Advances in Vertical Slipform Construction

Improved yoke designs and laser controls have resulted in more economical construction and faster slipping speeds

By Bob Risser

If construction speed is a priority when you build a tall concrete structure, slipforming may be the answer. Slipforming differs from conventional concrete forming because the forming panels move semicontinuously in relation to the concrete surface being formed and form ties are not used.

Improvements in this advanced construction technology have made large projects even more economical than ten years ago; larger yoke capacities and better laser guidance systems result in more efficient and faster slipping rates.

Traditionally used to construct high-rise building cores of at least 25 to 30 stories, vertical slipforming in recent years has been used primarily for agricultural structures, such as storage silos and feed plants, and for very large offshore oil platforms.

System Components

A vertical slipform system consists of five basic elements:

- Forming panels (slipforms)
- Walers
- Yokes
- Jacks and jackrods
- Work or storage decks and scaffolding

Figure 1 shows the components of most modern slipforming systems.

The slipforms are raised on jacks, which climb on vertical rods or tubes that remain buried in the concrete. The jacks are mounted in upside-down U-shaped steel assemblies called yokes. The slipforms are attached to the yoke legs; scaffold brackets and work deck joists are attached to or bear on the slipform walers. The yokes resist hydrostatic concrete pressure (replacing form ties) and transmit vertical scaffold and work deck loads to the jacks.

Once the vertical slipforming process is started, concrete is placed continuously in the form in 4- to 10-inch layers (6 to 8 inches is average) at a constant rate. Vertical rebar, horizontal column ties, and through-wall ductile ties can be placed in advance of form movement. However, horizontal rebar cannot be positioned until the crossbeams of the yokes are raised above the location of the reinforcing steel.

The rate of form raising (see table) is determined by how fast concrete, horizontal rebar, and built-in items such as blockouts and beam connections can be placed. Ambient and concrete temperature, relative humidity, ventilation, concrete cement content, type of cement, and slump all affect the rate of concrete set. Retarding and accelerating admixtures are often used to match this rate with the rate of material placement.

Slipforming can substantially reduce forming costs on structures with a relatively constant cross section and enough height to reduce the unit cost of form construction to a competitive level. Minimum economical height is 30 to 40 feet for silos and bins, 8 to 10 levels for shear-wall buildings and small cores, and 12 to 15 stories for heavily reinforced office-building cores.

New Technology

Significant progress has been made during the past 15 years in slipform jacking systems, form details, and operating procedures.

High-capacity yokes. Though hydraulic-jack technology and lifting capacities (typically 3, 6, or 22 tons) have changed little in the past 20 years, yokes have become larger to ease several aspects of the construction process (Figure 2). Larger, high-capacity yokes allow greater spacing between yokes for placing blockouts and inserts in the structure. Typical spacings between high-capacity yokes are now as much as 21 feet, compared with past spacings of about 7 feet. Fewer yokes also minimize interference in placing rebar, allowing workers on some projects to place preassembled rebar cages into the slipform. Using greater spacing between walers, however, requires support-

Typical Form Raising Rates

Structure Type	Inches Per Hour
Grain silos	8-18
Coal silos	10-20
Office-building cores	15-25
Shear-wall-supported apartment buildings	20-30
Underground shaft lining	20-50

ing the slipform panels with larger walers to reduce deflections.

Since it is essential for the yoke to resist the hydraulic pressure of the concrete in the forms, high-capacity yokes also allow slipform designers to use taller yokes, which have greater clearance between the yoke crossbar and the top of the form. Typical clearances have increased to about 36 inches, allowing workers to stand while placing the bars instead of kneeling. Since horizontal reinforcing steel cannot be placed until after the yoke crossbar passes the location of the rebar, greater clearance gives steel workers more time to set the rebar in place before the next lift of concrete is placed in the forms (Figure 3).

Guidance systems. The aspect of slipform construction requiring the most skill is keeping the structure plumb and level as the forms are raised. In recent years, contractors have turned to economical, reliable laser technology to guide the slipform process.

Vertical lasers are used to monitor the slipform and structure for plumb and twist. A typical practice is to place vertical lasers on corners of the bottom of the core with targets on the slipform deck. By monitoring where the lasers on the ground hit targets on the middle working deck, the jacking operator can tell if the slipform is rotating or out-of-plumb and then correct it. Using lasers in this manner allows one field engineer to monitor the position of the structure as it rises, instead of the two or three engineers required when using plumb bobs and surveying equipment.

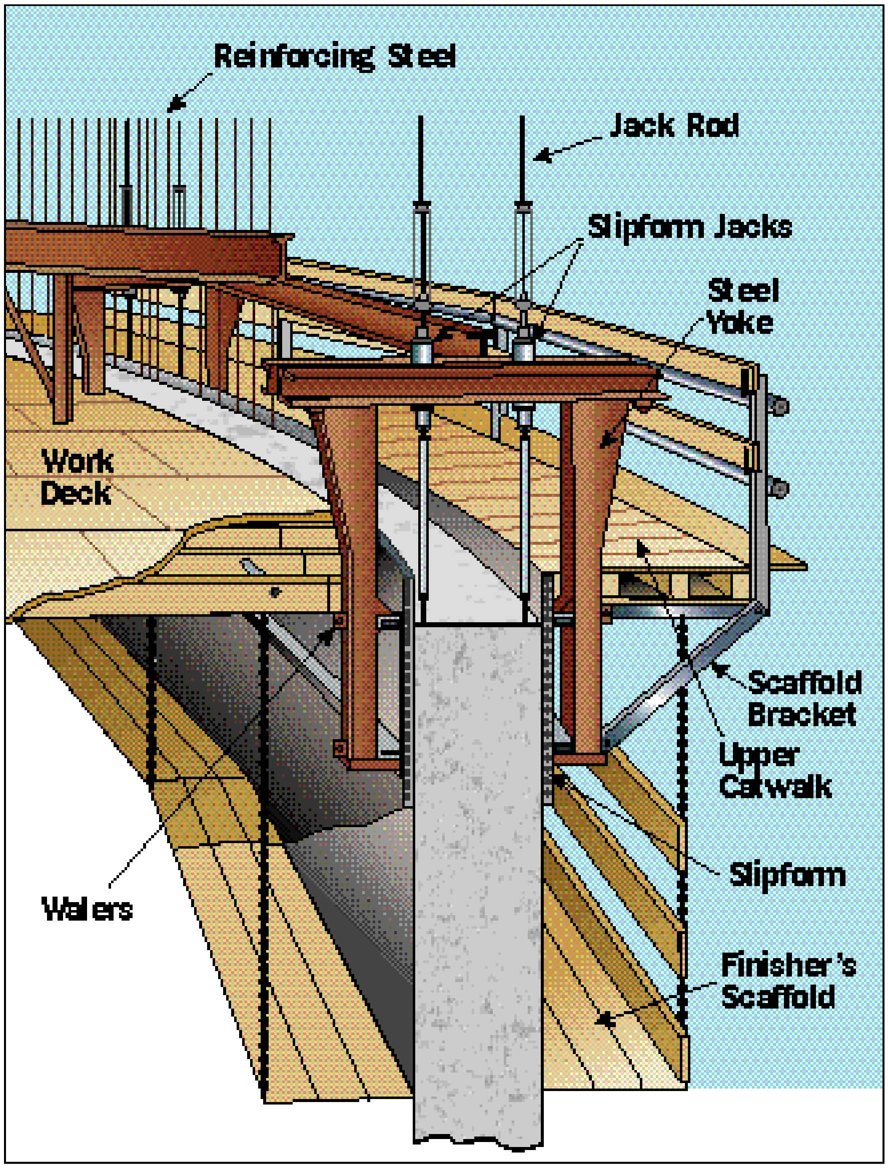

Figure 1. **Typical slipform configuration with deck and finishing scaffold supported on walers.**

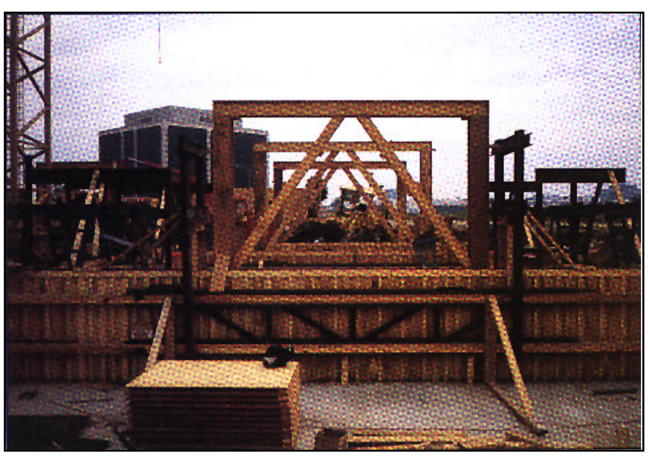

Figure 2. **High-capacity yokes allow greater spacing between yokes and greater clearances between the yoke crossbar and the top of the slipform.**

Laser technology can also be used to keep the slipform level as it rises. Level-plane lasers are mounted to jack rods, so elevation can be easily checked from a stationary point. As with the vertical laser, using this technology allows one field engineer to monitor levelness and mark elevations for all rebar, blockouts, and insert locations.

Form Materials

Different form materials may be required for vertical slipforming, depending on the height of the structure being slipformed. For storage silos and buildings under 200 feet tall, most contractors still use plywood forms. For taller structures, a variety of materials has been used by contractors to meet the demanding conditions of vertical slipforming.

The most popular forming mate-

Figure 3. **Greater spacings between yokes give contractors more room to place blockouts for openings and connections in structures. Greater clearances also give workers more time to place horizontal rebar before the next layer of concrete is placed in the slipform.**

rial for taller structures is plywood lined with a more durable material, usually plastic (Figure 4). The main purpose of the lining is durability: a 300-foot-tall high-rise structure requires the equivalent of 75 reuses of a 4-foot-high slipform panel.

Plastic and other smooth surfaces also reduce friction between the moving form and the concrete and provide a smoother finish. Also, concrete does not adhere well to the surface of plastic-coated forms. This prevents a buildup of small amounts of hardened concrete on the bottom portion of the form, which can create grooves in the fresh concrete as the slipform moves up the structure.

One experienced slipform contractor even manufactures custom-made, fiberglass-coated plywood forms. Another contractor has successfully used ⅝-inch solid plastic sheets instead of plywood forms.

Concrete Placement

Traditionally, concrete has been moved by crane and bucket up to the work decks of slipform systems, and then buggies have distributed the concrete into the forms evenly around the structure. Dedicating a tower crane solely for this purpose requires using the crane at night to transport rebar and other materials and equipment up to the work decks of the slipform or the use of another tower crane on the job to perform those tasks. The expense of this scheme has led some contractors to pump the concrete to hoppers on the work decks, where buggies or slick lines transport the fresh concrete to the forms. On one circular silo job, the contractor placed a conveyor in the middle of the work deck. Using a concrete pump to fill the conveyor hopper, workers filled the forms evenly around the structure by wheeling the end of the conveyor continuously in a circular pattern.

Faster Slipping Speeds

The advances in vertical slipforming technology have led to faster production rates, increasing the economic advantage of slipforming on suitable projects. Ten years ago an acceptable slip rate was about 8 to 9 inches per hour; today's slipform systems can easily achieve 15 inches or more per hour, allowing contractors to reduce costs by eliminating an entire work shift. These faster slipping speeds also better accommodate restrictions on night work and free the crane so it can bring materials up to the work deck during the day. Because contractors can slipform at a speed of one floor per day, they can stop each evening at preplanned locations, such as elevator lobbies on high-rise building cores, to place heavy reinforcement.

Because the slipping speed is a critical element in the economics of using slipform construction, special care is required regarding concrete mixes. For example, contractors and concrete suppliers must balance the characteristics of a pumpable concrete mix with the need for maximum uniformity in concrete setting rates. Concrete mixes may also need to be adjusted to account for changes in temperature and other variables. Before the slipform passes, the concrete must gain sufficient strength without setting to avoid high friction with the moving forms. An experienced and highly skilled crew is essential for balancing the many factors that affect the slipforming process and achieving the best results.

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Figure 4. **Plastic lining is commonly attached to plywood forms to provide the durability necessary for slipforming structures taller than 200 feet.**