19.1 Introduction

Today’s building construction projects are highly mechanized. With the growing industrialization of construction and the gradual shift to offsite prefabrication of structural and finishing elements that are then assembled (rather than produced) on site, production equipment is increasingly making room for transportation equipment. Thus, material handling and lifting equipment dominates construction sites as an essential resource, constituting a major part of the project’s construction cost.

The typical concrete-construction building site will employ several or all of the following equipment types: (1) cranes, (2) material handlers, (3) concrete pumps, (4) hoists and lifts, and (5) forming systems. Concrete is commonly produced on-site only in the case of large projects requiring high concrete volumes or transportation distances that are too great for the supply of ready-mixed concrete. Earthmoving equipment is used for the initial, substructure phase of construction and often during final landscape development work but is hardly seen on the jobsite throughout construction of the structure itself (unless construction progress at various parts of the project is sequenced such that one part of the project is already above ground while another may still be under ground).

* Associate Professor of Construction Engineering and Management, Technion–Israel Institute of Technology, Haifa, Israel; specializes in construction equipment selection, operation, management, productivity, economics, and safety. Unless otherwise noted, all photographs in this chapter were taken by the author.
Of the above-listed equipment types, cranes are the most conspicuous machines on-site, not only because of their size but also because of the vital role they have in transporting materials and building components vertically and horizontally. When selecting equipment for the project, cranes are the centerpiece of the process, and decisions made on the selection and location of cranes commonly govern the selection of other equipment; therefore, cranes are discussed throughout this chapter in greater detail than other equipment types. The North American construction industry has traditionally been a mobile-crane culture (Shapira and Glascock, 1996); the number of mobile cranes in the United States is far greater than the number of tower cranes, which are the epitome of construction in Europe and the industrialized Far East. Tower cranes, however, have been increasing their presence in the United States since the early 2000s. Whereas mobile cranes are still by and large the backbone of the U.S. construction industry, the demand for tower cranes is on the rise. American contractors now favor tower cranes to a growing degree, and crane rental companies are responding to the demand by increasing the share of tower cranes in their fleets (Bishop, 2000; Shiffler, 2006b). High-rise construction has always been predominated by tower cranes, but now these machines are often seen on mid-rise and low-rise projects, as well, particularly for concrete construction of buildings, given the type of work and long service durations involved, as well as the all too often constricted sites that cannot accommodate mobile cranes.

Equipment offered and used for building construction has seen other changes in recent years. Most notable is the abundance of telescopic machines used for moving materials and workers about the jobsite. Modern telehandlers now replace the traditional forklifts. Coming with a variety of front-end attachments, these machines are gradually taking over other equipment as well, such as backhoe-loaders and small rough-terrain mobile cranes. Telescopic aerial work platforms and scissor-type lifts are often used on works for which conventional scaffolds commonly had to be erected. Sometimes a great number of these and other light, versatile, and mobile units may be seen on just one construction site.

This chapter focuses on equipment typically used for concrete construction on today’s building sites. Forming systems, also undergoing significant modernization in recent years, are an integral component of today’s on-site equipment for concrete building construction. Formwork design and forming systems in general are treated elsewhere in this book (see Chapter 7), but this chapter, in its last section, addresses mechanized form systems for building construction.

19.2 Equipment Selection

19.2.1 General

Selection of equipment (often termed equipment planning) for a construction project is one of the major functions and decision-making processes carried out by the construction company planning the construction of the project. This is due to the key role in the success of the project played by the selection of the appropriate equipment. Simple, “regular” projects, especially if similar to projects the company has previously built, may not pose a challenge in terms of equipment selection; however, when the project is no longer “regular,” and definitely in the case of complex and large-scale projects, equipment selection also becomes very complex and challenging. This is due mainly to the following reasons, which should also serve as general guidelines for conducting the selection process:

- A great variety of makes and models is available for each type of equipment which, by itself, generates a great number of alternatives.
- For many equipment types, and particularly for cranes, selection also means the consideration of various location alternatives, within the overall site layout planning.
- For most equipment types, selection cannot be carried out separately for each type because they are interrelated (e.g., cranes, concrete pumps, and forming systems).
- The consideration of equipment alternatives is often interrelated with the consideration of construction methods (e.g., cast-in-place vs. precast concrete elements), thus the circle of options widens further.
• Constructing a building is a dynamic process that continues to change throughout the project life. Equally variable are the equipment requirements. With the high level of uncertainty typically inherent in construction projects, equipment planning is frequently reexamined and occasionally even revised during construction.

• Construction companies commonly build several projects concurrently, each requiring its own equipment planning, and individual equipment plans that look into utilizing equipment owned by the company must be in concert with each other.

• Feasible equipment alternatives are primarily evaluated and compared on the basis of costs; however, a great many qualitative and intangible factors that are difficult or impossible to quantize must be considered systematically to ensure the selection of a “good” alternative (Shapira and Goldenberg, 2005).

The following example demonstrates these issues (Goldenberg and Shapira, 2007).

### 19.2.2 Example

Figure 19.1 is a site layout drawing for the construction of a 42-floor, 470-ft-high residential and office tower sitting above a 60-ft-high podium of commercial space. The building is set in a confined site, located within a busy urban area and in proximity to congested throughways; the entire area is occasionally subject to strong winds. The structural frame of the building is cast-in-place concrete, but the contractor is free to convert the external walls of the tower into precast elements. Construction progress for the concrete work for the tower is scheduled at one floor per week, and overall construction time is set at 24 months.

#### 19.2.2.1 Alternatives

As shown in Figure 19.1, major equipment for the project (Alternative 1) includes two tower cranes ($C_1$ and $C_2$) and a concrete pump with a placing boom ($P$). Not shown in the drawing is a self-climbing wall system for the forming of all tower walls (external and core walls). With placing of concrete for all tower elements carried out by the pump and climbing boom and with the crane-free operation of the automatic climbing form system, only one crane ($C_1$) satisfies all other required lifting services for the tower (mainly...
rebar, slab forms, and various finish materials). This is a full-height (520 ft) external crane, whose mast is braced to the west façade of the tower. The second tower crane (C₂) is a much shorter (100-ft), freestanding crane that serves the lower structure (commercial floors); this crane is located inside the building in openings left in the floors. The stationary concrete pump is located outside the southeast corner of the building, in close proximity to a gate for the entrance of ready-mixed concrete trucks. The placing boom and concrete supply pipeline climb inside the elevator shaft. Other equipment on the site, not shown in the drawing, includes a passenger lift serving the tower, as well as a telehandler serving the lower structure (but also the entire site as a multipurpose utility machine).

Each one of these equipment types offers a great variety of options in terms of specific makes and models entailing various dimensions, capacities, and other important work parameters. Related to these factors are locations of the equipment. For example, if the tower crane serving the high-rise structure (C₁) were placed inside the building in a climbing configuration, a shorter jib would suffice to secure full coverage of the high-rise building, and only a small portion of the sections currently making up the external crane mast would be required. On the other hand, dismantling an internal climbing crane is a much more complicated and costlier operation than that for an external tower crane.

Decisions on each major equipment type affect the entire equipment array on site. For example, another lifting solution (Alternative 2) would be two full-height external tower cranes, one on each side of the high-rise building (east and west façades). Concrete placing can then be accomplished with the cranes, eliminating the need for a concrete pump. The costly automatic climbing wall-form system may also be relinquished, but at the likely cost of extended work hours due to crane time overload. The cranes will also have to provide partial lifting services to the lower structure, within their reach and lifting capacity limits; otherwise, lifting for the lower structure would be done by the telehandler. Concrete for the lower structure is to be placed in this alternative by a truck-mounted pump and placing boom. The pump can be stationed in various locations along the north and west façades.

The interrelation between equipment selection and construction methods can be exemplified by the possible conversion of the tower's external walls from cast-in-place to precast concrete. Drawn from Alternative 1, the current case is likely to have the tower crane servicing the high-rise structure located inside the structure as an internal climbing crane. This way, the crane can handle the heavy precast elements along the circumference of the tower with a shorter jib; by moving the crane from the façade of the tower inside, the problem of installing precast wall panels at close proximity to the mast of the crane is also avoided. In this alternative, no forming of the external walls is required, and the use of the automatic climbing system is reduced to the core of the tower only.

Note that, in some cases, not only are equipment selection and construction methods interrelated such that the latter affect the former, but also vice versa. This brings into the picture the concept of constructability, where, among other things, equipment planning may begin as early as the design of the building. In such cases, the major equipment to be used on the project is taken into account in the course of design; alternatively, the initial design is revised. An example is the reorientation of a large set of wide-span precast concrete beams whose placement in the building according to the original orientation designed would not be possible with the crane already purchased for the project by the owner.

Alternatives 1 and 2 are merely two alternatives among several possible for this project. The feasibility of each alternative, in terms of satisfying all lifting and other logistics requirements, must be investigated and guaranteed before any cost comparison is conducted. The main parameters considered for each equipment type in the course of generating alternatives and investigating feasibility are mentioned separately for each equipment type in the subsequent sections of this chapter.

Cost estimates of each alternative examined will be affected by procurement patterns of the various machines. Procurement, in turn, essentially a matter of company policy (to own or rent equipment), is often dictated by the availability of existing company-owned equipment not engaged on any of the company’s other projects. This could apply to whole machines or part of a machine; for example, even if the company owns the two tower cranes required for Alternative 2, it might still have to rent a portion of the mast sections for the two exceptionally high external cranes.
Cost estimates must also take into account on-site service durations of each individual equipment unit, as derived from the schedule developed for each alternative. These schedules, in turn, must conform to the required construction progress and the overall construction time specified for the project. Figure 19.2 shows the schedules developed for major equipment in Alternatives 1 and 2.

19.2.2.2 Employment Times

Service durations of the various equipment units are closely associated with the planning of daily crane employment. Such planning is necessary to ensure the feasibility of each alternative. Table 19.1 is an example of crane employment times, as compared for the two equipment alternatives demonstrated in this section, focusing on the high-rise tower. Employment times are estimated on the basis of daily quantities of materials to be lifted and considering the predicted lift-cycle durations. Predicted lift-cycle durations should not be averaged but rather must correspond to the specific work conditions, as well as to the specific equipment reviewed. For example, the unit duration of 7.5 min per cu yd, as shown in Table 19.1 for concrete placement in slabs, corresponds to production rates of 8 cu yd per hr. Arithmetically, this could be achieved, for example, by the use of a 1.0-cu yd concrete bucket completing 8 cycles per hr (namely, 7.5 min per cycle), or by the use of a 2.0-cu yd bucket completing 4 cycles per hr (namely, a 15-min actual cycle time). Because bucket size virtually does not affect travel time, larger buckets would commonly be desirable, as they save crane time and entail overall higher productivity. (Note, though, that an increased concrete placing rate may require larger placing crews.) Here, however, enters another factor, which is the lifting capacity of the crane at the desired concrete placing location. A fully loaded 1.0-cu yd bucket weighs about 4800 lb (including self-weight); the respective weight of a 2.0-cu yd bucket is 9200 lb, or 4.6 tons. This is more than the maximum lifting capacity offered by many tower crane models at the jib end. For this reason, preparation of a crane employment table, such as Table 19.1, must relate, among other things, to the specific crane model and bucket size designated for the project.
Another factor—in addition to bucket size and crane lifting capacity—that must be taken into account when actual cycle times are estimated is vertical travel distances. The values entered in Table 19.1 correspond to a building height of about 450 ft—namely, the top floors of the tower structure in Figure 19.1. Vertical travel times take up a major portion of the overall cycle time in such lifting heights, depending on the specific hoisting speed of the crane model. (Note that, to increase speed, hoisting motors may usually be replaced by more powerful ones, for any given crane model, whether new or used.) Thus, if a crane employment table were to be prepared for a low-rise building, then travel times would be almost ignored, as they virtually play no role in lifting heights of up to 60 ft. In these cases, crane cycle times are governed mostly by loading and unloading (or rigging and unrigging) times and by the fine maneuvering time required for the lifting hook of the crane to approach the exact loading/unloading point (Rosenfeld and Shapira, 1998). It can be concluded, then, that for the lower floors of the tower structure, lift-cycle durations are likely to be much shorter, resulting in shorter overall crane employment times.

According to the total-time results given in Table 19.1, the one crane serving the high-rise tower in Alternative 1 is underemployed. Note that 15% idling time was added to the computed service durations. In Alternative 2, on the other hand, the two cranes serving the tower are overloaded; therefore, one of them has to continue its work into a full night shift.

Preparing the crane employment table, which essentially takes into account other major equipment as well, is necessary to ensure feasibility, to obtain overall service durations of the equipment on-site, and to serve as the basis for the cost estimates of the various equipment alternatives. The study of employment times required for the project often involves refinement of more general decisions made when equipment alternatives were generated and checked for feasibility. Finally, calculation of work time exposes tradeoffs between type and quantity of equipment, overall size of labor crews, and workday duration, as exhibited by the various equipment alternatives.

### 19.2.2.3 Cost Estimates

Table 19.2 is an example of cost estimates worked out for major equipment in Alternatives 1 and 2. Costs were estimated based on total service durations of the cranes, pump, and wall-forming system, as shown in Figure 19.2. The extended work hours and night shifts revealed by the crane employment analysis shown in Table 19.1 for Alternative 2 incur higher wages for equipment operators and other labor crews.
**Direct costs** of all equipment include capital costs (in case of owning) or rental costs, maintenance, insurance and licensing of owned equipment, deployment (transportation to the site and erection) and dismantling, climbing operations of cranes and placing booms (including work required to close openings left in slabs), operating costs (energy), and operator wages where applicable (always for owned equipment and, depending on the contracting base, “bare rental” or “all-included,” for rented equipment). For tower cranes, costs entailed by the specific crane configuration should be added (e.g., bracing to the structure and climbing mechanism for high cranes). Earthworks and foundations for the cranes, where applicable, are included in erection costs. There are time-dependent cost items (e.g., capital cost or rental), production-dependent cost items (e.g., operating costs), and fixed cost items (e.g., deployment). The values for all these, as shown in Table 19.2, are computed using the basics of engineering economics and common assumptions with respect to useful life, interest rate, maintenance rates, residual (resale) value of owned equipment, etc. These computations are beyond the scope of the current chapter; the interested reader should refer to Peurifoy et al. (2006) or any other similar book addressing the economics of construction equipment.

**Indirect equipment costs** in this example, with respect to major equipment, include auxiliary equipment (e.g., a telehandler for the low structure in Alternative 1) and labor wages in formwork. Note how the latter may constitute the largest single cost item (Alternative 2). Passenger lifts serve the high-rise tower equally in the two alternatives and are not included in Table 19.2. It should be noted that cost estimation

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**TABLE 19.2 Example Cost Estimates of Equipment Alternatives**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Cost Factor</th>
<th>Cost Estimate ($)</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower crane (C₁)</td>
<td>Capital cost (of owned equipment) or rental</td>
<td>377,000</td>
<td>310,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>78,000</td>
<td>74,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insurance, taxes, license</td>
<td>54,000</td>
<td>52,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transportation, erecting, dismantling</td>
<td>44,000</td>
<td>44,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ties, climbing device</td>
<td>102,000</td>
<td>102,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operator wages</td>
<td>160,000</td>
<td>160,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operating (energy)</td>
<td>24,000</td>
<td>24,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Climbing</td>
<td>6000</td>
<td>6000</td>
<td></td>
</tr>
<tr>
<td>Tower crane (C₂)</td>
<td>Capital cost (of owned equipment) or rental</td>
<td>278,000</td>
<td>360,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>14,000</td>
<td>34,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insurance, taxes, license</td>
<td>80,000</td>
<td>35,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transportation, erecting, dismantling</td>
<td>33,000</td>
<td>44,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ties, climbing device</td>
<td>(–)</td>
<td>(–)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operator wages</td>
<td>40,000</td>
<td>213,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operating (energy)</td>
<td>4000</td>
<td>32,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Climbing</td>
<td>(–)</td>
<td>6000</td>
<td></td>
</tr>
<tr>
<td>Concrete pump</td>
<td>Capital cost (of owned equipment) or rental</td>
<td>96,000</td>
<td>51,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>31,000</td>
<td>(–)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insurance, taxes, license</td>
<td>11,000</td>
<td>(–)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transportation, erecting, dismantling</td>
<td>(–)</td>
<td>(–)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operator wages</td>
<td>51,000</td>
<td>(–)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operating (energy)</td>
<td>9000</td>
<td>(–)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Climbing</td>
<td>38,000</td>
<td>(–)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Telescopic material handler</td>
<td>(–)</td>
<td>28,000</td>
<td></td>
</tr>
<tr>
<td>Forming systems</td>
<td>Capital cost (of owned equipment) or rental</td>
<td>682,000</td>
<td>(–)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>46,000</td>
<td>9000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insurance, taxes, license</td>
<td>38,000</td>
<td>(–)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transportation, erecting, dismantling</td>
<td>(Marginal)</td>
<td>(Marginal)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operating (energy)</td>
<td>(Marginal)</td>
<td>(–)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Labor wages for vertical elements</td>
<td>498,000</td>
<td>1,692,000</td>
<td></td>
</tr>
<tr>
<td>Total cost for alternative</td>
<td></td>
<td>2,444,000</td>
<td>3,262,000</td>
<td></td>
</tr>
</tbody>
</table>
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is much more than merely technical calculations; critical, big-picture decisions, on the one hand, and a
great many fine details, on the other hand, are equally embedded in the process and mirrored in its results.

With respect to specific project and company data that are behind the numbers appearing in Table
19.2, the following should be noted as examples of parameters affecting cost estimation of equipment
alternatives, in addition to those mentioned above:

• General—Capital costs and rentals reflect a specific given situation, in which part of the equipment
is owned by the company and part is rented. Additionally, part of the owned equipment may have
already exceeded its nominal useful life (and therefore no longer incurs capital costs). Note that
“equipment” in this respect is not necessarily the complete machine as configured for the specific
project; for example, the company may own a tower crane but not enough mast sections. Similarly,
it may have to rent a climbing device for its owned crane. This is a rather common situation with
equipment (such as mobile and tower cranes) that is modular in terms of its use and therefore
also in terms of its manufacturing and procurement; manufacturers and dealers of such equipment
cater this way to the great variety of different and changing requirements. On the other hand,
other types of equipment (mainly when viewed by the company as being more of specialized
equipment, given the company’s line of project types) are commonly procured in the complete
configuration required for a particular use. An example could be a climbing concrete placing boom
system, which would include the climbing mast, climbing gear, the placing boom, and all other
accessories.

• Climbing the cranes—For the external cranes (C1 in Alternative 1, C1 and C2 in Alternative 2), the
cost of climbing depends only on the number of climbing steps, as no completion works are
entailed in the floors (as would be with an internal crane). The number of climbing steps depends
on the freestanding height of the crane, as specified by the manufacturer, and on the height to
which the crane was erected initially. The higher these two are, the fewer the climbing steps
required. If any of these cranes were in an internal-climbing configuration, a much higher overall
climbing cost would result, due to (1) higher cost of each climbing step, (2) greater number of
climbing steps, and (3) completion works in the floors. The cost for climbing the concrete placing
boom in Alternative 1, an operation similar to that of climbing an internal crane, reflects these
differences. The short crane installed inside the lower commercial structure (C2 in Alternative 1)
is initially erected to its full-required height, which does not change during construction. Hence,
climbing costs in this case are incurred only by completion works of the lower structure’s floors,
and these are marginal.

• Location of concrete placing boom—As shown in Figure 19.1, and also mentioned above, the placing
boom transporting concrete from the stationary pump is located inside the elevator shaft. Elevator
shafts, as well as stairwells, are commonly part of the structural core of the building. As such, they
are a natural choice for the location of climbing booms and cranes, in terms of transferring loads
imposed by the equipment. Indeed, when such equipment is located elsewhere inside the building,
it usually requires temporary vertical shoring of the floors and sometimes additional bracing of
the permanent structure being constructed. However, from the viewpoint of the construction
process and progress, there are at least two disadvantages to locating climbing equipment in the
elevator shaft: (1) it delays the installation of the building’s permanent elevators; and (2) it may
interfere with, and therefore limit the choice of, forming systems for the walls of the core. As a
compromise, the boom can climb elsewhere in the core, rather than in the elevator shaft. Stairwells
should likewise be left free so as not to interfere with the installation of the stairs, as these serve
workers moving between the floors during construction.

• Ties and climbing device—The device used to climb an external crane, whether it is a freestanding
crane or a crane braced to the building, is modular equipment, often referred to as a climbing
cage. A company owning several tower cranes may be able to climb them using a smaller number
of climbing cages (owned or rented), depending on compatibility (due to make and model and
to the cross-section of the mast). This is a desired situation, given the high price of these devices.
The ties and climbing device costs appearing in Table 19.2 reflect a similar situation, where one climbing cage can climb both external cranes in Alternative 2. Hence, the procurement cost of the cage in Alternative 2 was taken into account only once \( C_1 \). The corresponding cost for the second crane \( C_2 \) is essentially that of the ties to the building, with a small addition for moving the cage between the two cranes (as mentioned above, the number of climbing steps in this case is small). No climbing device costs appear in Table 19.2 for the concrete placing boom, as these were computed within the concrete pump’s rental costs.

- **Deployment of cranes**—No fundamental difference in erection costs exists between the external crane \( C_1 \) and the freestanding crane \( C_2 \) in Alternative 1. Both are erected to their full, or nearly full, freestanding height, an operation that requires an erecting mobile crane. With similar jib lengths of the two tower cranes and pending comparable accessibility conditions to the site, a same-size mobile crane can be used, and the entire operation is similar in terms of other resources as well (erection team, duration). Deployment costs, however, do differ between the two cranes due to the much costlier transportation of all mast sections required for the high external crane. Another difference is in the crane foundations. Even if the two cranes are similar in terms of jib length and lifting capacity, a larger foundation is required for the high external crane due to its much higher weight (due mainly to the much greater number of mast sections but also to the likely larger and more robust cross-section of the mast). There is no fundamental difference in deployment costs between the two cranes in Alternative 2.

- **Dismantling of cranes**—Whereas crane erection is similar for both cranes in Alternative 1, the cranes that have to be dismantled at the end of construction are different. The same mobile crane that erected the external tower crane \( C_1 \) can also dismantle it. The freestanding tower crane \( C_2 \), however, now inside a 60-ft-high building from where it has to be pulled out, would require a larger mobile crane to dismantle it than the one needed to set it up. On the other hand, dismantling the external tower crane by a mobile crane must be preceded by climbing the tower crane down, in a process opposite that used for climbing it up (or else a much larger mobile crane would be required for dismantling). Thus, the overall cost of taking down the two cranes would still be similar, and the overall cost difference in deployment and dismantling could be attributed mainly to transportation and foundations. Note that lowering the external crane prior to dismantling it with a mobile crane is possible only as long as the jib of the crane can be aligned such that it does not make contact with the building. In some cases, the building geometry will not allow it, a constraint that must be borne in mind when crane location alternatives are considered.

- **Concrete pumps**—Three separate systems are combined together in Table 19.2 under the “concrete pump” category for Alternative 1: (1) stationary pump, (2) pipeline, and (3) climbing placing boom. This is specialized equipment commonly procured on a rental basis. In this case, transportation to the site, as well as erection and dismantling, were incorporated by the pump rental company within the monthly rate. The pump is brought to the site and the climbing boom system is installed in the building only after the first floors have been completed (see Figure 19.2). Thus, erection is assisted by the tower crane already on-site and so is dismantling. The service of the truck-mounted pump in Alternative 2 is procured on a quantity basis, but other rate systems are available. In the quantity-based rate system, there is commonly a fixed pumping rate for an initial concrete quantity plus a rate for each additional volume unit (cu yd). To estimate costs, therefore, the number of times the pump will be needed on site and the average concrete placing quantity on each time are assessed.

- **Forming systems**—As clearly evidenced from the costs in Table 19.2, the crane-independent automatic climbing wall-forming system used in Alternative 1 symbolizes industrialization more than any other single equipment used in the example project. Not only does it save precious crane time (which, together with the concrete pump, allows for the use of one crane only on the high-rise structure), but it also makes an enormous difference in terms of labor power needed on the project. The high cost of labor in Alternative 2 is due mainly to the much lower production rates achieved with manual forming as compared to the automatic system in Alternative 1, but
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19.2.3 Soft Considerations

If equipment alternatives were compared based on costs only, then, for example, Alternative 1, considerably less costly than Alternative 2, would be the one selected for the above-exemplified project. As mentioned earlier, however, the great variety of qualitative and intangible factors, if considered, may also to the need to work at night, when wages are much higher. The forms rental company that provides the automatic system and supervises its erection includes transportation costs for most parts of the system in the monthly rate. Erection and dismantling are carried out by the construction company workforce and their costs are included in labor wages. As for the forms used in Alternative 2, they are owned by the construction company and have exceeded their nominal useful life.

TABLE 19.3 Typical Soft Equipment Selection Factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Explanation/Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company policy toward own vs. rent</td>
<td>“Own” policy may result in purchasing equipment that, with a view to future projects, exceeds the requirements of a particular project, whereas “rent” policy is likely to produce a solution catering to the exact needs of that project only. Similarly, preference may be given to the use of owned, currently unemployed equipment (e.g., two small cranes) over rented equipment (e.g., one large crane), even if the latter would have otherwise been the optimal solution. Companies would generally look first into using their own equipment before other options are considered, even if cost comparisons would point to a rental-based solution.</td>
</tr>
<tr>
<td>Company project forecast</td>
<td>This factor influences current purchase vs. rent decisions and thus may affect the equipment selected for a particular project under discussion. It has a bearing on costs through the value given to the predicted return period in economic calculations.</td>
</tr>
<tr>
<td>Commercial considerations</td>
<td>The desire to start operating part of the constructed facility (in case of a cash-flow-producing asset) earlier than the rest of it may affect equipment selection (e.g., refraining from locating tower crane in underground parking of an office building if it may interfere with the early operation of the parking as a public facility before the main building was completed).</td>
</tr>
<tr>
<td>Procurement method and subcontracting</td>
<td>Quite often, the client/owner dictates certain requirements that affect equipment selection (e.g., using the client’s given equipment, providing craning services to other contractors on the same project, or forbidding the use of certain zones for locations of equipment). Another case example is of a joint venture project where the two construction companies decide to have identical equipment on site to simplify accounting between them (e.g., two cranes), even if another solution (e.g., a crane and a concrete pump) may otherwise be favored.</td>
</tr>
<tr>
<td>Company project specialization</td>
<td>A company may specialize in certain categories of construction (e.g., high-rise buildings, precast structures). This is reflected in the equipment it owns and operates and can have direct implications on the equipment available for a new project. It also influences the type, experience, and size of the company’s equipment maintenance department, which, in turn, affects cost estimates.</td>
</tr>
<tr>
<td>Dependence on outsourcing</td>
<td>Outsourcing increases dependence on factors outside the site management control, chances of mishaps, and uncertainty in general. Avoiding it may lead, for example, to favoring on-site plant for the fabrication of precast elements over ordering them externally.</td>
</tr>
<tr>
<td>Shifting responsibility to external party</td>
<td>Favoring ready-mixed concrete over on-site concrete production or favoring the ordering of precast elements over on-site fabrication has an advantage in terms of quality assurance of the product as well as contractual liability to this quality.</td>
</tr>
<tr>
<td>Working night shifts</td>
<td>Night shifts commonly result from either a tight schedule or traffic-induced difficulties in transporting concrete/precast elements to the site during the daytime. It may affect site management and is also an additional cause for safety concerns. Obviously, it incurs higher wages, which are reflected in the cost estimates.</td>
</tr>
</tbody>
</table>
point to the solution offered by Alternative 2, which otherwise is costlier. Alternatively, these factors may consolidate the selection of Alternative 1, as was made on economic grounds only. Certainly, if Alternatives 1 and 2 showed near enough the same costs, then the decision as to which one to select would depend entirely on adequate assessment of these qualitative and intangible factors. Table 19.3 offers a list of typical such "soft" factors, as these are usually termed (Shapira and Goldenberg, 2007). The following points are common to most soft factors:

- They are strongly connected to local cultures and traditions, as well as to the physical, organizational, and market environment. They express the uncertainty and intuition rooted in construction decision making, as well as the subjective judgment that is likely in the background of many seemingly pure technical calculations. Their consideration draws from the experience accumulated by the individuals who participate in the decision-making process and in the construction company.

### Table 19.3 (cont.) Typical Soft Equipment Selection Factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Explanation/Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tradition, previous experience</td>
<td>The types of equipment selected for the project may be heavily affected by experience and by tradition, whether on the market level (availability of technical support), company level (culture), or site management level (personal preferences). The same applies for the location of equipment (e.g., internal climbing crane or climbing placing boom located in the elevator shaft or elsewhere in the floor through openings in the slabs).</td>
</tr>
<tr>
<td>Redundancy of equipment</td>
<td>The need to have backup for contingencies (e.g., breakup of a machine) so as to avoid work stoppage may give advantage to using multipurpose equipment or excess equipment.</td>
</tr>
<tr>
<td>Obstacles on site</td>
<td>Obstacles commonly include overhead power lines and adjacent structures, which can affect productivity and safety. Fixed (rather than mobile) equipment may have an advantage; specialized operator aids may be required.</td>
</tr>
<tr>
<td>Labor availability</td>
<td>Labor shortage increases the attractiveness of higher mechanization in general and automated systems in particular. This goes beyond the need to pay higher wages, which should be taken fully into account in the cost estimates. Temporary unavailability of skilled laborers may impede work progress severely.</td>
</tr>
<tr>
<td>Noise levels</td>
<td>Give preferences to electric over diesel powered equipment; noise levels may also exclude night work.</td>
</tr>
<tr>
<td>Site accessibility</td>
<td>Narrow roads may limit the size of precast concrete elements or steel trusses transported to the site, which in turn may affect equipment size requirements (e.g., a greater number of smaller machines).</td>
</tr>
<tr>
<td>Heavy traffic</td>
<td>For projects located in urban areas near congested roads, heavy reliability on a continuous external supply (e.g., of ready-mixed concrete in large volumes overall) may be abandoned in favor of on-site production, even if the latter is much costlier (e.g., if the constructed facility takes up the entire area of the site, necessitating relocation of an on-site concrete production plant several times during construction). Night work is another solution (but it may have been reserved for supply of other materials/elements, such as precast panels).</td>
</tr>
<tr>
<td>Strong winds</td>
<td>In areas given to strong winds, tower cranes may be preferred over mobile cranes. Additionally, the use of forming systems that climb automatically without crane assistance may be considered to avoid craning of large forms that act like a sail.</td>
</tr>
<tr>
<td>Equipment age and reliability</td>
<td>Technological advantages aside, newer equipment is likely to encounter fewer operational problems and less downtime, thus offering better service overall.</td>
</tr>
<tr>
<td>Overlapping of crane work envelopes</td>
<td>Overlapping tower cranes often are unavoidable, whether because of reach limits or daily schedule demands. Careful work and designation of forbidden zones helps in coping with safety hazards, but work may be slowed down. The use of (costly) anticollision systems may be considered.</td>
</tr>
<tr>
<td>Obstruction of crane operator view</td>
<td>Even with signal persons, this could become a major safety hazard (lower productivity is another result), and hence should be taken into account when equipment selection and location alternatives are considered. Operator vision aids (e.g., crane-mounted cameras) offer a partial solution.</td>
</tr>
</tbody>
</table>
• If they are measurable, they exhibit a great variety of measurement units, which makes it difficult or even impossible to compare them on a common quantitative basis. Only seldom can they be expressed in monetary terms; primarily, they are altogether immeasurable.

• Often the particular decision arrived at by the consideration of one factor is in conflict with that arrived at by another. See, for example, in Table 19.3, “Dependence on outsourcing” and “Heavy traffic” vs. “Shifting responsibility to an external party.” Another example is using mobile cranes owned and readily available by the company vs. using rented tower cranes with which the site superintendent has good experience.

• They affect the initial decision-making process when they are considered, usually intuitively and at times even unconsciously, in the course of the alternative generation phase, alongside hard factors. In many cases, they have a bearing on costs and are taken into account in the cost estimation phase (e.g., see “Company project forecast” and “Company project specialization” in Table 19.3).

• Veteran project managers and other functionaries involved in equipment planning (e.g., equipment managers) may have the rich experience, professional skills, and tacit knowledge it takes to detect all soft factors relevant to the project and to consider them successfully, especially if they operate in a well-developed planning environment. However, the lack of practical tools for the systematic evaluation and consideration of soft factors often results in equipment solutions that eventually are found to be inappropriate or costlier than initially estimated.

It is all these points, and particularly the lack of practical methods and tools to integrate the consideration of soft factors within the entire selection process in a structured and systematic manner, that contribute to the complexity of equipment planning and to the potential realization of inadequate solutions.

A method presented by Shapira and Goldenberg (2005) to deal with this problem is based on a widely accepted multi-attribute decision-making technique referred to as the analytic hierarchy process (AHP). AHP, introduced by Thomas Saaty (1980), was developed to assist in the making of decisions that are characterized by a great number of interrelated and often contending factors. To make such decisions, the relative importance of the factors involved must be properly assessed to allow tradeoffs among them. The main feature of AHP is its inherent capability of systematically dealing with a vast number of intangible and nonquantifiable attributes, as well as with tangible and objective factors. AHP allows for incorporation into the decision-making process of subjective judgments and user intuition by producing a common formal and numeric basis for solution.

Recent implementation of the AHP-based equipment selection method to evaluate soft factors and to assess their impact vis-à-vis the results of cost comparisons, in a rational process that leads to the selection of a “good” equipment alternative for the project, is demonstrated in detail by Goldenberg and Shapira (2007). The method was examined and tested in real-life settings to satisfying results. The interested reader is referred to Shapira and Goldenberg (2005) to learn about the fundamentals and concepts of the method, and to Goldenberg and Shapira (2007) for an elaborate case study.

19.3 Concrete Equipment

The use of concrete as a building material involves equipment throughout production: from batching and mixing, through transporting and placing, to consolidating and finishing. This section focuses on major equipment commonly used for these operations.

19.3.1 Concrete Mixers

Concrete can be centrally mixed in a “wet” plant—a plant that has a built-in mixer—and transported to the site in truckmixers operating at agitating speed, centrally batched in a “dry” plant, and mixed in the truckmixer itself, which then drives to the site at agitating speed, or it can be produced on-site. On-site production is a viable solution mainly in case of exceptionally large concrete amounts or if the site is located remotely such that transport distances from the closest plant are too great. The view of a compact
mobile mixing plant on a small construction site in some parts of the world (e.g., Europe) is not rare; today, this equipment is highly automated, among other things, to ensure high concrete quality control. Where high concrete volumes are required, larger mixing plants with higher outputs are sometimes used on-site—for example, in dense urban areas with access difficulties due to traffic-congested roads. The great majority of today’s building sites, however, use ready-mixed concrete delivered to the site from the dry or wet central plant in truckmixers, also called ready-mixed trucks.

Truckmixers the world over are of the rear-discharge type (Figure 19.3a), but in North America, front-discharge truckmixers are used as well (Figure 19.3b). The drum in the front-discharge mixer is more elongated. This shape of the drum and the overall configuration of the truck result in a better weight distribution, which allows these trucks to meet road and bridge load restrictions better than the rear-discharge truckmixers. The front-discharge truckmixer allows the driver a more convenient approach to the discharge location; the driver’s ability to control the operation from the cab without leaving the cab is an additional advantage in bad weather. This carrier truck, however, is specialized equipment, unlike the standard carrier truck of the rear-discharge mixer, and therefore more costly.
The drum in the ready-mixed concrete truck, both of the rear- and front-discharge type, is a freefall-type mixer. Freefall mixers blend concrete by lifting the ingredients with the aid of fixed blades inside the rotating drum (in the case of a truckmixer, the blades are spiral) and then letting them drop by gravitation (hence, the term gravity mixer is also used for freefall mixers). This is unlike power mixers, which blend the concrete by rapid rotary motion of paddles, making them particularly suitable for dry mixes. The drum of the truckmixer is rotated in one direction for loading and in the opposite direction for mixing or agitating (i.e., it is a reversible-type freefall mixer).

When planning a pour with ready-mixed concrete, several points should be considered. The rate of concrete delivery is affected by the size of the truck (namely, the effective intake volume of the drum), distance from the plant to the site, the number of truckmixers allocated by the plant for the specific operation, and possible delays that may be caused by heavy traffic. In terms of site organization, maneuvering space must be ensured for the large and heavy trucks, as well as proper ground conditions for travel. If the site is too restricted to allow free truck movement, as is often the case in mid-city construction sites, provisions should be made to allow for the nearby waiting of trucks. Such operations require thorough planning, workers designated for traffic control, and communication means. Often, one traffic lane would have to be blocked for the duration of the pour, after coordination with the local authorities (Figure 19.4).

Truckmixers come in sizes up to 20 cu yd, with 8 to 12 cu yd being the most common size range. The most popular size appears to be gradually increasing, although it has stabilized at 11 cu yd for several years now. Truckmixers are sometimes equipped with a boom pump or belt conveyor (see below), which gives them greater operational flexibility and independence and can be particularly useful for small jobs (e.g., house renovation) requiring small amounts of concrete.
In Europe, the use of another type of concrete mixing equipment is quite common. This is the self-propelled mobile mixer. The compact rough-terrain wheeled carrier, similar to that of the telehandler (see below), carries a self-loading drum-mixer with high-discharge capabilities. Mixer volumes in current models are in the range of 1 to 6 cu yd. Concrete can commonly be discharged with chutes up to 30 ft horizontally and at heights of 3 to 7 ft; with a special hydraulically elevated drum, height discharge can be up to 10 ft. Not used much on building construction sites, this self-contained machine is particularly useful on spread-out, low-rise civil projects, such as long concrete walls, utility lines, or small repair works on airfields, where relatively small quantities of concrete are required at different locations. If aggregates and cement are stored near these locations, the self-loading mixer can travel between them and carry out concrete placing as well. Quite often, such projects are remotely located and are inaccessible to truckmixers. Under such conditions, the use of one machine that offers a solution for aggregate loading and concrete mixing, transporting, and placing is even more attractive.

19.3.2 Concrete Pumps

19.3.2.1 Uses and Outputs

Concrete pumps transport concrete by moving it through a pipeline at high placing rates. As such, a concrete pump is a single-purpose machine—namely, it cannot be the only material transportation equipment on the site (unless concrete is the only or primary material requiring transportation, such as in the construction of culverts and retaining walls or at the foundation phase of the building). Hence, concrete pumps are commonly used on building construction sites generally serviced by cranes, for one or more of the following reasons: (1) the crane is engaged in other lifting services, (2) a high placing output is required (typically for large pours), or (3) the location of the cast element is outside the reach of the crane. Concrete pumps are often also seen on sites where their ability to deliver the concrete while bypassing obstructions becomes useful, such as inside low-roofed spaces (e.g., tunnels), for renovation work on existing buildings, and on sites located such that access of any other transportation means is impossible (e.g., in old cities with narrow lanes). The effective pumping distance of common concrete pumps is 300 to 1000 ft horizontally and 100 to 300 ft vertically (although special pumps have moved concrete for much greater distances). The maximum theoretical output of commonly used pumps is 80 to 200 cu yd/hr, or even up to 300 cu yd/hr for the largest pumps available today, but these rates are rarely realized. Placing rates are determined in practice by the type and dimensions of the cast element, the size of the concrete placing crew, and the rate at which the concrete is fed into the intake hopper of the pump (an intake hopper can be seen in Figure 19.6b), the latter being dictated most commonly by gross truckmixer discharge cycle time. Effective outputs, in a properly organized placing operation and under normal conditions, are as follows:

- Common building elements of regular dimensions, 40 cu yd/hr
- Thick slabs and similar elements, 60 cu yd/hr
- Mass concreting of large elements (e.g., raft foundations), 80 cu yd/hr

19.3.2.2 Types and Configurations

The three main configurations of concrete pumping equipment are (1) a pump-and-boom combination, (2) a pump with a separate pipeline, and (3) a pump and pipeline with a separate, tower-mounted boom. The first of these is particularly efficient and cost-effective in saving labor and eliminating the need for pipelines to transport the concrete. The last of these, used mostly in high-rise construction, combines elements from the former two and is a less common configuration. The following description of these three configurations was adapted in part from Peurifoy et al. (2006).

19.3.2.2.1 Pump-and-Boom Combination

In this configuration (Figure 19.5), also termed a boom pump, the pump is mounted on a truck and equipped with a slewing boom to which a fixed-length delivery line is connected. The line is made of a
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Steel pipe, commonly 5 in. in diameter. The free end of the line has a flexible rubber pipe (end hose), 9 to 12 ft long, connected to it. The end hose eases the task of the worker who holds it and can also be used to slightly extend the boom’s reach.

Booms come in lengths of 60 to 210 ft, but the more commonly used booms are in the range of 80 to 140 ft. Hydraulically operated and articulated, booms in most truck-mounted pump models have four or five sections, but three sections for short booms and six sections for the longest ones are available, too. For a given boom length, a greater number of sections provides the boom with greater maneuverability, which may be an advantage in confined areas. Note that boom length is a nominal length and not the effective length of the boom. It indicates the maximum vertical reach of the boom, measured
from the ground, which includes the dead length from the ground to the first boom joint. Because this dead part is around 13 ft for most makes and models of truck-mounted pumps, the maximum horizontal reach of the boom, measured from the slewing axis of the boom, is always shorter by about 13 ft from the nominal boom length. Effective horizontal reach is even shorter, as loss of distance measured from the slewing axis to the front of the truck or to the truck side must be taken into account. Depending on truck make and size, the extended outriggers, by which the truck is stabilized while in operation, may also contribute to the shortening of the effective horizontal reach.

Truck-mounted pumps use one of two types of booms that differ from each other in their articulation mode. One type of boom extends convexly, but the other extends in a Z-like mode. Z-booms are particularly suitable for jobs with height restrictions (e.g., working under obstacles) and for confined spaces with low overhead, such as inside tunnels.

Because the reach of boom pumps is limited, these pumps use ready-mixed concrete, with the truck-mounted pump optimally positioned to enable maximum coverage of the concreting area for each concreting operation. If coverage from one location is not possible, the truck is relocated in the course of the operation. Relocation, however, interrupts work continuity and may cause delays, depending on the time it takes to fold the boom, retract the outriggers, move the truck, extend the outriggers, and unfold the boom to continue concrete placing. If the relocation was not planned, a line of waiting ready-mixed trucks may result as well.

Truck-mounted booms are available in two additional equipment configurations: as separate trailer placing booms and in combination with a trailer-type pump (see below). The trailer boom uses a two-wheel carriage with counterweights to help balance the extended boom. When combined with a trailer pump, the pump serves as a partial counterweight. In both configurations, the equipment is stabilized on outriggers when in operation. Booms in both cases are shorter than truck-mounted booms, and their maximum operation range is around 60 ft.

19.3.2.2.2 Pump with a Pipeline

In this configuration, also termed a line pump, the pipeline is a separate system that must be assembled and connected to the pump before pumping operations begin. The pipeline is laid from the location of the pump to the concrete casting area. The pump is located such that the ready-mixed concrete trucks have good access to it. In the case of on-site-mixed concrete, the pump would be placed with the hopper just under the discharge opening of the mixer. On spread-out projects, sizeable floor-area buildings, or high-rise projects comprised of more than one building, several pipelines can be stretched from one pump to various project zones, thus eliminating the need to relocate the pipeline with each change in casting location. A special pipeline gate is used to control which line is being used for any given pumping operation. Another option is to prepare several pipelines and relocate the pump according to the placement location. This latter option requires the use of truck-delivered ready-mixed concrete. In terms of its mobility, the pump is a stationary pump, trailer pump, or truck pump (not to be confused with the truck-mounted pump-and-boom combination). Figure 19.6 shows a truck pump being fed by truckmixers. Two mixers position themselves at the pump and feed it alternately such that concrete supply for the pump is continuous and a higher placing rate is achieved. Pipelines for concrete transportation use pipe diameters of 3 to 8 in. (with 5 and 6 in. being the most common sizes). The pipeline is assembled of straight and curved steel pipe sections connected to each other by quick couplings. Similar to the boom pump, here, too, the free end of the line has a 10- to 30-ft long flexible rubber pipe connected to it for better control of the concrete discharge location and for easier handling by the workers who have to direct the spreading of the concrete. To help with the difficult work of holding and moving the end of the concrete-filled pipe, a special lightweight distribution (or placing) boom can be used and crane-lifted for relocation as the concreting progresses.

19.3.2.2.3 Pump with a Pipeline and Tower-Mounted Boom

Given their limited boom length, boom pumps cannot provide solutions for high-rise buildings. Even the longest boom available, nominally 210 ft long, can practically place concrete in buildings no higher
than 14 floors. The solution is, then, to use the basic pump-and-pipeline configuration, render it with climbing capability similar to that of the internal-climbing tower crane, and enhance horizontal distribution reach and convenience by use of a boom-pump-type hydraulic articulated placing boom (Figure 19.7). This configuration, used above in the selection example (19.2.2), is today the preferred solution for concrete placing in high-rise structures. Depending on the size of the floor in the constructed building,
two such systems may be used concurrently (with one or two pumps). In this case, either two booms are used (as seen in Figure 19.7) or one detachable boom, with a quick boom–mast connection, is transferred as required between the two climbing masts. The hollow-section or lattice-type climbing mast on which the boom is mounted and the pipeline running from the pump to the boom are located next to each other inside the building. However, an external climbing mast, similar to the mast of a top-slewing tower crane, can also be used.

19.3.3 Power Trowels

The final operations in the production of concrete elements that involve equipment are consolidating and finishing. Immediately following placement, concrete has to be consolidated by the use of vibrators (see Chapter 30). Finishing may actually be required only in the form-free faces of the cast element. Typical faces are the upper surfaces in floor slabs, where finishing to a smooth face—if required—is attained by the use of power trowels (Figure 19.8).

The main part of the power trowel is the rotating blade system, commonly termed rotor or spider. When the blades rotate at high speed, frictionally engaging the concrete surface, they improve the density of the upper concrete layer, seal plastic cracks, and polish the surface to obtain a smooth and hardened
concrete face. Maximum rotating speed is in the range of 90 to 180 rpm. Several steps are involved in troweling (the first step of which is termed floating), and with each step and successive troweling cycle the blades are slightly angled. Power trowels come in various rotor sizes (diameters). Large-size rotors are advantageous in large open areas, where high production rates can be realized; in tight spaces and mainly for finishing around various obstructions, small-size rotors or small troweling discs (see Figure 19.8a) must be used.

FIGURE 19.8  Finishing of concrete floor by troweling: (a) walk-behind single trowel; (b) ride-on double trowel; (c) ride-on triple trowel.
Powered by electric motors or by diesel or gasoline engines, trowels come in either a walk-behind or a ride-on configuration. In terms of number of rotors, the most common are single-rotor (Figure 19.8a) and double-rotor (Figure 19.8b) trowels, but triple-rotor trowels are also available (Figure 19.8c). Single-rotor trowels are of the walk-behind type, and the two others are of the ride-on type. Rotor diameter varies from 2 to 5 ft, and the number of blades per rotor varies from four to six.

Power trowels can be quite heavy, ranging from 100 to 300 lb for the single-rotor trowels and up to 500 to 3000 lb for double-rotor and triple-rotor trowels; the two latter owe their additional weight to the extra rotors, riding engine, and operator deck. To be crane-lifted around the jobsite and for loading and unloading, the lighter weight machines are fitted with a lifting hook, whereas the heavier machines have a robust lifting system. The latter are often moved around the workplace on transport dollies and transported between sites on trailers.

19.4 Cranes

Construction cranes are classified into two major families: tower cranes and mobile cranes. In some regions, including North America, the term mobile cranes is often used to refer to truck-mounted mobile cranes only, and track-mounted mobile cranes are considered a separate family, referred to as crawler cranes. This chapter adheres to the two-family classification. Some machine types are almost equally tower and mobile cranes. They are listed in this chapter under the family of their origin. Use of the word family in this chapter implies that a great many different equipment types and configurations fall under each one of the two terms tower cranes and mobile cranes. This chapter presents the main types and equipment in use today, with a focus on cranes that typically serve on building construction projects. The lack of universally accepted classification and taxonomy for cranes attests, too, to the great variety of both very different and quite similar crane types and models available. Because the various types of cranes can be confusing, an effort has been made in this chapter to be consistent in the use of these terms and to clarify such confusions.

19.4.1 Tower Cranes

19.4.1.1 Introduction

Tower cranes, essentially in the same configuration as we know them today, became visible in the late 1940s when they helped rebuild Europe after World War II. The tower crane was a small-footprint machine suitable for tight urban construction sites for both low-rise and high-rise structures, and it was powered electrically for noiseless operation. Over the years, the tower crane has seen enormous developments in terms of reach and lifting capacity, as well as deployment and operation convenience, suitability to a wide range of work assignments and site conditions, and responsiveness to the great variety of needs and preferences of construction firms and crane rental companies. Its operating and control systems have undergone major changes in parallel with the technological developments of our times, as has its safety features. Although the electrically powered tower crane is still the most common one, diesel-powered models are available and used as well, particularly in North America.

In high-rise construction, tower cranes essentially provide the only solution for lifting materials other than concrete, which can also be, and often is, pumped up. In many parts of the world, however, particularly in Europe, tower cranes are widely used for all kinds of building projects, urban and rural, as well as on infrastructure projects such as bridges, utilities, and landscaping. Lightweight, fast-erecting models are the machines of choice for the construction of low-rise residential and commercial structures, and even one-story houses, in France, Italy, Germany, and Switzerland, to name but a few. In recent years, these lighter models have begun to show a modest but growing and noticeable presence in North America as well, on a variety of projects having traditionally employed mobile cranes (Bishop, 2004; Shiffler, 2006a).
Tower crane “forests” have been conspicuous these past years in, among other places, the renewal of unified Berlin as Germany’s new capital in the late 1990s; the Chinese cities of Shanghai and Beijing, which is preparing for the 2008 Olympic Games; and the unprecedented surge of office, condominium, and hotel complexes in the United Arab Emirates in the mid 2000s. Yet, in the United States, as well, the increasing use of tower cranes has recently led to many cities being dubbed “Crane City”; for example, 300 tower cranes were estimated to have been working in Miami alone at one point in 2006 (Shiffler, 2006b).

Because tower cranes can be mounted on rails, a traveling tower crane had traditionally been a common way to obtain a larger work envelope and better site coverage whenever site conditions allowed installing a railway. This solution allowed saving at least one additional crane, as long as lifting requirements in terms of service time could be accommodated by one crane only. This, however, is not the situation for today’s typical construction sites. The competitive construction atmosphere and the high priority given to meeting tight deadlines practically dwarf the costs of additional cranes on site. Furthermore, with the increasing industrialization of construction sites, cranes are now busy providing a variety of lift services and in frequencies far surpassing yesterday’s requirements, thus demand on crane time has increased manifold. Consequently, cranes are often utilized to their full daytime capacity (and, in many instances, their nighttime capacity also) to meet all lifting requirements within their work envelope, but in many cases one crane cannot provide all of the lifting services required within its own reach within the time allotted. The result is a growing number of multi-crane sites, as well as a greater extent of shared work zones created by overlapping crane envelopes. This, in turn, has driven other developments in recent years; these developments, such as the increased use of flat-top tower cranes and the growing demand for advanced anticollision systems, are addressed later on in this chapter. The photograph appearing at the beginning of this chapter is an example of a multi-crane site (also see Figure 19.13).

19.4.1.2 Types and Configurations

The two main types of tower cranes are top-slewing and bottom-slewing. The major differences between these two types are reflected in erection and dismantling operations of the cranes and in their maximum height. Erection and dismantling of bottom-slewing cranes are relatively simple and rapid, earning these cranes the nicknames of self-erecting and fast-erecting (the latter, however, should not be confused with the same term often used by manufacturers to describe certain models of top-slewing cranes). This, however, comes at the expense of their limited height. Top-slewing cranes, on the other hand, take much longer to erect and dismantle when more complicated and costly operations are involved, but their height is practically unlimited. For these reasons, bottom-slewing tower cranes are suitable mainly for short-term service durations on low-rise projects, while top-slewing tower cranes are suitable primarily for mid-rise and high-rise projects requiring long service periods. A 6-month cut-off time is often cited in the industry when referring to the service durations of these two crane types, but this approximation should clearly be used, if at all, for general indication only.

19.4.1.3 Top-Slewing Tower Cranes

19.4.1.3.1 Structure and Configuration

The main parts of a typical top-slewing tower crane (Figure 19.9) are as follows:

- **Undercarriage.** These cranes are usually stationary, and crane stability is accomplished in one of two ways: (1) the mast is anchored directly into an engineered concrete foundation in a no-undercarriage configuration using fixing angles (see Figure 19.10), or (2) a base frame is ballasted by modular concrete blocks. In a traveling configuration, stability is attained by a concrete-block ballasted undercarriage mounted on rails. Rail-mounted undercarriages are sometimes placed on short rails for stationary, nontraveling use if the crane was originally procured in this configuration. Assisting in maintaining the stability in each of these configurations are the
FIGURE 19.9  Top-slewing saddle-jib tower crane.

FIGURE 19.10  Anchoring the first mast section of a top-slewing tower crane into an engineered concrete foundation.
counterweights installed on the counter-jib of the crane which is the most recognizable feature of top-slewing tower cranes. The undercarriage of a traveling crane also carries the traveling motors for the crane.

- **Mast.** Often termed *tower*, the mast is assembled of modular lattice-type sections (hence, the term *sectional tower crane*, which is also used for top-slewing cranes). When being erected, always by another piece of equipment, the crane will rise, section after section, to a certain initial height. Later on, it can climb itself with the addition of more sections. A hydraulically operated telescopic climbing frame (or climbing cage) is used to raise the upper part of the crane, thereby making room for the insertion of a new section, which is lifted and moved into place by the crane itself (Figure 19.11). In that regard, then, the crane has no height limit. Typical section lengths are 10 to 15 ft, but various other lengths exist, including exceptionally long sections (e.g., 40 ft) for city cranes, where speed of erection (determined, among other things, by the number of sections) is of the essence. (Note that the term *city crane* is not exclusive for tower cranes, as it is also used for certain types of mobile cranes.)

FIGURE 19.11 Top-slewing tower crane climbing itself by the addition of new sections (Trump Tower, Chicago).
Operator cab. Located at the top of the mast, above the slewing ring, is the operator cab. It is either located co-centrically on the mast (as in Figure 19.9) or is attached to it on the side (as in Figure 19.12). Because tower cranes can rise to great heights, some crane models can optionally be equipped with a small elevator for the operator. In some European countries (e.g., Sweden and the Netherlands), such elevators, or similar means (e.g., a climbing operator cab), have recently become mandatory for cranes exceeding climbing heights of around 100 ft. (Note that the climbing height would be the full crane height in the case of a freestanding crane only; for taller cranes, braced to the constructed building, climbing begins at the top of the building or near its top, where a temporary bridge connects the building and the crane.) Today’s operator cabs feature a comfortable and ergonomic work environment. Cabs are optionally fitted with air conditioning and similar other comforts to support a safer and more productive work environment; in particular, the window area has been increased (see Figure 19.12) to allow better vision of the site and greater control of rigging and hook movement.

Slewing ring. This is the slewing (rotating) mechanism of the crane, located at the top of the mast right below the jib. It allows the entire upper part of the crane, which includes the jib and the operator cab, to slew while leaving the mast stationary. This is essentially what allows the mast to be braced to a permanent structure, thereby rising to any desirable height.

Jib. There are several jib configurations for top-slewing tower cranes. The most common configuration is the horizontal saddle jib, also known as hammerhead (see Figure 19.9). It has a counter-jib, which carries, in addition to counterweights, the main motors, controls, and cable drum of
the crane. The jib and the counter-jib are held by pendants (tie bars) connected to the top part of the crane, called the cathead or A-frame. A trolley moving along the jib (in a motion called trolleying) carries the lift cables and hook block. Similar to the mast, the lattice-type jib is modular, with several length options available within the maximum length prescribed for the given crane model. Flat-top cranes, also nicknamed topless, have a pendant-free, cantilever jib connected only to the mast (Figure 19.12). Sparing the use of a cathead, these cranes are particularly suitable for a shared-zone, multi-crane environment, where overlapping cranes must be set up to different heights (Figure 19.13). Because safety clearance must be maintained between the uppermost part of the lower crane and the jib-bottom of the higher crane, the entire length of the cathead frame, which could be as much as 40 ft, is gained in crane height when using flat-top cranes. This is also an advantage in situations with height restrictions, such as near airports. Flat-top cranes, however, have become very popular regardless of the above constraints due, for example, to their ease of set-up, and they now constitute a growing share of crane fleets in America. Another popular jib configuration is the luffing jib (Figure 19.14). Top-slewing cranes of this type, nicknamed luffers, do not use trolleys but rather change their operating radius by raising and lowering the jib. Many luffing-jib crane models feature a very short counter-jib; along with the luffing capability, it may be an advantage when the crane operates in proximity to other cranes or obstacles (such as nearby buildings). These cranes, therefore, are often seen in high-density urban construction. A moving-counterweight system for luffing-jib cranes, first introduced several decades ago, appears to have regained some interest recently. This mechanism increases the distance between the counterweight and the mast as the jib is lowered and thereby causes less stress to be placed on the crane’s structure. However, the moving-counterweight system has thus far had only limited use. (The two luffers in Figure 19.14 are fitted with moving counterweights.)

Top-slewing tower cranes are engineered to withstand high winds. This becomes particularly important at the heights these cranes often operate and is one of the advantages tower cranes have over mobile cranes. To ensure crane stability when the crane is unattended, tower cranes are left to slew freely with the wind, or to weathervane (see Figure 19.13).
19.4.1.3.2 Transportation, Erection, and Dismantling

Top-slewing cranes, disassembled to their basic parts, are transported by any number of large trucks to the worksite. Preferably, the site would have adequate space to store these parts for later connection to larger assemblies using a smaller mobile crane than the one needed later to erect the tower crane. These larger assemblies would then be lifted up by a bigger mobile crane for assembly and erection of the tower crane (Figure 19.15a). When no such storage space is available, the tower crane may have to be erected directly off of the transporting trucks. For an urban site on a busy street, just-in-time delivery of crane parts may be required to minimize street closures. As mentioned above, a top-slewing tower crane requires another crane to erect it. The erecting crane is almost always a mobile crane, often two mobile cranes, unless the site is to have two or more overlapping tower cranes located close enough to each other such that the big cranes can be erected first and then used to erect some of the others. Dismantling the tower crane when its service is no longer needed is essentially the same process in reverse (Figure 19.15b), except that it may become more complicated because a building is now standing where there had been an empty space when the tower crane was originally erected. Quite often, a larger mobile crane will be required for dismantling than the one used for erection. These processes take from a few days up to a few weeks, depending on the size of the crane erected or dismantled, its location with regard to the constructed building, and accessibility of the erecting or dismantling crane. Bad weather, particularly winds, may be a delaying factor. Earthwork and foundation work, when required, add to setup time. Dismantling a crane climbing inside the building is a particularly complicated, long, and costly process. It is addressed separately in the next section.

19.4.1.3.3 Operation Modes

The common operation modes of top-slewing tower cranes are freestanding, externally braced, internal climbing, and traveling:

- **Freestanding.** If the model-specific maximum freestanding height of the crane, as specified by the manufacturer, satisfies the requirements of the project, this would be the most economic solution. Top-slewing cranes can now stand free of braces to heights in the range of 200 to 400 ft, much higher than before. One of several advantages of freestanding cranes is the freedom to place them virtually anywhere in the site.
Externally braced. If lifting service is required to heights greater than those possible with a free-standing crane, the crane must be braced to the constructed building, either as a full-height external climbing crane or as an internal climbing crane. To be braced externally to the building, the crane must be placed as close as possible to the façade of the building. Braces (or ties) to the building, commonly spaced 30 to 100 ft apart, are expensive additions to the cost of the crane. These braces are made of steel and are engineered to stabilize the crane and prevent mast buckling while absorbing horizontal motions of the mast. The cost of these braces sharply increases with the distance from the façade. One other issue associated with an external braced crane is completion of the façade after the crane has been dismantled.

Internal climbing. The pros and cons of an internal vs. external climbing crane were mentioned earlier, as were those of climbing the crane in the elevator shaft or through openings in the slabs (see Section 19.2.2). A major issue with regard to an internal climbing crane is dismantling it at the top of the high-rise host building at the end of construction. In the case of more than one internal climbing crane servicing the building, the contractor should opt for taking down all cranes, but one, with each other. Sometimes, a high-rise building is serviced by two climbing cranes, one external and one internal, in which case the former may be able to dismantle the latter. In such cases, careful consideration of dismantling issues at the equipment-planning phase may affect crane location, lift capacity (i.e., greater than might otherwise be needed), and jib length (i.e., longer than might otherwise be needed). In most cases, if the use of an external tower crane for dismantling is not an option, then climbing cranes can be dismantled by one of two means: a mobile crane or a derrick. The mobile-crane option is faster and less complicated; however, it is an option only if two conditions are satisfied: (1) a mobile crane with the required vertical and horizontal reach is available, and (2) the vicinity of the building allows for setup of the mobile crane. It would be advantageous if the internal crane climbed near the façade of the host building.
alongside which the dismantling mobile crane would be set up. If a mobile crane is not an option, which is always the case in the construction of ultra-high-rise buildings, then the tower crane to be dismantled can erect a derrick (Shapiro et al. 2000), which can then dismantle the tower crane and, in turn, be dismantled manually and taken down in small parts using the building elevator. Similarly, a custom-made hoisting apparatus may be used instead of a derrick. Another option, though seldom used, is the use of a helicopter.

- Traveling. As mentioned earlier, the crane in this operation mode is essentially freestanding. The railway can be either straight or curved. Preparatory earthwork is required, and the crane manufacturer typically specifies the maximum grade allowed (commonly 1%).

### 19.4.1.4 Bottom-Slewing Tower Cranes

#### 19.4.1.4.1 Structure and Configuration

The main parts of a typical bottom-slewing tower crane (Figure 19.16 and Figure 19.17) include:

- **Undercarriage.** Unlike top-slewing cranes, which are often configured without an undercarriage, bottom-slewing cranes would always have an undercarriage to connect between the ground or any other supporting surface and the slewing crane. The undercarriage is commonly either stationary (Figures 19.16a and Figure 19.17b) or rail-mounted. Light models may have a wheeled undercarriage, but this is used only for infrequent crane relocations on the jobsite, without loads, and not for operation. In truck-mounted tower cranes (see below), the truck replaces the conventional undercarriage. Another configuration, seen mainly in Europe, is that of a crawler undercarriage (Figure 19.16b). Whenever it is not in motion, the crane is stabilized by outriggers.

- **Slewing ring.** The slewing ring of the top-slewing crane is located near the top of the crane, but the slewing ring of a bottom-slewing crane is located near its base, such that practically the entire crane—slewing platform, mast, and jib—can slew. For this reason, the mast cannot be braced to the building for increased stability, and its height is limited.

- **Slewing platform.** The slewing platform carries, in addition to the mast, the entire ballast of the crane, as well as the motors. To balance the crane, the ballast blocks are located at the rear of the platform, always opposite the jib. To be most effective, the greatest possible distance between the ballast and the mast would be desired. On the other hand, the smallest possible projection of the rear end of the platform from the footprint of the crane (as determined by the undercarriage) is desired to allow crane setup in close proximity to the building and for increased safety. Newer models, therefore, have a compact platform, compensated for by a high stack of ballasting concrete blocks.

- **Mast.** Earning the bottom-slewing tower crane the name telescopic tower crane (to distinguish from the sectional top-slewing crane), the mast of this crane is made of two to three telescoping parts. This type of structure is in line with the limited height of the crane and, even more so, with its rapid self-erecting concept. The operator cab is traditionally located at the top of the mast, or the crane can be operated from a control post at the lower part of the mast. Many new models now offer a climbing cab that can move along the mast for optimal view (Figure 19.17b). Wireless radio remote control of these cranes is now offered on most models. Masts are either lattice (Figure 19.16) or hollow section (Figure 19.17). Hollow-section masts used to be common only on smaller models but are increasingly being seen on larger models, as well. In smaller models, this hollow-section mast is often foldable instead of telescopic.

- **Jib.** The lattice-type jib is similar to the main jib (i.e., no counter-jib) and trolley system of the top-slewing crane; however, it is foldable for fast erection and dismantling and, in many models for a shorter jib work option. Some models feature a telescoping jib. Unlike top-slewing cranes, where the horizontal jib and the luffing jib are two different crane configurations altogether, the jib of the common bottom-slewing crane can usually be raised, though not in a sharp angle (commonly up to 30°), while maintaining trolley movement. This grants the initially height-limited crane an additional lifting height. Some models have an articulated jib, in which the part closer to the mast is horizontal and the outer part can be angled upward.
FIGURE 19.16 Bottom-slewing tower crane, lattice-type mast (two-part telescope): (a) general view, stationary undercarriage; (b) slewing platform and ballast, crawler undercarriage. Note the operator standing post.
FIGURE 19.17  Bottom-slewing tower crane, hollow-section mast (three-part telescope): (a) general view; (b) slewing platform and ballast, stationary undercarriage. Note the climbing operator cab.
19.4.1.4.2 Transportation, Erection, and Dismantling

Convenient transport, erection, and dismantling are the main features of these cranes. Towable by a truck or a semitrailer for transportation between jobsites, they are usually mounted on a designated wheeled undercarriage in a fully folded position (Figure 19.18). For relocation on the jobsite, partial folding suffices. Erection and dismantling are performed by the crane itself, using its own motors. Light models may be erected and dismantled within an hour, but heavier models may take up to one day.

19.4.1.4.3 Operation Modes

Operation modes of bottom-slewing tower cranes, as dictated by the means of their mobility, are stationary, rail-mounted, crawler-mounted, and truck-mounted:

- **Stationary.** The crane is stabilized by outriggers. It is folded partially or fully for relocation on the site, but light models can be towed in an upright position. Some models are self-propelled (for relocation only); moving on wheels, they require a hardened surface, usually with a maximum ground gradient as specified by the manufacturer. By no means is the crane allowed to move with a load.
- **Rail-mounted.** Same as with top-slewing cranes, this type of crane can travel with its load, assuming a work envelope whose size is limited only by the length of the railway.
- **Crawler-mounted.** This mode is suitable for operation in rough and sloping terrains. Bottom-slewing cranes of this type can accommodate both longitudinal and transverse gradients and are commonly equipped with a balancing mechanism. For lifted loads or ground slopes exceeding certain specified values, the crane must work on its outriggers.
- **Truck-mounted.** This is an old concept that has seen a renaissance in recent years. Essentially a hybrid configuration combining a mobile crane and a tower crane, it combines some key features of these two crane types—mainly, the mobility of the truck crane with the height and reach of the tower crane where lifting requirements do not call for a larger crane.

19.4.1.5 Technical Data

The major technical data relevant to selection of tower cranes, top-slewing and bottom-slewing alike, are (1) jib length, (2) lifting capacity, and (3) lifting height. These data determine the work options and ranges of a crane, as well as the crane's suitability for a given project or for a specific type of projects. Many other pertinent data, such as footprint dimensions, mast cross-section, motors power, and speeds,
are decisively dictated by these three parameters. Tower cranes are manufactured in a great variety of models in terms of jib length, lifting capacity, and lifting height, to cater for the great variety of building dimensions and construction methods. The broad range of tower cranes offered on the market can be classified into four classes by their size and designation:

- **Light cranes** are designated for maintenance and renovation works in buildings up to about four stories and for the construction of one- to two-story structures. These kinds of projects are characterized by material batches of 1000- to 2000-lb maximum weight and a relatively short duration of the crane on the jobsite; therefore, this class of cranes is manufactured as bottom-slewing cranes only.

- **Medium cranes** are designated for the construction of cast-in-place concrete structures using conventional or industrialized methods (e.g., using large form panels), with the possible combining of certain precast elements (e.g., flights of stairs). This category of structures is characterized by material batches of 2000- to 5000-lb maximum weight, varying crane service durations on-site (depending mostly on the height of the constructed building), and a broad range of building heights. Cranes in this class are manufactured both as bottom-slewing cranes, suitable mainly for structures up to eight stories high, and as top-slewing cranes, suitable mainly for structures six stories or taller. Because this kind of building constitutes the majority of buildings, these are also the most widely used tower cranes.

- **Heavy cranes** are designated for the construction of structures using precast methods or other methods that combine heavy elements. The central attribute of these structures is building components weighing 5000 to 13,000 lb. Cranes in this class are mostly top-slewing cranes; the small number of bottom-slewing models in this class fall in the lower part of this weight range.

- **Special-application cranes** are designated for the construction of unusual structures in terms of their size, weight of elements, or site conditions (e.g., nuclear plants, dams). These cranes, exceptionally large in jib length, lifting capacity, or lifting height, are always manufactured as top-slewing cranes.

Table 19.4 presents typical technical data for tower cranes by the classes listed above. Following are some explanations with regard to the headings in Table 19.4, as well as several other technical features of tower cranes.

**Jib length** is the maximum working radius, measured from the centerline of the mast to the centerline of the trolley at the jib end. It is the maximum length offered with any specific crane model; however, as mentioned above, most crane models can be configured with shorter jibs. The lifting capacity of the crane changes with the work (or lifting) radius, as determined by the distance of the trolley from the mast. The crane can lift its heaviest load (maximum lifting capacity) at a certain model-specific radius (often termed minimum radius), after which lifting capacity decreases gradually until it reaches its minimum at the end of the jib (jib-end lifting capacity in Table 19.4 but often referred to as maximum lifting capacity at maximum radius or tip capacity, for short). No heavier loads can be lifted at radii smaller than that minimum radius. Maximum lifting capacity at the end of the jib is governed by the structure and overall stability of the crane. Maximum lifting capacity at minimum radius, however, is additionally governed by the strength of the lifting cables. Most tower cranes can use either a single cable (two-part line) or a double cable (four-part line). With a double cable, maximum lifting capacity at minimum radius is doubled (though at the expense of a 50% reduction in hoisting speed). As for maximum lifting capacity at maximum radius, not only is it unchanged with a double cable but it also drops somewhat compared to a single cable, as the extra cable weight reduces the net lifting capacity.

Tower cranes are occasionally denoted by their lifting moment, commonly computed by multiplying the maximum jib length by the end-of-jib maximum lifting capacity. Note, though, that although it provides some indication of the size of the crane, this parameter discloses no information with regard to jib length or lifting capacity. Lifting height of a crane denotes the maximum height to which the lifting hook can be raised, which is slightly lower than the bottom of the jib. The maximum allowable height of a building to be serviced by a crane is at least 20 ft lower than the lifting height of the crane.
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Crane cycle time and work output are largely determined by the speed of the crane’s various motions, as has already been demonstrated above (see Section 19.2.2.2). Common speeds are as follows:

- **Hoisting** (vertical), 150 to 500 ft/min
- **Trolleying** (radial), 100 to 350 ft/min for top-slewing, 60–200 ft/min for bottom-slewing
- **Slewing** (circular), 0.6 to 1.0 rpm (0.8 for most makes and models) for top-slewing, 0.8 rpm for bottom-slewing
- **Traveling** (horizontal), 65 to 100 ft/min

When estimating cycle-time durations, due attention should be given to the normal mode of operation in which the crane operator exercises two, sometimes even three, motions simultaneously. Additionally, loading and unloading times have to be considered; in low-rise building, they constitute the major part of the cycle time. Unloading can be particularly long when accurate placing of elements such as flying forms or precast panels is required.

### 19.4.2 Mobile Cranes

#### 19.4.2.1 Introduction

Unlike the tower crane, which essentially is a stationary machine even when it has acquired some mobility capabilities, the mobile crane is what its name implies—a self-propelled mobile machine, capable of moving freely about the jobsite and between jobsites, as well. Contrary to the silhouette of the tower crane as a vertical mast with a horizontal jib at its top, the jib of the mobile crane—termed boom—is inclined and connected directly to the carriage of the machine. The variety of tower crane types, as presented above, may appear to be wide, but the mobile crane itself features a great many more types and models, and it can range in size from small machines that fit in the wagon of a pickup truck to gigantic machines that dwarf almost any other construction equipment.

Mobile cranes owe their extensive use in North America to the ambitious heavy civil and infrastructure projects this country has launched since the early 20th century. In part, this is also due to the developed agricultural machinery industry, thought to be the motivated power behind the birth of heavy construction equipment in the United States. Among other things, this has contributed to the great versatility of

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TABLE 19.4 Technical Data for Tower Cranes

| Class and Crane Type | Light Cranes | Medium Cranes | Heavy Cranes | Special Cranes
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jib length (ft)</td>
<td>50–80</td>
<td>80–150</td>
<td>100–150</td>
<td>150–180</td>
</tr>
<tr>
<td>Maximum lifting capacity (lb)</td>
<td>2000–5000</td>
<td>5000–18,000</td>
<td>5000–20,000</td>
<td>10,000–20,000</td>
</tr>
<tr>
<td>Lifting moment (ton-ft)</td>
<td>35–80</td>
<td>80–250</td>
<td>140–300</td>
<td>300–600</td>
</tr>
<tr>
<td>Maximum freestanding height (ft)</td>
<td>50–70</td>
<td>70–110</td>
<td>110–200</td>
<td>100–130</td>
</tr>
</tbody>
</table>

- a For rail-mounted traveling cranes: 100 ft for bottom-slewing, 230 ft for top-slewing, excluding special cranes.
- b Data provided do not include cranes at the far extreme of this range. The largest tower crane model known to have ever been manufactured, the K-10,000, can lift 220,000 lb at the end of its 330-ft long jib (i.e., 36,000 ton-ft lifting moment). About one dozen of these cranes have been manufactured (by the Danish manufacturer Krøll) and are known to be still operating at this time.
Equipment for Concrete Building Construction

Mobile cranes, which until merely a decade ago were equally associated with non-building operations, such as excavation, pile driving, and demolition, and with building construction per se. Even today, these machines find their main use in a great variety of civil engineering projects other than building construction. Some mobile cranes types, however, show great presence on building construction sites, whether for short-term tasks or throughout most of construction (Figure 19.19). If for no other use, they are the machines that set up the tower cranes at the onset of construction and dismantle them at the conclusion of their service on site. This is a classic demonstration of the mobile crane’s main features: its capacity to handle heavy loads and its rapid deployment. A relatively small mobile crane has a lifting capacity equal to that of a heavy tower crane. The high-end mobile cranes can lift hundreds of tons.

While the major types of mobile cranes are mentioned in what follows, the focus in this chapter is on the types used in building construction. It should be stressed that concrete building construction involves a great extent of duty-cycle work, namely, work in which the crane is engaged in repetitive lifts of relatively short cycle time. Handling a bucket for concrete placing is a typical example of such work. While tower cranes inherently are suitable for duty-cycle work, mobile cranes are not so. Because loads involved in cast-in-place concrete building construction are relatively low, mobile cranes—of various types—that are fitted for duty-cycle work are commonly of the small- to mid-size models.

19.4.2.2 Types and Configurations

Mobile cranes are characterized and distinguished from each other mainly by two parameters: their undercarriage (or carrier) and their boom. The two types of undercarriage are wheeled and crawler, and the two types of boom are lattice and telescopic. Combinations of these two parameters yield four different machine types; however, other parameters, such as mobility, accommodation of varying ground surfaces, and rigging mechanisms, add more types to the large class of mobile cranes. Common to all of these types is their suitability to meet lifting requirements in which they have an advantage over tower cranes: handling of heavy loads, short-term lifting services, and various transportation works requiring frequent relocation of the crane on the jobsite. These characterize the kinds of construction projects where the capabilities of mobile cranes are maximized.

19.4.2.2.1 Boom Configurations

The lattice boom is made of lattice-type steel sections, similar to the mast sections of tower cranes. The number of sections varies according to the desirable boom length. There are always two pyramid-shaped...
end sections. The length of the boom is fixed and cannot be changed in the course of work, unless the boom is lowered and sections are added or taken out, thus work height and radius change due to changes in the inclination angle of the boom. An auxiliary boom (boom extension), known as a fly jib, can be fitted angularly to the end of the main boom, giving the crane farther reach for better building coverage (see Figure 19.19). In larger crane models, this boom extension is often longer than the main boom of the crane.

The telescopic boom is made of telescoping sections. It is operated hydraulically, allowing boom length and inclination to change in the course of work. A short, straight, lattice-type extension boom can be connected to the end of the telescopic boom. When not in use, this extension boom is stowed next to the telescopic boom such that its connection is convenient and rapid (see Figure 19.21). Additionally, a short auxiliary boom, commonly of the hollow-section type, can be fitted to the end of the extension boom. A lattice-type fly jib, same as with the lattice main boom mentioned above, is also very common (see Figure 19.15a).

The main advantage of the lattice boom is its simple structure and, consequently, its lower cost. It is also the preferable boom for cranes with exceptionally high loading capacities. The telescopic boom, on the other hand, offers two important advantages that account for the growing popularity of this type of boom: (1) more efficient crane use due to the continuous adjustment of boom length in the course of work, and (2) much faster crane deployment, as compared to complicated rigging and unrigging of the lattice boom, which often requires the assistance of other lifting means and separate transportation.

The lifting capacity of the crane, whether equipped with a lattice or telescopic boom, changes with the boom's length and inclination angle. The minimum working radius is attained at the shortest boom length and the most upright possible boom position (i.e., minimum inclination angle when measured from the vertical). Although varying with crane configuration and model, this minimum radius is commonly taken as 10 ft nominally. This is important because mobile cranes are often denoted by their maximum lifting capacity at this nominal minimum working radius, although no standard universal rating system exists. For example, a 100-ton crane is likely to have a maximum lifting capacity of 100 tons, effective at a 10-ft radius, which corresponds to a lifting moment of 1000 ton-ft.

19.4.2.2 Truck Cranes

Truck cranes are suitable mainly for short-term lifting assignments; this is not the kind of a crane seen working for extended durations on construction sites. The superstructure of this crane, which includes the boom (lattice or telescopic), engine, counterweight, and operator cab, is mounted on a specialized carrier truck. Connecting the two is a slewing ring (“turntable”) allowing a full 360° rotation. The crane travels the public road system (with a retracted telescopic boom or partial lattice boom) essentially like any other truck but can also travel on rough roads. To utilize its maximum lifting capacity, the crane must be leveled and stabilized on its outriggers while in operation; it can operate while on its wheels to only partial capacity. Because of the high loads these machines transfer to the ground through the outriggers, mats of various sizes must be used to spread the load, as depends on the soil-bearing capacity. Together with the extended outriggers, these mats increase the overall width of the vehicle, which should be taken into account when planning the lift and the crane's exact location.

Lattice-boom truck cranes are gradually making room for telescopic-boom truck cranes, given the greater flexibility of the latter in moving between jobsites. This trend has been observed, initially in Europe and in recent years in North America, with regard to truck cranes in general, due to the growing popularity of all-terrain cranes (see below). However, truck cranes—both lattice-boom and telescopic-boom—appear to be maintaining their standing as a viable option when no particularly rough-terrain site conditions have to be accommodated, due mainly to their lower cost compared to all-terrain cranes.

A different style of truck crane has recently appeared on the market. Nicknamed the city crane and featuring a compact design, lower boom mounting, and a single dual-purpose (truck and crane) operator cab, it is designated mainly for urban work and travel. Often confused with truck cranes are truck-mounted cranes. The main difference is the carrier vehicle—a standard-type truck in the truck-mounted crane, a specialized truck in the truck crane; truck cranes also have, in general, higher lifting capacity. Truck cranes are manufactured as an integral (though often modular) unit by the same manufacturer, but different manufacturers supply the truck and the crane components for truck-mounted cranes.
19.4.2.2.3 Crawler Cranes
The revolving superstructure of the crawler crane is similar to the superstructure of the truck crane but is mounted on a crawler undercarriage. This change from the truck crane has several implications, in that the crawler crane has better maneuverability and offers outrigger-free work with rapid relocation within the jobsite but requires longer transfers between sites, including loading it on a haul truck. Given these qualities, crawler cranes (Figure 19.20) are particularly suitable for jobs with difficult ground conditions and for projects requiring frequent crane movement. Due to the usually long on-site service, the importance of convenient transfer between sites is reduced, and the majority of crawler cranes have traditionally been equipped with lattice booms. For some uses, however, a crawler crane with a telescopic boom might appear an appropriate option. For this reason, in addition to the growing attractiveness of telescopic booms in general, smaller crawler telescopic-boom crane models have recently begun appearing on the market. One application of such a crane would be on urban projects in areas where contact pressure with the street surface is restricted due to underground facilities. Wheeled or outriggered undercarriages may not be suitable under these conditions, but a rubber crawler telescopic-boom crane that can travel on pavement would be. A crawler undercarriage also serves as a platform for what is known as the American-type tower crane, which is a crawler crane rigged with a tower attachment made up of a vertical lattice boom fitted at its top with a luffing boom. In essence, this is a more robust version of the crawler-mounted bottom-slewing crane, exclusive of trolleying capability.

19.4.2.2.4 Rough-Terrain Cranes
Arguably the most visible mobile crane on a great variety of construction sites the world over, the smaller models of rough-terrain cranes are often used as high-mobility auxiliary equipment on building sites that employ tower cranes as the central lifting services providers. As implied by its name, the crane is designated mainly for lifting works on sites with rough terrain conditions and frequent relocation on the jobsite. The high-ground-clearance, wheeled undercarriage of this crane (Figure 19.21) has two closely spaced axles and large wheels. With a retracted boom, the crane has the ability to move on steep slopes; some models can manage grades up to 70% (35°). At the same time, the crane can travel the public road system, although commonly in speeds not exceeding 25 mph and in low driving comfort, which is why it is often hauled on a low-bed truck between jobsites. The operator cab is either a fixed part of the undercarriage or is part of the superstructure and rotates with the slewing of the boom (see Figure 19.21a). Usually equipped with a telescopic boom, it can also use a
quick-fitting, lattice-type extension boom to which an additional auxiliary boom can be added. Extension and auxiliary booms, stowed alongside the main boom, can be seen in Figure 19.21b, and the auxiliary boom is shown in Figure 19.21a. The rough-terrain crane can be utilized to its full lifting capacity when operating on its outriggers; however, because it is designated to provide lifting services requiring constant movement on the jobsite, it can carry loads while on its wheels and in motion, though to partial capacity only, depending on ground conditions, speed, working radius, and type of tires. In any case, moving with a load can be carried out only when the boom is oriented along the longitudinal axis of the crane. Model-specific allowable load ratings under various conditions are provided by crane manufacturers.
19.4.2.2.5 All-Terrain Cranes

Relatively new to North America, all-terrain cranes (Figure 19.22) combine the best of truck cranes and rough-terrain cranes. The number of models offered by manufacturers is constantly growing in response to the increasing demand for these telescopic-boom cranes worldwide. These cranes cannot accommodate ground slopes as steep as those manageable by rough-terrain cranes but their maneuverability is better than that of truck cranes. At the same time, they can travel public roads at much higher speeds and with greater comfort compared to rough-terrain cranes. Boom configuration and extension options are similar to those of rough-terrain cranes. Tilting operator cabs have become standard (Figure 19.23); they improve
operator view and increase operation efficiency while preventing neck strain. In terms of technology and features, all-terrain cranes are perhaps the most advanced and sophisticated mobile cranes offered today, as reflected in their high price and the high lifting cost per unit tonnage for these cranes.

### 19.4.2.2.6 Specialized Cranes

This class of mobile cranes includes a variety of enhanced lifting capacity machines only seldom used on concrete building construction sites. They usually feature a lattice boom stabilized by a rear mast and mounted on specialized trucks or crawlers, often with various other counterweight-carrying assemblies. These machines are perhaps the largest and most powerful of any construction equipment manufactured; their maximum lifting capacity now approaches 2000 tons. Accordingly, their transportation, setup, and dismantling are exceptionally complicated.

### 19.4.2.3 Technical Data

Table 19.5 presents typical technical data for mobile cranes.

### 19.4.3 Cranes in the Electronic Age

Developments in computerization and communication have not overlooked the world of construction equipment. Today’s novel crane models are electronically loaded with regard to their drives, controls, monitoring, and communication. Whether standard or optional, various advanced-technology features are aimed, among other things, at enhancing crane work productivity and safety. A multitude of auxiliary systems is offered by both crane manufacturers and the crane peripheral industry to support crane selection and operation, as well as equipment maintenance and fleet management. Many of the systems are integral part of new cranes only, while others can be fitted on used cranes as well, thereby upgrading their operation. Only three types of developments are mentioned here as examples of the abundance of systems available on the market:

- **Selection software.** These advanced graphics software packages are helpful in dealing with the “hard” technical and engineering aspects of crane selection and location, as well as lift planning. As a minimum, they serve as structured checklists of all site and machine parameters that have to be considered; however, their main asset lies in their facility to check a great number of alternatives instantly. Some of the packages offer crane databases containing built-in dimensions and capacities of common equipment models by various manufacturers. Most packages available on the market handle mobile cranes only, but some of them accommodate tower cranes as well (Meehan, 2005).

- **Camera systems.** Lifting operations involving concealment of the work zone or travel path from the operator’s eyes, often termed blind lifts, are very common in crane work, for both tower and mobile cranes. The use of signalers is the common solution the world over; no safe blind lift can be performed without a signaler—or several of them—using hand signs or radio communication, or both. In many countries, the presence of at least one signaler on a site using a crane is mandatory by law. Many crane-related accidents have been attributed, wholly or partly, to faulty signaling for various reasons (such as high worker turnover, inadequate signaler training, and language barriers, to name but a few). Crane-mounted video camera systems (Figure 19.24), available for both tower and mobile cranes, help overcome most of the safety problems associated with blind lifts. They also have the potential to increase crane work productivity due to speedier work and shorter cycle times. The camera, installed on the trolley of the tower crane or the boom end of the mobile crane, is permanently directed downward at the work scene, with the lifting hook constantly located at the center of the image. The video image is processed and the picture of the load and its immediate surrounds is transmitted, via wireless communication, to a monitor located in the operator cab (Howes, 2005; Shapira et al., 2008).

- **Anticollision systems.** Combining hardware and software, these systems are devised to prevent collisions of tower cranes operating in shared zones, a common safety hazard on construction sites employing more than one tower crane. The systems use wireless and various other advanced
**TABLE 19.5 Technical Data of Mobile Cranes**

<table>
<thead>
<tr>
<th>Maximum Lifting Capacity (ton)</th>
<th>Telescopic-Boom Truck Crane</th>
<th>Lattice-Boom Truck Crane</th>
<th>Lattice-Boom Crawler Crane</th>
<th>Rough-Terrain Crane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length of Main Boom (ft)</td>
<td>Maximum Hook Height with Fly Jib (ft)</td>
<td>Length of Main Boom (ft)</td>
<td>Length of Fly Jib (ft)</td>
</tr>
<tr>
<td>10</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>20</td>
<td>25–80</td>
<td>100</td>
<td>30–110</td>
<td>13</td>
</tr>
<tr>
<td>40</td>
<td>35–100</td>
<td>150</td>
<td>40–170</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>40–120</td>
<td>170</td>
<td>40–190</td>
<td>60</td>
</tr>
<tr>
<td>80</td>
<td>40–130</td>
<td>190</td>
<td>40–200</td>
<td>60</td>
</tr>
<tr>
<td>100</td>
<td>40–140</td>
<td>210</td>
<td>50–200</td>
<td>60</td>
</tr>
<tr>
<td>150</td>
<td>—</td>
<td>—</td>
<td>50–300</td>
<td>60</td>
</tr>
<tr>
<td>250</td>
<td>—</td>
<td>—</td>
<td>50–330</td>
<td>100</td>
</tr>
<tr>
<td>450</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>700</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1000</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*Note: Common ranges for all-terrain cranes (largest machines in parentheses): maximum lifting capacity, 40–300 (1300) ton; length of main boom, 100–200 (330) ft; maximum hook height with fly jib, 140–350 (560) ft.*
FIGURE 19.24 Video camera system mounted on a tower crane: (a) moving unit (camera case, batteries, solar panel) mounted on the service balcony of the jib’s trolley; (b) stationary unit (monitor, video decoder, controls) inside operator cab. (Photograph courtesy of Yehiel Rosenfeld, Technion, Israel.)
technologies to monitor the movements of the crane in real time; warnings are followed by automatically slowing down the crane motion and, eventually, by completely stopping the crane. Most anticollision systems are designed to prevent collisions with adjacent buildings and other obstacles, such as power lines, as well as slewing and trolleying over areas defined as prohibited zones, such as busy streets and public buildings. These added features make the systems useful on single-crane sites, as well. Due to the fairly high price of these systems and the tendency of construction firms to adhere to old, traditional solutions, the use of these systems so far has been limited primarily to multi-crane projects. Today, though, they have come to be appreciated by a growing number of construction firms that are opting to use them on sites with a small number of cranes, as well.

**19.5 Truck Loaders**

The truck loader, also known as a crane truck or boom truck, is a payload truck fitted with a crane, thus making up a combined hauling and loading self-contained unit. A subclass of the telescopic-boom truck crane and often confused with the similar truck-mounted crane (see Section 19.4.2.2.2), this type of equipment is listed here separately because the concept is completely different. Whereas the truck crane and truck-mounted crane are first and foremost cranes mounted on a wheeled carrier for mobility, the truck loader is initially a hauling truck that is then equipped with a loading crane (hence, the term loader crane is also used for this equipment). Several differences between truck loaders and truck cranes or truck-mounted cranes can be identified:

- The truck loader uses a standard commercial truck chassis, while the truck crane uses a specialized carrier (although the truck-mounted crane also uses a standard chassis).
- The truck loader transports its own payload, although it often provides lifting services other than to do with its hauled loads. Truck cranes and truck-mounted cranes have no cargo-hauling capacity whatsoever.
- Truck loaders are smaller than truck cranes, and their lifting capacity is reduced compared to that of truck cranes.
- The truck crane often requires special permits and provisions to travel public roads and city streets, but the truck loader is a regular vehicle in that regard.
- Truck cranes are commonly owned by crane rental companies (but sometimes by sufficiently large construction companies), whereas the truck loader is usually owned by its operator.
- Truck cranes may stay on-site for long hours or days, but truck loaders commonly provide short-term services, often staying on-site less than one hour and visiting several sites on the same day (hence, the terms taxi crane and service crane are often used for this equipment).

Truck loaders are characterized mainly by the type of boom: a knuckle-boom truck loader has an articulated folding boom; a stiff-boom truck loader has a straight telescopic boom. The end section of the knuckle boom can also extend telescopically. Some booms feature a basic folding configuration with a stiff-boom end section.

The use of knuckle-boom truck loaders (Figure 19.25) is more widespread, and the number of models of this type offered on the market is considerably greater than that of straight-boom truck loaders. The booms of both types are commonly mounted directly behind the truck cab, facing rearward. This way, most of the truck bed is left free for cargo. A newer and less common configuration is of a rear-mounted boom, leaving smaller space for cargo but allowing for increased lifting capacity, as the boom is supported directly on the rear axles. Featuring a slewing upper-structure resembling that of the truck-mounted crane, these rear-mounted boom models allow operation from a seat, often enclosed in a cab. This is in contrast to the regular truck loaders, which are operated from a stand-up station (most models have two such stations, one on each side of the truck, or even more). This makes a big difference in terms of operation convenience, particularly in bad weather. Typical dimensions and capacities of truck loaders are given in Table 19.6.
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On the construction site, truck loaders offer advantages in both of their service modes. As independent hauling and loading equipment, they can save crane time by self-unloading their cargo (or picking up cargo from the site), as well as by lifting it directly to where it is needed, within the reach limit of the boom. They also have an advantage in being able to drop off or pick up cargo outside the work envelope of cranes at the site. Their hourly operation costs are lower than those of on-site trucks or rough-terrain cranes which is why, on some low- to mid-rise building projects as well as many non-building project types, there is a preference to use truck loaders quite frequently on an on-demand basis, rather than maintaining a resident crane on-site (see Figure 19.25).

FIGURE 19.25 Knuckle-boom truck loader in form-assembly work.

TABLE 19.6 Technical Data of Truck Loaders

<table>
<thead>
<tr>
<th>Properties</th>
<th>Articulated Boom</th>
<th>Straight Boom</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Common Range</td>
<td>Largest Machines</td>
</tr>
<tr>
<td>Lifting moment (ton-ft)</td>
<td>10–200</td>
<td>500</td>
</tr>
<tr>
<td>Maximum lifting capacity (lb)</td>
<td>2000–40,000</td>
<td>60,000</td>
</tr>
<tr>
<td>Maximum radius (horizontal reach) (ft)</td>
<td>20–80</td>
<td>130</td>
</tr>
<tr>
<td>Maximum lifting capacity at maximum radius (lb)</td>
<td>1000–5000</td>
<td>20,000</td>
</tr>
</tbody>
</table>

* Maximum vertical reach above ground is 3 to 6 ft more than maximum horizontal reach in the smaller model and 10 to 14 ft more in the larger models. Most truck-loader models feature below-ground reach, as well.
19.6 Belt Conveyors

Placing concrete by belt conveyors had been popular in North America, particularly for high-volume, fast-rate pours. Belt conveyors, available in a variety of configurations, are still used but not as commonly as before, having been replaced gradually by the more popular concrete pump. One advantage of belt conveyors over concrete pumps is their ability to transport other bulk materials, such as sand and gravel, as well as concrete. Another advantage is their ability to transport coarse aggregate concrete and dry concretes, which a concrete pump cannot do.

Belt conveyors used in the mining industry, quarries, and central mixing plants are stationary and can be quite long; however, the use of belt conveyors for construction requires high mobility and, consequently, relatively short conveyors. Belt conveyors for placing concrete are either stand-alone portable units or equipment fitted onto a host carrier, such as a truck, mobile crane, or truckmixer. To be fed by a truckmixer, the feeder hopper of the conveyor must be adequately low. The concrete is then conveyed upward, either directly to its discharge location or to additional conveyor segments moving it further horizontally, upward, or downward to the final placement location.

A popular configuration is that of the truck-mounted telescopic conveyor (Figure 19.26), resembling a truck-mounted boom pump. The boom can rotate a full circle, and the truck can set up and operate under heights as low as 15 ft. Typical dimensions and capacities of this equipment are as follows:

- Maximum horizontal reach, 50 to 125 ft
- Maximum upward angle, 30°
- Maximum horizontal reach at maximum upward angle, 40 to 110 ft
- Maximum discharge height above ground, 30 to 70 ft
- Maximum downward angle, –10° to –15°
- Maximum discharge height below ground, 5 to 25 ft

A different belt-conveyor type, used mainly on civil-engineering projects requiring long conveying distances, is the series conveyor. It is composed of modular segments and typically conveys concrete up to 600 ft away from the feeding truckmixer.

19.7 Material Handlers

Telescopic-boom material handlers, known as telehandlers, first appeared in the early 1980s and have grown constantly in popularity ever since. They are today's classic multi-purpose equipment on construction sites, due to their high mobility, versatility, and reach (both horizontal and vertical).
increased popularity of telehandlers can be attributed to their usefulness on industrial, agricultural, and construction sites alike, as well as to the increasing use of materials packed and delivered to the site for forklifting on pallets. A variety of front-end attachments can easily and quickly be interchanged, so telehandlers can be configured not only as forklifts but also as cranes, front loaders, concrete buckets, access platforms, and more. Telehandlers (Figure 19.27) are wheel based and can commonly travel at up to 25 mph. They feature good site maneuverability on various ground surfaces due to their two axles and high ground clearance, as well as their advanced drive, steering, and lateral-balancing capabilities. To fully utilize their lifting capacity with an extended boom, most telehandler models operate on outriggers (often termed stabilizers with this equipment). Some telehandler models have performance enhancements such as a fully rotating upper structure (slewing handlers), forward horizontal boom motion at any height from the chassis, elevating forks, carriage side shift, and a tilting operator cab. The rapidly evolving telehandler market offers a great many models with ever-growing reach and capacity.
ranges. The telehandlers of the 1980s were able to serve up to three-story buildings, but telehandlers today can reach up to the ninth story. Some of the largest machines available today are not much different in size and capacity from small rough-terrain cranes. Typical dimensions and capacities are as follows:

- Maximum load capacity, 6000 to 20,000 lb
- Maximum vertical reach, 20 to 80 ft
- Maximum load capacity at maximum vertical reach, 2000 to 10,000 lb
- Maximum horizontal reach, 10 to 60 ft
- Maximum load capacity at maximum horizontal reach, 1000 to 4000 lb

### 19.8 Hoists and Lifts

The three main types of personnel lifts used on building construction sites are the mast-climbing passenger hoist, scissor lift, and aerial work platform. **Mast-climbing passenger hoists**, also used as material hoists, are the only personnel-movement solution for high-rise construction. No high-rise building is constructed anywhere in the world without using this type of hoist; on some buildings, several units are used. As construction progresses and the building rises, the constructor has to decide when to install the hoist; until it is installed, workers and other personnel must use the stairs (permanent or temporary). Typically, buildings ten stories and higher use passenger hoists; on taller buildings, the hoist may be installed early on, before the building reaches that height. When construction has reached the top and the permanent lifts have been installed, the hoist can be dismantled, although it often stays in service almost to the end of construction. The mast is erected outside the building next to the façade to which it is braced. After it is dismantled, some finishing work may have to be done where the ties were anchored to the building.

The climbing passenger hoist is a heavy-duty, old-concept machine that excels in safe performance. On the site, it is probably the first machine to begin running in the morning and the last one to shut down at the end of the workday; in between, it hardly ever stops. There are single-car and twin-car hoists (a twin-car hoist is shown in Figure 19.30). Car size varies from small \(2 \times 3\)-ft cars, which can take one or two passengers in addition to the operator, to large \(7 \times 15\)-ft cars capable of carrying a great many passengers. Maximum typical payloads vary from 1000 lb for the small car to 7000 lb for the large car. Electrically powered (by in-car motors), various hoist models operate at speeds up to 100 to 400 ft per min. The large-car high-speed models, capable of hoisting up to 40 passengers, are designated for service on ultra-high-rise buildings.

For a climbing hoist to be used, a landing deck and gate must be installed at each floor of the building. As a safety feature, the car would not start moving until the gate has been closed. No gate at any floor can open while the car is in motion. A gate opens only after the car has reached that floor and come to a stop at the exact level of the gate. Next to each door is a buzzer or call button that is used to call the hoist for service. Radio communication is frequently used, as well. Modern hoists now feature advanced-technology control systems; for example, with the twin-car hoist, the system can store all calls from the floors and send the car that is nearest to the floor to pick up passengers, thus reducing waiting times.

Probably the most widely used form of powered access, self-propelled **scissor lifts** for construction sites (Figure 19.28) were developed from similar industrial lifts. These four-wheel-mounted lifts can be used on smooth concrete or similar solid surfaces or as rough-terrain equipment. Operated from the upper deck or ground, the lift serves the worker using it by also hauling tools and materials, depending on the kind of work performed (e.g., lifting plywood boards for slab formwork) (see Figure 19.28). The platform may be raised only vertically, but most models offer a slide-out platform extension for increased access capability, as well as removable guardrails for easier loading and unloading of materials. Scissor lifts are used where less reach and height but greater workspace and lifting capacity are required. They are designed to provide larger platform work areas and generally to allow for heavier loads than aerial work platforms of the boom type. Common platform height is in the range of 20 to 60 ft, and lifting capacity is in the range of 500 to 2500 lb.

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Self-propelled aerial work platforms (often termed boom lifts) come in two main boom configurations: telescopic (straight) boom (Figure 19.29a) and articulated (knuckle) boom (Figure 19.29b). Reach is the main size identifier of these units; common maximum vertical reach is in the range of 30 to 120 ft, but some telescopic models extend as high as 150 ft. Common maximum horizontal reach is 20 to 60 ft; 80 ft maximum for the largest-size models. Lifting capacity of most models is 500 lb. Other than reach, machines also differ from each other in terms of maneuverability on various surface conditions and slopes, dimensions and their ability to move through narrow paths and operate in confined spaces, self-weight vis-à-vis load limits of the surface upon which they move and work, and platform size. Manufacturers offer a variety of standard and optional features that are likely to be used by workers performing their jobs from the platform. Examples include electrical outlets and air lines on the platform, as well as integrated generators with electric, air, and water lines running through the boom to the platform to power all kinds of tools (Hindman, 2005).

The articulated aerial platform is useful mainly for reaching up and over obstacles mounted on the floor and for reaching other elevated positions not easily approached by a straight boom. The telescopic, straight boom platform is especially useful for applications that require high reach capability. Booms of both types can be raised or lowered from vertical to below horizontal (although better under-reach can be attained with the articulated boom) and can be extended while the platform itself remains horizontal and stable. Articulated booms can often telescope their bottom or front section. In both boom-type machines, the operator can maneuver and steer the machine from the work platform even when it is fully extended and elevated.

19.9 Mechanized Form Systems

Mechanized cast-in-place concrete forming systems for specialized uses such as in bridge and tunnel construction have been in use for many years, and they are also widely used in the precast concrete construction industry; however, form systems for building construction, though increasingly industrialized and modernized, have not been mechanized for the most part. In fact, the classification of form systems as construction equipment, similar to other construction machines (such as cranes and pumps), is not taken for granted by many.
Two exceptions of long-standing mechanized form systems used in building construction are hydraulic tunnel forms for the combined forming of walls and slabs, and vertical slipforms. Dating many years back and originating in Europe, tunnel forms are three-dimensional room-size systems suitable for the construction of orthogonal spaces in buildings that are designed in a repetitive pattern. Hotels and office buildings are typical examples, although tunnel forms have also been widely used in America since the 1990s in apartment-building construction. After the pour, when it is time to strike the forms, they are trapped in hardened concrete at the sides (walls) and above (ceiling slab). The hydraulic mechanism of the form is then actuated to retract the forms forcefully inward from the encapsulating concrete to allow their removal. Unlike tunnel forms, slipforms were not originally devised for building construction but rather for silos, chimneys, and similar vertical structures characterized by minimal horizontal projections interfering with the continuous vertical movement of the form. Slipforms, however, soon found use as
well in the forming of elevator and utility cores in high-rise buildings. Slipforming is covered in Chapter 10. The remainder of this section describes a newer mechanized form system for walls and other vertical building elements. Interchangeably termed a self-climbing or automatic climbing system, it is essentially a crane-independent system that uses hydraulics to raise itself from one floor of the building to the next (Figure 19.30). Unlike the slipform, which is attached to the fresh concrete throughout the process, the self-climbing form retracts from the hardened concrete wall before climbing to the next level. The climbing rails and other load-carrying components of the hydraulic mechanism are supported on the hardened walls of the lower level. Two main differences between this system and a slipform that relate directly to the system’s primary designation as an automatic climbing system for use on buildings are that (1) it climbs by building floors, not continuously; and (2) it can accommodate horizontal elements, such as connecting slabs. Often nicknamed a vertical plant, it is perhaps the building form system closest to being considered equipment or a machine. Moving upward is a fully integrated, self-contained, three- or four-deck assembly, carrying a complete two-sided wall formwork system, climbing machinery, worker access platforms, material storage and reinforcing steel areas, weather protection and safety systems, and various worker utilities. Also available are provisions for concreting walls and slabs in one-pouring steps. These systems are not limited to building cores only and are often used for the entire vertical enclosure of the floors, offering integral solutions for column and beam formwork that are customizable for almost any façade design. If a climbing concrete placing boom is used, its climbing mast and running pipeline can be integrated in the climbing system, as well.

The climbing system is composed of several sections, termed platforms, depending on the size and layout of the system and the building elements formed by it (e.g., core walls only or entire building enclosure). Some climbing systems offer a central hydraulic system and climbing control such that the entire system can climb together. Other systems allow each platform to climb independently (as seen in Figure 19.30). Typically, these platforms carry 40 to 80 tons each; thus, the overall weight of the complete assembly carried up by the hydraulic mechanisms and supported by the host building can reach several hundred tons. The main advantages of these systems include: (1) savings in crane time required, (2) operability in bad weather and strong winds, (3) high production rates and fast progress, and (4) increased safety. Because of the considerable acquisition costs of these systems, they are viable solutions primarily for ultra-high-rise buildings (and other tall structures), where many reuses can be realized. A lower limit of 25 to 30 stories is the general rule of thumb; however, the economics of any specific use should be investigated by assessing the suitability of a particular system to the proposed architectural design, structural design, finishes requirements, use of other major equipment, weather, and more.
Acknowledgment

This chapter was written during the author’s sabbatical as a Visiting Professor at the University of Wisconsin–Madison. The author is grateful for the hospitality of the UW Department of Civil and Environmental Engineering. Some of the technical information on certain equipment types was compiled from commercial manufacturer material available for free public use on the Internet. This availability is thankfully acknowledged.

References


Bibliography

The following books offer additional reading on construction equipment and related topics:


Websites

In addition to information offered on the Internet by equipment manufacturers, the following websites are useful sources of current construction equipment industry and market information:

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www.constructionequipment.com (Construction Equipment)
www.cranestodaymagazine.com (Cranes Today)
www.enr.com (Engineering News Record)
www.hoistmagazine.com (Hoist)
www.liftlink.com (Lift Applications & Equipment)
www.mhia.org (Material Handling Industry of America)
www.scranet.org (Specialized Carriers and Rigging Association)
www.vertical.net (VerticalNet, including Cranes & Access)
Placing RCC at 500 cu yd/hr, Paradise (Burnett River) Dam in Australia. (Photograph courtesy of Ernest K. Schrader.)