Vertical slipforming as a construction tool

As contractors become more experienced in this highly specialized method of construction, a wide variety of applications becomes feasible

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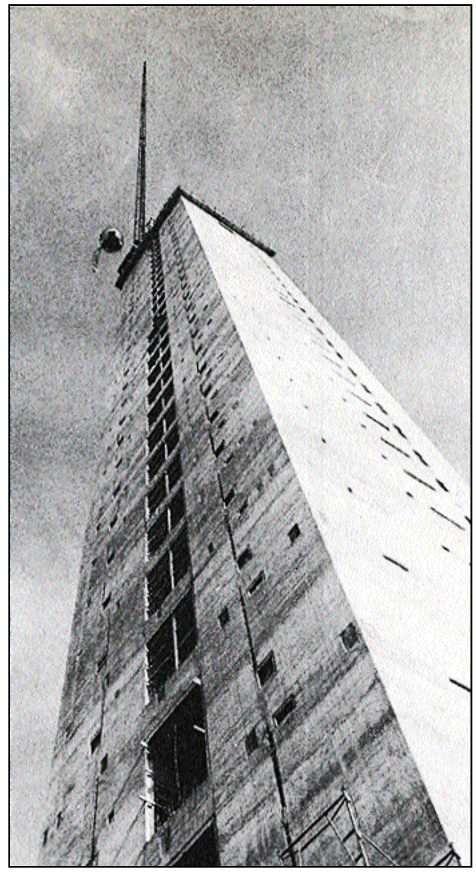
Slipforming has been closely associated with construction of storage bins and silos. For such structures slipforms have proved invaluable tools of construction by cutting cost and man-hours and at the same time permitting construction to proceed with maximum safety. Recently, however, with the perfection of fully automatic jacks and increasing competition in the construction industry, slipforms have been successfully applied to many other types of structures including bridge piers, building cores, apartment houses, chimneys, communications towers, cooling towers, and offshore drilling platforms, to name just a few. All indications are that contractors and engineers will continue to find new and more diversified applications for slipforming in other types of structures.

To gain optimum benefits from slipforming every effort must be made to incorporate the choice of materials and techniques into the design concept at the very earliest stages. The architect or engineer who leaves construction considerations entirely to the contractor is postponing these choices until it is too late to implement them without making revisions to the design that are almost prohibitively expensive and without the delays of such redesigns.

The slipforming process

Some of the more significant aspects of the slipforming technique will be given here and some criteria provided for evaluating the method for use in specific buildings or for use in conjunction with other construction techniques.

Slipforming is normally used to cast concrete walls, piers, towers or other structures capable of being extruded. In effect slipforming is an extrusion process in which the form (3½ to 6 feet(1)* high) is the die. In most extrusion processes the die is stationary but in slipforming the material is stationary and the die moves upward propelled by hydraulic, pneumatic or other means. Plastic concrete placed in the top of the slipform must lose its plasticity by the time the form has moved past and ceased to support it. Therefore the rate of initial set of the concrete determines the speed at which the slipform can proceed. Normally the setting time is two to three hours. With forms 4 feet(2) deep this means a possible speed of 4 feet every two to three hours or 16 to 24 inches per hour,(3) depending on such factors as the amount, type and grind of cement, concreting temperatures, and admixtures. Speeds higher than this have been achieved but more often speeds are lower. Eight to 12 inches per hour(4) is a common average because of delays due to placing inserts, reinforcing steel or concrete.



Slipforming 406-foot-high(50) core of Lincoln-Rochester Trust Company Building, Rochester, New York.

Because slipforming is an extrusion process, nothing can be cast using this process that is not within the confines of the die. In other words, the vertical trace of the

* Numbers in parentheses refer to metric equivalents listed with this article.

Slipformed and post-tensioned, the CN (Canadian National) Tower, Toronto, Ontario, is world's tallest freestanding structure at 1805 feet.[49]

forms cannot be crossed by any object until the forms have passed. This means that slabs, beams, corbels or other horizontal elements cannot be cast simultaneously with the walls, but they may be placed later.

Inserts that do not project outside the confines of the wall can, however, be utilized to provide attachments for floor members, openings, chases and even beam-and-girder frames. Some of the inserts placed during slipping include keys, bend-out dowels, pockets, weld plates, weld boxes, piping, electrical conduit and boxes, door frames, window frames, and prestressing conduits and anchors.

Architectural and structural impact

Construction by slipforming makes certain architectural benefits possible. One is the possibility of having a structure free from horizontal joints, formwork tie holes and surface voids. Another is the considerable freedom of form in plan at very small construction cost. On the other hand, variations may occur in the surface finish of the wall because of variations in speed or changes in temperature. If the slip operation is stopped often, variations in texture will probably occur between those concrete surfaces that become exposed while relatively fresh and those that remain covered by the form during the longer period of a stop. "Shingling" or "overpour" (that is, overlapping or running over the lower surface) may also occur where these stops have been made. The clearance required between stationary forming boxes and the moving forms will result in ragged edges at the perimeters of windows or other openings. As there is also some danger of honeycombing and leakage at corners and around openings, great care must be exercised to obtain sharply defined, uniformly colored edges. The architect who is considering the use of slipforming to obtain architectural concrete must integrate the likelihood of imperfections produced by the method into his aesthetic concept. An alternative is to use a skin of some sort to cover concrete surfaces that are formed less carefully and therefore less expensively.

The structural implications of the slipforming technique are impressive. It presents the possibility of casting, at more or less reasonable cost, a building core containing elevator shafts, stair wells, mechanical and utility spaces and lavatories. This core will be capable of taking all lateral forces on the building. Concrete or structural steel framing can be attached to this core and designed for vertical loads only, resulting in light members and low-cost connections.

When used with precast concrete sections, the core eliminates the necessity for difficult and expensive moment connections; it also reduces member sizes and weights. Slipformed cores make an excellent anchor for lift slab construction and box modules in systems building. Suspended floors are another interesting possibility.

Slipforming is being utilized effectively in the construction of bearing-wall designed buildings. In this system the slabs, whether cast-in-place, precast, steel or some composite of these, are cast or installed a few stories below the slipform. A system must be developed for construction of such buildings to reap the time savings and economy of construction inherent in this method.

Construction sequences

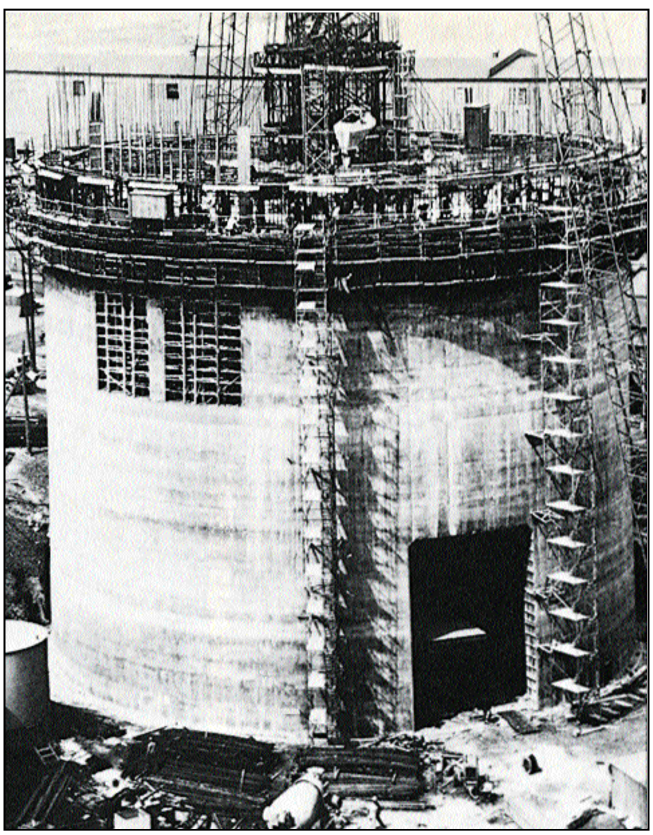
One construction sequence for bearing-wall buildings is to divide the structure into two sections, slipping each half on alternate days and placing the floors on a cycle that is one day out of phase with the slipforming. This results in a two-day floor cycle. Maximum speed has been achieved by a system in which three 8-hour shifts working around the clock perform all the operations required to produce a floor per day. To illustrate, at Bay View Terrace in Minneapolis, the midnight shift slipformed one story height of walls, the morning shift placed precast beams and the afternoon shift poured slabs for the floor system. Of course these operations were spread over two to three stories. Once the system was in full swing, a one-day floor cycle was achieved.

For core construction one of three methods is generally used. The first method is to construct the core completely to the top and then come back and place the main framing and floors. Work is usually done on a 24-hour basis, at a rate of 80 feet per week,[5] stopping for weekends. This is very effective in cold climates to beat the more expensive winter construction.

In another method, the core is erected on a floor-a-day basis for a week or two at a time and then an equal number of floors are placed. As an illustration, walls are placed for one week, floors for two weeks, walls for one week, then floors and so forth. This has the advantage that no men are working above other crews. The method greatly increases the efficiency of the floor placing operation and allows for earlier completion of the elevators and mechanical work.

The third method is to carry on the slipforming and floor construction operations simultaneously on a daily, one-floor-at-a-time basis. This method is used only when the core is not stable within itself and needs support from the floor system.

In all the above methods climbing cranes can be made part of the slipform system. These automatically rise with the forms and are used for all the other operations as well as slipforming.



Slipform with moveable collars created necessary taper for this 1250-foot-high[51] chimney, said to be world's largest. Structure is 116 feet[52] in diameter at base, tapering to 52 feet[53] at top.

Economy

Significant construction economies are possible with slipforming although it can be very expensive if improperly used. For example, it is possible to slide tapered structures using slipforms, but this is more expensive than sliding vertical walls. Most tall chimneys now being built in the power industry are nevertheless being slipped because it is worth a premium to cut the construction time in half or less.

The ideal slipform structure is one having relatively thick walls requiring 20 or more cubic yards of concrete per foot[6] of height, light reinforcing steel and no openings or inserts. Such a structure can be cast at extremely low cost and at a rate of 20 inches an hour[7] or better. The taller the structure the lower the first cost of the forming system itself per cubic yard of concrete placed. The cost is increased to the extent that the walls are made thinner, heavy complicated reinforcing steel is added and more carpentry is required to set openings, pockets, keys and inserts. Also, these factors reduce the speed of the slide. A break-even point will finally be reached at which there are enough complications to make conventional methods more advantageous.

It is difficult to set general quantitative rules for judging when slipform construction will be economical. The answer varies with the type of structure, geographical location, labor conditions, climate, site conditions, construction schedules and design sophistication. The following criteria will be of some help in making a preliminary analysis but it is recommended that a complete and accurate analysis be made before deciding to slipform any particular structure.

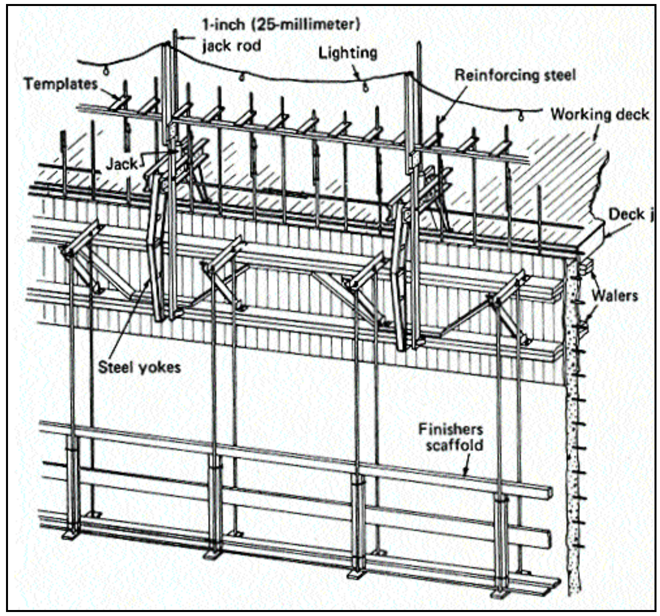
The major saving in slipform construction comes from the low cost of forms per square foot of contact area; forms 4 feet[2] high are good for heights of approximately 400 feet.[8] This gives a form reuse factor of one hundred with no stripping or resetting. Furthermore, working decks and finishers' scaffolds are part of the form, eliminating scaffolding that would otherwise be required.

Balanced against this saving in cost is the additional cost of premium pay. Slipforming is always associated with premium labor costs that come from working in shifts or overtime. Even on daily slides, a skeleton crew is required for an additional two hours to free the forms and prevent bonding to the concrete. This is accomplished by sliding an additional 15 inches[9] or so. Where shift work is permitted, sliding around the clock with three 8-hour shifts is the most economical procedure. The operation can be stopped over the weekend to keep the premium pay down to about 15 percent. Two 12-hour shifts are used when labor is short and extra inducement is required; this raises the premium pay to about 40 percent. In areas where shift work is not permitted, the premium pay may run as high as 67 percent; such cost is seldom justified. On daily slides the extra cost for the skeleton crew is usually about 20 percent.

The amount of concrete to be placed per foot (or per hour) is a major consideration because a minimum crew is required on even the smallest job; heavy concrete walls require less formwork, deck and scaffolding per cubic yard than delicate structures. Maximum economy is achieved at 20 to 30 cubic yards or more per foot[10] and economy stabilizes at that level. Below this yardage, the cost varies inversely with the cubic yards per foot but rises rapidly to infinity at zero cubic yards per foot.

It is difficult to set a minimum height of slide below which slipforming should not be considered. One reason for this is the possibility of reuse when multiple units are built. A development of 3-story apartment buildings in Kansas was slipped economically because of reuse. Repetitive reuse promises economical slipforming for industrial construction.

Economies also accrue from early building rental, short financing, lower construction overhead and minimized winter construction. The system aspect of slipforming has inherently excellent logistical capabilities for vertical transport. It provides work and storage platforms that are always at the required location and suspended cranes and hoists that rise automatically with the work (without using up space on the ground) and provide rapid movement of personnel.



TYPICAL SLIPFORM DECK

Design and construction of the forms

The slipforms are most frequently 4 feet[2] high and are constructed to produce the shape of the building in plan. Locomotion is accomplished by jacks climbing on smooth steel rods or pipe cast into the hardened concrete below. These jacks may be manual, electric, pneumatic or hydraulic and operate at speeds up to 2 feet per hour.[11] Jacks usually have capacities between 3 and 25 tons,[12] but much higher capacities are available. Working decks, storage decks and scaffolds are supported by the forms and carried upward with them.

The entire weight of the decks and supported scaffolds is transmitted onto the wales, through the yokes, and into the jacks and jack rods. The only function of the concrete is to support its own weight and to prevent the jack rods from buckling. In addition to the dead loads, live loads of 40 to 50 pounds per square foot[13] of deck and 50 pounds per linear foot[14] of scaffold must be supported. Storage for reinforcing steel, blockouts, inserts and other construction necessities must also be provided for in the design.

An important part of the load on slipforms is the friction or drag force of the concrete against the forms as they are jacked up. This loading is highly variable, depending on the temperature, moisture content, workability and rate of set of the concrete, as well as the ambient temperature and the smoothness and cleanness of the form surface. This force is kept within limits by building in a slight batter of about 1⁄16 inch per foot.[15] The sheathing is made impermeable by oiling or plastic treatment to prevent water absorption by the forms. Nonabsorption of water by the forms is important because a film of excess moisture has a beneficial lubricating effect. A drag load of 100 pounds per linear foot[16] of forms is sometimes used in form design.

Since the slipforms are subjected to the hydrostatic pressure of the plastic concrete, the sheathing must support this lateral pressure with beam action between the wales and as a cantilever at the bottom. The wales in turn must carry the hydrostatic pressure as horizontal beams between yokes. Although the material most commonly used is wood, slipform sheathing may be made from any number of materials. Wood has the ability to withstand racking and abuse without permanent damage and is relatively inexpensive to alter and repair. The wood most commonly used is 1-inch[17] staves in 4-inch[18] widths, tongue and groove or square ended, depending on the requirements of the job. Plywood ¾ inch thick[19] or Finnish sheathing is often used and although this has the advantage of reducing the sheathing labor requirement, these forms require stouter wales and bracing to prevent distortion during use than do staves. Plywood is less suited to curved surfaces because of bending difficulties.

Steel forms, though more expensive than wood, are justified if sufficient reuse is anticipated. They are more rugged, smoother and easier to clean but they are less flexible and do not lend themselves to easy alteration or repair during the slip operation.

Any form material may be used for sheathing as long as it has a smooth, strong, nonabsorptive surface and has structural stability throughout the range of moisture and temperature conditions expected.

Wood wales are usually built up of two or three plies with the joints staggered. Two-ply wales are always built of 2-inch-thick[20] material. Three-ply wales may be built of 2-inch material or a combination of 2-inch and 1-inch(21) material. Most forms have two wales, but additional wales may be required for plywood or very high forms.

The yokes are inverted U's consisting of two legs and a cross beam, the legs being attached to the wales and carrying the vertical loads in tension and the lateral loads as cantilever beams. The crossarm of the yoke must be designed as a beam supported at the center by the jack and subject to the moments from both the vertical and lateral leg loads. Although these yokes are normally steel they may be constructed of wood. A certain amount of adjustment is necessary to allow installation and use on more than one job, especially in the case of steel yokes which are more expensive than wood.

Propulsion

Usually, the rate of speed of the slip operation is controlled by the rate of set of the concrete and not by the capabilities of the jacking system. If the jacking rate is too high, plastic concrete may fall out from under the form, but if too slow, bonding to the form may occur, tearing the concrete or binding the form in place. Faster rates of slide are required in hot, dry weather and slower rates in cold, wet weather.

As the jack rods must carry the vertical loads without buckling, lateral bracing is necessary wherever there is no concrete present to give the necessary lateral support. Accordingly, wherever there are openings or walls are discontinuous jack-rod bracing must be built in (see drawing). Jacks may be set to miss such openings. When jack rods are suspended from a structure above the top of the slide, the jack rods are in tension, are better able to maintain the accuracy of plumb of the structure and require no lateral support.

Jack rods are usually spaced from 4 feet[2] on centers upwards to almost any spacing, depending on the form design and jack capacity. Yokes are most often designed at 5- to 8-foot[24] spacing, depending on the maximum allowable span of the wales, the curvature of the wall, building configuration, distribution of loads and load equalization. Jacks are concentrated at corners, deck beams, concrete hoppers, bridge landings, and other heavily loaded locations. The proper layout of the jacking system greatly affects the success of the slipform operation.

Jacks are almost always connected to operate simultaneously from a central pressure or power source and climb a predetermined stroke distance (such as 1 inch[25]) simultaneously every time the electrical or hydraulic system is activated. Although most jacks have excellent stroke accuracy, field conditions, mechanical imperfections, and load variations require continuous checking and adjustment of level as required. Self-leveling devices usually keep forms level automatically but the levels of jacks relative to one another can be adjusted by hand jacking or manipulating valves.

The working deck

Work-deck sheathing and joists are usually designed for dead load plus a construction live load of 75 pounds per square foot[26] or concentrated buggy wheel loads and other construction equipment loading, whichever is greater. Power buggies deliver such high lateral loadings to slipform decks that they must be used with caution if at all. Beams and trusses may be designed for a uniform live load of 40 to 50 pounds per square foot.[13] If the deck is to be used as a form to place a slab at the end of the slide (for example, a roof), the deck must be designed to take the weight of the slab plus construction loads.

The slipform working deck performs the important function of holding all the formwork together so that the various components act as a unit. The deck must also be capable of maintaining the plan dimensions of the structure throughout the height of the slide. The distances between walls must be kept within tolerances, square corners must be securely held and circular arcs must remain circular. The well constructed deck tends to remain level, prevent projections of the structure from moving out of position, and keep straight lines straight. Horizontal bracing utilizing wood, steel rods, steel plating, trusses and combinations of these is necessary to accomplish these functions and also to resist wind loads.

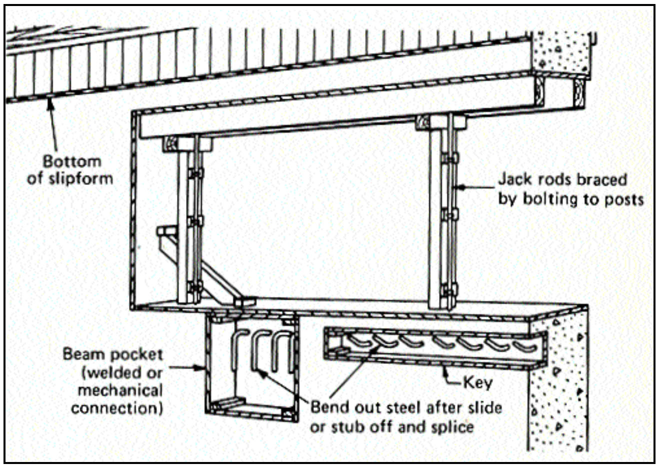
Blockouts

Since projections beyond the face of the walls will foul the moving forms, such projections, if required, must be added after the forms have passed. Corbels may be obtained by leaving pockets in the wall with dowels bent in so as not to project beyond the face of the wall. The dowels are later bent out and lapped or welded to the corbel steel before casting concrete. A steel shelf may be used, welded to steel plates cast flush with the face of the wall during the slide. Inserts must be rigidly attached to the reinforcing steel or other stationary object (such as form blockouts) to prevent displacement during slipforming. A welded connection is usually the most dependable.

Considerable versatility is possible within the confines of the forms. Segments of wall may be discontinued and resumed using stationary or moving bulkheads placed within the forms. Utilizing appropriate blockouts, walls may be reduced in thickness, buttresses picked up or discontinued, and beams and columns cast. Windows and door frames, piping, electrical conduits and boxes, and many other architectural and mechanical elements may also be placed into the walls as the slide proceeds. Beam pockets, slab keys, dowels and anchor slots may also be cast during the slide operation.

Concrete

Except for the careful control of slump, concrete mixes for slipforming do not differ from concretes to be used for construction by other methods. A slump of 4 inches, plus or minus 1 inch,[27] is most commonly specified because it becomes hazardous to place concrete with lower slumps. In hot, dry climates or with certain types of



TYPICAL FORMING DETAILS TO ALLOW FOR OPENINGS, BEAM POCKETS AND SLAB KEYS

aggregates and cement, higher slumps may be required. The use of vibration, retarders and workability agents is of course desirable but not for the purpose of reducing the slump below 3 inches[28] or reducing the free water necessary for lubrication.

The concrete is placed in the forms in even layers of 6 to 8 inches,[29] keeping the forms as nearly full as possible and spading or vibrating each layer as it is placed. It is highly recommended that concrete be placed alternately in clockwise and counterclockwise directions or that other placing sequences or systems be used to prevent repetitious loading and rotation of the structure as a whole. If the rate of slide is materially reduced, placing the concrete in thin layers of 2 to 3 inches[30] will decrease the time between successive placements and prevent cold joints.

It is important to keep slipform decks as nearly broom clean as possible in order to prevent spillings of set concrete from falling into the forms. The decks must be scraped and swept into clean-out openings or chutes provided for this purpose.

Control of set, workability, moisture content and temperature of the concrete is of great importance in slipforming operations. Retarding admixtures may be necessary in hot weather or when slide rates must be reduced to accommodate placing of a large number of inserts, placing heavy reinforcing steel, or other time-consuming operations. Mild doses of retarding workability agents are usually used to delay the set and increase plasticity without adding water. The use of ice in lieu of part of the mixing water to reduce the rate of cement hydration is highly recommended and is more effective and less dangerous than retarders.

In cold weather accelerators or high-early-strength cement are sometimes required to increase the rate of hydration, provide heat at a faster rate and reduce the setting time. Because of the danger of uneven rates of set in different parts of the slipform, the use of high-early-strength cement or accelerators can be dangerous and is recommended only in special situations. An increase in cement content will often solve cold weather problems most effectively.

Rate of slide

The rate of slide is checked by plunging steel rods into the concrete and measuring the amount of hard concrete that is in the forms. A minimum of 12 and maximum of 30 inches[31] is recommended. If there is less than 12 inches of hard concrete in the forms the slide speed must be reduced to allow the concrete to set further. If the amount of hard concrete exceeds 30 inches, the rate of slide must be increased to prevent binding of the forms.

The rate of slide can also be checked by standing on the scaffold below the forms and scratching the green concrete to see how hard it is as it comes out of the forms. This of course takes some experience.

Rebar considerations

Reinforcing steel for slipform work is in some respects more difficult to place and inspect and therefore must be detailed in a manner different from conventional concrete construction. The vertical steel is located to miss the yokes and is held in place at the top by templates attached to the deck and moving with it. The templates are placed at heights of from 4 to 10 feet[32] above the deck—the higher the better. The steel is lapped and tied to the rod below, the laps being staggered for structural reasons and to distribute the work load more evenly on the iron workers. Lengths of these vertical bars are usually limited to between 10 and 15 feet,[33] depending on the size of the bars, to reduce the whip which may develop on a windy day if the bars project too far above the templates.

Horizontal steel must pass under the yoke beams as the work progresses, a level at a time, and must be threaded through the vertical steel and the jack rods. This requires good detailing to make sure that it is physically feasible to place them. It may be necessary to add a few inches[35] to the length of horizontal bars to give the iron workers a reasonable tolerance in long continuous runs of steel. The vertical spacing of horizontal steel must be analyzed to obtain the most efficient placing in the field. Spacings of 10 to 12 inches[36] work very well and are recommended. On the other hand, the larger diameter bars are heavy, rigid and harder to place, so that this must be balanced against the spacing, limiting the bars to 1 inch[25] diameter and smaller if possible. As it is not always possible to maintain optimum size and spacing and furnish the required steel area, careful analysis and good judgment are necessary to come up with the most feasible solution for any specific project. Spacing down to 3 inches[28] and even bundling of bars has been used. Rods up to Number 18[37] have been placed in slipforms. Good detailing will actually make placing easy. With the slipform deck as a work platform, the rebar men can operate safely, comfortably and efficiently right at “ground level.”

The lengths of horizontal bars are limited to 20 feet[34] or less depending on the configuration of the particular structure. Bars longer than 20 feet[34] are difficult to handle in the field unless expensive crane handling is provided. Hooked and bent bars are made shorter to facilitate placing.

Ties and stirrups must be detailed to provide for placing from the sides. Ninety-degree hooks are used in lieu of standard hooks as these hooks can be rotated into position about their axes. As they cannot be dropped in from the top, ties must be detailed as open pieces that can be placed from the sides of columns, pilasters or walls and lapped to fully meet code requirements. Interference with the yokes must be avoided.

Since large areas of reinforcing steel cannot be inspected at one time, and since concrete placing cannot be delayed, inspection of reinforcing steel in slipform work requires a systematic procedure. The rebars are continuously swallowed by the concrete as the forms rise at a rate of 8 to 12 inches an hour[38] or more. It is therefore necessary that all horizontal steel be designed in horizontal layers; in other words, all horizontal steel should be at the same vertical spacing or at least in multiples of that spacing. This enables the rebar crew to place at one time a full set of steel as shown on the drawings. The inspector then can check layer by layer to make sure that no bars are omitted or improperly placed. Light steel such as hairpins, ties and corner bars that might be easily omitted must be carefully checked. In order to ensure proper vertical spacing of the horizontal steel, positive provisions are required for marking each layer. Some of the provisions available are as follows:

- Spaces are marked on vertical bars at several deck locations using tightly wound tying wire. (Keel marks get lost and are not effective alone.)
- Light angle irons are sometimes embedded in the concrete with holes to set the spacing. These angles are bolted together in sections as the slide progresses.
- Short bars which clear the yokes may be tied several courses ahead of the courses being placed as guides for the rest of the bars.
- Marking the ends of bars on the deck eliminates individual measurements each time a layer is placed and is a great help to both placing and inspection. These markers must be of a raised type such as double headed nails, V-notches, steel plates or wood blocks but must not be a tripping hazard to the men working on the deck.

There is little or no tying of steel in slipform work as the rebars may be placed directly on the concrete. Minor variation in spacing is usually not critical as long as the actual steel area provided is adequate and maximum allowable spacings are not exceeded. Tying must be provided as required to ensure proper clearance between the rebars and the forms.

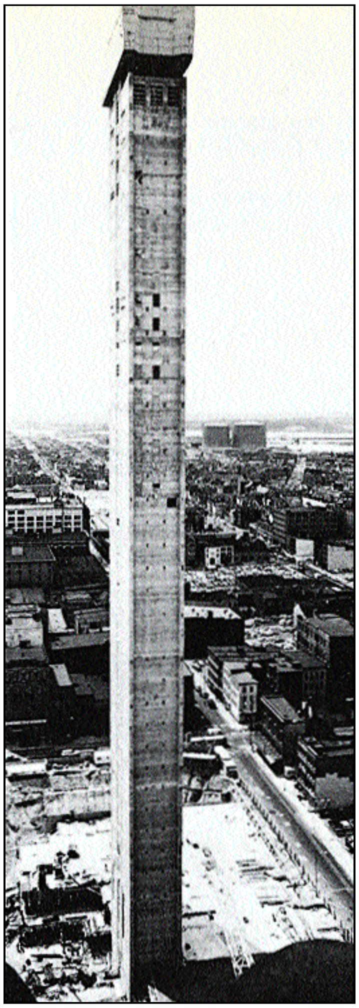
Control of tolerances

As with any other forming system, as the slide progresses there is a tendency for the forms to move out of line by translation, rotation, or a combination of both. Structures that are small in plan are more difficult to keep within tolerances but are also more readily brought back into proper alignment as they do not have the inertia of larger structures. Usually these movements are individually very small but they could total several inches[39] out of plumb in a tall building if corrections were not instituted. Careful surveillance of plumb deviations is necessary, and prompt but not hasty corrective action is in order. Since the forms are perpendicular to the deck any tilting of the deck will cause the building to grow in the direction towards which the deck is tilted. It is therefore very important that the deck be level at all times unless a tilt is required for correction.

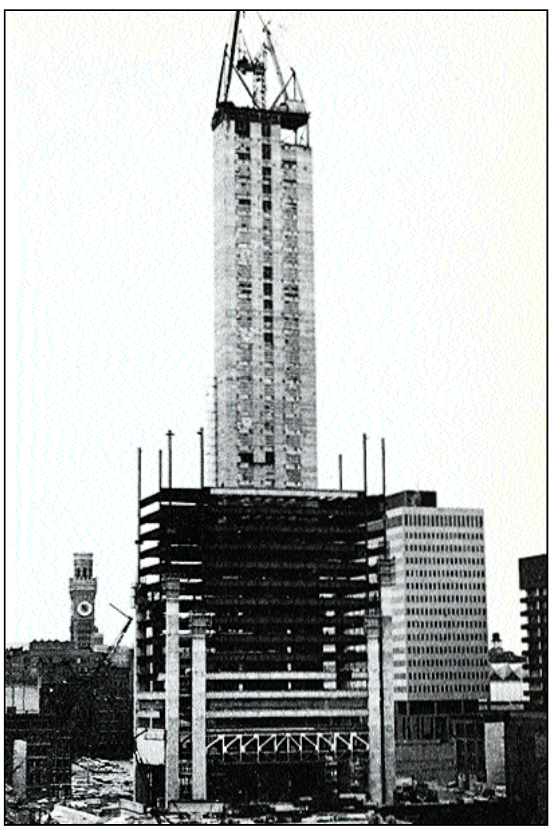
The forms must be strongly built and checked for level before the slide starts. During the slide, levels must be checked frequently to ensure that all jacks are operating within ½ to ¾ inch[40] of the correct elevation. Jacks that get too far ahead of their fellows are brought back into line by causing them to miss one climb. Jacks that lag behind may be manually brought up to proper level. In addition to the use of automatic leveling devices, frequent inspection is required to double-check the operation of the leveling system.

Frequently hack saw marks are cut into the jack rods at 12-inch[41] intervals and the jacks are checked against these marks. It is necessary of course to make sure that the saw cuts are accurately made. Water-level systems are also effective. With these a central tank is filled with water and plastic hose is run to the various jacking points where a vertical tube indicates the water level at each jack. Unless all air bubbles are expelled from the system, false readings will be obtained. In addition, periodic readings must be made to determine deviation from plumb of the various points of the structure. These readings may be required as frequently as every three hours for buildings requiring close tolerances and those with a plan that is particularly subject to drifting. Readings at twelve to twenty-four hours are usually adequate for most slipform construction having a stable plan and being required to meet the ACI tolerance of 1 inch in 50 feet[42] of height.

Vertical plumb readings must be made in two directions at right angles to each other in order to detect movement in any direction. Targets must be placed in several strategic locations around the structure on the forms themselves and must be clearly marked and self reading. Once the form has been raised a foot[43] or so, a transit or a carpenter's level is used to transfer the target line down to a chisel-cut in the concrete which can be used as a backsight for subsequent readings. To check the plumb a transit shot is taken of the form target and checked against the chisel-cut in the concrete. Plunging the transit for a second shot will eliminate any transit maladjustments.



Core 556 feet(48) high for United States Fidelity & Guaranty Company, Baltimore, Maryland, was slipped full height before second phase of work, erection of structural steel, began.



The optical plumb is essentially a weighted telescope which hangs freely like a plumb bob in a pivoted collar and transfers a plumb line of sight to a target box set at the base of the slide. Deviation from plumb is checked by direct reading through the telescope. A target box and mounting collar is required at every point to be checked, but one or two optical plumb telescopes can be moved to cover all positions. At great heights the optical plumb becomes difficult to use because of wind and vibration.

Today, laser beam instruments are gaining popularity for monitoring tolerances in slipform work.

Tolerances of 1 inch per 50 feet[42] of structure and 2 inches[44] for the full height of the structure (without regard to height) are reasonable. Nevertheless, the designer must remember that this tolerance is a minimum and that greater tolerances will save some headaches and result in maximum economy when conditions permit. Tolerances within ½ inch[45] have been almost consistently achieved when necessary in full cores to 400 feet;[8] good forms and procedures were of course necessary to achieve this. To expect such tolerance and include it in specifications is ordinarily excessive and unreasonable but all forms and procedures should be designed to achieve it.

Finishing and curing

Finishing provides no problems in sliding form construction because the concrete emerges from under the form in excellent condition for a float and brush finish. The finishing is performed comfortably from the hanging scaffold. The absence of joints and tie holes results in a finish that is very durable in any climate.

Curing is usually achieved by use of membrane curing compounds applied directly from the finishers' scaffold. Water curing using water lines hung from the forms is sometimes used but is subject to many problems. If water curing is used, fog type nozzles are recommended to prevent erosion or discoloration of the concrete.

Combining slipforming with other techniques

In recent years there have been several interesting combined uses of slipforming with other techniques. One such combination was the erection of central cores by the slipform method, and then the raising of the floor slabs into place using the lift-slab method. Cast-in-place concrete strips were used to close the connection between the slabs and walls. The Condominio Piedrahite in San Juan, Puerto Rico was designed and erected in this way, the core furnishing all necessary lateral stability to withstand hurricane winds.

The New York State Exhibit Pavilion at the New York World's Fair combined slipformed columns with a suspended cable roof assembled on the ground and jacked into place.

In Milwaukee, the superstructure shell of a 25-story apartment house was constructed in 35 days using slipformed walls, precast prestressed beams and cast-in-place floor slabs and working around the clock in three shifts.

Another interesting project is the IBM Building in Philadelphia. This 240-foot[46] structural steel building has four slipformed cores acting as backbone for the steel framing and at the same time providing vertical transportation and adding aesthetic value to the building. Connection of steel members to the cores was made by weld plates cast into the core concrete. The 535-foot[47] United States Fidelity & Guaranty Building achieved the same success in Baltimore.

In the above instances and in many others, the architects and engineers who designed these structures kept the execution of their design in mind from the very beginning. This has resulted in their using advanced concrete construction techniques to the best advantage and achieving for their clients buildings of quality as well as economy.

The future

Slipforming is destined to be an important member of the team in systems building and urban redevelopment. It increases our capabilities in speed of construction, automation, minimum disruption of an area, durability, fireproofing, soundproofing and use of local unskilled labor.

Slipforming is at least a half century old but it is still very young. We have advanced much in this technology in the last 10 years but there is still a great deal to learn. There are very exciting areas for further advancement: more automation, improved aesthetic finishes, better integration with other construction techniques and rapid construction generally.

Metric equivalents

(1) 1.07 to 1.83 meters
(2) 1.22 meters
(3) 406 to 610 millimeters per hour
(4) 200 to 300 millimeters per hour
(5) 24.4 meters per week
(6) 50 cubic meters per meter of height
(7) 510 millimeters per hour
(8) 122 meters
(9) 380 millimeters
(10) 50 to 75 cubic meters or more per meter
(11) 0.61 meter per hour
(12) 27,000 and 220,000 newtons
(13) 1900 to 2400 pascals
(14) 730 newtons per meter
(15) 5.2 millimeters per meter
(16) 450 newtons per meter
(17) 25-millimeter (nominal)
(18) 100-millimeter
(19) 19-millimeter-thick
(20) 50-millimeter-thick (nominal)
(21) 50-millimeter and 25-millimeter
(22) 150 and 460 millimeters per hour
(23) 180 to 300 millimeters per hour
(24) 1.52- to 2.44-meter
(25) 25 millimeters
(26) 3600 pascals
(27) 100 plus or minus 25 millimeters
(28) 75 millimeters
(29) 150 to 200 millimeters
(30) 50 to 75 millimeters
(31) minimum of 300 and maximum of 760 millimeters
(32) 1.22 to 3.05 meters
(33) 3.05 and 4.57 meters
(34) 6.10 meters
(35) a few multiples of 25 millimeters
(36) 250 to 300 millimeters
(37) 57.3-millimeter-diameter
(38) 200 to 300 millimeters per hour
(39) several multiples of 25 millimeters
(40) 12 to 19 millimeters
(41) 300-millimeter
(42) 1.7 millimeters per meter
(43) 300 millimeters
(44) 50 millimeters
(45) 12 millimeters
(46) 73-meter
(47) 163-meter
(48) 170-meter-high
(49) 550 meters
(50) 124-meter-high
(51) 381-meter-high
(52) 35.4 meters
(53) 15.8 meters

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