New insights on metrology during the Mauryan period

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Dimensional analysis of the oldest engineered caves at Barabar and Nagarjuni hills (dated to the Mauryan Period) has revealed that the basic length measure (*angulam*) of this period was 1.763 cm. The planning of these cave complexes was executed using the traditional measurement units mentioned in the *Arthasastra*, in particular the *danda* measuring 96 *angulams*. As the basic length measure is also noted in several Harappan civilization sites, this study confirms that Harappan metrological ideas were transmitted virtually unchanged from the Harappan civilization to the Ganga civilization, thereby proving the continuity of the people themselves who built their settlements upon this tradition.

Keywords: *Angulam*, *Arthasastra*, Mauryan period, metrology.

IT is of great scientific interest to explore the basic unit of measurement that was used in the Indian subcontinent over the ages. Variations indeed are expected in different regions or times because, intuitively, a unique standard for all times and places is unlikely. However, a direct connection was recently confirmed between the basic length measurement unit (traditionally called the *angulam*) of the Harappan civilization (3000–1500 BC) and the Gupta period (320–600 AD)[1]. Specifically, the Harappan *angulam* measuring 1.763 cm (determined from several Harappan civilization settlement plans, without any *a priori* assumptions, by Danino[2,3]) could coherently describe the dimensions of the 1600-year-old world famous Delhi Iron Pillar of the Gupta period[1].

The aim of this communication is to determine the basic unit of measure of the Mauryan period, which extends from the late fourth to the early second century BC[4]. The important Mauryan monarchs were Chandragupta Maurya and Ashoka. While there are different opinions on their precise dates, there is general agreement that Chandragupta Maurya reigned in the late fourth century BC and Ashoka (his grandson) ruled in the third century BC. The scientific method will consist of an analysis of dimensions of significant dated structures of this period. It must be emphasized that material evidences have been used as data sources.

The Mauryan period is significant in the study of metrology of Indian subcontinent because a dated document of this period, the *Arthasastra* of Kautilya, describes various length measures for the first time[5,6]. Metrology is the study of science of measurement, and includes all theoretical and practical aspects of measurements. The *Arthasastra* will be consulted once the basic measurement unit of the Mauryan period has been established from physical evidences.

A brief discussion on the construction materials of the Mauryan period is necessary to understand the importance of the structures analysed in this communication. Most structures of this period were constructed out of wood. However, the Mauryan period witnessed a revolution in construction technology in that the first man-made stone structures were engineered (i.e. carved out) in the subcontinent. The availability of (high) carbon steel for effectively working with stone may have been a contributory factor, in addition to its use in clearing the dense forests of the Ganga plains[7]. The well-known examples of stone constructions of the Mauryan period are the Ashokan pillars[8]. Analysis of the dimensions of the Ashokan pillars is compounded by the mutilated condition of most of the Ashokan pillars. Further, as one of the experts on Ashokan pillars, Falk[8], puts it, 'most of the available measurements cannot be verified, and some published ones are likely to be untrustworthy'. An associated problem is the deviation from the intended design that may have occurred during the production (i.e. fabrication) of the pillars[8]. The dimensions of the Ashokan pillars will, therefore, not be analysed in this communication in view of these uncertainties.

The earliest constructions that were designed and engineered out of stone, besides the Ashokan pillars, are the cells of Barabar and Nagarjuni hills, which are located about 34 km from Gaya in Bihar state[9–13]. Four caves were chiselled out at Barabar hill and these date to the time of Ashoka (circa 273–236 BC)[4]. The names of these caves are Visvamitra, Karna Caupar, Sudaman and Lomasa Rishi. The last one is particularly famous for its wonderfully carved doorway. It may be noted that this cave is the only incomplete construction because the circular cell inside at the end of the hall was only partially completed. Three caves, known as Vadathika, Vapiyaka and Gopika, were carved out of stone in Nagarjuni hills and these engineering structures date to the time of Ashoka's close successor, Dasaratha.

Falk[13] has rightly pointed out that 'whoever has visited these caves knows that their technology is absolutely breathtaking'. The rooms of the caves have perfectly rounded roofs, but more significantly all the surfaces have been skillfully polished, in a manner very similar to that was used to polish the Ashokan pillars. Such is the finish that Mookerji[4] remarked that 'the walls and halls at the rock cut caves at Barabar and Nagarjuni hills are still shining like mirrors'.

The dimensions of the caves are shown in Table 1, based on the most updated readings of Falk[13]. He further confirms that precise measurements were also made using laser methods and that these will be presented in his

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Table 1. Comparison of proposed and actual dimensions of the engineered caves at Barabar (first four entries), Nagarjuni hills (entries five to seven), and Rajgir (entries eight and nine). For the calculations, each *angulam* (A) was considered as 1.763 cm. Further, 96 *angulams* equal one *danda* (d)

Cave	Actual length (cm)	A	d	Proposed length (cm)	Percentage error	Actual width (cm)	A	d	Proposed width (cm)	Percentage error
Visvamitra	427	240	2.5	423	+0.95	254	144	1.5	254	+0.00
Karna Caupar	1023	576	6.0	1016	+0.69	427	240	2.5	423	+0.95
Lomasa Rishi	1016	576	6.0	1016	0.00	600	336	3.5	592	+1.35
Sudaman	1709	960	10.0	1693	+0.95	593	336	3.5	592	+0.17
Vadathika	511	288	3.0	508	+0.59	343	192	2.0	339	+1.18
Vapiyaka	512	288	3.0	508	+0.79	342	192	2.0	339	+0.89
Gopika	–	–	–	–	–	584	336	3.5	592	–1.35
Son Bhandar I	1029	576	6.0	1016	+1.28	523	288	3.0	508	+2.95
Son Bhandar II	695	384	4.0	677	+2.66	429	240	2.5	423	+1.42

forthcoming book *Photoatlas of Ashokan Sites*. He adds that 'most data have been confirmed and the few changes required do not affect the arguments'[13].

Some points are to be noted regarding the entries in Table 1. The dimensions of the Lomasa Rishi cave are the length and breadth of the main hall of the cave, which is complete. There is no length measure for the Gopika cave because the two ends of the cave hall along the length are semicircular and a reliable ground plan is not available[13]. The centres of the semicircular ends and, hence, the exact length of the hall are not known. The dimensions of two caves of Rajgir, dating to a slightly later period than the caves at Barabar and Nagarjuni hills, have also been included in Table 1 (last two entries), following Falk[13]. The surfaces of these caves are relatively uneven when compared to the caves of Barabar and Nagarjuni hills.

The analysis of the dimensions of these caves will be significant in understanding the metrology of the Mauryan period because, as Smith[14] first noted, carving the caves out of the hard rock of the hill stone would have required considerable energy and money to accomplish the task. This, therefore points out to a well-planned operation to create each of these caves. Strong support for the hypothesis that these caves were precisely planned constructions is the fact the two caves in Nagarjuni hill measure exactly the same and two caves in Barabar hill are of similar dimensions (see Table 1)[13]. This similarity in dimensions leads one to firmly conclude that a considerable amount of preliminary planning and designing took place before the building process itself started, which further enforces the 'belief that fixed measures were used'[13]. Therefore, these engineered structures are ideal examples to explore metrology of the Mauryan period.

The dimensions of the caves were analysed to find out the number of *angulams* that they were composed of. For this purpose, the Harappan *angulam* measuring 1.763 cm was used[2,3]. This same unit was used earlier for analysis of the dimensions of the Delhi Iron Pillar[1]. This value has archaeological support. The 1.75 cm standard is noticed in the markings on the Kalibangan terracotta scale[15] and the 1.77 cm standard on the Lothal ivory scale[16]. Moreover, the direct connection between the Lothal standard unit and the units in the other Harappan (bronze) and Mohenjodaro (shell) scales has also been established[17].

A number of *angulams* thus obtained were further analysed to understand the larger measurement unit that was operational. For this purpose, both *dhanus* (specifically the *garhapatya dhanus*[5], 1 D = 108 *angulams*) and *danda* (1 d = 96 *angulams*) were utilized. The best match was found for *danda* measure. These measures will be discussed in greater detail here. The result of the analysis is presented in Table 1. The remarkable feature of the table is, generally, the low error margin between the proposed and measured dimensions. The percentage error is defined as the deviation of the actual measurement from the proposed measurement, expressed in terms of percentage of the proposed measurement. In some cases, the match was perfect (i.e. zero per cent error).

It may be noted that even if the *angulam* had been taken as 1.75 cm based on the markings seen in the Kalibangan terracotta scale[15] or 1.77 cm based on the markings seen on the Lothal ivory scale[16], the errors would have been similarly low.

At this juncture, it may be useful to understand the classification of intermediate length units in terms of *angulams*, as stated in Kautilya's *Arthasastra*. This dated work of the Mauryan period mentions the division of scales in Chapter 20 of Book 2 (ref. 5). There are several measures defined in *Arthasastra*. Unfortunately, as Raju and Mainkar rightly point out[6], the *Arthasastra* was also responsible for laying the 'seeds of later confusion' in interpretation of lengths and area units because it lays down different measures with the same name. For example, there are three measures for *hasta* (24, 28 and 54 *angulams*), two for *kishku* (32 and 42 *angulams*), two for *danda* (96 and 192 *angulams*), two for *dhanus* (96 and 108 *angulams*) and two for *paurusha* (96 and 108 *angulams*). On analysing these units in the *Arthasastra*, Raju and Mainkar[6] concluded that the series of units connected with the *hasta* of 24 *angulams* (including subunits and multiples like 12, 96 and 108) was used for religious and commercial purposes. On further analysis of metrological measures mentioned in Sanskrit and other texts of later periods, Raju and Mainkar[18] showed that this measure of

24 *angulams* became increasingly popular. In most of these later texts[18], the 96 *angulam* measure is mentioned as *danda* and therefore, it is reasonable to define this measure with this name. Raju and Mainkar, in a further series of articles, explored the traditional measures (and their modern variants) of length and area in South India (specifically, Tamil Nadu[19,20], Karnataka[21], Andhra Pradesh[20] and Kerala[21]) in light of the examination of measures, as recorded in Sanskrit and other sources[6,18].

Turning the focus back on Table 1, it is clear that the dimensions of the caves can be well reconciled if one considers the *danda* unit of 96 *angulams*, with each *angulam* measuring 1.763 cm. One may ask the question why the 96-*angulam* measure was used and not the 108-*angulam* measure, because the latter was used in the design of the Delhi Iron Pillar[1]. There is a period of almost 650 years separating the engineering activities of carving out of the Ashokan period caves (~250 BC) and forge-welding of the Gupta period Iron Pillar (~400 AD). The possibility of a shift from a 96-*angulam* to a 108-*angulam* standard for religious purposes is unlikely as the *Arthasastra* mentions that the 108-*angulam* measure was used for religious purpose. A good insight on the situations when these measures may have been used can be obtained by understanding the religious nature of these structures. The Delhi Iron Pillar was constructed to serve as a *Vishnordhwaja* (Standard of Vishnu)[22] and therefore the direct connection with the divine may have necessitated the use of the 108-*angulam* measure. On the other hand, the caves at Barabar and Nagarjuni hills were meant for the use of ascetics[13]. Therefore, it is reasonable to propose that this 96-*angulam* measure may have been used for general purpose and religious activities relating to humans.

It may be pertinent to note here that Falk noticed that the unit of 85.5 cm could describe the dimensions of the caves of Barabar and Nagarjuni hills[13] as well as in the burial depth of several Ashokan pillars[8]. He chose to call this the 'Ashokan yard'. It is interesting to note that this unit turns out to be equal to 48 angulams (error + 1.04%), considering each angulam to measure 1.763 cm. This incidentally is half of the *danda* (i.e. 96/2 *angulams*). However, as expounded here, this 'Ashokan yard' unit of 48 *angulams* may not be appropriate to describe Mauryan measures, for the simple reason that it does not particularly figure in the *Arthasastra*. Analysis of other important dated structures of the Indian sub-continent, especially those involving exemplary engineering skills, will throw further light on the issue of use of 96-*angulam* versus the 108-*angulam* measure.

In summary, the present study provides firm understanding, for the first time, that the basic unit of measurement which was used in the Mauryan period, specifically during the reign of Ashoka (c. 273–236 BC), was equal to 1.763 cm. This unit seems to have certainly been in use at least till up to the Gupta period, based on the use of the same *angulam* measure in the analysis of the dimensions of the Delhi Iron Pillar[1]. This study further confirms the growing body of evidence that Harappan techniques, crafts, ornaments, art forms, customs, rituals and religious beliefs were transmitted virtually unchanged from the Harappan civilization to the Gangetic civilization[23,24].

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