

Construction of a Shallow Flat Soffit Precast Floor System

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This paper presents the construction sequences of an innovative precast concrete floor system. The proposed system has a flat soffit similar to cast-in-place flat slabs (no ledges or corbels) and a shallow structural depth compared to conventional precast floor systems. The new system is a total precast floor system that consists of precast concrete columns, precast/prestressed concrete rectangular beams, precast/prestressed concrete hollow-core planks, and cast-in-place composite topping. The system is ideal for six to eight stories buildings with 30 ft x 30 ft bay size, which is typical for hotels and office buildings. Quality, simplicity, and speed of construction are the main advantages of the new system in addition to being aesthetically pleasing. This is mainly due to minimizing cast-in-place operations and eliminating false work and formwork operations as well as the need for shear walls, which are time-consuming and labour intensive. This paper briefly describes the new system, its construction sequence, and preliminary cost analysis.

Key Words: Precast Concrete, Floor System, Beam Ledges, Column Corbels, Hollow-Cores

Introduction

Conventional precast hollow-core (HC) floor systems consist of HC planks supported on the ledges of inverted-tee (IT) precast prestressed concrete beams, which are in turn supported on column/wall corbels. Despite the advantages of these systems in terms of economy, speed of construction, and high quality of plant production, they require a significantly deeper structural depth compared to cast-in-place floor systems and the construction of shear walls to resist lateral loads. Moreover, the use of beam ledges and column/wall corbels results in a substantial increase in the total building height, which increases the cost of architectural, mechanical, and electrical (AME) building systems.

This paper presents an innovative precast concrete floor system that has a flat soffit similar to cast-in-place flat slabs (no ledges or corbels) and a shallow structural depth compared to conventional precast floor systems. The new system also has continuity in both directions that is adequate to resist lateral loads without shear walls. The new system is a total precast floor system that consists of precast concrete columns, precast/prestressed concrete rectangular beams, precast/prestressed concrete hollow-core planks, and cast-in-place composite topping. The system is ideal for six to eight stories buildings with 30 ft x 30 ft bay size, which is typical for hotels and office buildings. Economy, ease and speed of construction, and aesthetics are the main advantages of the new system. In addition, eliminating falsework and formwork operations as well as the need for shear walls, which are time-consuming and labor intensive, improves the construction safety and sustainability. No real building was built with the new system yet, however experimental investigations have proved the constructability and structural capacity of the proposed system. This system was developed by researchers at the University of Nebraska-Lincoln and was funded by two precasters: Concrete Industries (CI) Inc., Lincoln, NE; and EnCon Precast, Denver, CO.

This paper is organized as follows: First, the various floor systems currently available in the US market will be briefly described; Second, the components of the new system and its construction sequence will be presented; Finally, preliminary cost analysis will be discussed.

Current Floor Systems

Cast-in-place concrete flat slab floor systems are the most flexible floor systems. They also provide flat soffit and shallowest structural depth when post-tensioned (PTI 2006). The major drawbacks of the cast-in-place construction, in general, are the cost and duration required for shoring, forming, pouring, and stripping operations. In addition, post-tensioning operations increase the construction cost, duration and complexity as it requires the involvement of specialty contractors.

Open web steel joist floor systems are attractive solutions for commercial applications due to their light weight and ease of installation (Steel Joists Institute 2007). Metal decking is generally used to form a 2"-4" thick composite slab. The utilities can pass through the joist openings, saving the height needed for the utilities. However, as the steel prices continue to climb, these systems become less attractive. Also, false ceiling is required to cover the unattractive joists.

Precast concrete floor systems can be made of a wide range of precast concrete products, such as hollow core slabs, solid slabs, double tees, and inverted tee/rectangular/L-shaped beams. The top surface of these systems can be prepared for installation of a floor covering by placing thin non-structural cementations levelling topping, or a composite 2-3 in (PCI 1998). Concrete composite topping. Innovative precast floor systems have been developed over the last few decades by researchers and industry experts (Low et al. 1991, 1996). However, the main limitations of these systems are: low span-to-depth ratio, existence of beam ledges and column/wall corbels, and lack of resistance to lateral loads.

System Description

The new floor system consists of the following components:

- Precast concrete columns
- Precast/prestressed rectangular beams
- Precast/prestressed hollow core planks
- Cast-in-place composite topping

Figures 1, 2, and 3 show the plan view of the building and sections of the precast components designed for an office building that has 30ft x 30ft bay size and live load of 100 psf. It should be noted that the precast concrete columns are continuous for the full height of the building, while the precast concrete beams are made continuous before the cast-in-place topping is placed. This continuity is achieved by placing continuous reinforcement in the pockets at the beam ends and through the column openings. These pockets are filled with grout when the HC keyways are grouted. The cast-in-place composite topping is reinforced in the HC direction to provide partial continuity in the HC direction for lateral load resistance. All the components used in the new system are typical components that are easy to produce, handle, and erect. The 10 in. thick and 48 in. wide HC planks are the most affordable precast product due to their light weight and use in several applications. Also, the 48 in. wide and 10 in. thick beams are simple in fabrication, handling and shipping. All the connections in the new system are greatly simplified for the precaster and contractor to speed up fabrication and erection operations, which will result in the quick and wide use of this system. Figure 4 shows the beam-column connection and HC-beam connection and their reinforcement detail.

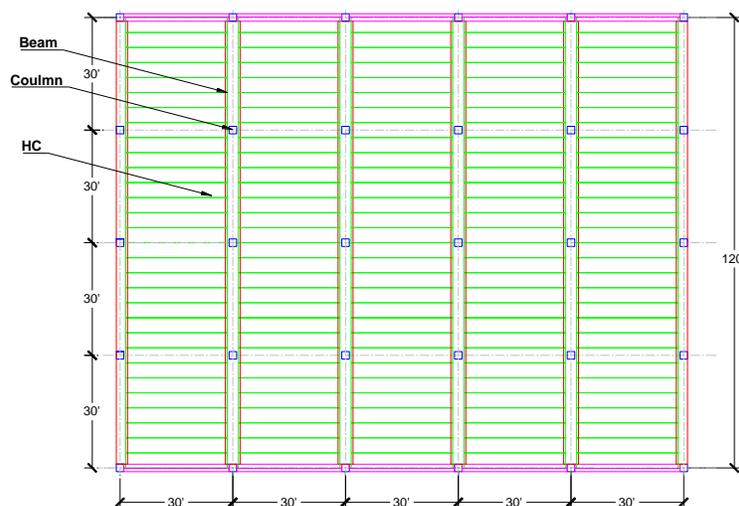


Figure 1: Plan, view of the example building

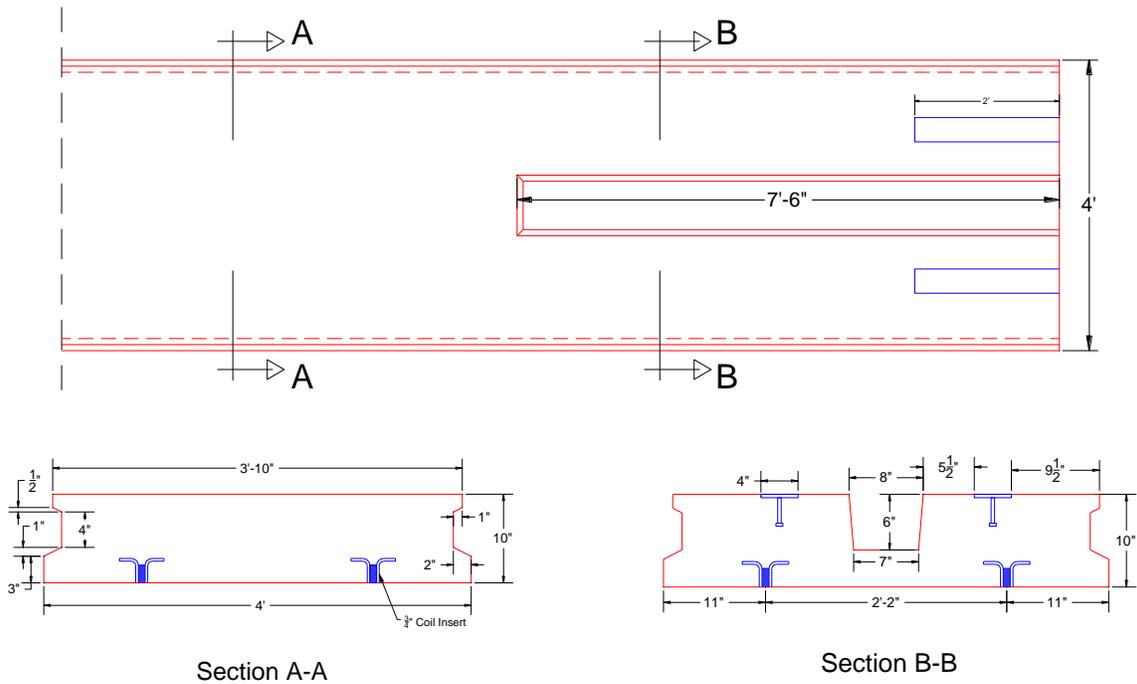


Figure 2: Cross Sections of Precast Beam

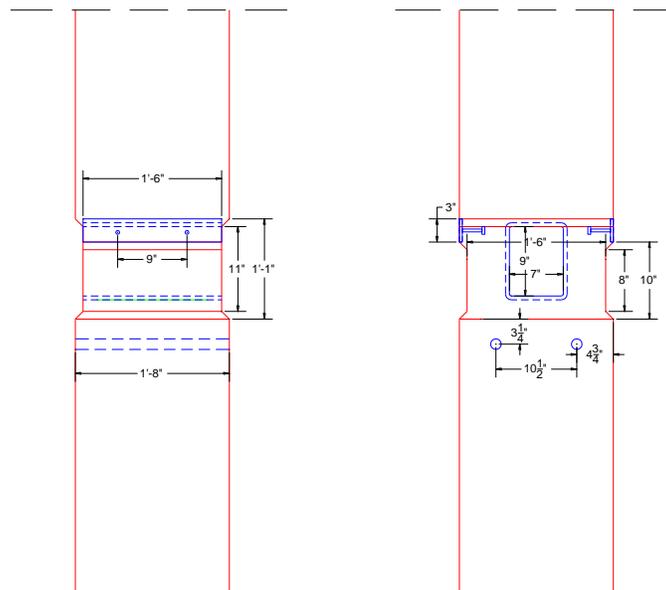


Figure 3: Elevation and side views of Precast Column

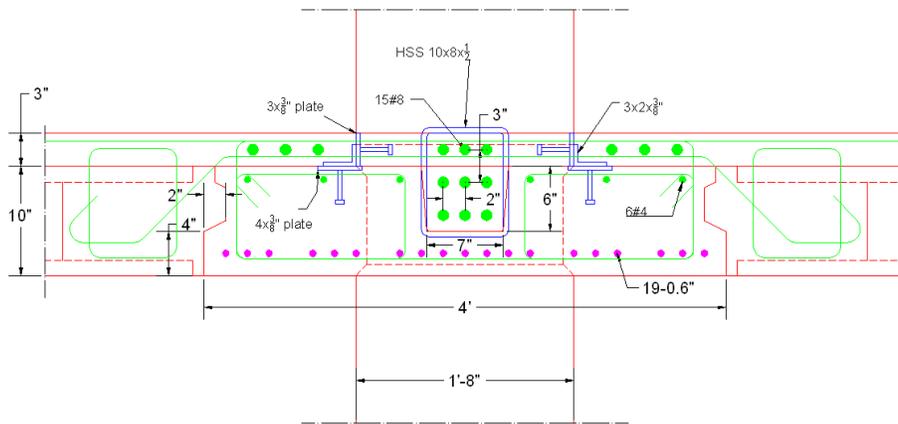


Figure 4: Column, Beam, and HC Connections

Construction Sequence

In order to examine the constructability of the proposed floor system, a full-scale specimen of 20 ft x 20 ft segment around an interior column was produced and erected at the structural laboratory of the University of Nebraska – Lincoln. All precast components were produced by Concrete Industries, Inc. (Nebraska, Lincoln) and EnCon (Colorado). The specimen was tested later to determine the structural capacity of the various components and connections, however, this paper only presents the construction sequence and associated challenges. Below are the ten steps of erecting the specimen along with the relevant photos and 3D representation.

Step 1) The precast column is erected and connected to the foundation, which is a reinforced concrete base of 4 ft x 4 ft x 3.5 ft in this case. Temporary corbels are installed. These corbels consist of two angles 3 in. x 5 in. x 3/4 in. each. The angles are bolted to the column using two 1 in. diameter bolts going through the 1-1/16 in. diameter holes in the column and four 1 in. diameter nuts as shown in Figure 5. These angles will act as temporary corbels to support the beam during construction, and will be removed afterwards.

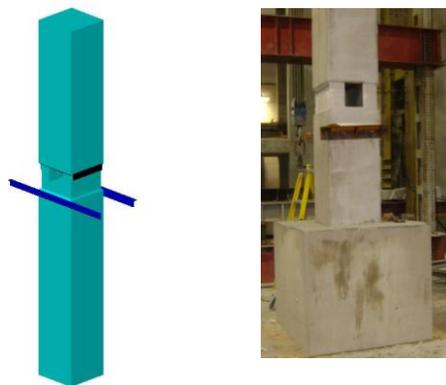


Figure 5: Erection of the precast column and installation of temporary corbels

Step 2) Precast/prestressed rectangular beams are placed on each side of the column so that the beams align to each other and beam pockets align to column opening. Beams are supported by the temporary corbels to carry loads during construction. The beams are placed at a distance of 1 in. from the column face in addition to the 1 in. recess in column sides, which creates a 2 in. wide gap between the column face and beam end to be grouted later. Two 38 \in. long angles (3 in. x 2.5 in. x 1/2 in.) are welded to the beam end plates and column side plates as shown in Figure 6. These angles are required to stabilize the beams during HC erection. The welding operation should be performed by certified welders.

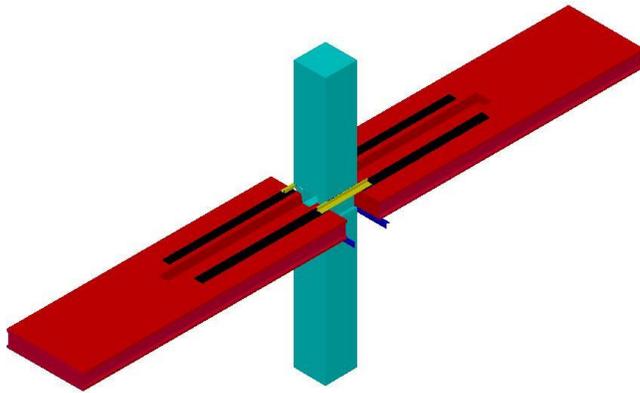


Figure 6: Erection of beams and welding of top angles

Step 3) Steel sections, such as two back-to-back angles or HSS tube, are used to work as temporary ledges for supporting HC planks. These sections are connected to the bottom of the precast beam using coil inserts and threaded rods as shown in Figure 7.

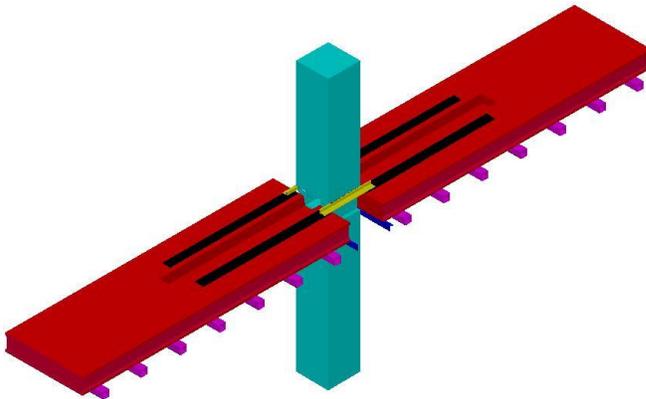


Figure 7: Installation of temporary beam ledges

Step 4) HC planks are placed on the temporary beam ledges on each side of the beam as shown in Figure 8.

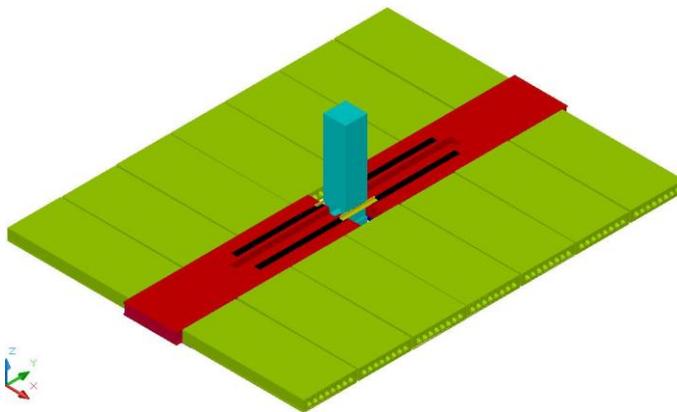


Figure 8: Erection of HC planks on temporary beam ledges

Step 5) Continuity reinforcement is placed in the beam pockets and through the column opening as shown in Figure 9. This reinforcement also represents the hidden corbel reinforcement needed for beam-column connection. In the same step, the hat bars connecting the HC planks to the beam are placed over the beam at the HC keyways.

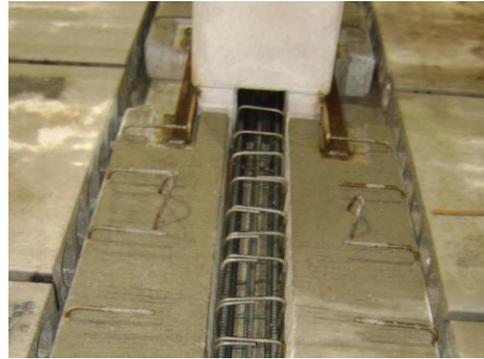
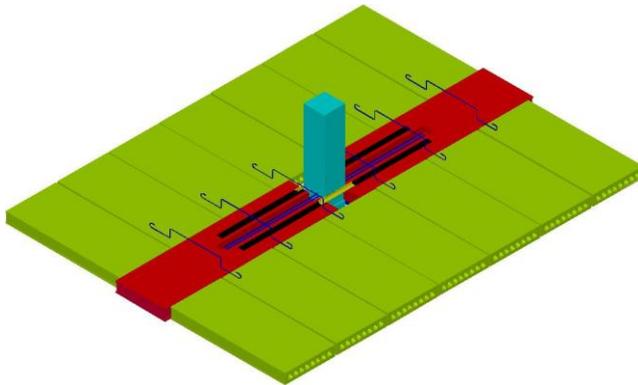


Figure 9: Installation of continuity reinforcement in beam pockets and hat bars in HC keyways

Step 6) The HC keyways, beam pockets, column opening, and shear key between HC planks and beam sides are all grouted using high slump 4 ksi grout as shown in Figure 10.

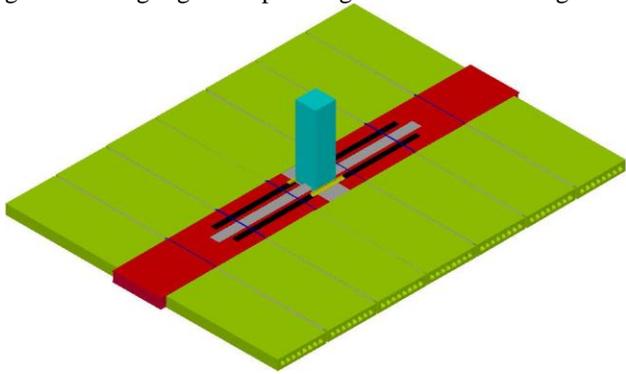


Figure 10: Grouting shear keys and beam pocket

Step 7) Second layer of continuity reinforcement are placed over the beam, as shown in Fig. 11

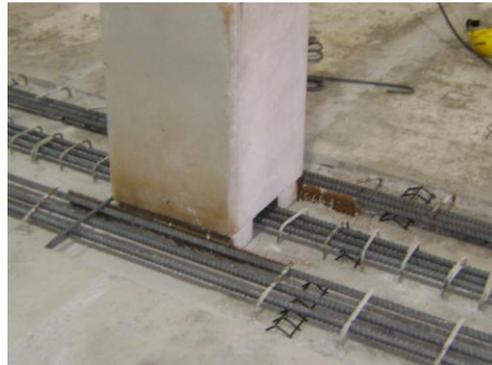
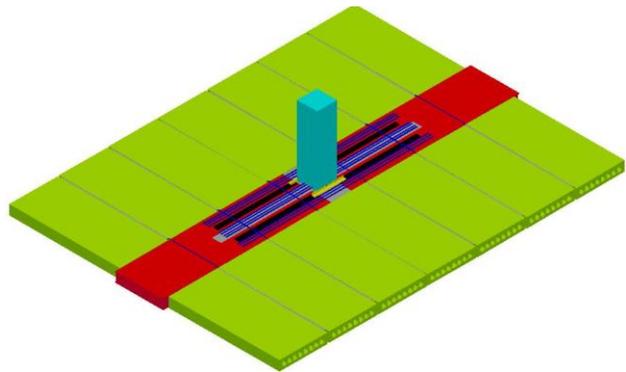


Figure 11: Installation of beam continuity reinforcement

Step 8) Welded wire reinforcement mesh is placed over the HC planks to reinforce the composite topping as shown in Fig. 12.

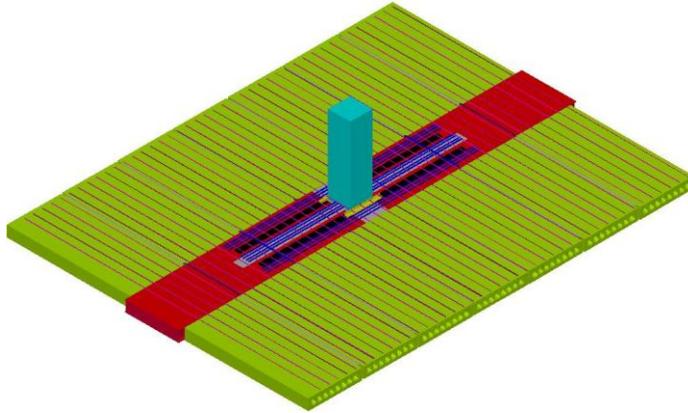


Figure 12: Installation of topping reinforcement

Step 9) Topping concrete is poured using medium slump 3.5 ksi concrete as shown in Figure 13.

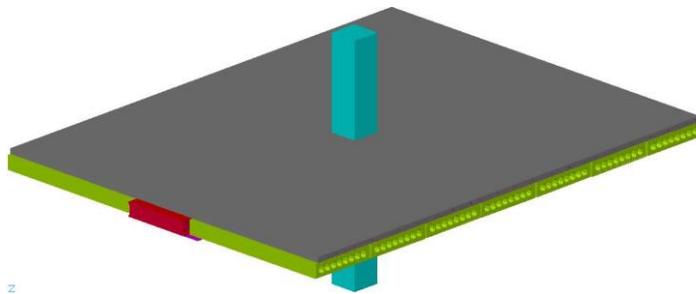


Figure 13: Pouring the concrete topping

Step 10) Finally temporary corbels and ledges are removed after topping concrete reaches the required compressive strength to provide a flat soffit as shown in Figure 14.

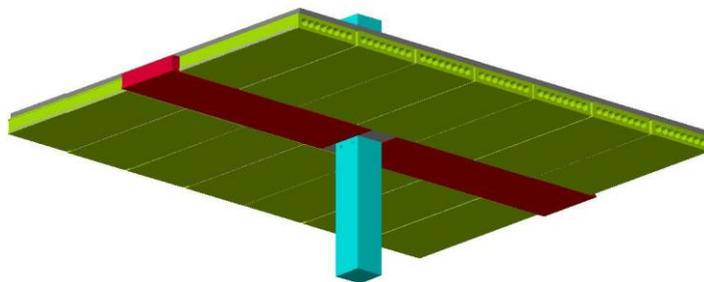


Figure 14: Removing temporary corbels and beam ledges

Preliminary Cost Analysis

Table 1 shows preliminary cost analysis of the of the proposed system verse cast-in place flat slab system. The estimation was obtained for one floor, as shown in Fig. 1 .The estimation of the cast-in place flat slab system was obtained by using RSMMeans 2010, section (03 30 53.40 (0920)) and (03 30 53.40 (1950)) for column and slab respectively and (<http://buildabout.com>)for post tensioning. The cost of cast in place column, slab and post-tensioning was \$117.67/ft, \$14.4/ft², and \$6/ft² respectively. The cost of the precast column, precast beam and HC with 2 in. topping were \$120 / ft, \$150/ft and \$9.9/ft² respectively. These estimated were obtained from Concrete Industries, Inc. Lincoln, NE and include material, labor, and construction equipment cost. The total cost of square feet of the cast in place flat slab system was \$22.86/ft² verse \$17.72/ft² for the proposed system.

Table 1: Cost comparison between cast in place flat slab system and precast flat soffit shallow floor system

Items	Cast-in Place Flat Slab System		Precast Flat Soffit Shallow Floor System	
	Column	\$117.67/ft	\$35,300	\$120/ft
Beam	N/A		\$150/ft	\$90,000
Hollow Core	N/A		\$7/ft ²	\$87,360
Cast-in Place Slab	\$14.4/ft ²	\$207,500	\$2.9/ft ²	\$41,800
Post-Tensioning	\$6/ft ²	\$86,400	N/A	
Total Cost	\$22.86/ft ²	\$329,200	\$17.72/ft ²	\$255,160
Duration	14 days		5 days	

Summary and Conclusions

The only option for constructing flat soffit shallow floors in multi-story residential and commercial buildings is using cast-in-place concrete floors, which is complicated, costly, and time-consuming. Current precast concrete floor systems require the use of beam ledges to support hollow core planks and column corbels to support beams, which result in projections that significantly reduce the clear floor height. The proposed floor system solves this problem by developing a shallow precast concrete floor system that eliminates the need for beam ledges and column corbels and provides a flat soffit. This system is a total precast floor that can be rapidly erected on site without false or form work operations that are time-consuming and labor intensive. Economy, structural efficiency, ease and speed of construction, and aesthetics are the main advantages of the proposed system. The paper presented the construction sequence of erecting the proposed system efficiently and smoothly using current construction practices with no need for specialized labor or equipment. The cost comparison between the proposed system and cast-in-place flat slab floors indicated the economy of the proposed system

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