Use of Pre-Tensioned Solid Floor Planks in Commercial Buildings

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Abstract—The normal precast slabs have lesser load bearing capacity and have lesser span to depth ratio compared to precast pre-tensioned slabs. Commercial buildings require large column free area. Pre-stressing of precast slabs allow high span to depth ratio hence large column free area. The main limitation of the hollow cores planks is the thermal insulation. If the hollow cores planks replaced with floor panels have comparative weight and structural capacity with thermal insulation, which will be more efficient, combined with shallow structure depth. This will save much energy, which results in decreasing the live cycle cost. The objective of the study is to estimate and compare the material cost, construction cost, time duration required for construction of a commercial building by steel framed precast slab type construction, steel framed precast pre-tensioned slab type construction, precast framed precast pre-tensioned slab type construction and cast in situ type construction, and to identify the commercial viability among them. The study of comparison is restricted to precast slabs and structural frames only. Considering the same plan, total floor area, floor to floor height and loading condition, the commercial building is designed and planned to be constructed in all four ways. The costs for all four types of construction such as material cost, precast yard set up cost, equipments for production and erection, labours for production and erection is estimated and MS Project is used for estimation of duration of construction for all four types of construction. It is found that savings of Rs.45 (7.2%) per sq.ft can be achieved by using cast in situ construction but by adopting Precast framed precast pre-stressed slab type construction we can get the building 156 days earlier from which we can get profit from operation. The labour management is tough in case of cast in situ type construction as the amount of labour involved is high in cast in situ construction when compared with other types.

Index Terms— Pre stressing, precast floor slabs, pre stressed solid slabs, slabs for commercial buildings, economical floor slabs, precast framed structures, steel framed structures.

1 Introduction

THE Indian metro cities have restricted the horizontal growth which led to vertical growth for building construction. Today, fast track construction is a rapidly growing economy, brings rising costs and therefore time saving in construction can compensate significant proportions of the overall construction cost. [16]

A conventional precast concrete floor system utilizes hollow core slab or solid core slab supported by precast/pre-stressed concrete inverted tee beams which are in turn supported on column corbels or wall ledges. It provides an economical and fire-resistant floor system with excellent deflection and vibration characteristics for both residential and commercial applications. Conventional precast concrete floor system cannot compete with cast-in place post tensioning flat slab floor systems when high span-to-depth ratio and flat soffit are required. The main limitation of the hollow cores planks is the thermal insulation. If the hollow cores planks replaced with floor panels having comparative weight and structural capacity with thermal insulation, which will be more efficient combined with shallow structure depth. This will save much energy, which results in decreasing the live cycle cost.

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The main objective of the study is to identify the commercial viability among steel frame with precast slab and precast pre-tensioned slab type construction, precast frame with precast pre-tensioned slab type construction, cast in situ type construction.

Considering the same plan, total floor area, floor to floor height and loading condition, the steel framed floor structure is designed with precast slabs and precast pre-stressed slabs, precast frame with precast pre-stressed slabs and cast in situ type construction. Estimation of resources such as labour, material, equipments and scheduling of considered type of construction is to be done in Microsoft project and cost required for production, erection as per CPWD rates for both type of construction will be calculated and determining the commercially viable option.

The building under study is a G+5 multilevel car parking structure. It is rectangular (28 m x 84 m) in plan with nominal height 15.75 m (3.15 m floor to floor height) and gross floor area 11650 m² (2352 m² at each floor). The building is designed and constructed as 4 m, 5 m, 6 m spans for steel frame with precast slab type construction and cast in situ type construction and 6 m, 8 m, 10 m spans for steel frame and precast frame with precast pre-stressed type construction. The typical floor plan of steel frame with precast floor type construction, cast in situ type construction is shown in Figure 1. The typical floor plan of steel frame and precast frame with precast pre-stressed floor type construction is shown in Figure 2.

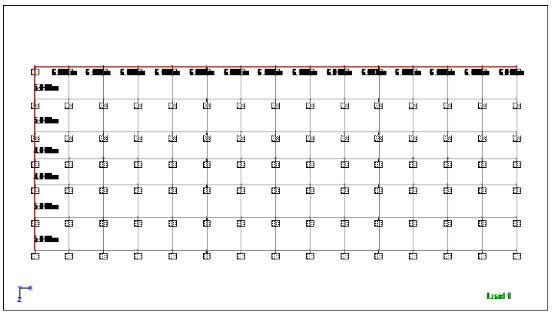

Fig. 1. Typical floor plan of steel frame with precast floor type construction and cast in situ type construction

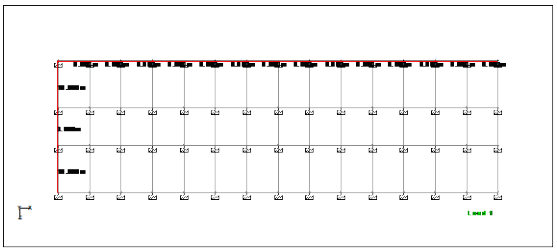

Fig. 2. Typical floor plan of steel frame and precast frame with precast pre-stressed floor type construction

2 Design of Frames and Slabs

The dimensions of precast pre-stressed slabs are 8 m x 1.2 m x 0.1 m (0.96m^3) and 10 m x 1.2 m x 0.14 m (1.68m^3). The grade of concrete used is M50. Clear cover provided is 35 mm. Characteristic strength of pre-stressing steel provided is 1860 N/mm^2. Stress relieved low relaxation 7ply strand-15.2 mm dia (139.4 mm^2, 1.094 kg/m) is used. Initial prestress applied is 70% F_{po} (1302 N/mm^2). The quantity of pre-stressing strands required is 131.28 kg for a 10 m slab and 87.52 kg for an 8 m slab. The pre-stressed slab requires minimum reinforcement of 28.11 kg for slab of 10 m span and 22.09 kg for slab of span 8 m. These slabs are checked for its safety against compression during transfer of prestress, flexure, shear, deflection and handling stresses.

The structural frame of steel framed precast slab type construction, steel framed precast pre-tensioned slab type construction and cast in situ type construction is done using Staad Pro V8i. The structural frame of precast framed precast pre-tensioned slab type construction is designed using ETABS.

For precast frame with precast pre-tensioned slabs the beams are made of inverted tee sections, L sections and rectangular sections. Inverted tee sections are used for interior beams along the length in the frames and edge beams are of L-sections. The tie beams are rectangular section of dimension 300mmx300mm. The inverted tee section has flange thickness 250mm, flange width 750 mm, web thickness and height of 250mm. The L section has flange thickness 250mm, width 500 mm, web thickness and height 250 mm. 25mm dia bars are used for reinforcement and stirrups is of 10 dia bars at 100 mm c/c spacing. Figure 3.4 and Figure 3.5 shows the picture of inverted tee section and L section respectively used in frames of precast frame with precast pre-tensioned slab type construction.

3 Planning

Detailed planning at the pre-production stage is very essential to ensure successful production, supply and erection of precast elements. The production programme and the resources are synchronised with the project schedule so that rate of production of precast elements matches with the rate of demand from the construction site including the buffer stock. Precast planning involves the detailed working on the following parameters.

3.1 Element Layout

Element layout forms the basic data for planning the precast project. Maximum weight of the element will be decided based on the capacity of the tower crane. The different type of precast elements and required number of such precast elements will be calculated based on drawings available. The maximum weight of the element in precast framed pre-tensioned slab type construction is inverted tee section of 12m length having 7.65 tonnes. The capacity of tower crane provided is 20 tonnes and is far above the maximum weight to be lifted by the crane.

3.2 Element Layout

Production schedule is planned to supply the required elements at the right time to site without hindering the progress of work. The type and size of mould required for production of various precast elements will be decided. Number and capacity of crane required for Demoulding, handling of rebars and handling of elements in precast yard will be decided based on weight of elements and number of handlings required for each element. The curing of precast elements can be done normally or steam curing can be adopted for early removal of formwork. If steam curing is used the capacity of steam boilers required should be decided.

The precast yard is 120 metre in length and 25 metre in width. It consists of seven numbers of 100m slab casting yard with 4 metre access road for transportation of materials, cast elements etc. 75 mm concrete basement is provided for casting and for yard access. The pre-stressed slab casting yard requires wedges, wedge expansion hold fasteners and pre-stressing equipment additionally when compared to non pre-stressed slab casting yard.

3.3 Production Planning

Monthly casting schedule is prepared based on the scope of elements to be produced. The details of average casting requirement per month and per day of various types of elements are calculated. Mould requirement is decided based on the production schedule and type of elements.

The total length of slab to cast is 11760 metres, columns to cast is 1134 metres, rectangular beams to cast is 2520 metres, inverted tee beams to cast is 1008m and L-Beams to cast is 1008 metres. Total length of precast elements to be produced is 17430 metres. The production capacity of the yard is 700 me-

tres per cycle. One cycle is seven days. It includes mould preparation (cleaning, oiling etc.,), placing of reinforcement, tendons, pre-tensioning, concreting, curing and transportation to storage yard. So total 17 cycles are required for production of 11760 metres of slabs and 9 cycles are required for production of beams and columns with available production capacity. Total duration required for production of precast elements is 182 days i.e. 26 cycles.

3.4 Erection of precast Elements

Erection of precast elements is done using a tower crane. The sequence of erection is planned by the erection team. The month wise erection schedules are prepared based on the scope of work and planned duration. Tower crane requirement for the site is decided based upon the daily or monthly erection targets, number of handlings of tower crane and operating radius of the tower crane. The capacity of the tower crane is decided based on the maximum weight of the element. The cycle time for erection of one steel column is 45 minutes. The cycle time for erection of one steel beam is 30 minutes. The cycle time for erection of a precast slab or a precast pre-tensioned slab is 20 minutes.

4 Construction Scheduling

The time scheduling is done using Microsoft project 2013. The scheduling is done for erection of columns, beams, slabs and concreting of 50 mm screed with reinforcement for prefabricated construction and casting of beams, columns and slabs for cast in situ type construction. The building is split into two zones. The scheduling is done such that for each floor zone I is erected first followed by zone II. Connection of slabs with beams and columns will be done by grouting. This is followed by topping reinforcement and 50 mm screed.

Duration required for steel frame with precast slab type construction is 247 days, steel frame with precast pre-tensioned slab type construction is 149 days, cast in situ type construction is 305 days and precast frame with pre-tensioned floor slab type construction is 149 days. This duration includes only erection of columns, beams, slabs and concreting of 50 mm screed with reinforcement for precast slab type construction and for cast in situ type construction it includes casting of columns, beams and slabs. When steel frames are used the savings in duration is 98 days i.e. 39.67% when pre-tensioned slabs are used over non pre tensioned slabs. When concrete frames are used there is a savings of 156 days i.e. 104.67% when precast frame with pre-tensioned slabs are used over cast in situ type construction.

5 Costing

For costing initially the quantities such as materials, labours, equipment required should be estimated. The rates were obtained from CPWD and the costs were estimated.

5.1 Material Cost

The materials required for steel framed precast slab type construction, steel framed precast pre-tensioned slab type construction, precast framed precast pre-tensioned slab type con-

TABLE 1
COMPARISON OF MATERIALS USED IN VARIOUS TYPE OF CONSTRUCTION

Items	Steel frame with Precast slab	Steel frame with Precast pre-stressed slab	Cast in situ	Precast frame - Precast pre-stressed slab
Concrete in slabs (m^3)	3659.04	1995.84	4621 (incl. Concrete in frame)	2902.28 (incl. Concrete in frame)
50mm concrete topping (m^3)	776.16	776.16		776.16
Pre tensioning strands (tonnes)		161.7		161.7
Reinforcement (tonnes)	357.1	36.18	290.98	332.09
Structural steel (tonnes)	1478.2	1056.72	-	-

TABLE 2
COMPARISON OF MATERIAL COST USED IN VARIOUS TYPE OF CONSTRUCTION

	Steel frame-Precast slab	Steel frame-Precast pre-stressed slab	RCC	Precast frame-Precast pre-stressed slab
Reinforced Cement Concrete	66.98	55.97	56.39	72.95
Structural steel	75.38	53.89	-	-
Total material cost	158.06	123.36	56.39	72.95

struction and cast in situ type construction is given in Table 1.

Material cost include cost of materials such as cement, aggregates, sand, admixture, pre-tensioning strands, reinforcements, buffing wheel, demoulding oil etc. The cost of formwork in topping slab is included for prefabricated type construction and the cost of formwork in slabs, beams and columns is included in cast in situ type construction. The total material cost for steel framed precast slab type construction, steel framed precast pre-tensioned slab type construction, precast framed precast pre-tensioned slab type construction and cast in situ type construction and percentage savings on materials cost is given in Table 2.

5.2 Precast Yard Setup Cost

The major cost involved in precast yard set up is excavation cost, 75mm thick concrete layer cost, and cost of moulds. The additional cost involved in pre-stressed precast yard is cost of anchorage wedges, wedge expansion hold fasteners and prestressing equipment cost which will be included in production equipment costs. But there will be savings in cost of moulds as depth of pre-tensioned slab is less compared to non pre-tensioned slab.

Steel frame with precast pre-stressed slab type construction requires precast yard with prestressing facility and the cost for setting up yard is Rs.2.19 million. Steel frame with precast slab type construction requires precast yard without prestressing facility and the cost for setting up yard is Rs. 3.09 million. Precast frame with precast pre-stressed slab type construction requires precast yard with prestressing facility and cost for setting up yard is Rs. 6.26 million. As the quantity of elements to be casted in precast frame with precast prestressed slab type construction is more the cost for setting up yard for it is more compared to other two.

5.3 Equipment and labour cost during production

The equipments and labours that are required for production of precast slab, beams and columns in precast yard are found out and the wages and hire charges are paid as per CPWD rates. The equipments required for production in precast yard are wheel loader of 1 cum capacity, water tanker of 5000litre capacity, batching plant of 75 cum/hour capacity, pump set of 4000 litres/hour capacity, vibrators 40 mm needle type, power trowel, transit mixer, pick and carry crane, DG set of 100kva/125 kva capacity, pre-tensioning equipment, bar bending machine, bar shearing machine and welding machine. The number of equipments required is based on productivity of the equipment. Labours and operators are required for operating the equipments and production of precast elements. The equipment hiring charge during production for steel framed precast slab type construction is 2.68 million, for steel framed precast prestressed slab type construction is 4.8 million, for precast frame with precast prestressed slab type construction is 7.24 million. The labour charges during production for steel framed precast slab type construction is 1.56 million, for steel framed precast prestressed slab type construction is 1.46 million, for precast frame with precast prestressed slab type construction is 2.24 million.

5.4 Equipment and labour cost during erection

The equipments and labours that are required for erection of precast slabs, beams, columns and steel columns are found out and the wages and hire charges are paid as per CPWD rates. The major equipments required during erection are tower crane of 20tonne capacity, diesel truck of 9 tonne capacity, pick and carry crane, boom placer, vibrators of 40 mm needle type and power trowel. The number of equipments required is based on productivity of the equipment. Labours and operators are required for operating the equipments and erection of precast elements. The equipment hiring charge during erection for steel framed precast slab type construction is 4.6 million, for steel framed precast prestressed slab type construction is 2.78 million, for precast frame with precast prestressed slab type construction is 2.78 million. The labour charges during erection for steel framed precast slab type construction is 3.77 million, for steel framed precast prestressed slab type construction is 2.27 million, for precast frame with precast prestressed slab type construction is 2.27 million.

5.5 Equipment and labour cost for cast in situ type construction

The equipments and labours that are required for construction of considered commercial building by cast in situ method are found out and the wages and hire charges are paid as per CPWD rates. The equipments required during construction by cast in situ method are front end loader of 1 cum capacity, tipper, water tanker of 5000litre capacity, batching plant of 75 cum/hour capacity, pump set of 4000 litres/hour capacity, vibrators 40 mm needle type, power trowel, transit mixer, pick and carry crane, DG set of 100kva/125 kva capacity, boom placer, bar bending machine, bar shearing machine and welding machine. The number of equipments required is based on productivity of the equipment. Labours and operators are required for operating the equipments and construction of building. The total cost of equipments and labours by cast in situ method construction is 30.57 million.

The amount of labour involved is more in cast in situ type construction compared to other types of construction. The labour and equipment cost for cast in situ type construction is more than double the labour and equipment cost required by precast frame with pre-tensioned slab type construction. The cost is more due to huge amount of labours and duration required for completion of building.

6 Results and Discussion

Due to higher span to depth ratio, the span of steel frames for Pretensioned floor type construction is high. So, there will be savings in concrete, structural steel. The amount of concrete required for cast in situ type construction is more compared to precast frame with precast pre-stressed slabs is due to non pre-stressing of slabs. The quantity of reinforcement required for precast frame with precast pre-stressed slab type construction is more when compared with other types of construction. The comparison of quantity of materials used in different type of construction is shown in Figure 3.

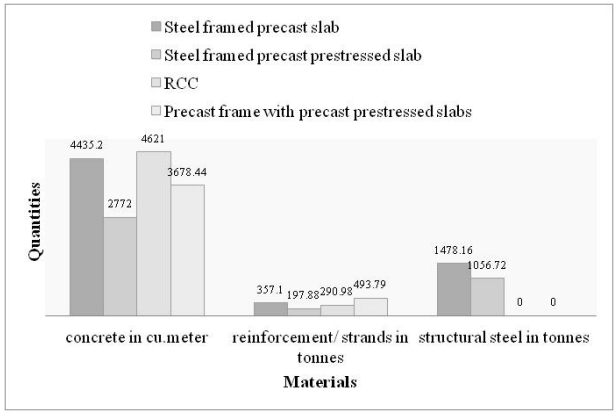

Fig. 3. Comparison of quantity of materials

The total cost of the materials used for all type of construction considered was arrived from CPWD Rates. The material cost of steel framed building is more compared to cast in situ and precast framed construction due to use of structural steel in frames. The material cost required for cast in situ type construction is less compared to precast frame with precast pre-tensioned slab type construction even though the concrete required for cast in situ type is more than later is due to need of lesser amount of reinforcement in cast in situ type construction compared to other. The comparison on cost of materials used is given in Figure 4.

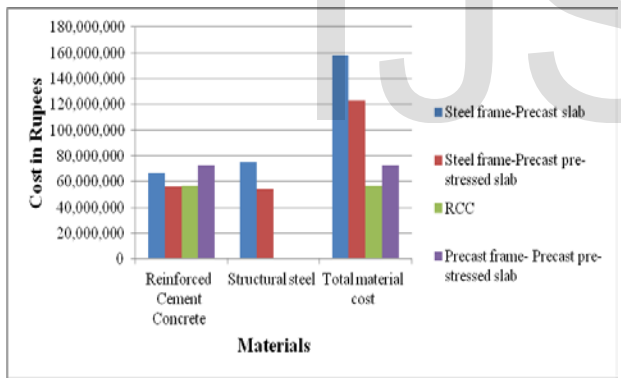

Fig. 4. Comparison of cost of materials (in Rs.)

The cost of production equipment and labour used in precast framed pre-tensioned floor slab type construction is more compared to steel framed construction as the former requires additional two months for production of precast beam and column elements required for frame construction**.** The equipment and labour cost for non pre-tensioned slab type construction is more because number of elements to be erected is more in this type of construction compared to pre-tensioned slab type construction. There will be savings in cost of hiring of labours and equipments due to lesser construction time if we use precast pre-stressed slabs. The amount of labour involved is more in cast in situ type construction. The cost required for labour and equipments by cast in situ type construction is more than double the cost required by other type of construction as the duration required for completion of cast in situ type construction is more compared to others. The comparison on cost of labours and equipments used in production and erection is given in Figure 5.

The cost due to Materials used, precast yard setup, equipment and labour hiring costs are added to find the total cost of construction of considered commercial building by steel framed precast slab type construction, steel framed precast pre-tensioned slab type construction, precast framed precast pre-tensioned slab type construction and cast in situ type construction. The total cost and its split up is given in table 3.

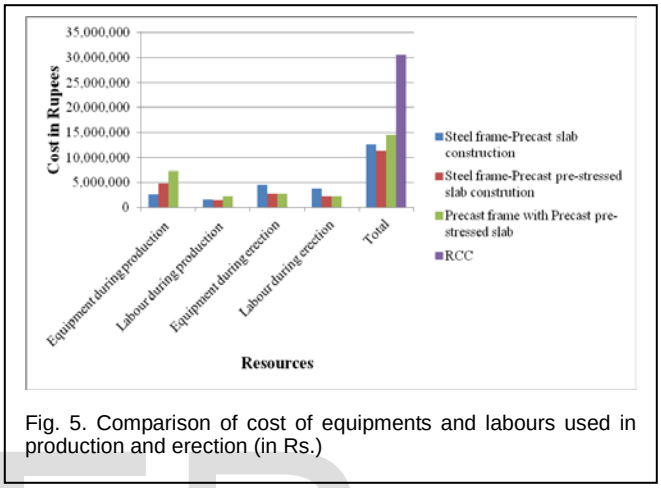

Fig. 5. Comparison of cost of equipments and labours used in production and erection (in Rs.)

Comparing steel framed precast slab type construction, steel framed precast pre-tensioned slab type construction, precast framed precast pre-tensioned slab type construction and cast in situ type construction the following conclusions are arrived

- The span of steel frame used for pre-stressed floor is longer compared to span of steel frame used for non pre-stressed floor.
- For the same depth of precast floor slabs the span of precast pre-stressed floor slabs is more due to which there is a saving in cost of materials.
- Cast in situ type construction is cheaper among the considered four methods of construction but it requires additional 156 days (104.7%) when compared to precast framed and steel framed pre-tensioned floor slab type construction. The construction of precast framed pre-tensioned floor slab type construction saves time, which would lead to an overall savings in net cost
- However, study is restricted to structural frame and slab only. If other items are also considered in the study like excavation work, finishing items, services, cladding etc. and also during construction preliminaries such as labour accommodations, their travelling and food expenses and many other factors related to time, then definitely, precast framed pre-tensioned floor slab type construction option will become cost effective.
- The use of Pre-tensioned floor slabs provides saving in cost and time compared to precast floor slabs with good thermal insulation and reduced live cycle cost.

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