# Shallow Flat Soffit Precast Floor System: A Construction Comparative Analysis

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**ABSTRACT:** *This paper compares the constructability, cost and schedule of a new shallow flat soffit precast floor system with a typical precast floor system. The new system consists of continuous precast columns without corbels, partially continuous rectangular beams without ledges, partially continuous hollow-core planks (HC), and cast-in-place composite topping. The main criteria in the design of the new system includes: span-to-depth ratio of 30, flat soffit floor system, economy, and consistency with prevailing erection techniques. The new shallow flat soffit precast floor system has a depth and flat soffit comparable to cast in place systems. It has no constructability issues and costs $23.60/square foot as compared to $21.90/square foot for a typical precast system. Although the new system takes 20% longer erection duration than typical precast system, the flat soffit and shallowness of the proposed system outweighs the cost and duration disadvantages. The continuous beam connections also have the added benefit of eliminating shear walls in moderate wind load conditions. This investigation uses a typical six story hotel or office building with 16 bays 30 ft (9.14 m) x 30 ft (9.14 m) for construction costs and schedule comparisons.*

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

## INTRODUCTION

Conventional hollow-core floor systems consist of hollow-core planks supported by inverted-tee precast prestressed concrete beams, which are, in turn, supported on column corbels or wall ledges. These floor systems provide a rapid construction solution to multi-story buildings that is economical and fire-resistant with excellent deflection and vibration characteristics. The top surface of hollow-core floor systems is usually a thin non-structural cementitious topping, at least 2 in. (5.1 cm) thick that provides a level surface. Despite the advantages of conventional precast hollow-core floor systems, they have two main limitations: a) low span-to-depth ratio and b) floor projections, such as column corbels and beam ledges. A 30 ft (0.76 m) conventional precast hollow-core floor bay would require a 28 in. (71 cm) deep inverted-tee plus a 2 in. (5.1 cm) topping, for a total floor depth of 30 in. (76 cm). This leads to a span-to-depth ratio equals to 12 (See design tables in section 3.11 of the 7th edition of PCI design handbook, PCI, 2010). In addition, this floor would have a 12 in. (31 cm) deep ledge below the hollow-core soffit and 16 in. (41 cm) deep column corbel below the beam soffit. While column corbels and beam ledges are common in parking structures and commercial buildings, they are not favourable in residential and office buildings due to aesthetics and increase building volume. False ceiling are used in these applications to hide the unattractive floor projections, resulting in reduced vertical clearance. Elimination of floor projections combined with shallow structural depth will improve the building aesthetics and overall economics.

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Post-tensioned cast-in-place concrete slab floor systems can be built with a span-to-depth ratio of 45 with a flat soffit, resulting in a structural depth of 8 in. (20.3 cm) for the 30 ft (76 cm) bay size (PTI, 2006). The major drawbacks of 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 because of the involvement of specialty contractors (PCI, 2004).

If the structural depth of precast floor systems can come close to that of post-tensioned cast-in-place concrete slab system, then precast concrete would be very favourable due to rapid construction and high product quality. Reducing the depth of structural floor leads to reduced floor height, which leads to savings in architectural, mechanical and electrical systems and may allow for additional floors for the same building height. The cost of operation and maintenance of office buildings is about 80% of the initial cost of construction (Snodgrass, 2008), so any small savings in these systems would have a significant impact on the building life cycle cost.

The main objective of this paper is to present a shallow flat soffit precast floor system and compares its construction sequence, cost, and duration against a typical precast system. The shallow flat soffit precast floor system is an innovative system with no ledges or corbels, similar to cast-in-place floors, and shallow structural depth when compared to conventional precast floor systems. The new system has continuity in both directions that is adequate to resist lateral loads that reduces the need for 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 story buildings with 30 ft (9.14 m) x 30 ft (9.14 m) bays, which are typical for hotels and office buildings. 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.

The next section is a review of the existing precast concrete floor systems followed by a description of the new system and its construction sequence. The new system is then compared on the basis of construction cost and duration against a typical precast operation

## CURRENT PRECAST FLOOR SYSTEMS

Low, et al. (1991 and 1996) developed a shallow floor system for multi-story office buildings. The system consists of HC planks, 8 ft (2.4 m) wide and 16 in. (40.6 cm) deep prestressed beams, and single-story precast columns fabricated with full concrete cavities at the floor level. The column reinforcement in this patented system is mechanically spliced at the job site to achieve the continuity (Tadros and Low, 1996). The beam weight and the complexity of the system design and detailing were discouraging to producers. Thompson and Pessiki, (2004) developed a floor system of inverted tees and double tees with openings in their stems to pass utility ducts. This floor system is appropriate and economical for parking structures as it does not provide either a shallow floor or flat soffit required for residential and office buildings

Simanjuntak (1998) developed a shallow ribbed slab configuration without corbels. This is accomplished by threading high tensile steel wire rope through pipes imbedded in the floor system and holes in the columns. The limitations of this system include the distance between columns, the time required to make connections, unattractive slab ribs, and weak lateral load resistance. Compton (1990) designed a system with a retractable hangar at the upper end of the beams that extends into a recess in the column. The system has low resistance to lateral loads and requires highly skilled labour.

Wise (1973) used composite flexural concrete construction to build two way and flat slabs with little to no formwork. The precast panels bear on temporary or permanent supports. They have one or more lattice trusses firmly embedded in the panel to provide longitudinal reinforcement. The disadvantages of this system include the shoring requirement and the size of the panels. Hanlon (1990) used modular precast components with a series of columns with wide integral capitals. Wide beams are supported by the capitals on hangars. This system works well with long span column grids. The disadvantage of the system is the requirement for heavy construction equipment to handle the heavy components. Composite Dycore Office Structures (1992) developed the Dycore floor system for office buildings, schools, and parking garages. This system consists of shallow soffit beam, high strength Dycore floor slabs. This is attached to cast-in-place/precast columns with block outs at the beam level. The precast beams and floor slab act as a form for the CIP operations.

Filigree Wideslab System was originally developed in Great Britain and is presently used there under the name of OMNIDEC (Mid-State Filigree Systems, Inc. 1992). It consists of reinforced precast floor panels that serve as permanent formwork. The panels are composite with cast-in-place concrete and contain the reinforcement required in the bottom portion of the slab. They also contain a steel lattice truss, which projects from the top of the precast unit. One of the main advantages of this system is a flat soffit floor that does not require a false ceiling. However, this system has poor thermal insulation and requires advanced techniques to produce due to the fabrication difficulties in lattice truss fabrication and installation (Pessiki et al., 1995)

Several efforts have been made to minimize the depth of flooring systems by combing steel and precast concrete products. Steel beams are used in Europe to support hollow core planks by their bottom flanges and the composite topping by their top flanges. The steel beams are plate girder (built up) sections, and rolled steel section (Board of Federation International Du Beton (fib) steering committee, 1999). These systems provide a high span-to-depth ratio, however, they are limited to about 20 ft (6.1 m) spans, which is reasonable for apartment/hotel buildings, but considerably less than the spans generally required for office building applications. These systems may merit further investigation if the fire protection issues of the underside of the beam can be satisfactorily resolved and if the cost of fabrication is comparable to the equivalent prestressed concrete beam.

In the United States, steel beams have been developed by Girder-Slab Technologies LLC of Cherry Hill, NJ, (2002). Similar to the European practices, the precast planks are supported on the bottom flange of the steel beams. The D-BEAMTM steel girder is a proprietary shallow beam that usually spans 16 ft (4.9 m), which would not suit typical office framing spans. Longer spans require extra manufacturing and shipping costs due to the 16 ft (4.9 m) span limit in the beam production.

The Deltabeam (Peikko Group, 2010), is a hollow steel-concrete composite beam made from welded steel plates with holes in the sides. It is completely filled with concrete after installation. Deltabeam acts as a composite beam with hollow-core, thin shell slabs, and in-situ casting. Deltabeam can have a fire class rating as high as R120 without additional fire protection. The Deltabeam height varies based on the required span. For a 32 ft (9.75 m) span, the Deltabeam can be as shallow as 23 in. (58 cm) including the 2 in. (5.1 cm) topping. Although this is 5 in. (12.7 cm) less than the precast/prestressed concrete inverted tee, it requires shoring for erection, adding shims to raise hollow cores up to match the level of the top plate, and additional fire protection operations if higher ratings are required. Bellmunt and Pons (2010) developed a new flooring system which consists of a structural grid of concrete beams with expanded polystyrene foam in between. The grid has beams in two directions every 32 in. (81 cm). The floor is finished with a light paving system on top and a light ceiling system underneath. This system has many advantages, such as lightweight, flat soffit, and thermal insulation. However, some of its disadvantages include the floor thickness, unique fabrication process of forms due to the special connections required

## PROPOSED SYSTEM

The shallow flat soffit precast floor system is proposed for hotel or office buildings in low-moderate seismicity zones. Figure 1 shows a plan view of a 16 bay office building with 30 ft (9.14 m) by 30 ft (9.14 m) bays. The shallow flat soffit precast floor system supports standard hollow core planks with 10 in. (25.4 cm) thick precast/prestressed rectangular beams supported by precast concrete columns. The 10 in. (25.4 cm) thick and 48 in. (122 cm) wide hollow core planks is the most affordable precast product due to simple fabrication, ease of handling and reduced shipping cost due to their light weight (CI, 2012). The connections are simple for precasters to produce and quick for contractors to erect. The entire system is topped with a cast-in-place composite topping.

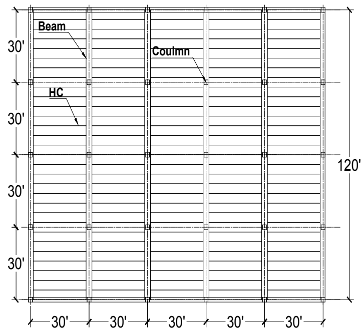


**Figure 1. Building Precast Plan View (ft = 0.3048m)**

The precast columns are continuous to the full height of the building. They include an opening at each floor level with a profile as shown in Figure 2.

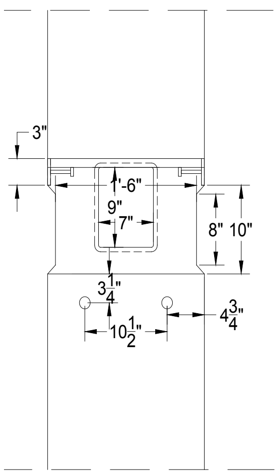


**Figure 2. Precast Column Elevation (in. = 2.54 cm)**

The beams are made continuous on site during the construction process before the topping is installed. The beam continuity is created by placing reinforcing in pockets at the beam ends. Figure 3 is the top plan view of the beam end that goes through column openings shown in Figure 2 to the opposing beam. Figure 4a and 4b show sections A-A and B-B of the beam, respectively.

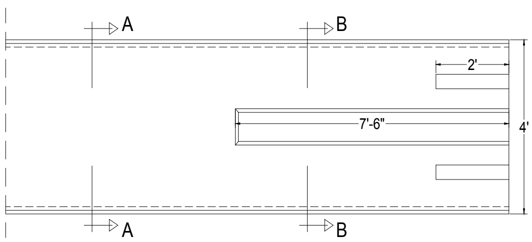


**Figure 3. Top Plan View of the End of the Sallow Flat Soffit Precast Floor Beam (ft = 0.3048 m)**

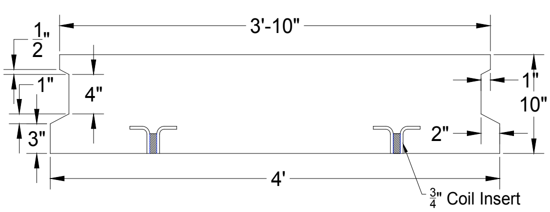


**Figure 4a. Cross Section of Sallow Flat Soffit Precast Floor Beam at A-A (ft = 0.3048 m)**

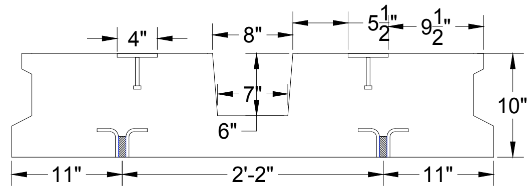


**Figure 4b. Cross Section of Sallow Flat Soffit Precast Floor Beam at B-B (ft = 0.3048m)**

The shear connection between the hollow core planks (Figure 5a) and the beam is provided by hat bars running from the core in one hollow core plank over the beam and into the core of the opposing plank. In addition, rectangular reinforcement loops are inserted into the core through a sleeve cut into the end of the hollow core (see Figure 5b). The pockets are filled with grout when the hollow core keyways are grouted. The top of the reinforcement loops are later cast into the concrete topping.

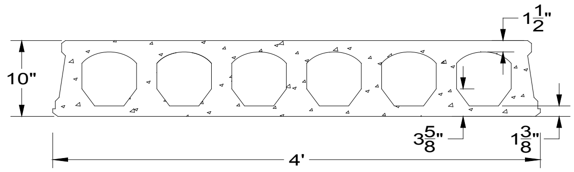


**Figure 5a. Cross Section of Typical Hollow Core (ft = 0.3048m)**

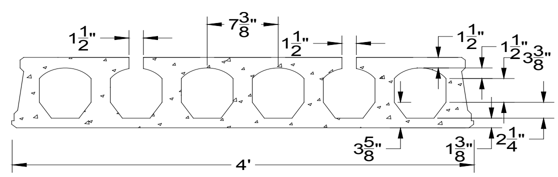


**Figure 5b. Cross Section of Hollow Core End with Slots (ft = 0.3048m)**

The cast-in-place composite topping is reinforced in the hollow core direction to provide partial continuity in the direction of the hollow core planks for lateral load resistance. Figure 6 shows the beam-column connection and hollow core-beam connection and the reinforcement detail. With the exception of the beams all components are typical and are easy to produce, handle, and erect.

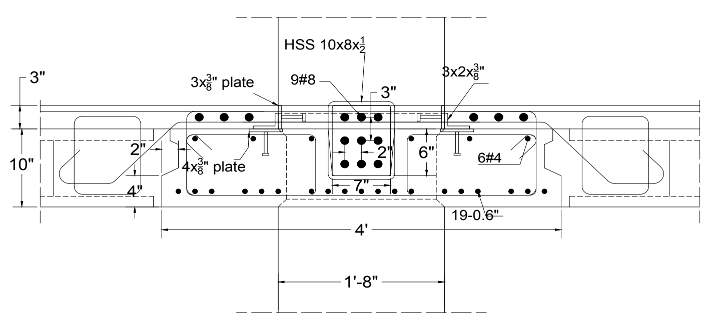


**Figure 6. Column, Beam, and Hollow Core Connection (ft = 0.3048m)**

The construction sequence of the proposed system includes the following ten steps:

Step 1) The precast columns are bolted to the foundation and temporary corbels are installed beneath the beam lines. The temporary corbels are 6 in. (15.4 cm) x 4 in. (10.2 cm) x ½ in. (1.3 cm) angles bolted to each side of the column. The 1 in. (2.5 cm) bolts go through two 1-1/16 in. (2.7 cm) diameter sleeves in the column (Figure 7). These angles are temporary, low cost supports for the precast beam during construction and can be reused several times.

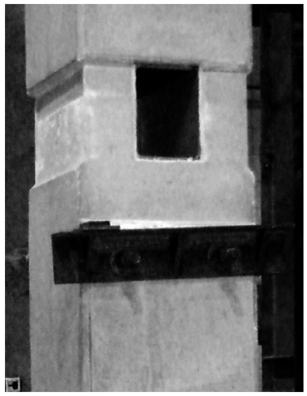

**Figure 7. Temporary Corbels**

**Step 2)** Precast/prestressed rectangular beams are placed on each side of the column so that the beams align with each other and the beam pockets align with the column opening. The beams are placed at a distance of 1 in. (2.5 cm) from the column face in addition to the 1 in. (2.5 cm) recess in column sides, resulting in a 2 in. (5.1 cm) wide gap between the recessed column section and the beam end to be grouted later. Two 38 in. (97 cm) long angles 3 in. (7.6 cm) x 2.5 in. (6.4 cm) x 3/8 in. (1 cm) are welded to the beam end plates and column side plates as shown in Figure 8 to stabilize the beams during HC erection.

**Figure 8. Installation of Beam Angles**

**Step 3)** Hollow tube steel sections are installed as temporary ledges to support the hollow core planks. The tubes are connected to the bottom of the precast beam using coil inserts and threaded rods as shown in Figure 9.

**Figure 9. Temporary Beam Ledges**

**Step 4)** HC planks are placed on the temporary beam ledges on each side of the beam as shown in Figure 10.

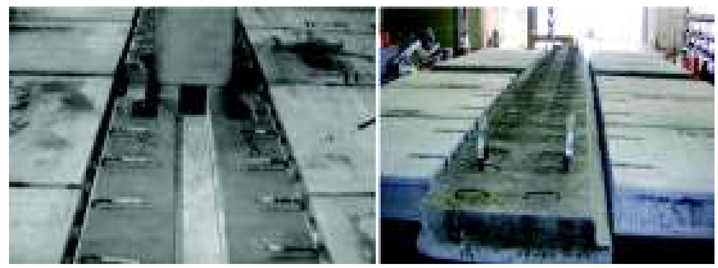

**Figure 10. Hollow Core Planks on Temporary Beam Ledges**

**Step 5)** Continuity reinforcement is placed in the beam pockets and through the column opening as shown in Figure 11. This reinforcement includes the hidden corbel reinforcement needed for the beam-column connection and the hat bars connecting the HC planks to the beam placed over the beam at the HC keyways.

**Figure 11. Continuity Reinforcement and Hat Bars**

**Step 6)** The hollow core keyways, beam pockets, column opening, and shear key between HC planks and beam sides are all grouted using high slump 4 ksi (27.6 MPa) grout as shown in Figure 12.

**Figure 12: Grouting shear keys and beam pocket**

**Step 7)** Second layer of continuity reinforcement is placed over the beam, as shown in Figure 13

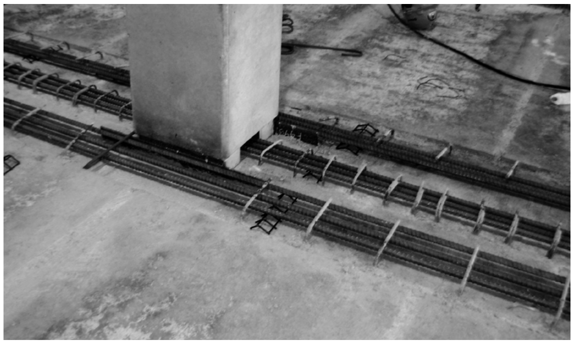

**Figure 13. Beam Continuity Reinforcement**

**Step 8)** Welded wire fabric is placed over the HC planks to reinforce the composite topping.

**Step 9)** Topping concrete is poured using medium slump 3.5 ksi (24 MPa) concrete.

**Step 10)** Finally, the temporary corbels and ledges are removed after topping concrete reaches the required compressive strength to provide a flat soffit.

## CONSTRUCTABILITY, COST, AND SCHEDULE ANALYSIS

This section compares the constructability, cost and schedule of the proposed system with a typical precast floor system. The cost and schedule analysis refers to a single 120 ft x 120 ft (36.6 m x 36.6 m) elevated floor slab as shown in Figure 2.

## CONSTRUCTABILITY ANALYSIS

The shallow flat soffit precast floor system appears to have no major constructability issues. The temporary corbels, Step 1, are easy to install as are the temporary beam ledges, Step 3. A rolling scaffold provides easy access to both. Welding the two 38 in. (97 cm) long angles to the beam end plates and column side plates, Step 2, take slightly longer than welding a typical inverted T beam to the column but requires no exceptional skill or equipment. Placing the beams, Step 2, and the HC planks, Step 4, are no more and no less complex than standard precast floor systems. Placing continuity reinforcement, Step 5 and 7, while not complex, are additional steps required for the shallow flat soffit precast floor system that requires more steel reinforcement. The grouting operation, Step 6, is comparable to other precast floor systems with the exception of the need for slightly more grout for the beam pocket and column opening. Placing the welded wire fabric, Step 8, and the concrete topping, Step 9, are identical operations for both the shallow flat soffit precast floor system and the typical precast floor system. Removing the temporary supports at the column and the hollow core planks is a simple, albeit additional operation.

## COST ANALYSIS

Table 1 shows a cost analysis comparing the shallow flat soffit precast floor system to a typical precast floor system. All cost data was developed using RSMeans Building Construction Cost Data 2011 unless specified otherwise. For clarity, the estimate line items in this section coincide with the construction steps described in the proposed system section of this paper.

**Table 1. A Cost ($US) Comparison between shallow flat soffit and typical precast floor systems per floor**

| Item | Shallow Flat Soffit Floor System | | | | Typical Precast Floor System | | | |
|---|---|---|---|---|---|---|---|---|
| | Materials | Labour | Equipment | Total | Materials | Labour | Equipment | Total |
| Step 1-Column | 29,150 | 7,838 | 4,373 | 41,361 | 33,125 | 8,906 | 4,969 | 47,000 |
| Temporary Corbel | 322 | 777 | 160 | 1,259 | | | | |
| Step 2-Beam placement | 111,901 | 4004 | 2226 | 118,131 | 95,360 | 4,004 | 2,226 | 101,590 |
| -angles vs. corbels* | 750 | 305 | 122 | 1177 | | 777 | 312 | 1089 |
| Step 3-HC Supports | 3000 | 1457 | 300 | 4,757 | | | | |
| Step 4-HC Plank Install | 93,600 | 11,856 | 6,614 | 112,070 | 103,500 | 13,110 | 7,314 | 123,924 |
| Step 5-Continuity Reinf. | 2,961 | 1,659 | 0 | 4,620 | | | | |
| Step 6-Grout | 7,725 | 1,260 | 420 | 9,405 | 5,974 | 974 | 325 | 7,273 |
| Step 7-2$^{nd}$ Continuity Reinf. | 6,642 | 3,526 | 0 | 10,168 | | | | |
| Step 8-WWF Installation | 2,995 | 3,960 | 0 | 6,955 | 2,995 | 4,514 | 0 | 6,954 |
| Step 9-Concrete Topping | 12,240 | 11,376 | 4,032 | 27,648 | 12,240 | 11,376 | 4,032 | 27,648 |
| Step 10-Remove Supports | | 1846 | 380 | 2,226 | | | | |
| Total cost | | | | 339,777 | | | | 315,478 |
| Cost per square foot ($m^2$) | | | | $23.6 ($254.0) | | | | $21.9 ($235.8) |

*There are two corbel welds per column approximately 6 in. (15.24 cm) long in the overhead position from a scaffold vs. the two 36 in. (0.91 m) long angle welds in the horizontal position from the deck. It was determined that it would take approximately 15 minutes per column for the former and twice as long per column for the later at $58.05/hour for welder and equipment.

There are 25 precast concrete columns on each floor. Since the depth of the inverted-tee beams in the typical precast system are 28 in. (71 cm) compared to 10 in.(25.4 cm) in the shallow flat soffit precast floor system, the typical precast columns are 12.5 ft (3.8 m) per floor compared to 11 ft (3.4 m) per floor for the shallow flat soffit precast floor system to provide 10 ft (3.05 m) equivalent clearance. Columns of the shallow flat soffit precast floor are assumed to be have the same cross section and reinforcement as those of the typical precast floor systems .

Temporary corbels are attached to each shallow flat soffit precast floor system column. Installation productivity is listed at five per hour with two structural steel workers and two rolling scaffold while removal rates are estimated at 10 per hour. This is based on actual field measurements from two full scale installations. The angles are 6 in. x 4 in. x 0.5 in. (15.2 cm x 10.2 cm x 1.3 cm) and are 2 ft (0.61 m) long with a weight of 16 pounds per lineal foot (23.81 kg per meter). There are 40 reusable angles per floor at a cost of $32 each resulting in angle material cost of $1,280. Two, 1 in. (2.5 cm) diameter and 2 ft (0.61 m) long all thread rods fasten the angles to the columns through 1-1/16 in. (2.7 cm) diameter holes precast into the 25 column. The cost for 50 rods is $650 for a total material cost including angles of $1,930. Assuming a reuse rate of six give a total material cost of $322 per floor.

Twenty beams are installed in either system and installation costs are similar because of the similar weights between the two systems (RSMeans Building Construction Cost Data 2011, section (03 41 05.10 1400) There are eight spandrel beams that are the same for either system since they are concealed within the exterior wall. The cost of the eight spandrel beams is $3,425 each. The beam material costs for the shallow flat soffit beam system and the inverted-tee were priced from the manufacturer at $150 and $120 per lineal foot, respectively. Inserts are cast into the beam for field installation of the temporary plank supports.

Installation of the temporary plank supports is estimated at 20 supports per hour with two structural steel workers and two rolling scaffold units while removal rates are estimated also at 20 per hour. This is based on measurements from full scale field installation. The 5 ft (1.52 m) long temporary supports are 4 in. x 4 in. x 0.25 in. (12.3 cm x 12.3 cm x 0.64 cm) tubes that weigh 12 pounds per lineal foot (17.86 kg per meter). There are four supports per plank and 120 planks. Each support is estimated to cost $50 plus $5 for bolt and washer resulting in total material cost of $18,000. With six reuses material cost per use is $3,000 per floor.

Continuity reinforcement is only required with the shallow flat soffit precast floor system. There are two layers as indicated in Steps 5 and 7 in the construction sequence. There is 3.1 tons (2,722 kg) of reinforcement required in the first layer and 8.2 tons (7,439 kg) in the second.

There are 16 bays, 30 ft x 30 ft (9.14 m x 9.14 m), that require approximately 4 yd3 (3.06 m3) of grout for each bay regardless of operation. The shallow flat soffit floor system requires an additional 0.5 yd3 (0.38 m3) per column to fill the beam and column pocket.

Welded wire fabric is identical for both operations as is the concrete topping. There was 15,840 ft2 1,445 m2) of welded wire fabric and 14,400 ft2 (1,338 m2) of 2.5 in. (6.4 cm) concrete topping.

## SCHEDULE ANALYSIS

The schedule results are shown in the table below. Durations were determined from the daily output in Table 2. One crew was assumed for each activity in order to develop a consistent comparison. Other durations were taken from the estimated productivity described in the previous section. Since the focus of this analysis is on the difference between shallow flat soffit precast floor system and a typical precast operation, it was determined unnecessary to incorporate factors like learning curve, mobilization, equipment delays, weather, etc. since these would have a similar effect on either floor system.

**Table 2. A Schedule Comparison between shallow flat soffit and typical precast floor systems**

| Item | Shallow Flat Soffit Precast Floor System (Days) | Typical Precast Floor System (Days) |
|---|---|---|
| Step 1-Column | 2.5 | 2.5 |
| -Temporary Corbel | 0.5 | N/A |
| Step 2-Beam placement | 1.5 | 1.5 |
| -Weld angles | 1 | 1 |
| Step3-Temporary HC Supports | 1.0 | N/A |
| Step 4-HC Plank Installation | 3 | 3 |
| Step 5-Continuity Reinforcement | 0.5 | N/A |
| Step 6-Grout | 0.5 | 0.5 |
| Step 7-2nd Continuity Reinforcement | 0.5 | N/A |
| Step 8-WWF Installation | 3 | 3 |
| Step 9-Concrete Topping | 3.5 | 3.5 |
| Step 10-Remove Supports | 0.5 | N/A |
| Total durations in days | 18 | 15 |

## SUMMARY AND CONCLUSIONS

The shallow flat soffit precast floor system has a flat soffit and shallow depth comparable to cast-in-place floor systems. The constructability comparison of the shallow flat soffit precast floor system against a typical precast floor system using inverted-tees revealed no constructability issues. The additional operations were accomplished with crews typically mobilized for a precast operation. The cost of the shallow flat soffit precast floor system including columns for a 10 ft (3.05 m) clear height is 23.6 per square foot ($254 per square meter) compared to $21.9 per square foot ($235.80 per square meter) for the typical precast floor system which is only 7.7% increase. The schedule indicates that one floor of the shallow flat soffit precast floor system would take 18 days compared to 15 days for the typical precast assuming single crew for either operation, which is 20% higher. The advantages of the flat soffit and shallowness of the proposed system outweighs this slight increase in its cost and construction duration. In addition, the continuity of the shallow flat soffit precast floor system minimizes the need for shear walls commonly used in multi-story residential and commercial buildings. The constructability and cost of the proposed system compares favourably with a typical precast floor system at it follows standard construction practices with no need for specialized labour or equipment.

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