CHAPTER 3

Considerations on Overland Transport of Construction Materials

1. Paved Roads

The heaviest overland transport during pyramid construction occurred between the quarries and the pyramid sites. However, substantial traffic must also have existed along shorter routes—for example, transporting materials and food from Khufu's harbor and the Nile riverbank to the construction site, or moving sun-dried mudbricks manufactured along the river.

Popular books on ancient Egypt often describe such transport simply as being carried by people or dragged on wooden sledges. Yet ever since walking across the sandy ground at Giza and Dahshur, I have doubted this explanation.

Hollywood films often depict desert scenes shot in the dune fields of Morocco, leading many to imagine desert sand as fine, loose grains into which one's feet sink deeply. But the sand around Giza and Dahshur is quite different. Although there are occasional pockets of soft sand in hollows or at the foot of hills, these are exceptions.

Most of the ground consists of sand mixed with limestone fragments, as shown in Fig. 3-1, and one's feet hardly sink at all.

This raised a question for me: Could a wooden sledge really be dragged over such terrain?

On loose sand, wetting the surface to reduce friction is understandable. But on sand mixed with sharp limestone fragments, a wooden sledge would quickly splinter and deteriorate, making transport far from easy.



Fig. 3-1. Sandy ground at Dahshur (photographed in 2008)

The famous relief in the tomb of Tehutihetep shows a large statue being hauled on a sledge by many workers, but that scene represents a ceremonial event, not a daily operation. For a one-time ritual, it would be more practical to sieve sand or bring uniform sand from a Nile sandbar than to pave a road. However, for routes with heavy, continuous traffic, it is natural to assume that paving was carried out—and indeed, remains of paved pathways have been found.

I believe that the construction roads were not paved with stone slabs but with sun-dried mudbricks, which were available in large quantities and suitable for simple paving.

Furthermore, I propose that stone blocks were transported not on sledges but on rollers over these paved roads. The following is a proposed specification for such roads, assuming the need to sustain a massive throughput—233 blocks per day—even under the most conservative calculations.

Fig. 3-2 illustrates the imagined process of constructing a paved road using sun-dried mudbricks.

A: Ground leveling.

The essential requirement is to maintain horizontal alignment and avoid unevenness—similar to railway subgrade preparation.

Dahshur's terrain is mostly flat sandy ground, requiring little cutting or filling, making leveling extremely easy.

Giza, by contrast, has many limestone outcrops, so some excavation would have been necessary.

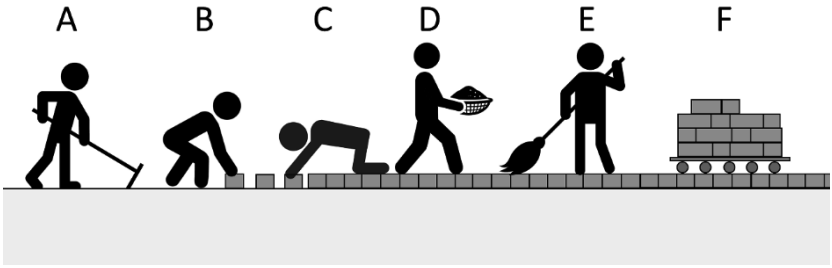

Fig. 3-2. Conceptual diagram of road construction using sun-dried mudbricks

Even if the route became somewhat indirect, keeping the gradient below 5/100 (2.86°) would greatly ease transport. This slope is noticeable when walking but manageable even for elderly people, and on a bicycle it can be climbed without standing on the pedals.

B: Transporting and staging the mudbricks.

Assuming bricks of 30 × 15 × 10 cm weighing about 8 kg each, even a 10-meter carrying distance would be heavy labor. This may have been the most manpower-intensive task.

C: Laying the bricks.

Workers pull the staged bricks into place and fit them tightly. Avoiding unevenness is essential, though gaps of a few millimeters would be acceptable.

D: Transporting sand for infill.

Since the entire area is sandy, the transport distance is minimal.

E: Filling gaps with sand.

F: Completed mudbrick pavement, over which materials—including mudbricks themselves—are transported using rollers.

For ordinary stone-transport roads, a width of 2 meters would suffice even for large core blocks. However, considering waiting areas and passing during transport, I assume a width of 3.6 meters, created by laying 12 bricks (30 cm wide) side by side.

A team of six workers, each responsible for two bricks, could complete one row in about four minutes. This advances the pavement by 15 cm. Thus:

40 minutes → 1.5 m

11-hour workday → 24.75 m

30-day month → 742.5 m

A group of about 20 workers could likely perform this operation. Brick consumption would be:

1 day → 1,980 bricks

1 month → 59,400 bricks

As noted in Chapter 1, 1,000 workers could produce 100,000 mudbricks per day, so 59,400 bricks per month is trivial. Mudbrick production would not have been a bottleneck.

Even the relatively distant Menkaure quarry is only 1.5 km from the pyramid. With five such road-building teams working in parallel, the major road network of Giza could have been paved within a few months.

The first paved road was likely the route from the Nile riverbank—where mudbricks were produced—to the Giza construction site.

Because the sandy ground at Giza and Dahshur is firm and mixed with limestone fragments, it does not easily deform under load. Once paved with mudbricks, the surface would not sink readily. Mudbricks are extremely strong under vertical compression, making such roads more durable than they appear.

Although mudbricks are weak against torsion and may crack, even broken bricks remain as compacted fill and do not significantly reduce road strength. Moreover, because the structure is simple—bricks laid on sand and gaps filled with sand—damaged sections could be repaired quickly by removing bricks, leveling the sand, and replacing them.

Thus, the durability of mudbrick roads likely depended more on ease of maintenance than on inherent structural strength.

At Giza, remains of what appear to be mudbrick-paved roads still exist. In front of Menkaure's pyramid, a mudbrick causeway—traditionally attributed to his successor Shepseskaf—has been identified. However, Dr. Mark Lehner has suggested that because this mudbrick road terminates at an older quarry from Khufu's time, it may actually have been a stone-transport ramp.



Fig. 3-3. Conceptual diagram showing many workers pulling a stone block

2. Wooden Rollers

Numerous experiments have been conducted in the past in which many people drag Egyptian stone blocks. The NOVA pyramid-building experiment also attempted this. Yet every time I read the reports or watch the videos of these experiments, I feel not merely doubt but a strong sense of discomfort.

The reason is that these experiments generally resemble what is shown in Fig. 3-3. The people in Fig. 3-3 are not actually pulling the stone with arm strength; they are using a falling-forward motion that relies on body weight. With enough people, the stone will indeed move. It does serve as "evidence that it moved."

However, the question immediately arises: Do they really believe this work could be continued for 11 hours a day, every day, for seven months? There is a vast gap between "being able to move it once" and "being able to move it continuously for long hours every day." What they demonstrated is essentially a one-time, unsustainable show.

From a mechanical standpoint, this motion involves repeatedly pulling with body weight, stopping, pulling again, stopping—an endless battle against static friction. Static friction is always greater than kinetic friction, and this method demands the maximum static friction every time. Rationally, one should maintain motion and stay within the lower kinetic-friction regime.

Furthermore, to achieve the throughput required to transport several hundred core blocks per day, an enormous workforce would have been necessary. For a few dozen stones, increasing manpower might work. But for several hundred, tens of thousands of workers would be required

solely for stone transport. Forcing such heavy labor every day during the inundation season—summer—would be utterly unsustainable. This is likely why, until a few decades ago, pyramid construction was believed to rely on slave labor. A mistaken assumption about construction methods produced a mistaken view of history.

Let us now discuss friction coefficients.

Assuming a weight of 3 tons:

The static friction coefficient for a stone placed on sand is about 0.6–0.8, requiring 1800–2400 kgf to start moving it.

A wooden sledge sliding on wet sand has a kinetic friction coefficient of about 0.2–0.3, requiring 600–900 kgf.
(kgf is a conventional unit representing the force equivalent to the weight of a mass in kilograms.)

However, in rolling motion, resistance decreases dramatically. Because bearings and axle technology had not yet developed in the Old Kingdom, and because axle strength was insufficient, transporting multi-ton stones on wheeled carts was impossible. Without wheels, the only rolling-based transport method available was the roller. But rollers are useless on sand: they sink and fail to rotate. Thus, rollers require a paved transport road.

Roads paved with mudbricks do exist archaeologically, but after 4000 years mudbrick often erodes back into soil, so such remains are not universally preserved. For this reason, Egyptology has rarely considered



Fig. 3-4. Wooden roller exhibited at the Metropolitan Museum of Art (Courtesy of The Metropolitan Museum of Art, New York. Accession Number: 26.3.308.)

rollers, and the famous relief of hauling a colossal statue on a wooden sledge from the tomb of Tehutihetep has overshadowed alternative transport methods.

Yet the Metropolitan Museum of Art displays a roller discovered beneath a limestone sarcophagus in a Middle Kingdom tomb at Thebes. The MET cautiously states that it was "likely used to aid in its transport," but the object itself is labeled as a roller. Given its position beneath the sarcophagus, the likelihood is high. The MET lists its length as 65 cm; from photographs, the diameter is about 7 cm.

Among the MET's vast holdings—many not on permanent display—the fact that this extremely modest wooden roller continues to be exhibited carries a certain significance. It suggests that the MET is quietly highlighting the overlooked reality that rollers were used in ancient Egypt.

The rolling resistance of wooden rollers on a prepared surface varies with surface irregularities and the material of the rollers, but it can generally be expected to fall within the range of 0.05 to 0.1. Moving a 3-ton block therefore requires approximately 150 to 300 kgf of force.

To achieve a throughput of one block every 1.3 minutes, workers must be able to apply this force continuously and reliably. The challenge is not momentary exertion but sustaining a workable level of force over long periods. To investigate what might be feasible, I conducted a series of experiments at home using an exercise expander fixed to a pillar.

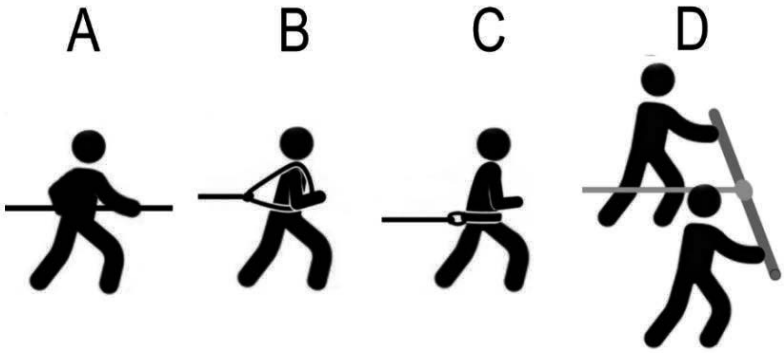

Fig. 3-5. Experimental methods for pulling loads

The first method, shown in Fig. 3-5 (A), involved pulling a rope held beside the body. Because the rope is positioned laterally, the wrist twists, and the method depends heavily on grip strength. Fatigue set in quickly. It is workable for short bursts but unsuitable for sustained labor.

Method B used shoulder straps, similar to wearing a backpack. This reduced the effort compared with A, but the load concentrated on the shoulders and clavicles, making it impractical for heavy or prolonged work.

Method C attached the rope to a wide hip belt, similar to the pulkka used in northern Europe. By transferring the load to the pelvis, this method significantly reduced bodily strain and proved far more comfortable.

However, while B and C are effective for an individual hauler, they present operational difficulties in coordinated group work—particularly the need to branch the rope radially.

The breakthrough came the next day, while I happened to be pushing a shopping cart. This led to method D: instead of pulling a rope, workers push a horizontal bar attached to the rope. This posture uses the palms rather than the grip, allows a forward-leaning stance, and enables workers to apply body weight. For short periods, one can even lean onto the bar, producing substantial force. The method is inherently suited to cooperative work and can scale to teams of twenty.

In posture D, a worker can push roughly 20 kgf for several tens of minutes, 15 kgf for sustained heavy labor, and about 10 kgf comfortably. With rolling resistance between 0.05 and 0.1, sixteen workers can therefore move a 3-ton block.

Transport routes at Giza—except for areas such as the western quarry—are generally 500 m to 1 km. Even at a slow speed of 2 km/h, the trip takes only 15–30 minutes, avoiding prolonged heavy exertion.

The principal drawback of method D is the large number of horizontal bars required. Because Egypt lacked abundant timber, suitable materials must come from sources not used for conventional carpentry.

The most promising candidate is the leaf stalk (rachis) of the date palm.

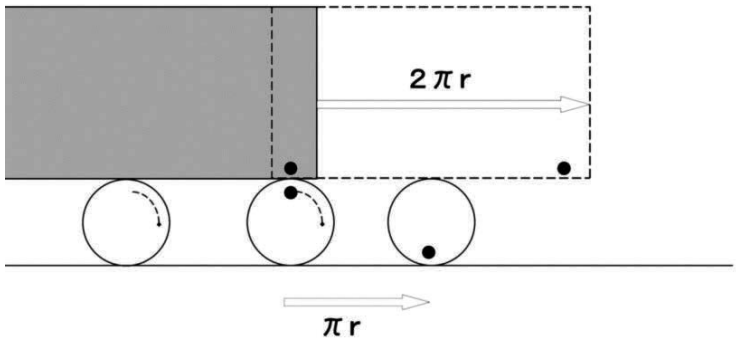

Fig. 3-6. Operation of rollers

These rachises can reach lengths of about 4 m, and historical examples show that they can be split and bundled to make benches or beds. At EXPO 2025 in Osaka, the UAE Pavilion imported more than two million date-palm rachises and bundled them into structural members roughly 1 m in diameter.

The spiky lower portion of a date palm trunk is the remnant of fallen leaf bases. As the palm grows, old leaves dry and fall away, providing an almost inexhaustible supply of dried rachises. A single rachis is not strong enough as a structural member, but bundling them with straw rope or papyrus yields adequate strength for use as horizontal bars. The bundled portion also provides natural cushioning for the hands.

Let us now consider how rollers function. Modern readers are familiar with wheels, but rollers behave somewhat differently. When a block moves over a cylindrical roller, friction causes the roller to rotate. A half-rotation advances the roller by πr, where r is the radius. The block also advances by πr relative to the roller, but because the roller itself moves forward by πr, the block advances a total of 2πr.

Because the block moves at twice the speed of the roller, the roller beneath the trailing edge is left behind. Rollers must therefore be supplied in front of the block, and those left behind must be carried forward.

Fig. 3-7 illustrates this situation. Worker A carries a roller from position B to the front, while worker C places rollers ahead of the block.

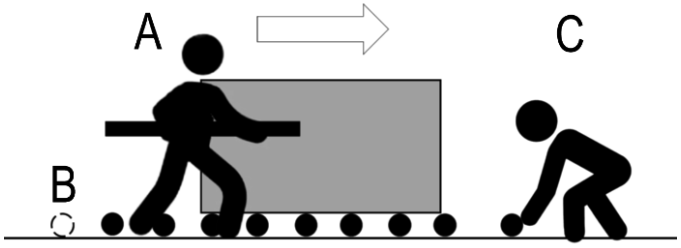

Fig. 3-7. Commonly imagined method of placing rollers

At first glance this seems workable, but as noted earlier, with method D the block can advance at about 2 km/h, or 0.56 m/s. If rollers are spaced at 30 cm, the block leaves behind nearly two rollers per second (1.85).

This makes tasks A and C extremely demanding. Task A can be mitigated by increasing personnel, but task C—placing rollers in front—cannot easily be shared among multiple workers and is difficult to sustain. Thus, the commonly imagined method shown in Fig. 3-7 cannot maintain a speed of 2 km/h.

I therefore considered a different approach: arranging rollers in advance and returning displaced rollers to their original positions. This concept is shown in Fig. 3-8.

In Fig. 3-8, when a block of length L moves to the right, each roller under it also shifts by L. For convenience, six rollers (A1–F1) are shown under a block of length L. Roller A1 moves to A2, F1 to F2, and so on. After the block passes, rollers remain behind. A roller at P2 only needs to be rolled back to P1. Since most pyramid blocks are under 2 m long, this return distance is small, and rolling the roller back is easy.

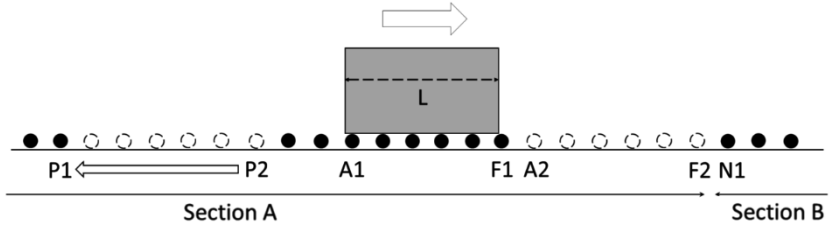

Fig. 3-8. Section-responsibility system and roller-position management

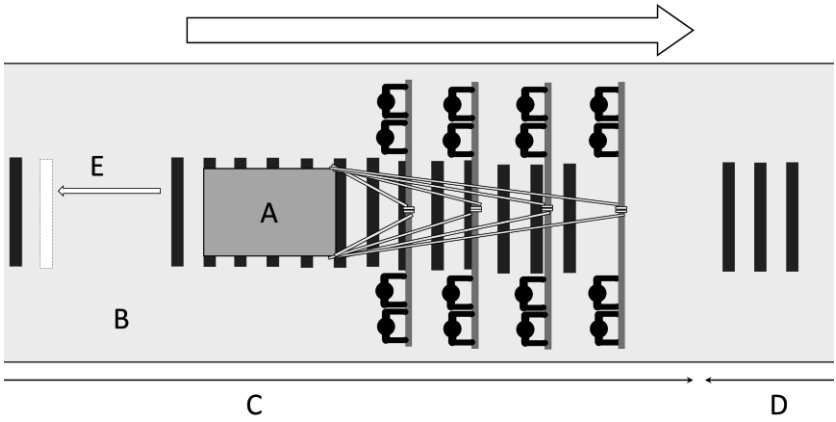

Fig. 3-9. Summary of transport concepts

Section B to the right of N1 is handled by another crew, and rollers there are already in place. Because block lengths vary, spacing must be adjusted at section boundaries by narrowing intervals or temporarily removing rollers.

With this method, restoring roller positions becomes easy, allowing uninterrupted transport.

However, this requires assigning workers to fixed sections. If 500 blocks per day are transported—one every 1.3 minutes—at 2 km/h, the spacing between blocks is 43.3 m. If two blocks occupy the same section, the system fails, so sections of about 30 m are practical. With two lanes, spacing doubles to 86.6 m, allowing longer sections and easier roller restoration.

Fig. 3-9 summarizes the ideas discussed so far. Block A is tied to a rope and pushed via a horizontal bar. Workers can step over rollers if spacing is around 40 cm, and with practice this becomes easy. For clarity, the figure shows workers arranged in four rows of four, though two rows of eight would also work.

In Fig. 3-9, A is the block, B is the mud-brick ramp, the towing method uses a horizontal bar, E represents workers restoring rollers, and C and D represent section boundaries. With a speed of 2 km/h and a frequency of one block every 1.3 minutes, spacing is 43.3 m, so sections are assumed

to be 30 m. Four workers per section suffice.

For a 600-m route, divided into 20 sections, 80 roller workers are needed. About 14 blocks occupy the route simultaneously, requiring 224 haulers. Thus, roughly 300 workers can transport blocks at 1.3-minute intervals, completing the 600-m route in 18 minutes. Allowing for return, rotation, and rest, a workforce of about 500 would be adequate to move 500 blocks per day on a single route.

In other words, each worker transports a 3-ton block over 600 m per day.

Finally, regarding the rollers themselves: they must be treated as consumables, subject to wear, deformation, and cracking. Imported cedar is out of the question, and even acacia, sycamore fig, and tamarisk are too valuable. The practical option is the core wood of the date palm.

Published data (Engineering Properties of Date Palm Trunk Applicable in Designing a Climber Machine) give compressive strengths of 4.5 MPa longitudinally and 1.1 MPa radially. Since rollers are made by slicing the trunk and shaping 10-cm-diameter cylinders, the relevant value is the radial strength of 1.1 MPa.

Supporting a 3-ton block on six rollers yields 500 kgf per roller. Assuming a 1-cm-wide contact strip over a 1-m block width gives 100 cm^2 of area, or 5 kgf/cm^2 (~0.5 MPa). This is below the proportional limit of 1.1 MPa, meaning deformation remains largely elastic and recovers as the roller rotates.

In this stress range, rolling resistance does not exceed 0.1 and likely falls within the assumed 0.05–0.1 range.

As for the towing rope: even with rolling resistance of 0.1, moving a 3-ton block requires 300 kgf. With four rows of four workers, each rope bears 75 kgf. In Chapter 1, I noted that a 20-mm rope with a safety factor of 1/15 has a strength of 80 daN, which is sufficient.

These considerations demonstrate that rollers made from the core wood of the date palm can indeed support the transport model shown in Fig. 3-9.

Column 2. "Excuse me, but how do you pronounce your name?"

In Japan, this is a question that occasionally comes up when exchanging business cards for the first time. It may be hard to believe for people from Western countries, but when a rather uncommon name is written in kanji, even Japanese people often have no idea how to read it. Place names in Kyoto are even more extreme—an entire parade of difficult and irregular readings. Uzumasa (太秦), for example, is something that even many Japanese cannot read.

What may be even more incomprehensible to Westerners is that Japanese people can still recognize written text even when they cannot pronounce it. They know the kanji themselves, so even if they do not know the correct reading, they will internally assign some arbitrary pronunciation—remembering 太秦 as something like "Futohata," for instance.

In Western countries, too, one might occasionally hear the question "Excuse me, how do you pronounce your name?" when encountering German, Polish, or French names such as Schwarzenegger. Superficially the phenomenon looks similar, but the underlying cognitive process is quite different. The intention behind the Western question is closer to "I cannot remember it unless I can pronounce it." Japanese people, on the other hand, will simply remember the written form even if they cannot pronounce it.

In Egyptological publications written in Western languages, it is standard practice to provide phonetic values alongside hieroglyphs. In this book, however, I have deliberately chosen not to include phonetic values. The reason is simple: even if phonetic values are provided, the transcription system is one that only trained Egyptologists can actually pronounce. For general readers, it offers little benefit. Moreover, even if an Egyptologist can pronounce it, there is no guarantee that the reconstructed pronunciation matches ancient Egyptian speech.

Hieroglyphs, however, can at least be recognized visually by Western

readers as symbols. For example, the birth name of King Khufu is written as , with the phonetic value Hwfw. Yet the transcription Hwfw does not even contain the letter K, nor does it include vowels. Ordinary readers cannot possibly read it aloud.

As for what  represents—whether a sieve, a placenta, or something else—there are various theories. But is it not far easier simply to remember it as "something like a sieve, a chick, a slug-like creature, and a chick," and associate that cluster with Khufu?

For this reason, in the pages where the hieroglyphs  appear, I have not added phonetic values. You do not need the readings; remembering the meaning is enough. For example:

 represents sailing up the river with a sail

 represents going down the river using oars

 represents a boat

If you remember them by meaning, they fully serve their function as logograms.