ARCHAEOLOGY

Pyramid power, people power

Ian Stewart

How many men does it take to build a pyramid? It's a vexed question, made all the more so by our ignorance of just how the pyramids were built. Herodotus reported that it took 100,000 men to construct the Great Pyramid, but he wrote two thousand years after it was erected, and he wasn't terribly reliable. But we may not need to know *how* the pyramids were built to get a good estimate of the manpower required: the mere fact that they *were* built, in an age not noted for heavy machinery, gives a surprisingly effective handle on the question. Or so Stuart Kirkland Wier argues, with a fair degree of conviction, in the *Cambridge Archaeological Journal* (**6**, 150–163; 1996).

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Donald Wong

Stone cladding in the suburbs: the Great Pyramid of Khufu (or Cheops) at Giza on the outskirts of Cairo. A big job for the builders, but was the workforce really as large as the 100,000 given by Herodotus?

His method is, in effect, a back-of-the-envelope time-and-motion study. Such calculations often put matters into a proper perspective — for example, the manpower requirement of the Apollo Moon-landing was about the same as that used to construct York Minster, a large mediaeval cathedral. Here, the calculations remove much of the mystery from the pyramids, revealing them as a substantial, but entirely plausible, civil engineering project for their time.

Wier takes as his example the biggest pyramid, that of Khufu at Giza, which dates from the 26th century BC. It was originally 146.7 m high, with a square base 230.4 m on a side. Its volume was therefore 2.59×10^6 m^3, and its mass about seven million tonnes. Although it is unlikely that the builders would have known in advance how long Khufu's reign would be, it is reasonable to take the entire reign as the building period. So they would have had about 23 years — 8,400 days, ignoring stoppages for bad weather, strikes or public holidays — to complete their work.

Wier assumes that the pyramid was built from stone blocks that were quarried, shaped, moved and installed using human muscle-power alone — no doubt via the intermediary of levers, pulleys and other mechanical aids. The pyramid was mainly built in layers from bottom to top. Horizontal transport was on wooden sledges — that much seems highly likely from several sources. We have little idea how vertical transport was performed, but for these purposes the method doesn't greatly matter: what matters is the energetics.

Dividing the volume by the total time, we find that on average the builders had to install 309 m^3 of rock per day. A uniform rate of construction is unlikely, because the taller the structure becomes, the harder it is to lift the rock into place, and the less space there is for men to work. So it seems likely that the installation rate was faster early on, and dropped off later. Wier considers several specific schedules, but the results are much the same in all cases.

The average amount of useful work that a man can perform in a day is about 2.4×10^5 joules — maybe rather more for an experienced worker. The potential energy of the completed pyramid, relative to ground level, is 2.5×10^{12} joules. Therefore, lifting alone would require at least 1.04×10^7 man-days, or 1,250 men over the 8,400-day schedule. This ignores quarrying, shaping and inefficiency. Nevertheless, it puts the issue into perspective: 1,250 men is not an outrageous workforce for an Egyptian king.

For a better estimate, historical detail comes into play. We know where the blocks were quarried, so the terrain and the distance over which they must have been transported are also known quantities. We can even estimate the coefficient of friction of Egyptian sledges. A scene from the tomb of nomarch Djehutihotep at Deir el-Bersha shows a 5-m-high stone statue being pulled along by 172 men. The statue would have weighed some 58 tonnes, so each man was pulling about 330 kg — a coefficient of sliding friction of 0.034, using Wier's assumption that the workers exert a force of about 11.5 kg. Other depictions, and modern experiments with water-lubricated sledges, all lead to a figure of around 0.1.

Putting all this information together, Wier obtains lower and upper estimates of around 9,500 (12,800) men at the start, tailing off to about 2,000 (2,600) when the height reached 100 m, and then dropping rapidly until the final few metres were installed by just 35 (41) men. Alternatively, the workforce could have been constant throughout, with the rate of progress depending on the stage of construction. Men could have been traded between tasks, quarrying, shaping, dragging or installing as necessary. The result this time is between 8,380 and 10,600 men. No doubt the reality was more complex, but for ballpark figures, who cares? As Wier says, "One may suppose that the ancient architects determined the size of the pyramid they wished to construct, or the largest workforce they wished to maintain, then gathered the men and set to work". They had plenty of experience by the time they tackled the really big pyramids, so they should have been able to work out the required numbers.

In broad terms, a workforce of about 10,000 men would have been enough. Since the population of Egypt at the time was probably about 1.1 to 1.5 million, this is less than one per cent of the population. We conclude that there is nothing especially remarkable about pyramid building in terms of manpower; the difficulty was to maintain continuity of organization over periods of several decades. And although Wier does not say so, the calculation also casts doubt on theories that the pyramids were used to soak up surplus labour, to keep the populace in work and avoid political and social unrest. The problem is that they would not have soaked up *enough* — the reduction in the unemployment rate would have been only 2.5 per cent of the (male) labour force. □

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