Rational Design of Shoring-Tower–Based Formwork

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Abstract: Although formwork based on high shoring towers is a very common solution for forming elevated slabs and other concrete elements over high spaces, the trade literature furnishes neither detailed guidelines nor basic cost data for the design of such formwork. The present paper presents a method for the design of elevated-slab formwork using scaffold-type towers as the vertical shoring element. The method includes the definition of a basic tower layout and its properties, an algorithm for determining the distances between the various elements of the formwork, and key information as a basis for economic evaluation of alternate design solutions. Whereas the algorithm directly solves a general case of a flat, nonconstrained slab, the method as a whole readily applies to elevated slabs and other high-rise concrete elements of any kind. The method has been found particularly useful when computerized. It may become even more important when incorporated into an intelligent design system that will take into account shape and load constraints exerted by particular cases.

INTRODUCTION

In construction practice, the forming of concrete elements commonly involves two types of issues: selection and design. The use of industrialized formwork (e.g., ganged wall forms, flying slab forms, and tunnel forms), in which selection is the main construction-phase issue, has been steadily increasing; however, conventional, site-fabricated formwork provides suitable solutions in many other cases and is still extensively employed. Specialized cases of conventional formwork design are normally handled either by the constructor's staff specialists or by outside consultants. Yet, in the majority of cases, the design of conventional formwork (in which selection normally plays only a secondary role, due to constructors' tendency to use elements already in their possession) has traditionally been carried out by a site functionary, such as a project engineer, superintendent, or foreman, depending on the regularity of the element to be formed. This practice quite often results in poorly designed formwork, sometimes expressed in uneconomical solutions or physical failures. Both can be attributed to the lack of basic data and to incorrect design approach. "Rational design" means design based on a structured procedure that yields solutions that both meet the static requirements and are economical.

The literature on formwork design, whether general [e.g., Peurifoy (1976), *Formwork* (1986), and Hurd (1989)] or specific [e.g., Ringwald (1985)], typically addresses conventional formwork design with a rational approach for common concrete elements (e.g., regular-height slabs, beams, and walls). Several studies [e.g., Christian and Mir (1987) and Tah and Price (1991)] have taken the issue even further and developed computerized solutions. However, one type of conventional formwork—although widely used—has received little attention with regard to rational design. This type is formwork for elevated (i.e., higher than normal) elements having steel or aluminum shoring towers as the form's main vertical support. The scant attention this type of formwork has received with respect to form design may be explained by (1) the addressing of elevated slabs—particularly the simple cases—as if they were regular-height slabs, with no understanding of the full economic meaning of using shoring towers instead of regular shores; and (2) the fact that concrete elements supported by such formwork are often irregular and variegated, thus less suitable for the uniform treatment more easily applied to standard, regular cases.

This paper presents a rational approach to the design of elevated–concrete-slab formwork that is based on shoring towers. More specifically, the paper provides key information for calculating the cost of using shoring towers within a slab-formwork system and introduces an algorithm developed for the solution of a general case of such formwork. It should be noted that although shoring towers find their main use in formwork for elevated elements, the approach presented here is by no means limited to such elements and can readily apply to regular-height slabs/elements as well.

Scope and Focus

Elevated concrete slabs are typical elements in a multitude of commercial, public, and industrial constructed facilities. Although the slab's elevation itself may not directly affect the general layout of the slab form's shoring towers, it definitely has an impact on the proportional cost of the towers within the formwork, and on the overall formwork cost. By common estimates, formwork may account for 40–60% of the cost of cast-in-place concrete (Nunnally 1993). With elevated slabs, this share may be even higher (Illingworth 1987). Thus the higher the slab, the greater the effect the rational design approach can have on overall cost reduction.

For common-height slabs—around 3 m—telescopic props (or adjustable shores) are usually used as vertical shoring. With suitable longer inner tubes, these props can also be used for heights greater than 3 m; but in heights greater than 4–5 m their use becomes highly problematic, due to individual prop buckling, overall system instability, and work inconvenience. Around that height, then, shoring towers start to provide a preferable solution, the usefulness of which significantly increases with the height. Other solutions for elevated slabs, such as drawer-type forms (*NOE* 1988; *EFCO* 1991) that eliminate the need for vertical shoring, do exist as well. But unlike shoring towers, the use of these alternate solutions is limited (e.g., using drawer forms is feasible only when the building includes closely spaced, parallel bearing walls or column rows for the form mounting) and not as widespread. In any case, the choice of forming system is a classic preliminary selection question [see, e.g., Hanna and Sanvido (1991) and Hanna et al. (1992)].

Shoring towers are sometimes used for purposes other than formwork for cast-in-place concrete elements; for example, as temporary support scaffolds for precast elements as well as access scaffolds for workers, tools, and materials. The present paper treats shoring towers only in the capacity of their major use, i.e., as formwork. At the same time, some

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information included here, along with the overall approach presented, may apply to the towers' other uses as well.

Although generally resembling each other in their overall configuration, dimensions, and basic components, shoring towers from different manufacturers may vary in some other features (e.g., basic-frame design, assembly method, and carrying capacity). Barring the few instances in which a specific tower type is indicated, the present paper generally addresses all kinds of commonly used towers. At the same time, it is particularly relevant (though not limited) to the shoring towers used in building construction, mainly characterized by a carrying capacity of 50 kN per leg (200 kN for a typical four-leg square or rectangular tower).

For more detailed information on types of shoring towers, their structural design, properties, and performance, the reader is referred to pertinent literature [e.g., Brand (1975) and Hurd (1989)]; manufacturers' catalogues [e.g., *Patent* (1992), *PERI* (1992), and *Symons* (1992)] are the best sources of technical data on available products.

GENERAL APPROACH

Elevated versus Regular Slabs

In terms of formwork members, elevated and regular-height slabs are basically distinct from each other only in the element that bridges the height difference between the floor and the deck form; i.e., for elevated slabs, shoring towers are used instead of individual props (single-post shores). Similar to prop-based formwork, the goal in tower-based formwork is to find that combination of distances between elements that will result in the most economical solution for a given set of formwork elements. Like prop-based formwork, tower-based formwork is also concerned with distances between joists and stringers; distances between props are analogous to distances between towers.

On the surface, this may not appear to be a major difference. However, props are point elements in their horizontal projection, so what must be determined here is their spacing, as governed by the maximum possible span of the joist elements in one direction, and the span of the stringer elements in the perpendicular direction. Towers, on the other hand, have a two-dimensional cross section, which means that in addition to distances between towers (in two directions), whatever is happening on the towers (i.e., the span of the elements lying on them) must be addressed as well (again, in two directions). This geometric distinction necessitates several definitions and notations, as follows.

Basic Tower Layout

A basic tower layout (Fig. 1) is composed of a uniform tower grid, in which the distances between the towers in each of their two directions are the same (but the distances in one direction are not necessarily identical to those in the other). One direction of the tower grid is also the direction of the joists; the other is the direction of the stringers.

We arbitrarily define the direction of the stringers as the direction of "tower rows." Thus we refer to distances between rows, and to distances within rows. The row direction (also the stringers') is designated X, and the perpendicular direction (also the joists') is designated Y.

A distinction is made between elements lying "on towers" or "on tower rows," and those lying "between towers" or "between tower rows" (see Fig. 1). Stringers lying on towers and joists lying on tower rows are assigned the subscript A, and stringers lying between towers and joists lying between tower rows are marked by the subscript B.

Formwork elements are assigned identifying subscripts as follows: 1—sheathing; 2—joists; 3—stringers; and 4—towers. A distinction is made between an element's fixed length, L, and its calculated/determined span, l, in a given tower layout. Note that the span of element i is, by definition, the distance between elements $i + 1$ ($i = 1, 2, 3$). The variables L and l assume somewhat different roles in the case of towers ($i = 4$): l is not applicable, and L_{4X} and L_{4Y} are the tower's respective horizontal dimensions in the direction of the stringers and joists. By these definitions, we also get $l_{2A} = L_{4Y}$, and $l_{3A} = L_{4X}$.

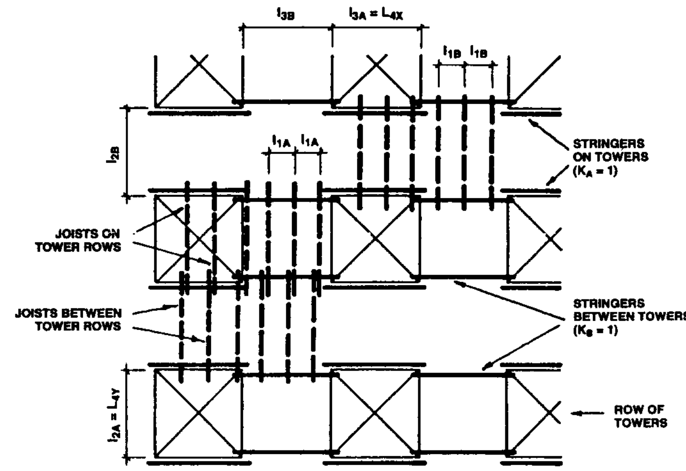

FIG. 1. Basic Tower Layout

ALGORITHM

The following is a general algorithm for the design of a shoring-tower–based form for a flat concrete slab. The input includes the required dimensions and material properties of the elements selected, as well as the data needed for the calculation of the overall vertical load on the formwork (e.g., slab thickness and live load). Needed also are the basic static formulas (for bending, shear, bearing, and deflection) by which the maximum allowable distances l_i can be calculated. The relevant loading cases (e.g., uniform load on multiple spans) are specified in the algorithm's steps wherever needed. The formulas can be found in any basic book that addresses form design [e.g., Hurd (1989) and Nunnally (1993)] and are not detailed here.

Basically, the algorithm calculates the distances (spacing) between the joists, stringers, and towers (i.e., the spans of the sheathing, joists, and stringers, respectively), with a top-down calculation sequence. The value adopted for each l_i ($i = 1, 2, 3$) will not be greater than the smallest of all the values obtained by the various strength and deflection checks conducted for that l_i.

In general, the distances between the joists are governed by the maximum allowable span of the sheathing elements. Yet, unlike the joists lying between tower rows, the spacing of the joists lying on tower rows may have to be reduced because of the tower's fixed measurements that dictate the joists' span (i.e., in case these measurements are greater than the tower rows' spacing). In any event, due mainly to safety considerations, the joists' spacing—both on and between tower rows—is determined in such a way that the sheathing element is supported with no cantilevers on its two sides.

The distances between the tower rows are similarly governed by the maximum allowable span of the joists. The distances between the towers within the rows are dictated by the maximum allowable span of the stringers, but may be further constrained by the carrying capacity of the towers. In most cases, though, the latter is unlikely (this has been the writer's experience in numerous cases of formwork design for elevated slabs).

The output of the algorithm is a set of values for l_i (i = 1, 2, 3). In fact, the algorithm yields two solutions for any element alternative: one with a single stringer between towers, and another with double stringers (see below) between towers (the number of stringers on towers being determined by the given length of the tower in the stringers' direction). The economic trade-off between the overall number of stringers and towers can then be evaluated to select the more economic solution.

The resulting layout can be used as is for any flat concrete slab, or for large areas of flat slab in a one- or two-way slab supported by beams. Adjustments (e.g., reduction of joist and/or stringer spans) may be necessary, as dictated by the slab's overall dimensions. Also, for practical reasons, a tower placed next to a wall should be no closer than a minimum distance from the wall (around 20 cm, measured from the tower leg's axis) so as to leave room for tower footings and to allow manipulation of the tower's screw jacks.

By adopting its philosophy, the algorithm can apply to shoring-tower–based formwork for any other type of elevated concrete element as well, be it two-dimensional (e.g., ceilings) or one-dimensional (e.g., beams), with square/rectangular or triangular towers. It should be made clear that, in any case, overall stability of the formwork must be addressed. Although the guidelines are the same as those dictated by codes for any other type of formwork, the risk of not following them is greater, given the height magnitude that may be involved.

Basic Postulations

The solution method and the algorithm stand on the following postulations.

Layout Uniformity

In a given tower layout, only one kind of element is used for each formwork member: sheathing, joists, stringers, and towers (lengths of joists and stringers, though, may vary). The same is true for l_i (i = 1, 2, 3), the distances between the elements, with a differentiation between l_A for elements on towers (or on tower rows), and l_B for elements between towers (or between tower rows).

Static Scheme

Sheathing elements are addressed as uniformly loaded multiple-span elements; joists and stringers are addressed as uniformly loaded single-span (simply supported) elements. With the sheathing this is always the case; with joists and stringers it is usual (with occasional exception): Given the high carrying capacity of the towers, the distances between them—in both directions—would normally utilize the full (or almost full) length of the joist/stringer elements, making them single-span elements. If the joist and/or stringer elements at hand cover two spans (e.g., $L_3 \geq l_{3B} + L_{4X}$), then the corresponding loading case should be employed in the relevant algorithm's steps.

The algorithm does provide for cases in which the joist spacing relative to the stringer's span would not permit the load(s) on the stringer to be addressed as uniform but rather as concentrated load(s). The algorithm verifies this issue according to the ACI guidelines (Hurd 1989).

Number of Stringers

Tower U-heads, typically 10–20 cm wide, can accommodate up to four stringers. It may be possible, then, to attach two or more elements together, thus strengthening the stringer. (This may be preferable to introducing an additional element as a stringer, which may also turn out to be too heavy.) In practice, though, an overlapping must be made possible; thus the algorithm addresses the possibility of only two attached elements (that is, "double stringers"). If wider tower heads are at hand, or if the design points to the possibility of overlapping three stringer elements on one side with one element on the other (e.g., when the tower's length in the direction of the stringers is much smaller than the anticipated span of the stringers between the towers), then the algorithm still applies, with a slight modification in the load calculation for each stringer (step 15).

Steps

Loads and Elements

Step 1. Calculate q_s, the overall uniform vertical load per unit area on the formwork.

Step 2. Select one alternative of elements for shoring towers, stringers, joists, and sheathing.

Sheathing

Step 3. Calculate $l_{1,\max}$, the maximum allowable span of the sheathing elements (also the maximum possible spacing of the joists), for a loading case of uniform load on multiple spans (no need to check shear and bearing stresses). The load per unit length on the sheathing element, q_1, is given by $q_1 = q_s \cdot b_1$, where b_1 = an arbitrary width of the sheathing element.

Step 4. Calculate the initial value of n_1, the number of spans of the sheathing element, by $L_1/l_{1,\max} \leq n_1 < L_1/l_{1,\max} + 1$, n_1 integer, where L_1 = length of the sheathing element.

Step 5. Calculate l_{1B}, the span of the sheathing elements (also the spacing of the joists) lying between the tower rows, by $l_{1B} = L_1/n_1$.

Joists

Step 6. Calculate $l_{2B,\max}$, the maximum allowable span of the joists lying between the tower rows (also the maximum possible spacing of the tower rows), for a loading case of uniform load on a single span. The load per unit length on the joist, q_2, is given by $q_2 = q_s \cdot l_{1B}$. Check local bearing stress between the joist and the stringer if timber elements are used as joists and/or stringers.

Step 7. Determine l_{2B}, the span of the joists lying between the tower rows (also the spacing of the tower rows), $l_{2B} \leq l_{2B,\max}$. The need to determine a value for l_{2B} that is smaller than $l_{2B,\max}$ may arise from constraints such as the geometry of the supported concrete element, or if $l_{2B,\max} > L_2$, where L_2 = length of the joist. In the latter case, set l_{2B} as L_2.

Step 8. Check $l_{2B,\max}$ vis-à-vis L_{4Y}, the length of the tower in parallel to the direction of the joists. If $l_{2B,\max} \geq L_{4Y}$, then $l_{1A} = l_{1B}$, where l_{1A} = span of the sheathing elements lying on the tower rows. Otherwise, substitute $n_1 = n_1 + 1$ and repeat steps 5 and 6 until an $l_{2B,\max}$ is obtained that meets the condition $l_{2B,\max} \geq L_{4Y}$. Adopt the value of the corresponding l_{1B} as the value of l_{1A}. If l_{1A} is smaller than the minimum desirable value for this span, then return to step 2 and start again with another alternative of elements (e.g., stronger joists).

Stringers

Step 9. Calculate $l_{3B,\max}$, the maximum allowable span of the stringers lying between the towers (also the maximum possible tower spacing within the rows), for a loading case of uniform load on a single span. The load per unit length on a

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single stringer ($K_B = 1$), q_3, is given by $q_3 = q_s \cdot (l_{2B} + L_{4Y})/2$. Check bearing stress between the stringer and the tower head if timber elements are used as stringers.

Step 10. Determine l_{3B}, the span of the stringers lying between the towers (also the tower spacing within the rows), $l_{3B} \leq l_{3b,\max}$ (see step 7 regarding the need for determining an l_{3B} value that is smaller than $l_{3B,\max}$). If $l_{3B,\max} > L_3$, where L_3 = length of the stringer, then set l_{3B} as L_3.

Step 11. Check load on the tower vis-á-vis P_T, the load-carrying capacity of each tower leg. If $P_T < q_3 \cdot (l_{3B} + L_{4X})/2$, where L_{4X} = length of the tower in the direction of the stringers, then $l_{3B} = 2P_T/q_3 - L_{4X}$.

Step 12. Check the ratio l_{3B}/l_{1B}, to validate the assumption of uniform load on the stringers. If $l_{3B}/l_{1B} \geq 3$, then go to step 14.

Step 13. If $2 \leq l_{3B}/l_{1B} < 3$, then repeat steps 9–11 for a loading case of two concentrated loads, each equaling $q_3 \cdot l_{3B}/2$, on a single span. If $1 \leq l_{3B}/l_{1B} < 2$, then repeat steps 9–11 for a loading case of a single concentrated load, $q_3 \cdot l_{3B}$, on a single span. If $l_{3B}/l_{1B} < 1$, then return to step 2 and start again with another alternative of elements (e.g., stronger stringers).

Step 14. Assign l_{3B} as $l_{3B(K_B=1)}$, for a single stringer and as $l_{3B(K_B=2)}$ for double stringers.

Step 15. Repeat steps 9–13 for double stringers lying between the towers ($K_B = 2$). The load on each stringer is $q_3/2$, half the load used in step 9. In cases where bearing check was the governing factor in determining $l_{2B,\max}$ in step 6, then steps 6–8 must be repeated for double stringers prior to repeating steps 9–13.

Step 16. Determine K_A, the number of attached stringers lying on the towers. If $l_{3B(K_B=1)} \geq L_{4X}$, then select a single stringer ($K_A = 1$). If $l_{3B(K_B=1)} < L_{4X}$ and $l_{3B(K_B=2)} \geq L_{4X}$, then select double stringers ($K_A = 2$). If $l_{3B(K_B=2)} < L_{4X}$, then return to step 2 and start again with another alternative of elements (e.g., stronger stringers).

KEY COST FACTORS

As with any other conventional formwork, the overall construction cost considered in the economic comparison of design alternatives for shoring-tower–based formwork is composed of material and labor costs (equipment cost typically being associated with industralized formwork). Within these cost components, two factors are of special interest with regard to the shoring tower: work-input data for erecting and dismantling (labor), and the number of reuses (material). Current literature provides little or no information on these factors.

Work Input

Worker-hour inputs in erecting and dismantling shoring towers, as shown in Table 1, were determined by exhaustive work studies on construction sites. The data were collected by the common production management method of direct/stopwatch time study (Mundel 1978; *Introduction* 1979), including rate assessment and allowances for setup, relaxation, and contingencies, to produce the standard times shown in Table 1. These times do not include time required for repairing faulty work or resulting from deficient work organization, nor do they cover managerial staff hours. The studies of erecting and dismantling were conducted in fair weather, so weather was not recorded on any day as an influential factor. No other major on-site problems occurred that affected productivity. All work crews were generally experienced in shoring-towers erection.

Towers of two heights were observed: 5 and 8 m. These correspond to elevated slabs 5.5 and 8.5 m clear height between the floor and the supported slab, respectively. The 0.5-m difference between the slab and tower height is the cumulative height of the footings, stringers, joists, and sheathing. Erection and dismantling of both four-leg and three-leg towers were studied. The four-leg towers were either 1.40 × 1.40 m squares or 2.00 × 1.20 m rectangles. No differences in work inputs were observed between these two shapes. The three-leg towers were 1.40 × 1.40 m triangles. All studied towers had the same basic-frame design. Each tier in the square and rectangular towers was made of four such frames, and the triangular towers had three such frames in each tier. Note that this tower configuration, in which the tiers are made of identical basic frames (perhaps differing only in length), is one of the two common shoring-towers configurations. The other configuration, for which work inputs were not recorded within this study, is of square/rectangular towers in which each tier is made of two parallel ladder frames connected by cross braces. Triangular towers are not possible with this configuration. Variations of these two configurations exist as well.

TABLE 1. Work Inputs in Erecting and Dismantling Shoring Towers

	WORK INPUTS (WORKER-HOURS)			
	Four-Leg Tower (Square/Rectangle)		Three-Leg Tower (Triangle)	
Activity (1)	H = 5 m (2)	H = 8 m (3)	H = 5 m (4)	H = 8 m (5)
Erecting	2.29	3.20	1.83	2.56
Dismantling	0.40	0.64	0.32	0.51
Total	2.69	3.84	2.15	3.07

Note: H = shoring-tower height.

Towers were assembled and dismantled manually by two-worker teams. The following tasks, listed by work sequence, were included in the times recorded:

1. Erection
   - Carry tower parts from staging area to assembly location (up to 30 m away).
   - Oil tower screws.
   - Mark tower locations on floor (the proportional time of marking each tower in the overall layout).
   - Prepare wood footings.
   - Erect and level tower base.
   - Assemble tower (maintaining plumb).
   - Adjust tower height.
   - Install temporary work platforms on towers.
2. Dismantling
   - Oil tower screws.
   - Lower tower by closing adjustment screws.
   - Remove temporary work platforms (after stripping sheathing, joists, and stringers, a task not included in the times recorded).
   - Dismantle tower.
   - Separate tower base plates from wood footings.
   - Carry tower parts back to staging area.

The time inputs obtained from these studies are much larger than those occasionally appearing in manufacturers' brochures. Such commercial data, which presumably do not take into account all the aforementioned work tasks and are not scientifically based, may be unrealistic and should not be used in work estimates or in economic evaluation of alternatives unless properly verified. Note also that when the data presented in Table 1 are applied to specific jobs, they should be used with care; these are average data that may be affected by the inherent difficulty of computing productivity rates in the construction industry (Horner and Thomson 1981; Touran 1988).

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TABLE 2. Number of Reuses of Elements in Elevated-Slab Formwork

Element (1)	Number of Reuses: Annual (2)	Overall (3)
Shoring towers	4	60
Joists and stringers	5	75[a]

[a]For metal elements only.

Number of Reuses

Theoretically, the possible number of shoring towers' reuses should not differ from that of other metal elements used in formwork, such as steel beams, adjustable shores, or tunnel forms. The number commonly applied in these cases is in the range of 200–300 uses (Selinger and Shapira 1985), which takes into consideration not only the element's useful life—allowing up to 600 uses (*Formwork* 1986)—but also intermittent use, as well as the occasional need to alter elements.

In practice, however, shoring towers are used a much smaller number of times over their entire economic lives, as governed by the relatively long duration of each use. From data collected on construction sites in the course of the present study, it was found that, on average, the duration of each use of shoring towers in the construction of 5–10 m high elevated slabs was two months. Elevated slabs require this longer use time than regular slabs not only because of their height difference but also because (1) elevated slabs typically ceil considerably larger spaces than those under standard slabs, so preparing the slab for concreting takes longer (i.e., given the tendency to concrete the whole slab at once); and (2) elevated slabs usually involve sizable clear spans, so concrete curing takes longer and the towers are in use for a longer time before they can be dismantled.

If shoring towers were used continually, it would mean six uses per year (at two months per use), or a total of 90 uses over an economic life of 15 years. Given common idle times, also supported by data from the companies in charge of the observed sites, these values were reduced to four uses per year, or 60 overall uses.

The pattern described above also affects the number of reuses of joist and stringer elements. The numbers obtained for these, though, are slightly higher than for towers, given the other uses these elements (unlike towers) may have when not engaged in elevated-slab formwork. Table 2 summarizes the data obtained. Note that in the case of joist/stringer elements, the annual number of uses is applicable to any material, whereas the overall number of uses applies only to metal elements.

CONCLUSION

The wide body of knowledge on formwork design has so far lacked an important chapter addressing that class of concrete elements with forming based on shoring towers. Although the literature has generally treated the shoring tower as not much more than the individual prop's offshoot, this paper attempts to give shoring towers their appropriate weight within the large family of conventional formwork elements.

Adopting a rational approach to form design, with a design procedure and basic design data as its two major components, the paper provides an algorithm and key information for economic design of shoring-tower–based formwork for elevated concrete elements. Both the algorithm and data presented are intended to benefit not only researchers, but also practitioners of formwork design.

Employed in numerous structures, this method has been found particularly useful when computerized and combined with design tables for specific types of shoring towers and joist/stringer elements. It may gain still further in importance when incorporated into an overall intelligent system that will perform other tasks as well. Such tasks may be (1) the preliminary step of determining initial tower layouts for particular cases, in which various shape and load constraints are likely to play a significant role; (2) taking into account the formed element's boundary conditions; and (3) offering advice in matters of formwork-element selection.

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APPENDIX II. NOTATION

The following symbols are used in this paper:

b_i = width of element i;
K = number of attached stringers;

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L_i = length of element i;
l_i = span of element i;
n_i = number of spans of element i;
P_T = load-carrying capacity per leg of shoring tower;
q_i = uniform load per unit length on element i; and
q_s = overall uniform vertical load per unit area on formwork.

Subscripts

A = location on rows of towers (for joists) or on towers (for stringers);
B = location between rows of towers (for joists) or between towers (for stringers);
$i(1, 2, 3, 4)$ = element of formwork (sheathing, joists, stringers, and towers, respectively);
X = direction of stringers; and
Y = direction of joists.

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