CHAPTER 6

Considering the Construction Process of the Pyramid

1. Examination of the Fundamental Workflow

When a new large-scale factory begins mass production, the process typically starts with a site survey, followed by the basic design of the facility layout, construction of the plant, procurement of major equipment, preparation of tools and fixtures, recruitment of workers, and finally trial production before full-scale manufacturing can commence.

As I have emphasized repeatedly, the construction of a pyramid—particularly in the case of Khufu's Pyramid, which required the extraction and placement of 2.3 million stone blocks—should be understood not merely as civil engineering but as a mass-production system. Sustained and smooth operation required a high degree of process organization and workflow management.

This was not the first project of its kind. Through the construction of the Meidum Pyramid, the Bent Pyramid, and the Red Pyramid, substantial know-how had already been accumulated. The personnel responsible for these projects would have gained experience and subsequently applied it to the construction of Khufu's Pyramid.

In other words, Khufu's Pyramid—despite its unprecedented scale—was considered feasible precisely because the builders already possessed the necessary expertise. It was not an improvised undertaking.

In this chapter, I proceed under the assumption—supported by evidence from the Meidum and Bent Pyramids—that core masonry and the placement of unfinished casing stones were carried out in parallel, that scaffolding and ramps were extended upward with each completed

course, and that after the core reached its full height, the casing stones were cut and polished, followed by the removal of scaffolding and ramps.

2. Constraints Imposed by the Geometry of a Square Pyramid

Unlike modern high-rise office buildings, which are typically rectangular prisms, a pyramid is a square pyramid, a distinctive form that imposes important constraints on workflow management.

It is intuitively clear that if the side length is reduced to one-half, the area becomes one-quarter; if reduced to one-quarter, the area becomes one-sixteenth. The same principle applies to the number of stones required per course.

Although actual pyramids use larger stones at the bottom and smaller stones at the top, I simplify the calculation by assuming uniform block size. With a base length of 230 m and 203 courses, the approximate total number of blocks can be estimated using:

Total blocks=$(n/3)\times 203$

where n is the number of blocks in the first course.

Given the known total of 2.3 million blocks, we obtain:

n=33,990 blocks in the first course

≈184 blocks per side

Block width≈1.25 m

Using this model, the number of blocks per course decreases rapidly: 1st course: 33,990, 10th course: 31,043, 20th course: 27,925, 50th course: 19,561, 100th course: 8,921, 150th course: 2,405

These values are approximate, but the key point is that the number of required blocks decreases quadratically as construction progresses upward. In reality, the decrease is less steep because upper stones are smaller, but the overall trend remains valid.

3. Imagining Myself as a Mason Working on the Pyramid

Earlier, I estimated the total length of the ramp at 6.2 km, but because

the pyramid is a square pyramid, the side length decreases with height, and so does the length of the circumferential ramp. For example, at the 80th course, near the stress-relieving chambers above the King's Chamber, the ramp length has already shrunk to about 4 km, and the remaining distance from the 80th to the 203rd course is only 2.2 km.

At this point, I tried to imagine myself as a laborer working on the upper levels of the pyramid. Near the Giza plateau, archaeological remains of workers' barracks have been found. Stonecutters working on the ground and transport workers moving blocks from the quarries to the pyramid may have commuted from these barracks. But what about the workers on the upper levels?

If it were me, I would likely not return to the barracks each day. Instead, I would sleep and live on the broad working platforms of the pyramid itself. Rain is extremely rare in this region, so a simple mat would suffice for sleeping comfortably in summer. Facilities for cooking, food distribution, and latrines were likely set up in corners of these platforms. With work and living spaces adjacent, there would be no commuting time, and rest breaks and shift changes would be extremely efficient.

But then I realized: what happens near the top?

Such spacious platforms cannot exist near the summit. Moreover, the number of core and casing stones decreases drastically, and the working area becomes extremely limited, restricting the number of workers who can operate there. And the summit is 6 km away from the ramp entrance at ground level.

What would the construction site have looked like from afar during this final stage, when only a small number of workers were building the last section of the ramp, placing the final core stones, and installing the final casing stones?

In the early stages, vast numbers of workers transported and laid out the core stones at the base. Even after ramp construction began and the pyramid rose upward, large numbers of workers were still involved. Compared to that, the number of workers near the summit would have been dramatically smaller, making the site appear almost inactive—even

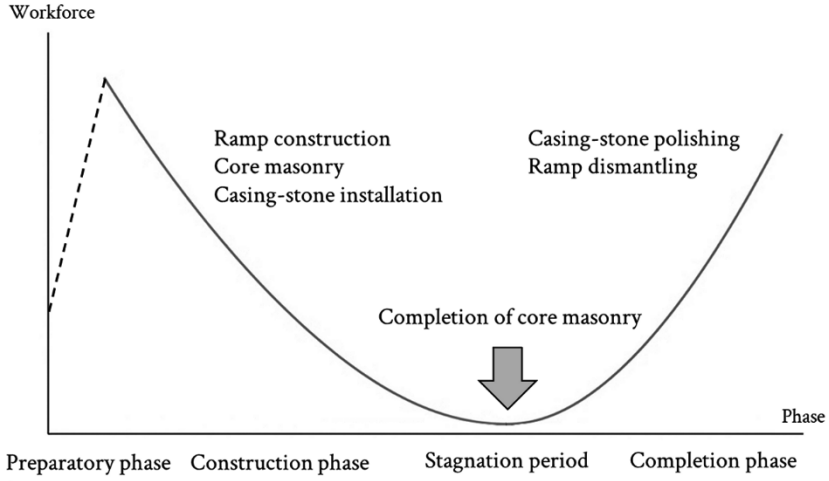

Fig. 6-1. Workforce Dynamics and Construction Phases

though the project was approaching its most critical milestone: the completion of the core and the installation of the final casing stones.

Those few workers near the summit must have worked with great determination. Yet even if supervisors wanted to push progress by adding more workers, there was simply no space to deploy additional personnel. Supervisors would have been powerless in the face of such physical constraints.

Thus, even though the number of stones per course decreases sharply as construction progresses, the time required per course does not decrease proportionally. This is an important point.

When viewed in this light, pyramid construction was not a uniform process. The number of workers required varied dramatically depending on the stage of construction.

4. Changes in Required Workforce Over the Construction Period

Fig. 6-1 illustrates, in schematic form, how the number of workers fluctuated throughout the construction process. As shown in the figure, the construction period of a pyramid can be divided into four major

phases: the preparatory phase, the construction phase, the stagnation phase, and the completion phase. In the first half of the project, the primary tasks were the construction of the ramp, the laying of core masonry, and the placement of casing stones. In the latter half, the main tasks shifted to cutting and polishing the casing stones and dismantling the ramp.

4-1. Preparatory Phase:

In the case of Khufu's Pyramid, this phase included:

initiation of basic design,

site surveys,

bedrock investigations (including test pits and excavation of the subterranean chamber),

quarrying and stockpiling of core stones,

preparation of casing stones,

production and accumulation of sun-dried mudbricks for ramps and scaffolding,

construction of transport routes and ramps for stone and material delivery,

excavation, dredging, and construction of Khufu's harbor,

construction of workers' barracks,

establishment of the project management structure,

and leveling of the bedrock.

It is difficult to estimate the exact labor dynamics of this phase, but once bedrock investigations began, a substantial workforce would have been required. When the feasibility of pyramid construction was confirmed, infrastructure development and the construction of workers' facilities likely began almost simultaneously. Bedrock leveling alone would have required a very large number of workers.

4-2. Construction Phase:

This phase marked the beginning of full-scale construction:

laying of core masonry,

placement of casing stones,

and construction of ramps and scaffolding.

On the design side, detailed planning would have progressed from the entrance passage, ascending passage, and Queen's Chamber to the King's Chamber and its stress-relieving structures, accompanied by verification experiments.

On the construction side, the first course of a square pyramid requires the largest number of stones, and these stones are also the largest in size. Thus, a very large workforce was needed to launch the project with a massive initial effort. However, this did not require mobilizing new workers from scratch; many of the workers already engaged in infrastructure development and bedrock leveling during the preparatory phase could be reassigned.

Here the unique geometry of a square pyramid becomes critical: with each completed course, the working area shrinks, and accordingly, the required number of workers for masonry, quarrying, and transport decreases.

In Fig. 6-1, the decline is shown as a quadratic curve, but if one ignores practical constraints such as maximum workforce capacity, the theoretical decline would resemble a cubic curve, dropping even more sharply. Such a curve is unrealistic, so a quadratic approximation was used.

This observation reveals an important fact:
the farmers conscripted during the agricultural off-season were not kept for twenty years straight.

It is incorrect to imagine "tens of thousands of farmers being conscripted continuously for two decades." Many would have been released from duty after only a few years, and the number of exempted workers would have increased rapidly as construction progressed.

4-3. Stagnation Phase:

As the completion of the core approached, both the quantity of stone and the available working space decreased, forcing a reduction in workforce. Compared to the early stages, only a few dozen workers

would have remained near the summit, and the frequency of stone deliveries would have dropped dramatically. To an outside observer, the project might have appeared to have come to a halt.

By the time the final core stones and casing stones were placed, the workforce had shrunk to a minimal number.

The celebration marking the completion of the long construction process was likely attended only by this small group—the vast majority of workers, supervisors, and designers had already left the site. Few of those who had witnessed the beginning of construction would still have been present.

With the completion of the core, the nature of the work changed dramatically. The main tasks now became finishing and polishing the casing stones and removing the ramp. Initially, the limited working space allowed only a small number of workers, but as work descended to lower courses, the required workforce increased again.

4-4. Completion Phase:

Although finishing the casing stones and dismantling the ramp are part of the final stage, the workforce curve during this phase differs greatly from typical construction projects. As work progresses downward, the surface area of the casing increases, causing the required workforce to rise sharply.

Estimating the labor required is difficult because the time needed to cut and polish high-quality Tura limestone varies greatly depending on the required flatness and surface finish. Polishing, in particular, can dramatically change the total labor hours.

Intuitively, however, the time required for cutting and polishing the casing stones may have exceeded the combined time needed to quarry, shape, and transport a core block. As noted in Chapter 2, tools and production equipment may have been used for quarrying and shaping non-visible surfaces, but finishing the visible casing surfaces had to be done on scaffolding around the pyramid, relying primarily on small tools and manual labor.

One can easily imagine the scene: as the ramp was gradually removed, large numbers of workers and craftsmen crowded around the final courses of casing stones, cutting and polishing them. And once polishing was complete, the workforce would have collapsed from its peak to near zero almost instantly.

Although this topic lies slightly outside the main scope of this book, it is worth noting that managing a construction project with such extreme fluctuations in workforce requirements presents several challenges:

simultaneous ramp-up of many different types of work,

dramatic changes in required skills and occupations between phases,

stagnation-phase management: workforce reductions, reassignment of supervisors, and what might be called "unemployment management" for specialized craftsmen.

5. Seasonal Variations in Work Activities and Workforce Requirements

5-1. Inundation Season (Agricultural Off-Season):

The majority of the labor force responsible for the core tasks of pyramid construction—quarrying, transporting, and setting stone blocks—is now understood not to have been slaves, but rather farmers conscripted during the Nile's inundation, when agricultural work was impossible.

In addition to quarrying and masonry, workers would also have been engaged in:

construction of ramps and scaffolding,

expansion and maintenance of core-stone stockyards,

reinforcement and repair of transport routes,

and other forms of infrastructure development.

These tasks required large numbers of workers and were well suited to the agricultural off-season.

5-2. Low-Water Season (Agricultural Busy Season):

Once the primary labor force—the farmers—returned to their fields,

most construction activities would have slowed dramatically. However, certain tasks were actually best suited to the low-water season.
These included:

collecting Nile mud, the raw material for sun-dried mudbricks,

dredging and maintaining Khufu's harbor,

and especially exploiting the fact that "Khufu's Basin" dried out completely, becoming an ideal site for large-scale mud extraction and brick production.

Other activities likely carried out during this season include:

expansion of quarries,

maintenance and improvement of transport routes,

production and replenishment of consumables such as tools, rollers, and ropes,

and general preparations for the resumption of full construction during the next inundation.

Most of the lower-ranking administrators responsible for supervising pyramid construction probably remained at Giza year-round, even during the agricultural busy season. It is plausible that many of them engaged in mudbrick production, a task requiring little specialized skill.

5-3. Tasks Conducted Throughout the Year:

Certain tasks required skilled, year-round specialists, including:

surveying,

stone cutting,

shaping and polishing,

and toolmaking.

Infrastructure maintenance—such as repairing transport routes, ramps, and scaffolding—was essential for maintaining productivity and therefore likely continued year-round. Technical administrators involved in design and planning would also have remained on site throughout the year.

Bread, the staple food of ancient Egypt, was dense, low in moisture, and resistant to spoilage. Because it stored well, bakeries likely operated at high capacity year-round, building reserves for the next inundation

season when labor demand surged.

Merer's diary suggests that even seemingly simple operations, such as harbor work, were managed by a highly subdivided bureaucratic structure. As described above, pyramid construction involved tasks that varied dramatically by construction phase and by season.

Given the nonlinear and highly variable nature of the worksite, it is reasonable to conclude that the management of pyramid construction was far more sophisticated and meticulous than modern observers might assume.