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Recent trends in the production and use of precast concrete hollow-core units

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The paper gives a brief description of the various processes available for the production of precast concrete hollow-core units. The machinery used is fairly simple making it possible for production units to be set up in as many areas as possible. The special features of the hollow-core unit are given at the end of the paper.

Hollow concrete core units are a fast growing single item for use as roofing and walling members in building construction in many developed and developing countries. Several highly efficient mechanised processes are available for producing these units with minimum labour and good quality control. Earlier production methods used high slump concrete where the core or hole was created by a rigid material; *i.e.* steel tubes or inflated rubber tubes, until such time as the concrete had reached its final set or sufficient strength to be self-supporting. Individual moulds were used generally for casting these units. With the introduction of prestressed concrete, the moulds are either used for applying prestressing force, or laid end to end on a long line prestressing bed. For large scale production, these methods required a high capital expenditure on the moulds, with a relatively low output per man hour.

As the precast concrete construction has gained popularity in several countries due to increased labour cost and requirement of higher speed in construction, several mechanised production equipment have been developed to cast these units. This equipment utilises modern production techniques developed in other industries to cope up with the present trends. Most of the new processes utilise a long line continuous method of production using prestressed concrete to achieve economy. This equipment uses slipform process or extrusion process for manufacturing the units. The shape of the hollows will vary according to the manufacturing process or the type of equipment used. Four such machines developed elsewhere available for the mechanized production of these units are reviewed in the paper. All these machines have been in use for several years in various countries for producing prestressed, precast concrete hollow-core units for roofing/flooring and walling units for use in building construction. The equipment is designed to produce 1200 or 2400-mm wide standard units with varying depths from 150 to 300mm.

All equipment is simple and easy to maintain and operate. The units are produced in centrally located plant which gives a uniform reliable product with consistent high-strength camber, depth, and width. The rate of production with the equipment described is quite high; a typical plant can produce upto 400m² area of units per 8-hour shift with a maximum of a six man crew, including the mixer operator and the stock piling crew. There are various production systems in which the production cycle starts with the filling of concrete receiving hopper of the casting machine after the preliminary cleaning, oiling and laying of prestressed reinforcement strands over the casting bed. The machines move on the guide rails along the bed and deposit the concrete to the specified cross-sectional dimensions making the hollows continuously. The details of the processes along with the equipment used is described below.

Span deck system

The equipment for this system is based on the principle of slipform process by placing the aggregate as core material inside the casting and recovered after curing the unit, *Fig* 1. The equipment is available for casting 1200 or 2400-mm wide standard units. It consists of the following main assemblies.

Casting bed: It is fabricated from a flat steel plate stiffened with steel sections. The sides to form the necessary mould are made out of aluminium alloy and

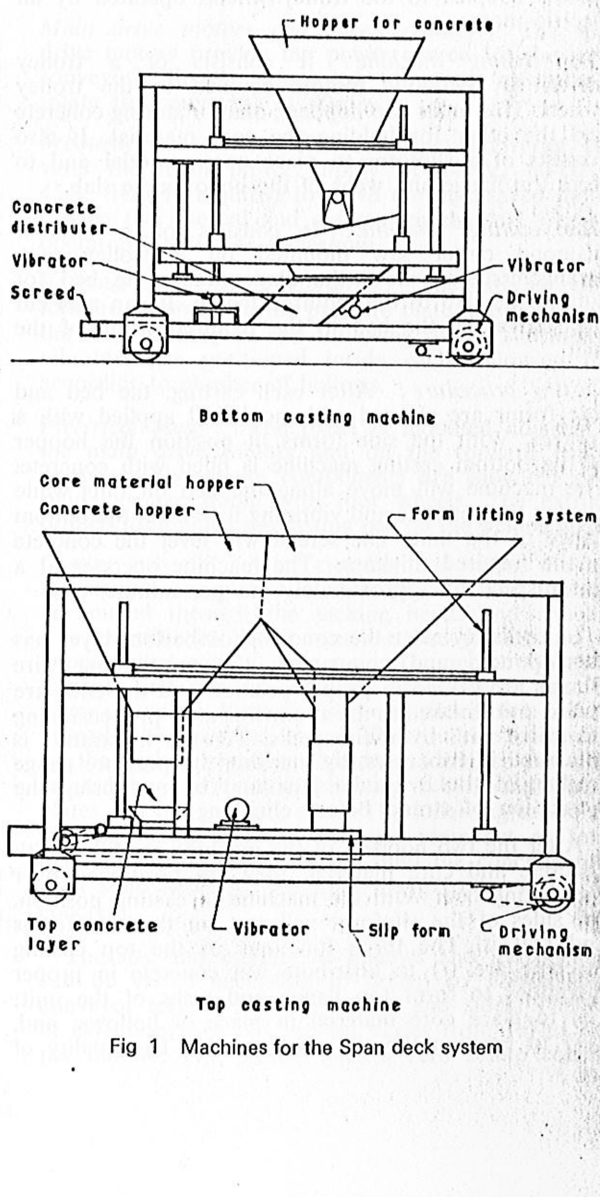

Fig 1 Machines for the Span deck system

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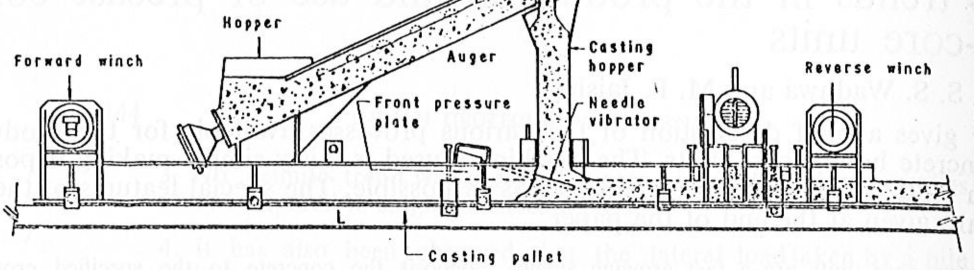

Fig 2 Extrude-all casting machine

can be operated by a hydraulic actuator to fix them to the bed for casting or to remove them after curing. The length of the bed varies upto 120m. There are abutments at the ends of the bed to anchor the prestressing strands. Hot water or steam pipes are placed below the bed to cure the concrete after casting.

Bottom casting machine: This consists of a trolley holding a concrete hopper with driving system to run the trolley along the bed. The bottom casting machine places the concrete to form the bottom layer of the unit on the bed and vibrates the concrete with a screed vibrator. The trolley is driven by hydraulic motors coupled to the trolley wheels operated by an electric motor.

Top casting machine: It consists of a trolley driven by hydraulic motors coupled to the trolley wheels. This holds two hoppers, one for storing concrete and the other for holding the core material. It also consists of a slipform to place core material and to form top flange and webs of the hollow core slab.

Slab cutting machine: It consists of a circular diamond cutter saw mounted on a trolley with arrangements to move the blade across the bed for cutting the slab to the required length. It can also cut the slab along the bed to the required width of the unit.

Casting procedure: After each casting, the bed and side forms are cleaned and mould oil applied with a sprayer. With the side forms in position the hopper of the bottom casting machine is filled with concrete. The machine will move along the bed on rails while placing the concrete and vibrating it to form the bottom flange of the unit. The screed will level the concrete to the required thickness. The machine operates at a linear speed of approximately 6m per minute.

Immediately after the concrete for bottom layer has been poured and compacted, the prestressing wire strands are placed in proper position and the ends are pulled and chucked to the abutments after pre-tensioning the wires with hydraulic jacks. Tension in strands is measured in two ways, by marking the pressure gauge reading of the hydraulic jack and by measuring the elongation of strand before chucking.

After the two hoppers of the machine are filled with concrete and core material, they are positioned over the casting bed. With the machine in casting position, the sides of the slipform will rest on the side forms and seal it. The three functions of the top casting machine are (*i*) to distribute wet concrete in proper quantities to form top flange and webs of the unit; (*ii*) to place core material in place of hollows; and, (*iii*) to position the strands precisely. The quality of the product depends upon the proper operation of the top casting machine. This will operate at a linear speed of approximately 3m per minute.

Curing: After completing the casting, the concrete is allowed to attain initial set before heat is applied. The casting is then covered with a canvas or polythene sheet for maximum retention of heat and moisture and for protection from the weather outside. Curing is done either by hot water circulation below the bed with pipes or by steam circulation. The ambient curing temperature under the bed cover is attained by increasing the temperature uniformly at a rate of 20°C/hr. An ambient curing temperature of 70 to 75°C is maintained for 6 to 8 hours to attain the required strength.

Bed stripping and releasing of strands: Four cylinders are made with each bed for checking the required release strengths. The cylinders are placed adjacent to the bed under cover. These are cured in the identical conditions as the product at the locations where the samples were collected. A normal initial release strength required is about 250kg/cm². The strands are released by gas cutting, using a low oxygen flame or by cutting with abrasive saws. Releasing of strand is usually performed simultaneously at both ends of the bed to minimise possible sliding or shock to the product.

Product removal and core material recovery: After releasing the strands, the units are cut to the required length with the cutting machine. Gantries are used to remove the slabs from bed using strand hooks provided in the casting for lifting connections. The units are transported in horizontal position to the core material recovery area and one end of the unit is tilted up to dump the core material into a portable hopper and losses are replenished as required. The concrete used in this process is of strength 350kg/cm² at 28 days, and the slump of concrete is 150mm. The aggregate used for concrete is normally of 12-mm and below and pea gravel, or lightweight aggregate of 20-mm size is used as core material. The process can be used for casting, flooring, roofing as well as wall panels. As it uses fluid concrete the connection plates or inserts as desired can easily be placed during the casting process. Various top surface finishes such as broom finish, ribbed finish or raked finish can be easily produced.

X-trudall system

The equipment of this system utilises the slipforming method of casting on a long line flat steel pallet. Machines are available for casting 1200-mm and 2700-mm wide standard units, with a thickness of 150 to 300mm, *Fig* 2. Unlike the previous system, this machine will cast the finished unit in a single run over the pallet. The machine comprises the following sub-assemblies:

Winches: For forward and reverse movements two hydraulic power winches are provided. The winch ropes are hooked to the anchors provided at the ends of the pallet. Variable speed control permits to regulate the casting speed as required.

Hoppers: There are two hoppers, one for storing the concrete and second for transferring concrete to the forming chamber.

Screw conveyor: A covered screw conveyor is provided which conveys concrete from charging hopper to casting hopper at a controlled rate.

Pressure plate and finishing roller: There are two pressure plates to control the flow and to finish the product to the required thickness. Hydraulic power rollers with water spray gives smooth finish to the product.

Internal needle vibrators: High-frequency needle vibrators are fixed at the bottom portion of the casting hopper to fluidise and consolidate the concrete mix in the forming chamber.

Core forming tubes: Steel circular tubes are fixed below the casting hopper in the forming chamber, to form the required hollows in the unit.

Side plates: The side plates which move along with the machine will control the width of the unit and form the required configuration to the side of the product.

Control panel: All the controls to operate the machine are provided on a panel which can be operated by one man, who controls all the functions of the machine.

Casting process: The steel pallet is first cleaned, and oiled and prestressing strands are pulled and chucked, after which the machine is positioned over the pallet. Concrete is filled in the charging hopper and conveyed by means of screw conveyor to the casting hopper. The level of concrete in the casting hopper is controlled by varying the speed of screw conveyor. As the concrete falls from casting hopper into the forming chamber over the pallet the high-frequency needle vibrator completely consolidates the concrete. The steel tubes in the forming chamber will form the circular hollows in the unit. The rear pressure plate and side plates determine the final configuration of the product. The rate of casting can be controlled with the help of variable speed winch. Generally the linear casting speed ranges between 1.5 to 2.5m per minute. The concrete used in system is of 350kg/cm² compressive strength and the slump is 30 to 50mm. The system can be used to cast solid slabs also.

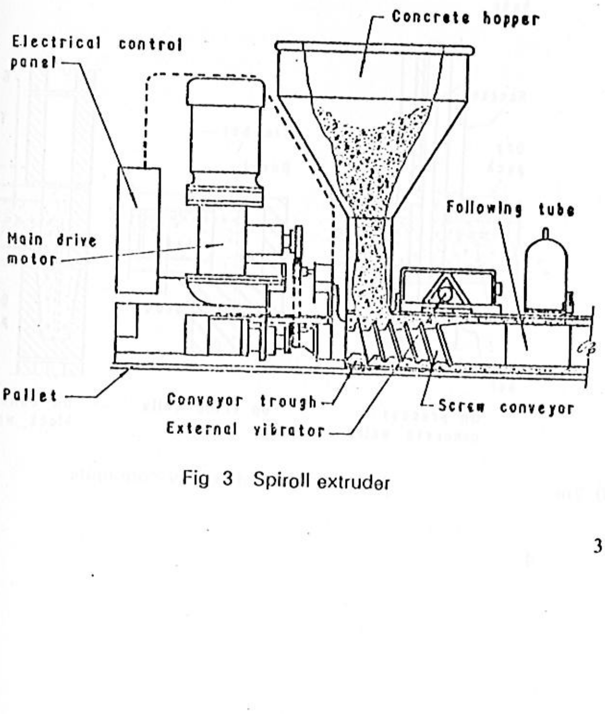

Fig 3 Spiroll extruder

Spiroll system

This system casts, among other sizes, 1200-mm wide standard units of various depths, *Fig* 3. The system is based on extrusion process, using zero slump concrete and a screw conveyor. The equipment is self propelled since the machine moves away from the extruded product by the action of screw conveyor. The machine consists of:

Concrete hopper: The hopper is of about 1-m³ capacity with wide spout placed over the input ends of the screw conveyor.

Screw conveyors: The screw conveyors are approximately 450mm long and are positioned centrally in their respective conveyor troughs followed by following tubes. The screw conveyor and following tubes are manufactured from high carbon alloy steel, heat treated for wear resistance.

Following tubes: The following tubes act as die and form the required diameter circular hollows in the unit.

Side forming plates and pressure plates: The side forming plates control the width of the unit and form the side configuration of the unit. Pressure plates give the unit the required finish and control the thickness of the unit.

Main drive motors and speed reducer: The main drive motors provide the power source for the screw conveyors directly connected to speed reducers, to rotate the conveyors at 40rpm.

Frequency converter: The frequency converter converts the main power supply of 440-V, 60-Hz to 45-V, 180-Hz required to drive the high-speed motors driving the internal and external mechanical vibrators operating at 10,800 cycles/min.

External and internal vibrators: The external vibrators are mounted on the pressure plate, positioned over the screw conveyors and following tubes. The internal vibrators are positioned inside each following tube according to number of hollows.

Electrical panel: The panel is mounted adjacent to the main drive motors and on the forward end of extruder. The above components are mounted on a rigid carriage frame with four wheels. The extruder propels itself along the casting bed on the welded guides.

Casting process: After cleaning and oiling the bed, the strands are placed in their position and the ends are pulled through the jacking heads and chucked. The extruder is placed over the bed guides and the hopper filled with the concrete. The screw conveyors, external and internal vibrators are switched on. The screw conveyors force the concrete under high pressure towards the following tubes. The concrete is fluidised by the high frequency vibration and takes the shape created by the rotating following tubes, side forming plates and top pressure plate. The following tubes, side forming plates and top pressure plate act as forms maintaining the desired shape until the concrete turns to a solid mass by the time the extruder leaves the concrete.

The size and number of hollows and the thickness can be varied according to design by changing the conveyor screws, following tubes and sides. The rate of extrusion with this process varies from 1.0 to 1.5m per minute. The process uses a zero slump concrete

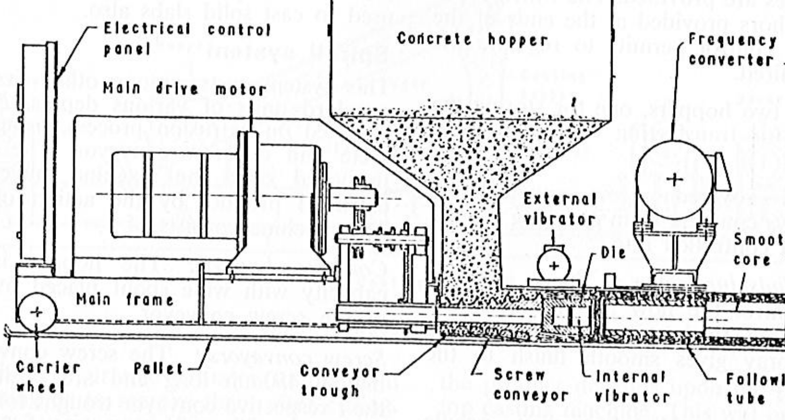

Fig 4 Dy-core extruder

of 350kg/cm² strength, with maximum aggregate size of 10 to 12mm.

Dy-core system

The equipment for this system produces 1200-mm wide standard units, with depths ranging from 150 to 300mm, *Fig* 4.

This system operates on the same principle, namely the extrusion process as the Spiroll system except a few changes in the screw conveyor and following tubes assembly. In the Dy-core system, the screw conveyors, die assembly and following tubes are fixed concentrically in the conveyor troughs, but the die assembly and following tubes are stationary. They do not rotate with screw conveyors and the extra length of following tubes provide additional guide and support, free from vibration to the casting. The die and following tubes are not circular, the shape can be changed to give maximum structural advantage to the units.

The operational procedure of the casting system is similar to the Spiroll system explained earlier.

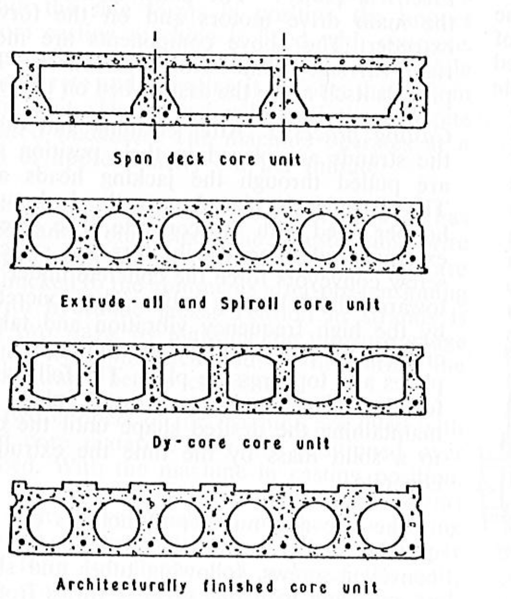

Fig 5 Cross-sections of various types of core units. 12m×0.2m

Products and their use

By using these production methods very high concrete strengths can be achieved with uniform camber control, quality and eliminating strand slippage. A variety of standard cross-sections produced by the different processes are shown in *Fig* 5. The slabs are produced in standard widths; thickness may vary from 100 to 300mm depending on required span lengths.

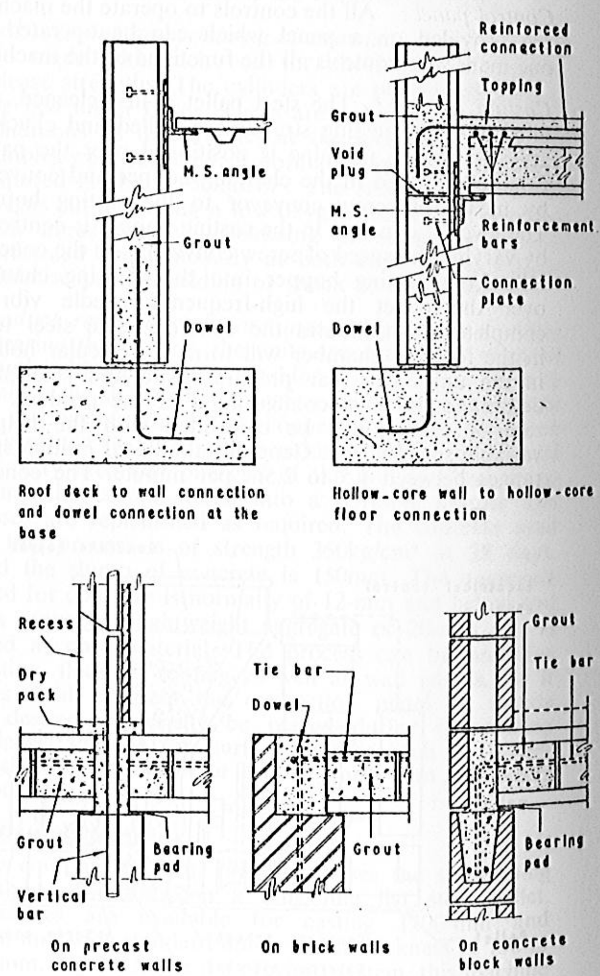

Fig 6 Use of hollow-core units

The prestressed concrete hollow-core unit is an extremely versatile structural component. The unit can be integrated into a complete building system using the most economic framing components suitable to needs and prevailing conditions. These slabs have been used in various buildings as floor and roof slabs. They have also been used as load bearing walls and non-load bearing walls and are highly adoptable to large housing scheme consisting specific designs because of the repetitive characters of the components. Hollow core slabs are used in single and multistoreyed buildings as floor and roof panels. They are used in industrial buildings such as warehouses, workshops, factories, as well, floor and roof panels. *Fig* 6 shows the use of precast concrete hollow-core slabs as walls and floors in different situations.

Conclusions

The above systems discussed are suitable for industrialised production methods, where efficient material handling transportation and erection methods are used. For efficient running of the plants, proper planning and scheduling of projects and production is essential. The selection of the equipment for production depends upon the prevailing situations and the inherent characteristics of the equipment available; and needs a thorough study of total production process before taking up a project. Prestressed precast hollow-core units produced by these methods possess the following features :

(*i*) The slab is 30 to 50 percent lighter than a cast in place slab, with equivalent or more strength. It reduces dead load on the foundations resulting in economical foundations and savings in raw materials.

(*ii*) As the core slab allows longer spans, fewer columns and beams are required.

(*iii*) The units can be erected under inclement weather conditions. They are precast, cured, cut to required lengths at manufacturing plants, where quality control can be exercised efficiently.

(*iv*) Hollow-core floor installation can save 250 to 350mm of height per storey of building where large spans are employed.

(*v*) Immediately after erection, a working surface is provided for other trades.

(*vi*) Very fast erection rates are possible, with proper scheduling and good conditions.

(*vii*) The unit has a smooth finish resulting from the steel pallets of uniform casting surface, due to which ceilings present an attractive appearance without any finishing. For residential buildings painting is the only finishing required.

(*viii*) Hollow-core concrete units provide higher fire rating (minimum 2 hours), reducing insurance premiums on buildings.

(*ix*) The units and the equipment have the potential to use and produce new products such as underground utility ducts, precast side walls, bridge decking, canal crossing and power poles.

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