Work Inputs and Related Economic Aspects of Multitier Shoring Towers

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Abstract: Shoring towers are the common formwork solution for high-clearance construction. Because towers account for a remarkably high percentage of the cost of the constructed concrete element, work input data and related economic aspects of tower erection constitute important information for constructors. This paper presents three case studies of high multitier shoring towers, each representing a different tower type. Tower data, major construction parameters, and work inputs for each case are presented. Findings are compared and discussed, and due conclusions are drawn. Finally, recommendations on measures expected to increase the economy of shoring solutions using multitier towers are offered, and some restrictions on the adoption of work input data are listed.

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Introduction

Multitier shoring towers are the common formwork solution for cast-in-place concrete elements spanning high spaces (Bennett and D'Alessio 1996; Peurifoy and Oberlender 1996; McAdam and Lee 1997). Because the cost of such towers takes the overall forming cost higher than the common—in themselves quite high—estimates of 40–60% of the cost of the reinforced concrete frame (Simons 1991; *Formwork* 1995; Hurd 1995; Hanna 1999), it is vital for constructors to possess information that would assist them in achieving economic solutions. This information includes primarily work-input data, as well as other related information on erection methods, crew size, and the like. Whereas this kind of information is quite scarce with regard to more common height towers, up to 10 m (33 ft) high (Means 1988, 1998; Shapira 1995; Shapira and Goldfinger 2000), it is practically nonexistent in the technical literature for extremely high towers, in the range of 15–60 m (50–200 ft) [60 m (200 ft) was suggested by Johnston (1996) as the upper limit for tower erection, although Smith had maintained (Smith 1990) that, when adequately braced, towers can be stacked to almost any height]. This, despite the fact that the cost share of such extremely high towers may be so high as to render the cost of the concrete and concrete placing themselves almost inconsequential.

This paper presents three case studies of what would be defined as extremely high towers: 17, 26, and 60 m (57, 87, and 200 ft) high. The number of towers involved makes each case too small a sample to allow generalization of quantitative conclusions. The results, however, are indicative of the type of towers investigated; they are also sufficiently sound for the drawing of qualitative rules regarding the economy of tower selection and use.

Methodology

Tower Types

Frame configuration and main tower characteristics for the models addressed in this study are presented in Table 1 and Fig. 1. The three models represent three different tower types, as determined mainly by frame configuration, tier composition, and tower assembly method. ALUMA (Canada) is a typical ladder and cross braces tower; examples of other models of this type are SYMONS and PATENT 20 K (U.S.), as well as PAFILI (Greece), and ACROW (U.K.). KABIR (Israel) towers are noted for a single basic frame, four of which make up each tier; similar models are GODON (France) and PAL (Switzerland). The PERI Multiprop (Germany) tower is made up of single props (which may also be used independently) connected by truss frames; the same concept is used, for example, by MEVA and HÜNNEBECK Alutop (Germany). It should be noted that there exists an additional tower type, not addressed in the current study, which is made up of tiers turned 90° in relation to each other; such towers are, for example, PERI ST100, HÜNNEBECK ID15, ISCHEBECK Titan (Germany), and DOKA d2 (Austria). Tower classification and the implications of the various configurations on the economy of tower erection are the subject of another study (Shapira and Raz 2003).

Tower Height

The height of the tower is the predominant attribute by which shoring towers are referred to in this paper. Hence it is important to have a non-ambiguous definition for "tower height." Fig. 2 illustrates three possible definitions of this term, denoted by h_1, h_2, and h_3, all used in practice: h_1 is used, for example, to calculate the number and height of tiers for a given tower; h_3 is the one commonly used to refer to tower height in general. For work-input investigation, h_2 is the definition best representing the height of the element studied, and therefore it is the one used in the present paper.

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Table 1. Profile of Tower Types

Tower model	Tier configuration[a]	Load capacity[b] (kN per leg)	Frame material	Frame size[c,d] (m)	Frame weight[d] (kg)	Miscellaneous
(a) ALUMA	Each tier is made up of two parallel frames of the configuration shown in Fig. 1(a), connected by two pairs of cross braces[e]	80	Aluminum	Width: 1.83 Height: 1.50 1.80 2.10	 19.0 20.0 21.0	Connectors required between frames; pins required to connect frames to steel cross braces (weighing 5–11 kg and allowing frame spacing of 0.91–3.05 m)
(b) KABIR	Each tier is made up of four frames (of the same width, or two of each width) of the configuration shown in Fig. 1(b), connected to each other	50	Steel	Width: 1.20 Height: 1.00 1.25 Width: 2.00 Height: 1.00 1.25	 10.0 12.0 15.0 17.0	Tower requires bottom base frame, assembled from four tubular steel members; no connectors or pins required for tier or tower assembly
(c) PERI Multiprop	Typical tower section is made up of four telescopic props, connected by sets of four frames[f] (of the same width, or two of each width), as shown in Fig. 1(c)	60	Aluminum	Width: 2.22 2.58 Height: 2.60– 4.80[g]	12.2 13.6 23.8	Bolts (or designated coupler) required to interconnect props; frames connect to props (either outer or inner tube) by means of wedge couplings

[a]For square or rectangular towers; KABIR-type frames permit assembly of triangular towers as well.
[b]As advertised by manufacturers; safety factors may vary.
[c]Common sizes, as used in current study; other sizes may exist.
[d]For PERI Multiprop towers: width of frames (add 0.08 m to obtain width of tower) and height of props, weight of frames or props.
[e]Cross braces may also be used to connect parallel frames of adjacent towers, to produce a continuous tower row.
[f]Frames may also be used to connect props of adjacent towers, to produce a continuous tower row.
[g]Changing height of telescopic prop.

Erection Sequence

A shoring tower is not a single formwork element, but almost always part of an array composed of several identical/similar towers erected one next to each other. Because the erection sequence of the entire array may affect work inputs, it should be recorded and constitute part of the information provided along with work-input data. In principle, there are three different possible sequences by which to erect a tower array: (1) vertical: each tower is assembled to its full height before work progresses to the next tower; (2) horizontal: the entire array is erected tier after tier; and (3) a combination of the two above methods, as illustrated by Fig. 3 (tower array represented by six towers, numbers and arrows denoting tier assembly sequence within and between towers). Selecting the particular erection sequence for a given job would normally be the choice of the erection crew, and would be determined by factors such as tower configuration, erection method (e.g., with/without crane assistance), and workers habits; the combined method, however, is the one usually favored in most cases, as observed in the current and earlier studies.

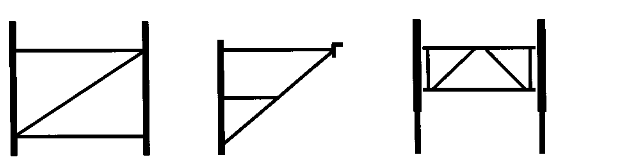

Fig. 1. Tower frame configurations

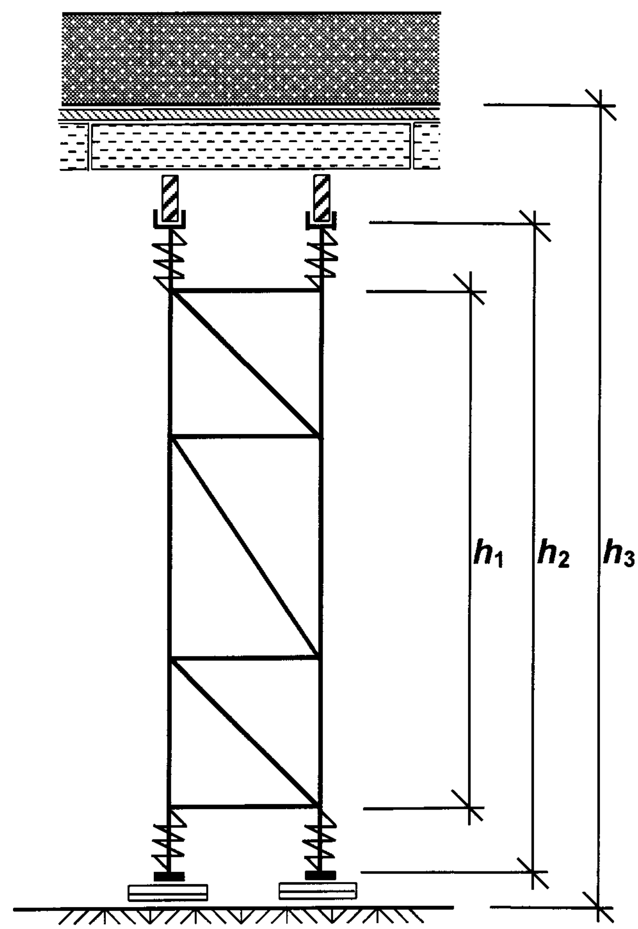

Fig. 2. Definition of "tower height"

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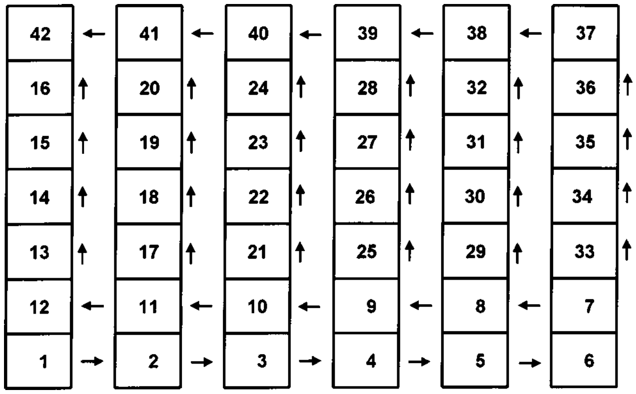

Fig. 3. Combined erection sequence of tower array

Findings

17-m- (57-ft-) High KABIR Towers

Project and Towers

Two identical tower arrays were investigated, each composed of a 12-tower row (Fig. 4), for a total of 24 towers. The towers shored the formwork for two concrete beams elevated 17.5 m (58 ft) above ground level, running along the building's two parallel facades. Therefore tower erection work was conveniently executed, on two long uninterrupted strips of ground.

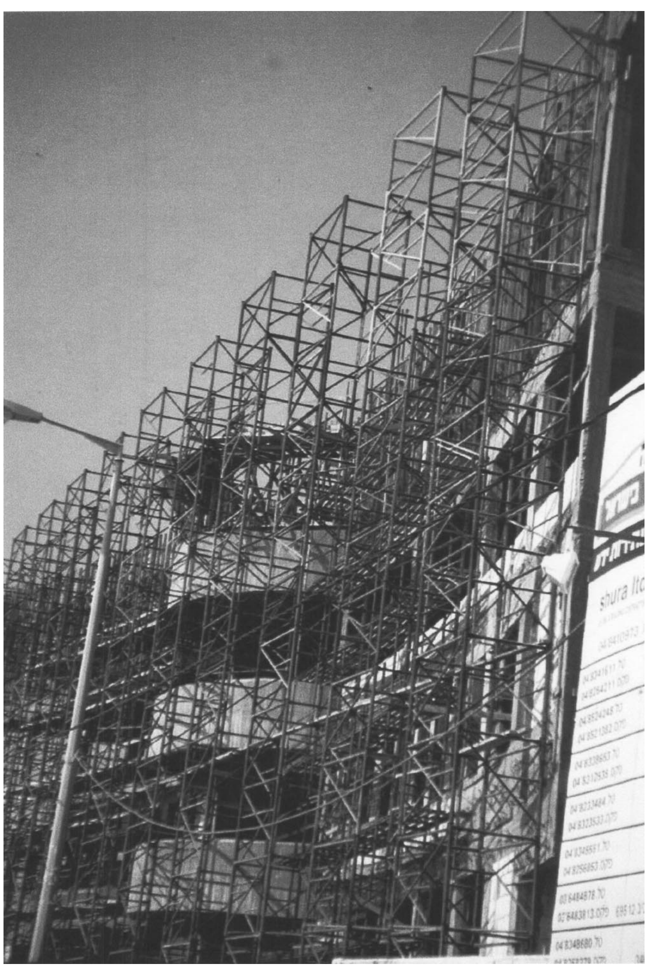

Fig. 4. 17-m-high KABIR towers

Each tower row was 50 m (167 ft) long and was made up of 2.00×1.20 m (6×4 ft) towers spaced at 2.20-m (7-ft) intervals. The towers were oriented with their long side parallel to the direction of the row. Slight variations were evident in the composition of some of the towers, but most of them were made up of 14 tiers: ten 1.25-m- (4-ft-) high tiers and four 1.00-m- (3-ft-) high tiers. This is the combination that produces, as desired, the minimum number of tiers (for the given KABIR frame heights). Frames 1.25 m high made up the bottom seven (or six) tiers and the top three (or four) tiers, while the remaining middle part of the towers was made up of 1.00-m-high frames. This composition was dictated by the order in which frames were supplied to the site, and not by economy considerations (as listed under "Recommendations" at the end of this paper). Total net height of the tiers was 16.5 m (55 ft), and the height of the tower's fixed parts plus jack extension added 0.50 m, for an overall height of 17 m (57 ft).

Construction

Main construction parameters were as follows:

1. Fair weather conditions.
2. Staging area (from where parts were transferred to tower erection zone) located 15 m (50 ft) from the end of the 50-m- (167-ft-) long tower row, hence average transfer distance of 40 m (133 ft).
3. Work crew composition, maintained throughout erection: (1) Two workers for the initial tasks of location marking, sill setting, and base assembly, as well as erection of the first two tiers; (2) three workers for tower erection, from the third tier to completion.
4. Erection method and subtasks (see also Fig. 5): (1) One worker, positioned at all times at top of tower, connects frames to assemble the tower tier; (2) second worker, positioned one tier below tower top, raises frames by ropes and hands them to the worker on top; (3) third worker, positioned on the ground, brings tower parts from staging area and rigs them for lifting.
5. Entire array (i.e., each tower row) erected by the combined erection sequence, as depicted in Fig. 3.
6. Manual work; all towers erected in situ.
7. Bracing: (1) Each tower braced internally using five diagonals (integral parts of the tower), one every three tiers, as prescribed by the towers' manufacturer; (2) each tower restrained to the permanent structure; (3) the entire tower row is braced by cross horizontals and diagonals.

Work Inputs

Total erection input was measured to be 16.17 worker hours per 14-tier 17-m- (57-ft-) high tower [16.17 worker hours per tier (whpt)]. This work input included relatively high inputs for top screw jack and tower head assembly (0.75 whpt) and for final height adjustment and leveling (1.83 whpt). These two tasks were carried out in horizontal sequence, after completion of tier assembly of all towers. This may explain the high work inputs, in that workers handle themselves slowly while moving about the 17-m-high towers, including the relocation of temporary work platforms.

Bracing work input (excluding internal tower diagonals), also included in the total figure, was 1.75 whpt. As a representative value, it may be more appropriate to relate bracing work, due to its nature, to the overall area of the tower row facade, rather than

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Fig. 5. Erection of KABIR towers

to each tower. In the present case, this area was 850 m^2 (9,400 sq ft), and thus work input was 0.025 worker hours per m^2 (0.002 p/ft^2).

Work input of 16.17 whpt reflects a work output of 1.5 towers per 8 h workday for a three-worker crew, or close to two towers per 10 h workday.

26-m- (87-ft-) High PERI Multiprop Towers

Project and Towers

The investigated array included seven towers, used to shore the formwork for an elevated, 26.5-m- (88-ft-) high concrete slab (Fig. 6), which was part of a cantilevered narrow roof running along the building's perimeter. Tower dimensions were 2.66×2.30 m (9×8 ft), as determined by the length of the frames connecting the telescopic props (a variety of frame lengths is offered by the manufacturer).

PERI Multiprop and other towers of the same type are not composed of tiers, and therefore cannot be addressed by number of tiers. As can be seen in Figs. 6 and 7, each repetitive vertical section is made up of four props and a number (usually three, depending on the prop's length) of sets of four truss frames each: two sets connected to the prop's outer tube, one set connected to its inner tube. The props are interconnectable to each other by outer–outer, inner–inner, or outer–inner connections. In addition, props may be placed with the inner tube on top of the outer tube, or upside down. The resulting tower's assembly versatility apparently constitutes a tower-composition design advantage; it necessitates, however, preplanning so that the location and orientation of each prop and frame are not left to the discretion of the erection crew (unlike with other tower types, which can be assembled only in one way). In the present case, the tower included 15 sets of four frames (60 altogether) connected to six tiers of complete (outer and inner tube) props.

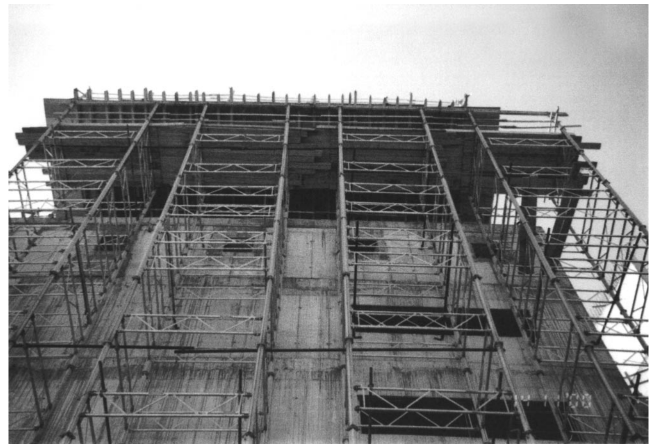

Fig. 6. 26-m-high PERI Multiprop towers

Construction

Main construction parameters were as follows:

1. Fair weather conditions.
2. Staging area located 60 m (200 ft) from tower preassembly zone.
3. Work crew composed most of the time of five workers and occasionally of four workers. As explained in the following section, rate assessment was 80%, reflecting redundancy of one worker (as supported also by no clear task allocation to the fifth worker, other than assisting the rest of the crew when needed). Hence optimal size of work crew was determined as four workers.
4. Each tower erected in two stages (see also Fig. 7): (1) Horizontal preassembly of first, 13-m- (43-ft-) long half tower, tilt up, and lifting for installation on tower bases; (2) horizontal preassembly of second, 13-m-long half tower, tilt up, and lifting for connection on top of first half. Preassembly

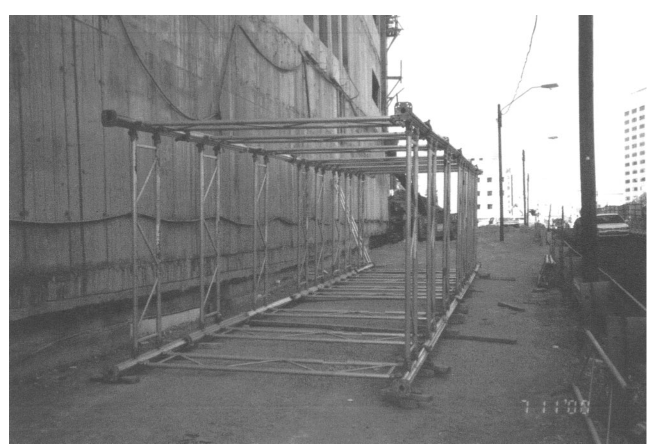

Fig. 7. Horizontally preassembled 13-m-long PERI Multiprop tower section

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assisted by ladder, as height of laid-down tower is 2.30 m (8 ft). Each erected half tower anchored to the permanent structure immediately following erection.
5. Entire array erected in vertical sequence, i.e., each complete tower after the previous.
6. Work assisted by an on-site tower crane; crane is overscheduled, resulting in frequent pauses (taken into account in work-input processing) while waiting for crane service.
7. Bracing: (1) Each tower restrained to the permanent structure by five pairs of steel tubes anchored to the concrete wall; and (2) entire tower row braced by cross horizontals at three levels.

Work Inputs

Measured erection input was 51.6 whpt. Considering a 10 h long workday, this result reflects an output of one tower per day for a crew of five workers, including all brace work. However, unlike the previous case, work rate (*Introduction to work study* 1992) in the present case was assessed at only 80% (based on the observer's expertise and supported by the assessment of the experienced superintendent on site). This means, from a practical point of view, that a crew of four workers carrying out the work at a "normal" pace (i.e., 100% rate assessment) would perform the same amount of work during the same time. Therefore, the corrected assembly work input (i.e., standard time) is $51.60\times0.80 = 41.28$ worker hours per 26-m- (87-ft-) high tower, reflecting a work output of about one tower per day (10 h) for a four-worker crew.

60-m- (200-ft-) High ALUMA Towers

This case was reported in detail and in broader scope elsewhere (Shapira et al. 2001); its summary is brought here with the current paper's particular focus.

Project and Towers

The investigated cluster of towers (Fig. 8) consisted of four separate 2.44×1.83 m (8×6 ft) towers and one continuous 3.95×1.83 m (13×6 ft) ten-leg tower, made up of three 0.91-m (3-ft) and one 1.22-m (4-ft) modules. The towers supported the forming deck for a 12×5 m (40×16 ft) cantilevered slab, which was a part of the 18th floor of a high-rise building, projecting from the building's main contour more than 60 m (200 ft) above ground level. One factor affecting tower layout was a tower crane adjacent to the building and anchored to its walls, with horizontal steel-beam ties crossing through where the shoring towers might rise (see Fig. 8). This was also the crane used in tower erection and dismantling.

The towers were made up of 28 identical 2.1-m- (7-ft-) high tiers, the maximum tier height offered by the manufacturer. The total height of 60 m (200 ft) was obtained by the bottom and top extension screw jacks.

Construction

Main construction parameters were as follows:
1. Fair weather conditions.
2. Tower parts located adjacent to tower preassembly zone, with practically no transfer distance.
3. Erection and dismantling crew composed of four workers; composition maintained throughout the entire construction, in terms of both individuals and personal tasks.
4. Erection method and subtasks: (1) In-place, conventional assembly of first three tiers; (2) horizontal preassembly of remaining tower tiers, three at a time, and connection of the preassembled tiers onto the rising tower. Two workers were responsible for rigging the preassembled tiers on the ground, while the other two were in charge of unrigging the preassembly and securing it to the tower. The latter two workers were originally located on the ground, helping with assembly, but later moved to the top of the tower. In order to move between the ground and top of the tower the workers used the passenger hoist serving the building, as well as temporary passageways from the building to the adjoining towers.
5. Entire tower array erected by horizontal sequence, but utilizing a three-tier-at-a-time assembly.
6. Work assisted by tower crane on site, both for lifting of preassembled tiers during erection and for clearing the floors of tower parts during dismantling.
7. Bracing: (1) Primary braces consisting of ten horizontal arrays of interconnected steel tubes (parallel and perpendicular to the building, as well as tubes running diagonally across the orthogonal tubes), connected to the tower frames and anchored to the permanent structure (by inserts in the external walls, or tied, through wall openings, to telescopic props restrained by the floors); (2) secondary bracing consisting of steel tubes running diagonally in vertical planes parallel to the building facade, and connected to intersecting horizontals.

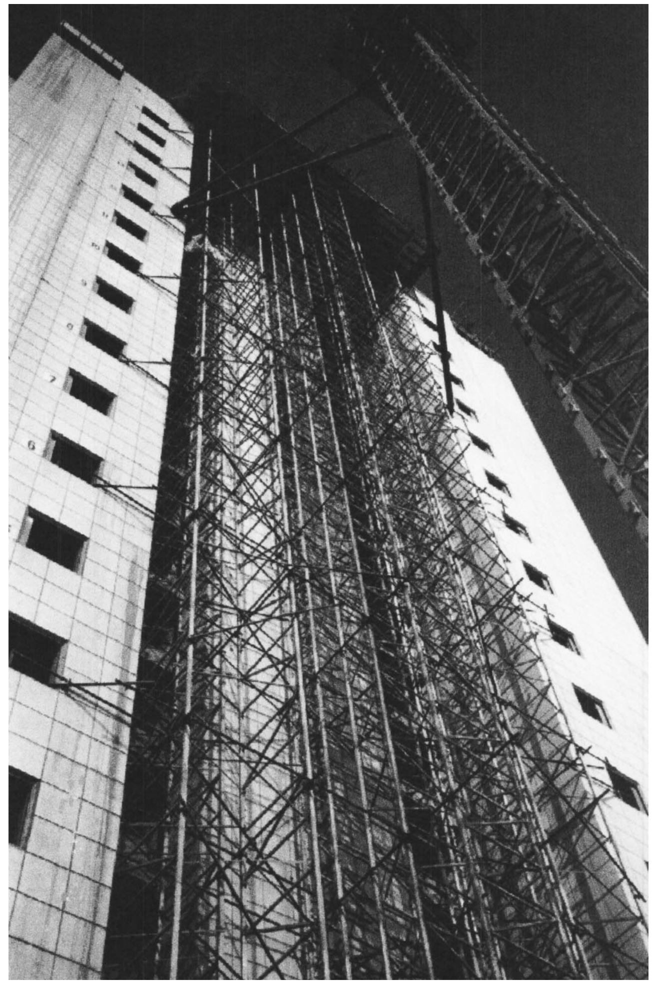

Fig. 8. 60-m-high ALUMA towers

Work Inputs

Total assembly work inputs obtained for the 28-tier 60-m- (200-ft-) high towers were 85.54 whpt. With a four-laborer crew working 11 h per day, this input means nearly 2 days for the complete erection of one such tower (upper-deck forming not included). The breakdown of this total by tasks was: lower tower part (base plus first two tiers): 6.77 whpt; main tower body: 72.00 whpt; and bracing: 6.77 whpt. Total dismantling input was 83.07 whpt: disassembly of tower and bracing: 47.69 whpt; removal of elements from floors: 14.15 whpt; and preparation of elements for transport to next project: 21.23 whpt.

Discussion

Comparison of Work-Input Results

Field Results

It is interesting to compare work-input field results for the various tower types and heights, as well as to compare field results with predicted results.

Comparing results for different tower types could indeed be telling for towers of the same height. This paper, however, has presented cases with different tower heights which, in addition to the small samples investigated, allow for a general comparison at best. Two rules pertaining to such comparison, as determined in a previous study (Shapira and Goldfinger 2000), should be borne in mind at any rate: (1) Work inputs are not linearly proportional to tower height, but accelerate with height; and (2) when discussing work inputs, the number of tiers composing the tower is more indicative of tower height than its height measured in meters (feet).

Based on the results of the present cases, and bearing in mind the above-listed limitations and rules, it could be determined that:

1. Towers of the type represented here by PERI Multiprop (props with connecting frames) take longer to erect than towers represented by KABIR (single basic frame): work inputs for the erection of the former 1.53-times-higher towers (26 versus 17 m) were 2.55 times higher than the latter's (41.28 versus 16.17 whpt). The difference is even more distinct, considering that the towers exhibiting the higher work inputs were erected with the assistance of a crane, whereas the others were erected manually.
2. Towers of the type represented here by PERI Multiprop take longer to erect than towers represented by ALUMA (ladders and cross braces): work inputs for the erection of the 57% shorter towers (26 versus 60 m) were only 52% lower (41.28 versus 85.54 whpt). Erection was crane assisted in both cases.
3. No clear conclusion can be drawn with regard to ALUMA versus KABIR tower types, based only on the present results. This is because the increase in work inputs (85.54 versus 16.17 whpt, i.e., 5.29 times more, for 3.53-times-higher towers) may not necessarily be attributed to slower work, but possibly to the above-mentioned acceleration of work inputs with height.
4. Bracing work appears to account for approximately 10% of the total erection work input (8% for the ALUMA towers, 11% for the KABIR towers).

Field versus Predicted Results

Partial comparison of field results with predicted results is made possible by use of the work-input prediction model developed in an earlier study (Shapira and Goldfinger 2000). The model, based on time studies of 14 different crews on seven sites, pertains to two ladders-and-braces tower models, ALUMA and ACROW. For ALUMA towers, work inputs are given by the following expressions:

assembly:

$$y=0.0035x^3+0.024x^2+0.36x+0.30 \tag{1}$$

disassembly:

$$y=0.0028x^3+0.016x^2+0.15x+0.01 \tag{2}$$

where x=number of tiers and y=assembly or disassembly work inputs [Eqs. (1) and (2), respectively]. The model was originally restricted to towers of up to 30 m (100 ft) in height, as it included only standard manufacturer-recommended stability provisions and did not take into account the special bracing systems that might be required for higher towers. The applicability of the model to the present case of 60-m- (200-ft-) high towers is furthermore questionable when considering the crane-assisted work in this case, as opposed to the all-manual work assumed for the model.

When computing Eqs. (1) and (2) for the present case ($x=28$), the results are an assembly input of 106.03 whpt (versus actual field results of 85.54 whpt, or 19% less) and a disassembly input of 78.22 whpt (versus 84.07 whpt, or 6% more). Thus, in spite of the model's expected limited applicability, it still yields results that, in the absence of other data sources, constitute a reasonable approximation.

The model can also be useful in comparing the results of the present ALUMA and KABIR towers. When computing Eq. (1) for $x=14$ (i.e., the number of the KABIR towers' tiers), the work input obtained is 19.65 whpt. ALUMA towers, however, require only eight tiers to reach the height of 17 m (57 ft). With $x=8$, Eq. (1) gives the result of 6.51 whpt, that is 60% less than the KABIR tower assembly–input field results. Hence, the main problem of the KABIR towers, work inputwise, is the relative small height of their frames (the largest KABIR frame is 1.25 m high versus 2.10 m for the ALUMA frame).

A similar comparison with the present PERI towers yields predicted result of 14.12 whpt for 12-tier 26-m- (87-ft-) high ALUMA towers. This value is 66% lower than the actual field result for the PERI towers, and thus provides further support for the conclusion drawn above as to the relative high work inputs involved in the erection of this latter tower type. Likely explanations are: (1) the tower's large footprint dimensions in the range of 2–3 m (7–10 ft), which make assembly work cumbersome; and (2) complicated assembly method, compared to the two other tower types, involving a considerable number of connections.

Dismantling Work Inputs

Unlike many other kinds of formwork, the dismantling of shoring towers accounts for a substantial proportion of the total work input. Furthermore, this proportion increases with the tower's height. In the present case of the extremely high ALUMA towers, dismantling work input was nearly the same as that of the erection, accounting for 49% of the total work input. Even if preparation of elements for transport to the next project is not taken into account, the proportion is still 42%. Lower figures are found in lower towers (Shapira and Goldfinger 2000): For ALUMA towers in the height range of 3–18 m (10–60 ft), dismantling work inputs account for 21–38%, respectively; the proportions for 2–16-m- (7–53-ft-) high ACROW towers are 24–26%, respectively.

Thus, although different tower models (even of the same tower type) exhibit different dismantling input proportions (of the total work input), it is still plausible to roughly estimate dismantling inputs when only erection inputs are given, as is the case with the present KABIR and PERI towers. Based on the above-listed pro-

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portions, dismantling inputs for these two tower types, rising to the heights of 17 and 26 m (57 and 87 ft), respectively, would be in the range of 25–40% of their total work inputs, or 30–70% of their given erection inputs. Analysis of work inputs has also shown that in all-manual work, dismantling-to-erection input ratio is lower as compared to more advanced work methods (e.g., crane-assisted, preassembly of large sections). Hence, dismantling inputs of the present KABIR towers are likely to be in the lower zone of the above-listed 30–70% range, while the PERI towers' would be in its upper zone.

Recommendations

Because work inputs dominate the economy of shoring solutions involving multitier towers, measures taken by the constructor at all design, selection, planning, and execution stages that would result in lower inputs, are bound to increase the solution's overall economy. The following recommendations were identified in the course of the current study with regard to such measures:

1. Selection of tower type: select towers with high average tier size (height), as determined by: (1) size of largest frame and (2) variety of tier sizes available (e.g., a tower with tier sizes of 1.50, 1.00, and 0.75 m is preferable to one with tier sizes of 1.25 and 1.00 m).
2. Selection of tier size (for a given tower type): select largest frames possible, to minimize number of tiers for a given tower height; when two (same type) towers rising to the same height are made up of different number of tiers, erection of the tower with the smaller number of tiers will incur lower work inputs.
3. When using various tier sizes, place the larger (i.e., heavier) tiers first (at the bottom of the tower) and the smaller tiers last (at the top of the tower).
4. Select stringers and joists such that tower spacing will be the greatest possible; towers are commonly utilized only to a small percentage of their load carrying capacity.
5. Select towers to correspond to the expected loads. Towers with capacities exceeding the expected loads not only bear no advantage, but also tend to be heavier (resulting in higher work inputs) and/or costlier.
6. There is an advantage in selecting a tower type with which the work crew is familiar; tower types often differ greatly from each other, and experience acquired with one type does not guarantee efficient work with another.
7. Compose the optimal crew size, with clear task allocation for each worker. Too small a crew makes it hard to maintain individual tasks, and the shifting of workers from one task to another increases work inputs; too large a crew means wasted resources. Optimal crew size depends to some extent on tower type and erection method, as well as on transfer distance of tower parts; it is usually governed, however, by tower height. As a rule of thumb, two workers suit low towers (up to three tiers), mid-rise towers (up to six tiers) require three workers, and towers higher than six tiers will be efficiently erected by four workers.
8. Tower parts should be placed as close as possible to erection zone; this must be considered as early as stage in which parts are supplied and unloaded at the site.
9. Towers allowing horizontal preassembly on the ground may have an advantage when a crane is available to assist with the erection of large assemblies. At the same time it should be borne in mind that with some tower types, horizontal preassembly may incur higher work inputs compared to other types erected in situ.
10. Erecting the entire tower array in a horizontal sequence involves frequent movement of workers and temporary decks between towers; this could be avoided by using a vertical sequence. On the other hand, towers rising to great heights must be erected simultaneously (i.e., horizontally) so that they can be tied to each other. Therefore a combined sequence may be the best solution overall.
11. Bracing the towers (by connecting them to each other and/or to the permanent structure) must follow design rather than intuition; inadequate bracing may cause failure, and therefore intuition often results in excess bracing, which increases work inputs needlessly.
12. When shoring a linear concrete element (e.g., beam, as opposed to slab), towers that can be assembled as triangles may have an advantage, as work inputs for three-leg towers are roughly 80% of that required for four-leg towers of the same type (Selinger and Shapira 1985).
13. When erecting towers from horizontally preassembling sections and subsequently lifting them, work inputs are affected (more than with vertical in situ assembly) by the tightness/spaciousness of the preassembly and lifting area.

Summary and Application

Table 2 summarizes work inputs and outputs as measured and processed in this study. Because of the inherent difficulty in generalizing productivity rates in construction, due mainly to the varied work environment and worker skills (Price and Harris 1992), care should always be exercised when applying work-input results from one case to another. Furthermore, the small-size samples involved here call for caution when applying the results; yet these results will always be more useful than results based on "guesstimates."

As found in the current study, as well as in former investigations of shoring-towers-related work inputs (Shapira and Goldfinger 2000; Shapira et al. 2001), the following construction parameters should be considered when adopting work-input results, obtained in one case, to another (several parameters pertain specifically to shoring towers, while others are general and apply to any formwork):

1. Erection and dismantling method (with/without crane assistance, horizontal preassembly on the ground, or vertical in situ assembly). Crane assistance and preassembly would incur lower inputs.
2. Distance of staging area from erection area. The greater the transfer distance of tower parts, the higher the work inputs.
3. Tightness of site. The more constricted the assembly zone, the higher the work inputs.
4. Shape and size of overall tower array (small number of towers supporting irregular concrete element with geometric constraints versus great number of towers in a regular and repetitive pattern).
5. Complexity of bracing system, including number of required connections of towers to each other and to permanent structure.
6. Experience of workers and their familiarity with particular tower type used.
7. Employment mode of workers. Higher work inputs may be expected for workers contracted on an hourly-wage base, lower inputs for workers contracted on productivity base.

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Table 2. Summary of Work Inputs and Outputs

Tower model	Tower height[a] (m)	Number of tiers	Tower cross section (m)	Construction parameters	Work inputs (worker hours per tower)			Work outputs (towers per 10 h workday[c])			
					Assembly	Disassembly	Total	Crew size	Assembly	Disassembly	Total
KABIR	17	14	2.00×1.20	• 24 towers • Manual work • In situ assembly • Transfer distance of elements: 40 m	16.17	—[e]	—	3	1.86	—	—
PERI Multiprop	26	(15)[b]	2.66×2.30	• 7 towers • Crane assisted • Horizontal preassembly • Transfer distance of elements: 60 m	41.28	—[e]	—	4	0.97	—	—
ALUMA	60	28	2.44×1.83	• 6.5[d] towers • Crane assisted • Horizontal preassembly • Transfer distance of elements: inconsequential	85.54	83.07	168.61	4	0.47	0.48	0.24

[a]Height of entire tower assembly, measured from bottom of base plates to bottom of stringers lying on tower heads.
[b]Multiprop towers cannot be defined in terms of tiers; this is the number of sets of four frames along the tower.
[c]As was common on most sites observed; multiply all results by 0.8 for 8 h workday.
[d]The ten-leg continuous tower assembly considered as 2.5 towers.
[e]Not measured; see text for estimate.

8. Safety regulations. Harnessing of workers (varies with height in different places) slows the work.
9. Length of workday. Working in extra time and/or under bad lighting conditions incurs higher work inputs.
10. Expected weather (extreme high/low temperatures, rain).

The kind of information and data provided in this paper on work inputs, erection methods, and crew sizes will be useful for a variety of construction management functions with regard to high-clearance construction based on shoring towers. The results may be used by project/company functionaries in charge of scheduling, cost estimating, and contracting with formwork rental suppliers. Typical uses are as follows:

1. Work inputs (in units of worker hours per tower with a given number of tiers) used for cost estimates;
2. Work outputs (in units of towers per time per crew, taking into account common crew sizes) used to assess of duration of tower use, as may be required in case of rental or planning for next use, and for scheduling;
3. Comparison of rental alternatives of different tower types for a given tower height; and
4. Determination of normative production rates as a basis for worker premium or subcontracting.

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