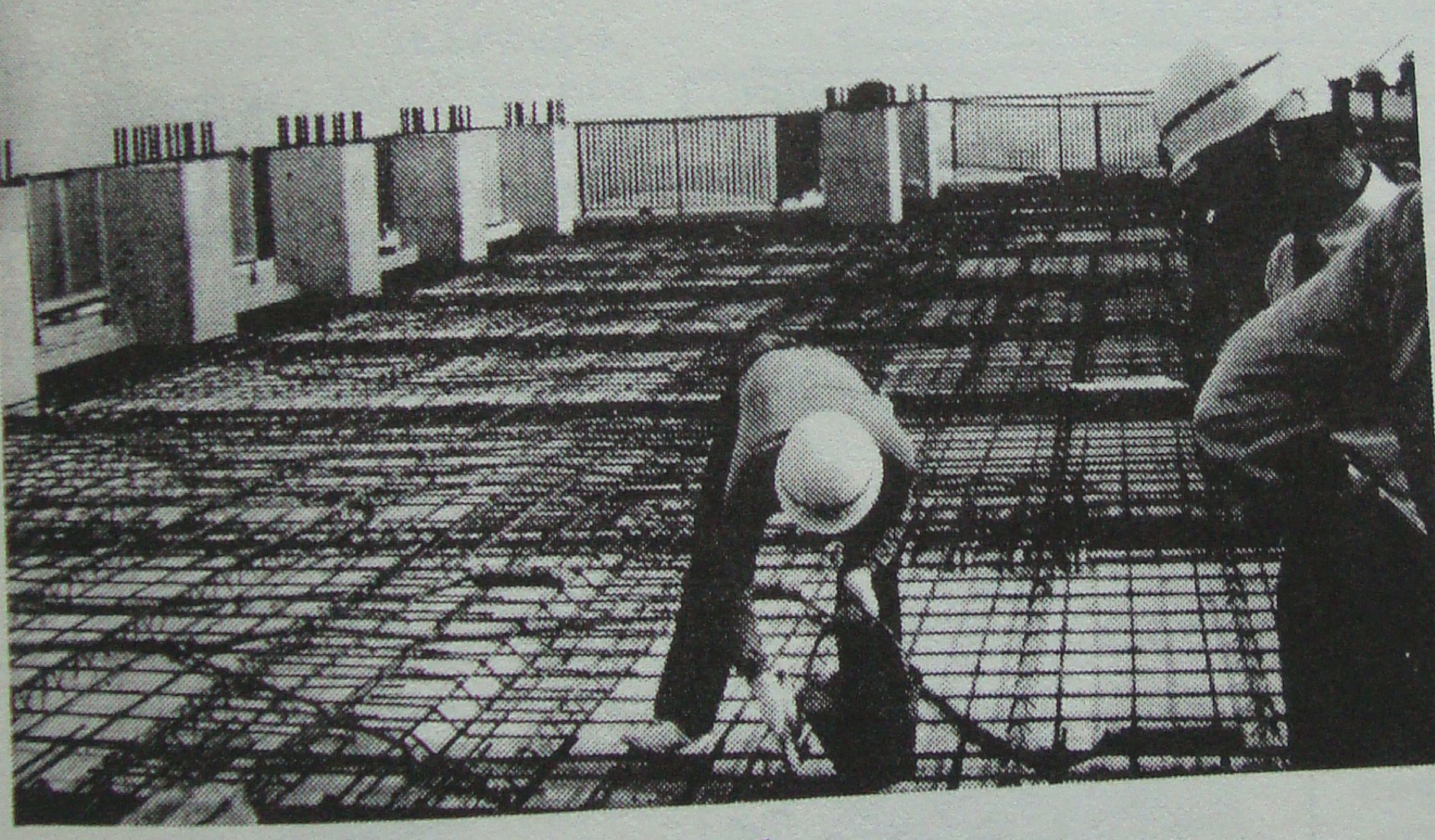


Figure 8
Addition of diaphragm steel over the half-thickness precast concrete "stay-in-place" forms. This was followed by a topping of fresh concrete which also included the "closure pours" completing the beam end connections.

These have been developed especially for making "blind" connections of precast concrete elements. The large closure pour was thus eliminated and it was replaced by a thin joint between the column ends which was filled at the same time and with the same high-strength, non-shrink grout as was used in the sleeves to develop the reinforcing bars.

The steel components of the beam ends were joined either with bolted steel plates or by butt-welding reinforcing bars, or by a combination of both methods.

(Fig. 7). The space between the beam ends was then formed and later poured at the same time as placing the topping concrete for the floor slab.

Half-thickness floor and balcony slabs called Omunea (similar to the Omni system) were set in place on the beams and upon temporary shoring. Additional slab reinforcement in the upper portion of the floor slab was installed as required. (Fig. 8). To tie the entire floor diaphragm together, ready-mixed topping concrete was then placed over the precast floor panels and at the same time, filled all of the spaces between the ends of the beams and all locations of negative reinforcing steel in the beam-column units.

The net result was that all of the openings between the precast concrete elements were joined by splicing the reinforcing bars and the openings were filled with grout or concrete. Accordingly, the reassembled precast elements were combined in such a manner as to create the equivalent of a monolithic reinforced concrete structure.

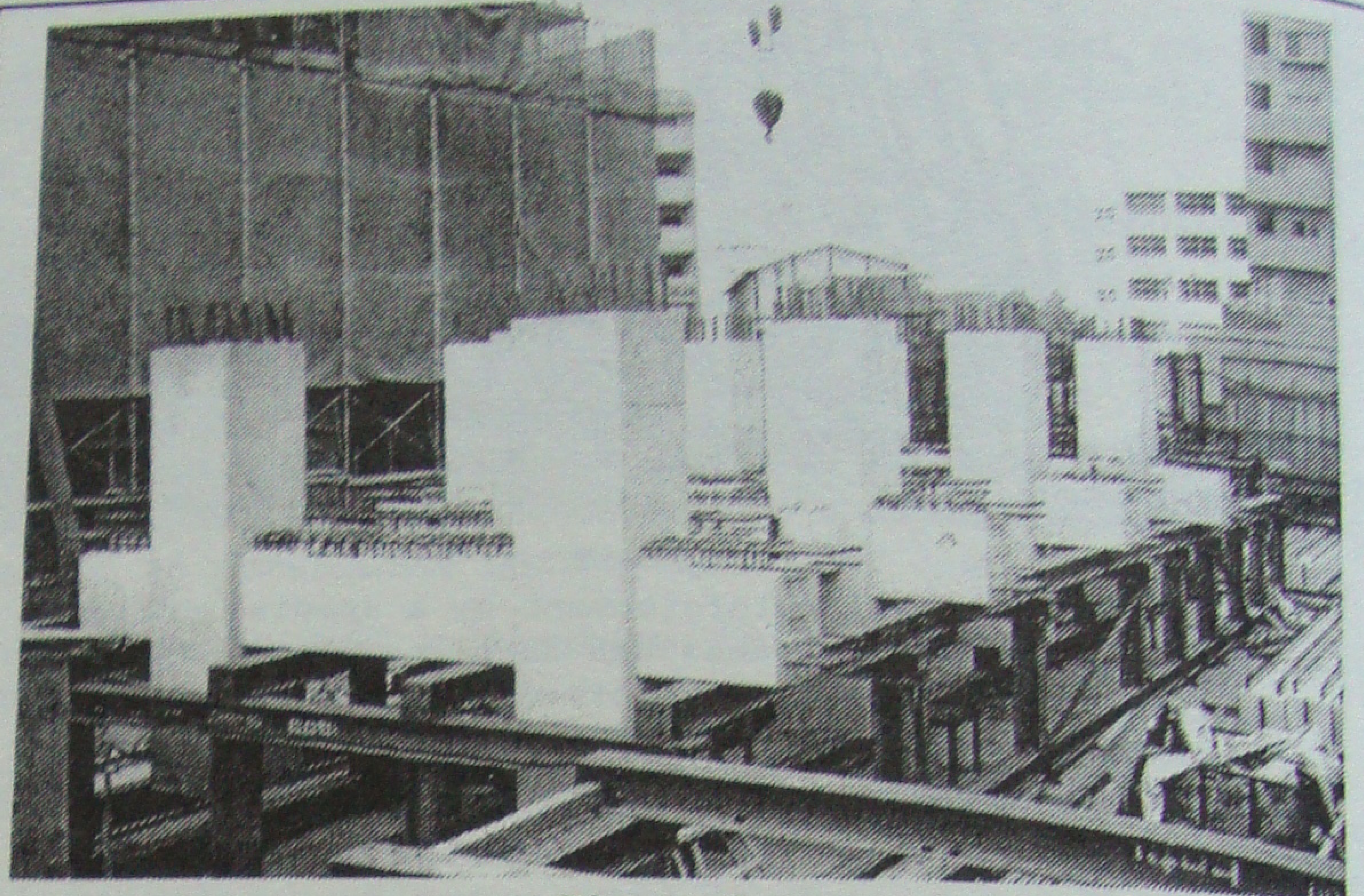


Figure 9
Completed precast concrete "cruciform" elements ready for erection.

MANUFACTURE OF PRECAST CONCRETE ELEMENTS

The contractor elected to use both plant and site precast concrete fabrication methods for the structural elements. Half-thickness floor and balcony slabs, as well as precast concrete in-fill non-structural partitions, were manufactured offsite and delivered to the site according to the schedule. Columns and beams were fabricated on site. (Fig. 9).

The entire operation was simple and straightforward. There was so much repetition of the precast elements that continuous modification of the forms and procedure was unnecessary. This is one of the key factors in improving the efficiency of field construction.

Ordinary ready-mixed

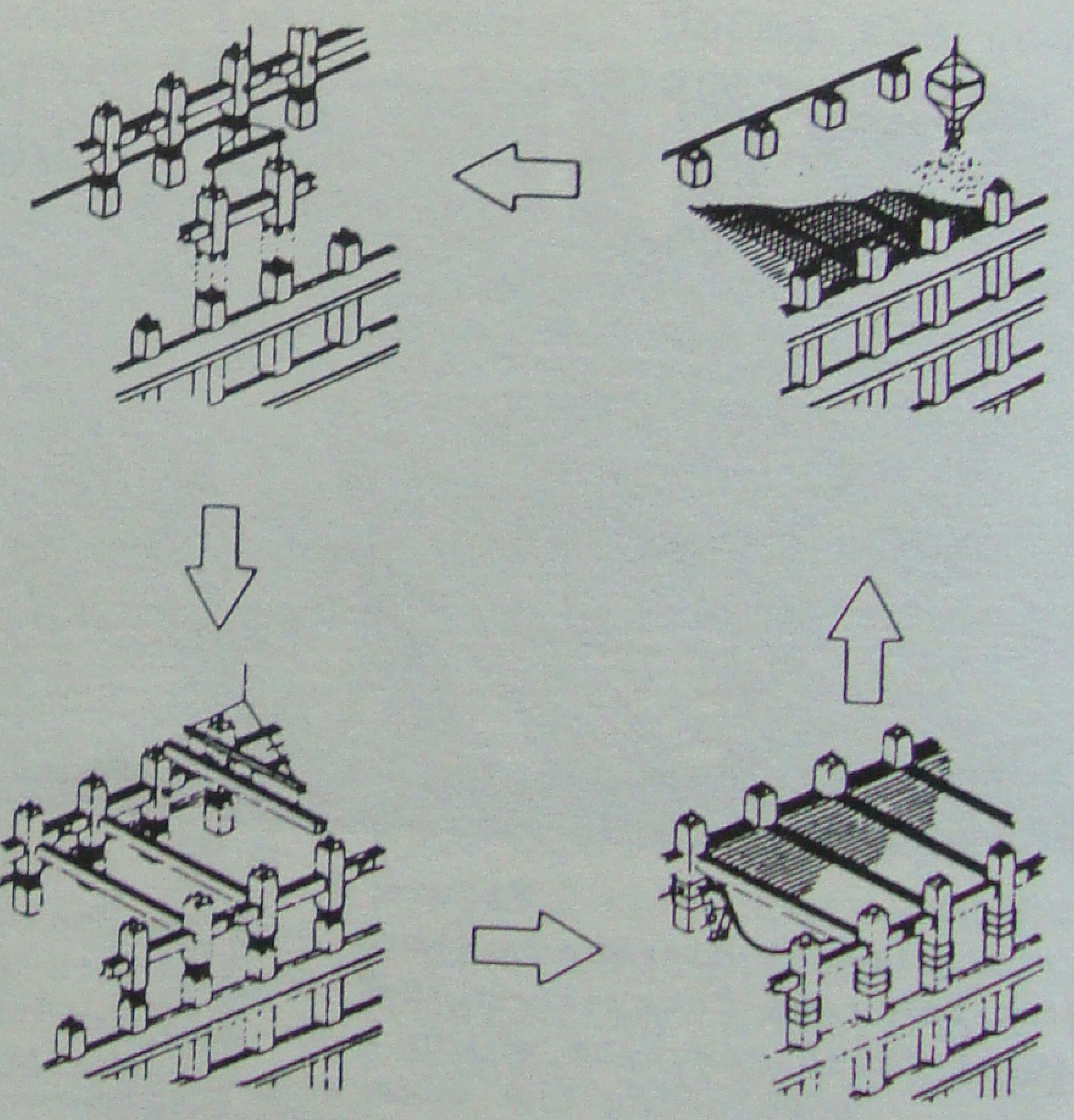


Figure 10
Sequence of erection.

concrete was delivered to the site plant by several different companies. The design strength of the concrete was 4200 psi (300 kg/cm2) at 28 days. A low slump of less than one inch was specified.Concrete was chuted from the truck directly into a bucket which was lifted by a small crane into position to pour the concrete.

ERECTION AND ASSEMBLY

Two climbing tower cranes were located at strategic positions, one outside the building and one in the atrium, both being able to reach the plant and material delivery sites at the base of the building. Fig. 10 shows a typical erection sequence for each floor.

Temporary shores were positioned and set to proper grade. The precast concrete cruciforms were lifted directly from the storage yard position to the erection floor. (Fig. 11). Fig. 12 shows the element being set into position on the temporary shoring.

The next operation was to install the beams. (Fig. 13) In some cases, these elements contained embedded steel plates which were simply bolted together. For those elements without plates, these too were set on temporary shores.

Figure 11
Precast concrete beam/column cruciform element being raised by tower crane to its position on the structure on the 27th floor.

After installing the high strength spiral stirrups, the reinforcing bars in the beam ends were butt-welded using a special gas enclosed arc welding process.

At the same time, workmen installed a temporary grout dam around the interface opening between the column ends. When the dam was sufficiently strong (usually in about one day), using an electrically-driven grout pump, all of the mechanical connection sleeves as well as the bedding space were filled with a special high-strength non-shrink cementious grout in a single operation.

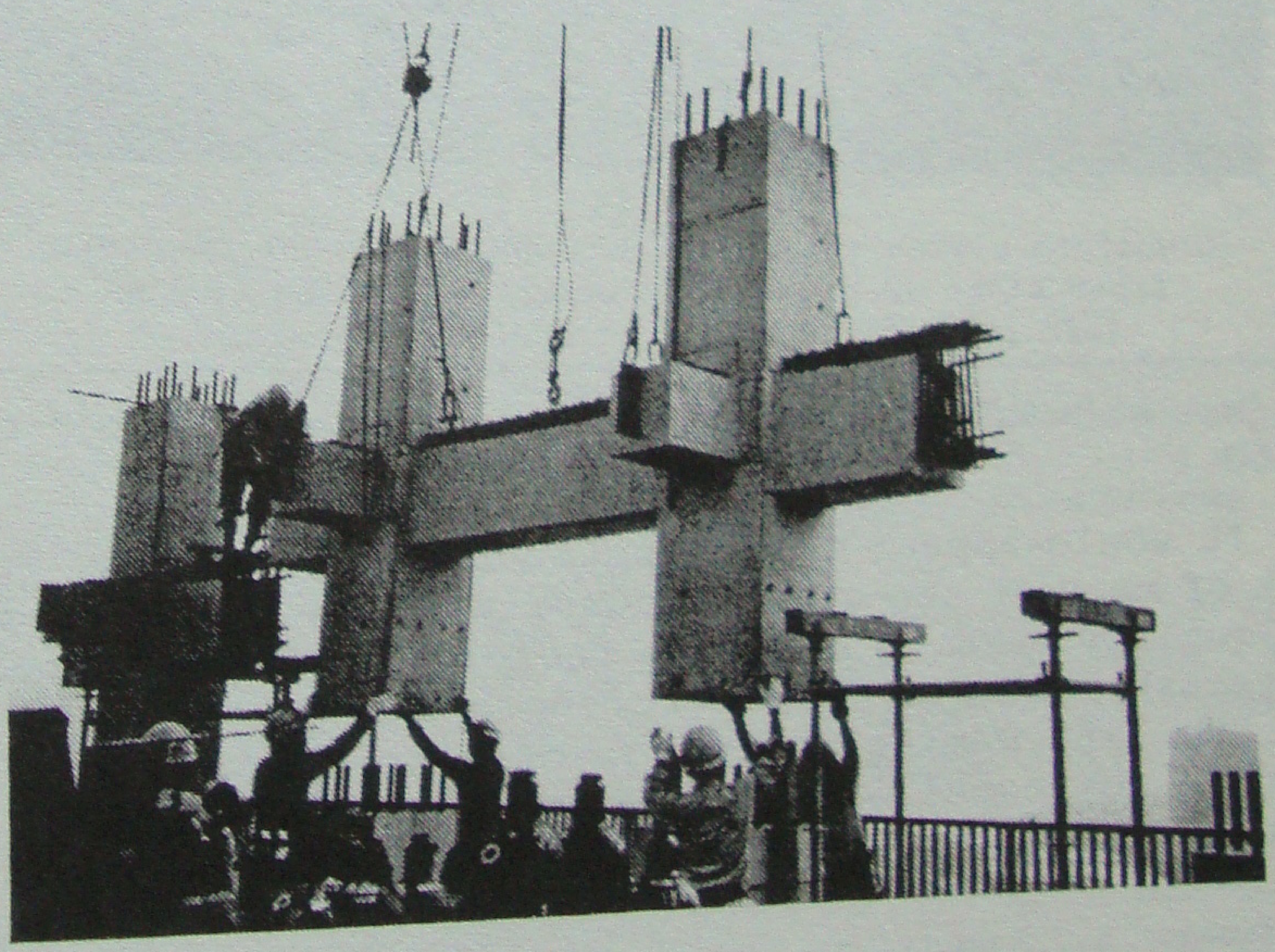


Figure 12
Cruciform element being lowered into position on shores which have been previously set to correction elevation. NMBSS sleeves in the column bases receive the rebar dowels extending upward from the lower column unit.

Half-thickness precast concrete floor and balcony slabs manufactured offsite were then set in place on the beams. Fig. 15 shows the structural frame and floor

Figure 13
Precast concrete beam being installed between cruciforms.

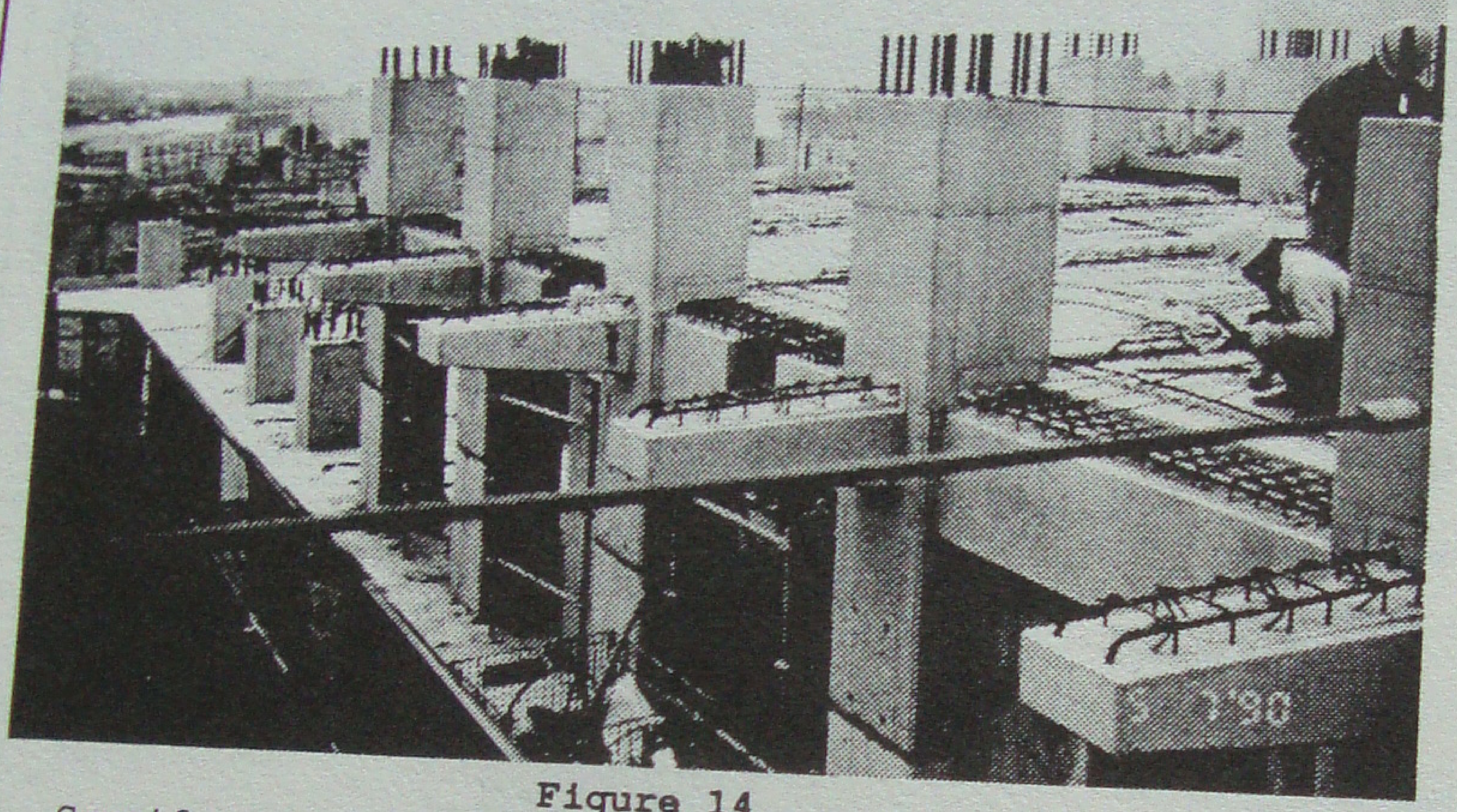


Figure 14
Cruciform elements and half-thickness precast concrete floor slabs in place. Outriggers extending to the left support precast concrete balcony slabs.

system adjacent to the atrium. Reinforcing bars were installed in the deck, and a cast-in-place concrete floor was placed.

After sufficient curing time, the cycle was repeated. Each completed floor cycle took six days. The floors below were available to the follow-on trades shortly thereafter.

CONCLUSION

The paper describes a number of new and bold innovations for the construction of high-rise reinforced concrete frame structures in a highly active seismic regions. Not all of these techniques and procedures are universally applicable. Some are uniquely suited to Japanese labor and construction methods. However, some important lessons which can be learned might include the following:

High-rise reinforced concrete buildings can be and are being designed and constructed in a region of high seismic risk.

The use of precast concrete for portions of such structures is feasible and enhances the project schedule and reduces the number of skilled field laborers required in the field.

It would appear that construction technology in Japan may be out-distancing that of many of the other industrial countries. Innovation and concern for safety and quality seem to be major factors in the construction industry. The fact that a precast concrete manufacturing company, the Maeda Construction Company, Ltd., won the 1989 Deming Award for efficiency is an interesting commentary on their concern for excellence.

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