Constructability Improvement of Steel Silos during Field Operations

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Abstract: Steel silos are widespread around the world, and are used for storing different materials, including cement, fertilizers, grains, and raw materials. Building a new silo provides a fairly big storage capacity within a short period of time. There are many types of steel silos, including field-welded silos, bolted silos, bolted silos with corrugated steel sheets, and silos (with small capacities) completely fabricated in shops. This paper presents a new method of construction that has been used in Egypt to build bolted silos with corrugated steel sheets. This method mainly features inverting the traditional sequence of field tasks, such that the building operation starts with the uppermost part of the structure and proceeds to the lowermost part. The method requires that the completed parts of the structure be lifted up, using specially devised tripod-mounted hoists, so that building operations always take place at grade. The new method is described in this paper in detail, along with the problems encountered during field operations. In addition, the merits, in terms of the basics of construction management, are discussed. They are cost, schedule, quality, and safety. Finally, this paper presents a new method that offers substantial opportunity for enhancing constructability of steel silos during field operations.

INTRODUCTION

Constructability is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives (*Constructability* 1986). O'Connor and Davis (1988) concluded that the constructability is enhanced when innovative construction methods are used. They related the innovations in construction methods to innovations in sequencing of field tasks, temporary construction materials/systems, hand tools, construction equipment, constructor-optional assembly, temporary facilities directly supportive of field methods, or postbid constructor preferences. In addition, they classified the prompters of construction innovation in a certain circumstance to needs for ad hoc focused studies; needs for work-around solutions to actual problems; and risk-management solutions to potential field problems. This paper presents a new method of construction of steel silos which offers substantial opportunity for enhancing constructability during field operations.

A silo structure is composed of two systems. The first system represents the civil work of the silo project that is basically the body of the silo that contains the stored material. The second system represents the material handling aspect, which is the equipment used for material charging and discharging. The civil work of a silo project is made up of three components, including a silo top cover, silo walls, and a silo bottom. Each of these components has several construction methods. However, the scope of this study is limited to the field operations of the silo wall and top cover. The fact that silo work can be accomplished using different types of resources makes it a good candidate for constructability enhancement.

Bolted silos with corrugated steel sheets are used extensively since they resist deformations. This type of silo is usually fabricated of corrugated steel sheets of 2.8-mm thickness, which is gradually reduced to 0.4-mm sheets at the top of the silo. Sheets of 2.0 × 1.0-m dimensions are delivered by the manufacturer to the site. The sheets are rolled at the shop to form the curvature that creates the required radius of the silo when constructed. The silo is erected on a reinforced concrete base, and the discharging equipment and interior ventilation ducts are embedded in the concrete base. The traditional method of construction involves using an interior scaffolding inside the silo to erect and bolt sheets in place. Extra lifts of the scaffold are added as work proceeds. In addition, external scaffolding is erected outside the silo to provide a platform for another worker to help in fastening bolts and handling sheets. After the walls are erected and the top covered, the interior scaffolding is taken apart and is moved outside through an exit door at the bottom of the silo.

This paper introduces a new method for the construction of bolted silos with corrugated steel sheets. This method offers a substantial opportunity for enhancing constructability during field operations. The novelty in this method is represented by inverting the sequence of field operations such that the uppermost part of the silo is completed at grade and then lifted up gradually to allow the building of the successive parts. The purpose is to work always at grade, thus eliminating the need for scaffolding, and to attain the other benefits of working at grade. This method has already been used to build many silos of capacities up to 1,500 × 10^3 kg (12-m diameter × 23-m height) in Egypt. The main objective of this paper is to document this experience so as to maintain awareness and share experience among constructors.

METHOD OF CONSTRUCTION

The following steps describe the method of construction of a 500 × 10^3 kg silo.

Before any erection work on the silo takes place, a reinforced concrete base with a level surface is cast in place. Ventilation air ducts as well as discharging equipment are embedded in the right place in the concrete base. The diameter of the concrete base is about 60 cm larger than the diameter of the silo body. The projection in the concrete base is used to support the tripods used in the lifting operation and to provide anchorage for the silo. The concrete base is allowed to cure adequately before starting any erection work to avoid premature cracking.

The building of the silo body is initiated with the assembling of the first lift, which is the uppermost lift in the completed silo wall. It is erected by assembling nine sheets of 0.4-mm thickness. In the shop sheets are perforated along the perimeter with 10-cm spacing between holes. The first lift is built by fastening sheets together along their short sides. The joint along this side is double perforated to allow the use of two bolts at each horizontal row to resist tension forces. Assembly is accomplished using 10-mm nuts and bolts with two

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rubber coated washers adjacent to the sheets to insure tightness. Fastening is done using handheld power fasteners. Crews of two workers are assigned to the assembling process. One is located outside the silo to handle sheets, put them in place, and insert bolts in holes; the second is inside the silo, using a power fastener to screw on nuts. This step is completed once the nine sheets of the first lift are together.

Step three is to fix a 135-degree angle along the top rim of the completed lift. This connecting angle provides a proper joint between the wall of the silo and the top cover. This angle is used only at the rim of the uppermost lift.

Step four is the building of the top cover of the silo. The cover, which is conical in shape, is composed of a cap and 27 trapezoidal segments. The trapezoidal segments are bolted up to the cap, laterally to the adjacent segments, and down to the connecting angle along the rim of the wall.

After completing the top cover, the other parts associated with it are installed, including the feeding system, the vents, the top ladder, and the doors of the top inspection openings. Fig. 1 shows the silo after completion of the uppermost lift and the top cover. At this stage all the inspection procedures needed to check for quality of this top portion of the silo are performed, since the whole structure is at grade and all parts are accessible to inspectors.

Step six involves the preparation for the lifting operation. The preparation work involves setting nine tripods that are to be used for the lifting operation at the locations of the vertical joints of the corrugated sheets. The tripod, which is shown in Fig. 2, has two front legs and one back leg that moves back and forth relative to the front legs to adjust their verticality. Each tripod is equipped with a small wire hoist of a 2,000 kg capacity. The hoist is fixed to a steel angle that is welded to the two front legs of the tripod at a suitable height to enable manual operation. The wire of the hoist is routed over pulleys at the top of the tripod. The tripod is set with the front legs resting on the concrete base to give firm support, and the third

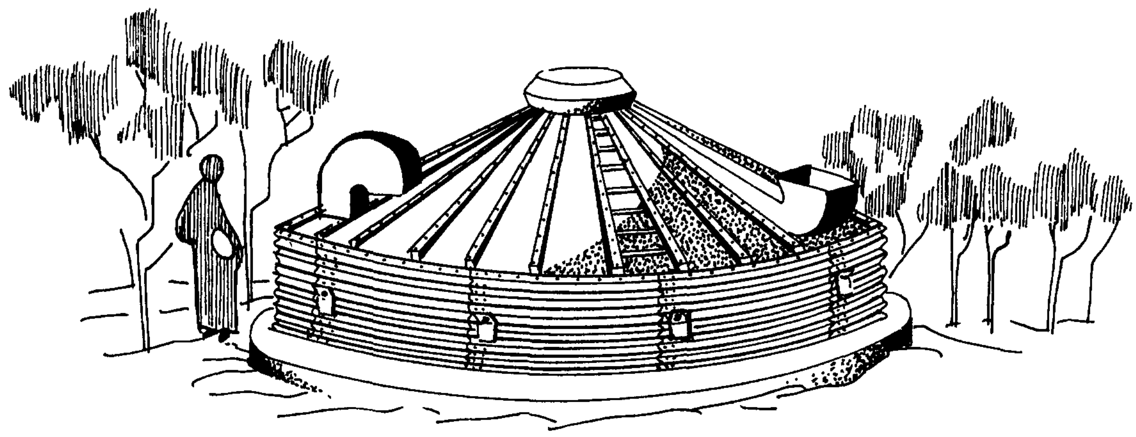

FIG. 1. Silo after Completing Uppermost Lift and Top Cover

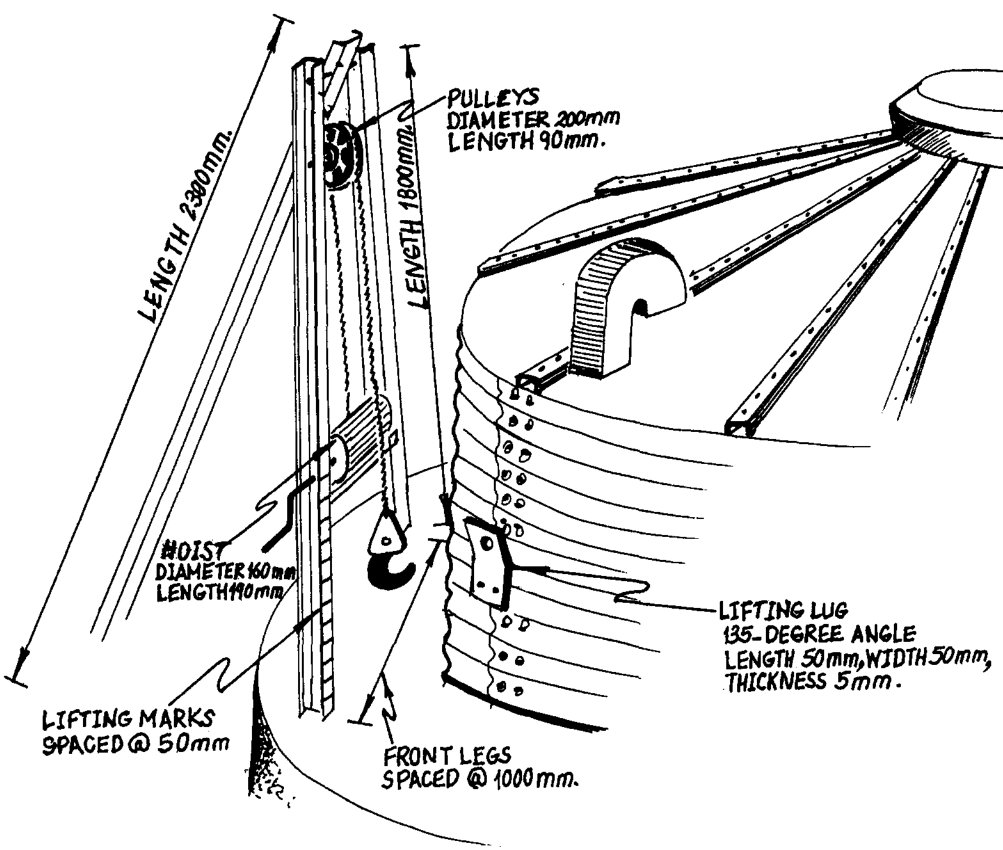

FIG. 2. Tripod Hoist, and Steel Lifting Lug that Have Been Used in Lifting Process

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leg is set so that it keeps the two front legs as vertical as possible, with some clearance between the tripod and the silo wall. After verticality adjustments, the third leg is stuck into the loose soil around the silo to stabilize the tripod. The hook of the hoist is hooked up to a steel lifting lug that was fastened previously to the fourth horizontal row of the bolts at the vertical joint. The lifting lugs are used temporarily in the construction operation and can be dismantled and disposed of afterwards. The total weight of the silo after completion is about 5,000 kg, so each hoist carries about 555 kg, which is within capacity.

After preparation, the lifting operation starts. The lifting at the nine tripods' locations proceeds simultaneously and at the same rate to insure the uniformity of load distribution, stability, and verticality of the silo. To insure a uniform rate of lifting, marks (spaced at about 50 mm) were made on the two front legs of each tripod. Lifting is performed in steps, one mark at a time, to minimize the tilting of the structure. The marks on the front legs were found very helpful in minimizing tilting when the lifting process is performed with fewer workers than the number of tripods. In this situation, one worker needs to take care of more than one tripod. The lifting process continues until there is enough room to erect another lift of sheets, which is about 1.0 m. Once the worker stops manual operation, the hoist locks itself automatically, thus preventing the silo from dropping down. Fig. 3 shows the completed portion of the structure lifted to the desired level.

Step eight is to add the second lift form the top of the silo. The bolts of the horizontal joint between sheets are fastened first, followed by the bolts of the vertical joint. Erection proceeds until nine sheets are erected. The inspection procedures to check for quality of the work can be done as work proceeds by having an inspector watching its progress and inspecting some manually, or afterwards, when the whole lift is completed. Fig. 3 shows the stage at which the sheets of the second lift are moved and the erection operation is going on.

After the work is completed with the entire second lift and the inspection procedures for the quality assurance are performed, the nine hoists are released and the whole structure is rested on the concrete base.

Since the vertical joints of two successive lifts are staggered, the tripods are shifted to the locations of the new vertical joints. Then a new iteration of the lifting operation can start.

The work proceeds according to the outlined steps until the erection of all the lifts of the silo wall is completed; then, the silo is lowered to the concrete base. Fig. 4 shows the completed silo with the vertical ladder installed, all the tripods completely released, and the temporary lifting lugs removed. In addition, Fig. 4 shows the installed mechanical feeding system and the one-panel scaffolding that was used throughout the construction operations of this silo.

After completing the silo, a steel angle is used to anchor the whole silo body to the concrete base. The angle is bolted to the silo body and the concrete base. Cement grout was used for caulking.

PROBLEMS ENCOUNTERED DURING CONSTRUCTION

1. Sometimes when it is very windy there is a danger of the entire lifted silo being airborne and overturned. This difficulty was overcome by releasing all the hoists and resting the silo completely on the concrete base.
2. Initially, the holes of the sheets were used to hook up the hoists, but it was noticed that some deformation of the holes took place. Temporary steel lifting lugs were then used to hook up hoists.
3. The tilting problem was resolved by drawing marks spaced at about 50 mm along the legs of the tripod. These marks insured the verticality of the silo body at any time during the lifting operation. In addition, using marks enabled the use of fewer workers than the number of hoists.
4. With the first constructed silo, sheets with different thicknesses were mixed up at the construction site, which consumed a lot of time to sort sheets. Organizing the work to avoid the problem of mixing up sheets drastically reduced the time necessary to find the right sheet. This was accomplished by marking the boxes containing sheets to show the number of the lift, and then opening only one box at a time.

EVALUATING NEW METHOD

In the following paragraphs, the merits of the new method will be discussed based on the basics of construction management, namely, cost, schedule, quality, and safety.

Cost

The new method described herein reduces costs in Egyptian pounds (£E), of the construction of a $1{,}500 \times 10^3$-kg silo with a diameter of 12 m, scaffolding height of 20 m, and circumference of 38 m as follows:

1. The silo was completed in only three working days using a crew of seven workers; the daily rate of a worker is £E 20.
   The total labor cost: $3 \times 7 \times 20 =$ £E 420.
2. Costs of internal and external scaffolding with an estimated construction duration of four weeks include
   Renting costs: $20 \times 38 \times 2 \times$ £E 1.0/week/m^2 of silo wall $\times$ 4 = £E 6,080.
   Erection and dismantling: $20 \times 38 \times 2 \times$ £E 6.0/m^2 = £E 9,120.
   Total cost = £E 15,200.
3. The total cost savings include the costs of scaffoldings and the costs of labor for the extended period in the project duration, which is about 22 working days, assuming that the same crew will be used.
   Total costs of scaffoldings = £E 15,200.
   Labor cost ($22 \times 7 \times 20$) = £E 3,080.
   Total cost savings = £E 18,280 (about $5,037 U.S.).
4. The cost of manufacturing a tripod and purchasing a hoist are £E 150 and £E 1,200, respectively. These costs will be minimal when averaged out on many silo-building projects.
5. The use of scaffolding increases the total project cost through the increased overheads due to the elongated construction period.

Schedule

The elimination of the time required for erecting and dismantling scaffolding, handing sheets up to the scaffolding, and the high productivity of workers when transferring elevated work at grade resulted in the completion of the big silo in only three working days. Using the traditional method would have resulted in a total construction time of four weeks, with much of that time wasted in construction methods rather than the actual silo construction.

Quality

It is very easy when work is at grade to perform inspection to make sure that the technical aspects are completely fulfilled. Part of the effort to assure quality is made by the workers, because they are aware that their work is accessible all the time and can be inspected easily and thoroughly.

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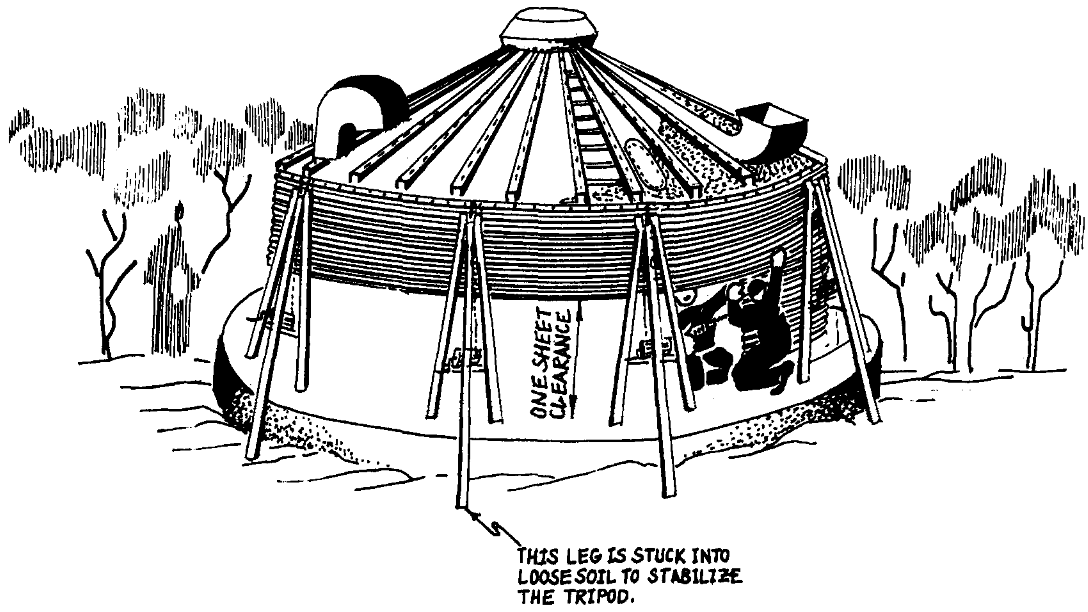

FIG. 3. Operation of Erecting Second Lift from Top

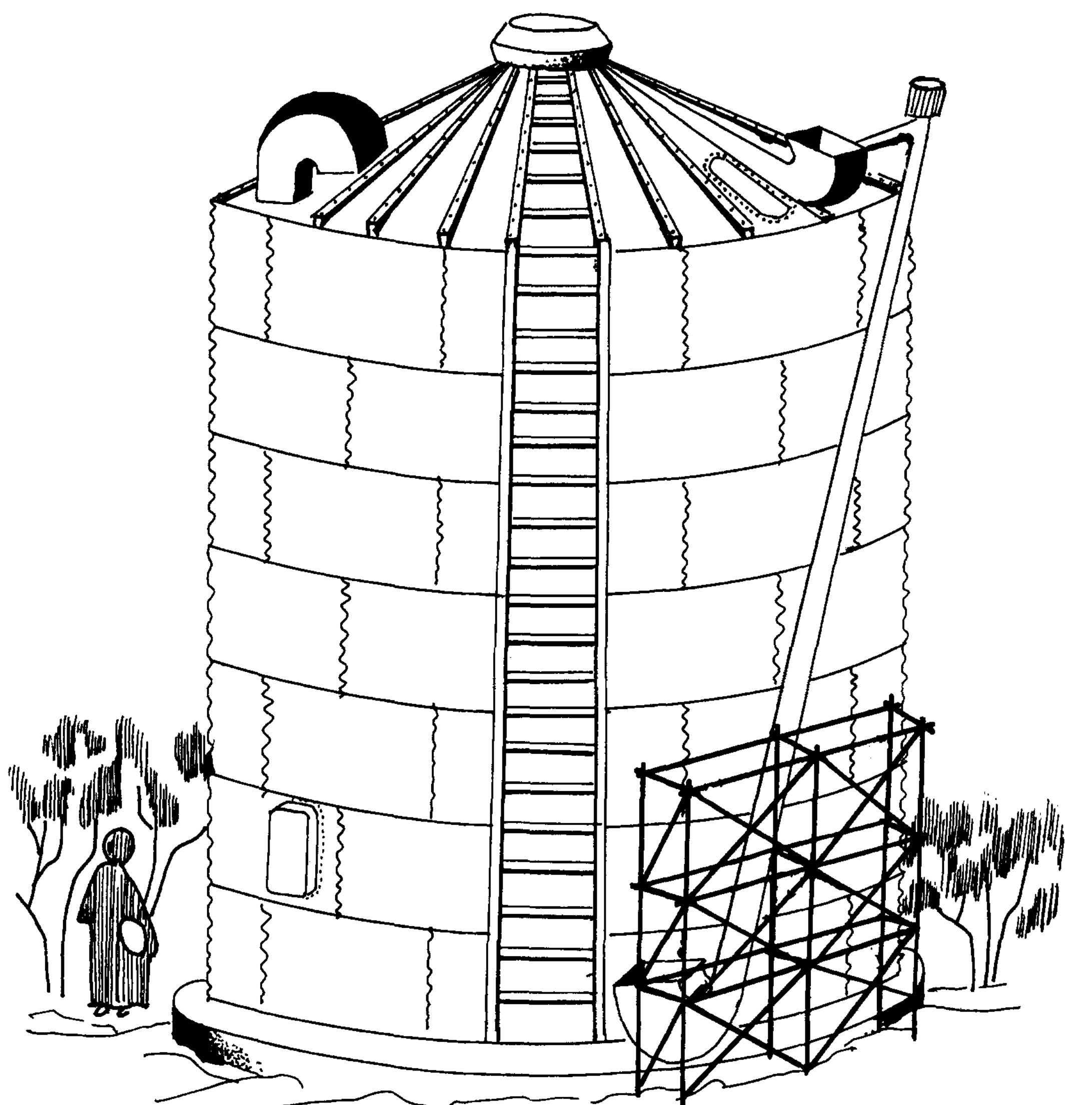

FIG. 4. Completed Silo with Vertical Ladder, and Feeding System Are Installed in Place

Safety

There is no doubt that safety can be enhanced by transferring elevated work to at-grade work. However, caution must be exercised during the lifting process to avoid tilting. In addition, during heavy winds the structure must be rested on the concrete base quickly.

Other Issues

1. The internal scaffolding should be erected over the whole interior area (not only along the circumference) to enable erecting the top cover.
2. A big storage area is required for the scaffolding before and after erection.
3. It is easier to install the heavy mechanical equipment at grade.
4. Sometimes there is no room at all to erect external scaffolding or to brace it adequately to prevent lateral movement of the scaffolding. Conversely, the third leg of a tripod requires extremely limited space to stabilize the tripod. In addition, the third legs carries negligible load and so there is no need for any precautions to prevent it from making lateral movements.

As outlined before, constructability improvement is achieved in this method by inverting the sequencing of field tasks such that the uppermost part of the silo is built first, followed by the lower parts; using temporary materials that are represented here by the steel lifting lugs; and devising special hand tools (the tripod-mounted hoist). According to the classifications of O'Connor and Davis (1988) for circumstantial prompters of construction innovation, the main prompter to develop this new technology in this circumstance is the "work-around" solutions to potential field problems. As the nomenclature implies, this new method mainly isolates delays in erecting and dismantling scaffoldings, and in working at elevated places, and it allows for progress at the basic silo-building operation.

CONCLUSIONS

This paper describes a new method that offers substantial opportunity for enhancing constructability of steel silos during field operations. This method mainly features inverting and sequencing of field tasks and devising tripod-mounted hoists to lift the uppermost part of the structure such that field operations always take place at grade. The main impetus to develop this new method was the need to isolate delays in erecting and dismantling scaffolding, and to work at elevated places to allow for the progress of basic silo-building operations.

APPENDIX. REFERENCES

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