wightiana Lindl., an endangered species from Andhra Pradesh, India. *J. Spices Aromat. Crops*, 2000, **9**, 77.
6. Negrutiu, I., Shillito, R. D., Potrykus, I., Biasini, G. and Sala, F., Hybrid genes in the analysis of transformation conditions. I. Setting up a simple method for direct gene transfer in plant protoplasts. *Plant Mol. Biol.*, 1987, **8**, 363–373.
7. Cocking, E. C., A method for the isolation of plant protoplasts and vacuoles. *Nature*, 1960, **187**, 962–963.
8. Power, J. B. and Cocking, E. C., Isolation of leaf protoplast: Macromolecule uptake and growth substance response. *J. Exp. Bot.*, 1970, **21**, 64–70.
9. Bajaj, Y. P. S., Protoplast culture and regeneration of haploid tobacco plants. *Am. J. Bot.*, 1972, **59**, 647.
10. Xu, Z. H., Davey, M. R. and Cocking, E. C., Organogenesis from root protoplasts of the forage legumes *Medicago sativa* and *Trigonella foenum-graecum*. *Z. Pflanzenphysiol.*, 1982, **107**, 231–235.
11. Hammatt, N., Kim, H. I., Davey, M. R., Nelson, R. S. and Cocking, E. C., Plant regeneration from cotyledon protoplasts of *Glycine canascens* and *G. glandestina*. *Plant Sci.*, 1987, **48**, 129–135.
12. Russell, J. A. and McCown, B. H., Culture and regeneration of *Populus* leaf protoplasts isolated from non-seedling tissue. *Plant Sci.*, 1986, **46**, 133–142.
13. Murashige, T. and Skoog, F., A revised medium for rapid growth and bioassays with tobacco tissue cultures. *Physiol. Plant.*, 1962, **15**, 473–497.
14. Triggs, H. M., Triggs, G. S., Lowe, K. C., Davey, M. R. and Power, J. B., Protoplast systems for spice crops: Cardamom (*Elettaria cardamomum*) and vanilla (*Vanilla planifolia*). *J. Exp. Bot. (Suppl.)*, 1995, **46**, 48–49.
15. Geetha, S. P., Nirmal Babu, K., Rema, J., Ravindran, P. N. and Peter, K. V., Isolation of protoplasts from cardamom (*Elettaria cardamomum* Maton.) and ginger (*Zingiber officinale* Rosc.). *J. Spices Aromat. Crops*, 2000, **9**, 23–30.
16. Takabe, I., Labib, G. and Melchers, G., Regeneration of whole plants from isolated mesophyll protoplasts of tobacco. *Naturwissenschaften*, 1971, **58**, 318–320.
17. Bajaj, Y. P. S., *Biotechnology in Agriculture and Forestry. Medicinal and Aromatic Plants II*, Springer-Verlag, Berlin, 1989, vol. 7.
18. Minoo, D., Nirmal Babu, K. and Peter, K. V., Conservation of *Vanilla* species *in vitro*. *Sci. Hortic.*, 2006, **110**, 175–180.
19. Minoo, D., Nirmal Babu, K., Ravindran, P. N. and Peter, K. V., Interspecific hybridization in vanilla and molecular hybridization of hybrids and selfed progenies using RAPD and AFLP markers. *Sci. Hortic.*, 2006, **108**, 414–422.

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Computer simulation studies on Delhi Iron Pillar: Estimation of weight

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A computational approach for estimation of weight of the world-famous Delhi Iron Pillar has been presented. The CATIA V5R16 software was used to prepare component drawings based on dimensions from the literature. The weight of the decorative bell capital was estimated as 646 kg and the main body as 5865 kg, thereby giving the entire weight of the pillar as 6511 kg. The methodology utilized in this communication can be employed to determine precise weights of significant historical objects.

Keywords: Computer modelling, Delhi Iron Pillar, simulation studies, weight estimation.

THE Delhi Iron Pillar located in the courtyard of the Quwwat-ul-Islam mosque near Qutub Minar, New Delhi stands testimony to the high level of skill achieved by ancient Indians in the metallurgy of iron and steel[1,2]. A recent photograph of the Delhi Iron Pillar and its computer-simulated model are shown in Figure 1.

The pillar was originally erected around AD 402, in front of a Vishnu temple complex to serve as a 'Standard of Vishnu' at Udayagiri (situated close to modern-day Sanchi near Bhopal, Central India) by Chandragupta II Vikramaditya (AD 375–413). Udayagiri was known as Vishnupadagiri during the Gupta period[2]. The pillar, in its original location, also served an interesting astronomical function, namely the early morning shadow from the pillar fell in the direction of the foot of Vishnu's image in one of the important temples at Udayagiri in the time period around summer solstice[3].

The pillar was shifted by Iltumish (AD 1210–1236) from Udayagiri to its present location in the Qutub Complex[3,4], sometime around AD 1233.

The Delhi Iron Pillar has attracted the attention of archeologists, corrosion scientists and engineers because it has withstood atmospheric corrosion for more than 1600 years. The earliest scientific studies on the pillar were undertaken by Robert Hadfield in 1912. In the late 1950s and early 1960s, the buried underground region of the pillar was excavated and examined by a team of archaeologists and scientists[5]. New insights on historical, scientific and technological aspects of the pillar are available in Balasubramaniam[2].

It is important to understand the physical nature of engineering materials and in this regard, the use of computer

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modelling has been gaining significance. In this communication, the use of computer modelling to estimate the precise weight of the Delhi Iron Pillar is presented. The approach is novel in that the precise dimensions of the pillar have been utilized to simulate the Delhi Iron Pillar on the computer. In future, it is hoped that the computer modelling studies will be extended to understanding the forging conditions of the pillar and explaining some surface features noticed on it (like the horizontal insert at the level of about 5 ft from the stone platform). In the present work, the CATIA V5R16 software was used to model and understand the engineering design of Delhi Iron Pillar and estimate the weight of its constituent components.

Figure 1. (***a***) Delhi Iron Pillar and (***b***) its computer-simulated model.

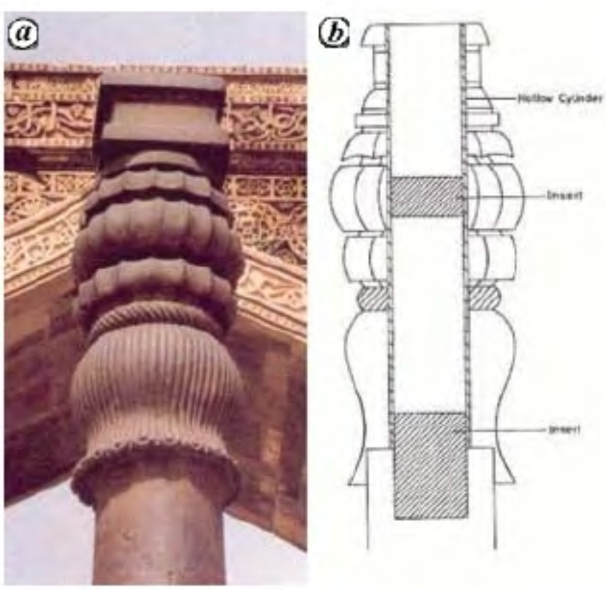

Figure 2. Decorative bell capital of the Delhi Iron Pillar. (***a***) Full view[1] and (***b***) fitting methodology over hollow cylinder[6].

The dimensions of various components of the pillar, namely the main body and the decorative bell capital, have been reviewed by Balasubramaniam[2]. The earliest measurements were obtained by Beglar in the 1870s and recently, measurements have been recorded by Ghosh[5] in 1963 and Ashok Kumar and co-workers (see Balasubramaniam[2]). The detailed dimensions of the decorative bell capital of the pillar has been measured[6]. Utilizing these data, it is possible to model the structure of the Delhi Iron Pillar on the computer.

The decorative bell capital of the pillar is a symmetrical object. It was originally topped with a chakra (i.e. a circular disc)[7]. The decorative bell capital was constructed out of seven distinct components (Figure 2 *a*).

It may interest the reader to note that lead-based solders were used for joining the components together[8]. These consisted of the following[6]. The bottom-most part is a reeded bell structure which has been manufactured using iron rods of almost similar diameter (0.75 modern inches which is equal to the Indian unit of measurement, angulam). A slanted structure is provided on top of the reeded bell structure. The next three components are rounded structures with the topmost one being only half-rounded. This is due to perspective considerations (namely when the pillar is viewed from the bottom, as it would normally be, this half-rounded part would appear curved in perspective). A round disc comes above this and finally the box pedestal atop the round disc (Figure 2 *a*). The base of the box capital contains holes at the four corners, one of which is completely empty, while the others have remnants of iron rods sticking out from them. These have been proposed for holding images of animals (lions, for example), which were probably changed depending on the season of the year[3]. The top of the box pedestal contains a hollow slot in which a chakra must have been originally fitted[7].

With regard to the fitting methodology employed to join the various components together, detailed analysis has shown that the individual components were shrunk fit around a hollow cylinder. This is schematically shown in the cross-section of the decorative bell capital (Figure 2 *b*). The hollow cylinder would have also helped in handling the part during its fabrication and also for joining the capital to the main body of the pillar using an insert[6].

The available dimensions of the pillar were utilized to create a computer image using feature-based modelling software CATIA V5R16. A feature is defined as the smallest building block that can be modified individually. These features can be modified any time during the design and modelling process, thereby providing greater flexibility to the design. The parametric nature of the software package has the ability to use the standard properties or parameters in defining the shape and size of a geometry. This property renders the designing process easy. In addition, the software has different work benches such as Part Design, Assembly Design and Drawing Workbench. The bidirectional associativity that exists between all these workbenches ensures that any modification made in the model in any one of the workbenches is automatically immediately reflected in other workbenches[9].

Figure 3. Computer simulation of complete decorative bell capital of the Delhi Iron Pillar.

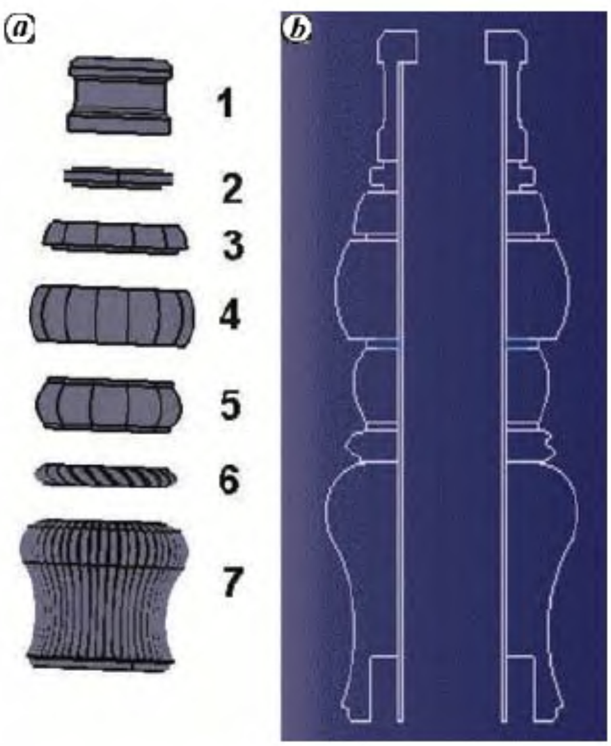

Figure 4. Computer modelling of (***a***) various sections of the decorative bell capital and (***b***) the fitting methodology employed (shrink fitting of the components over the hollow cylinder).

The complete simulated view of the Delhi Iron Pillar is presented in Figure 1 *b*. This can be compared with the full view of the pillar shown in Figure 1 *a*. The results show that it is possible to obtain fairly good reproduction of the object as long as precise dimensions are known. The software approach is relevant because individual sections of the pillar, such as decorative bell capital can be modelled. This is shown in Figure 3. Since the precise dimensions of the individual components that make up the decorative bell capital are known, it is possible to separate the contribution of each of the components (Figure 2 *b*). Interestingly, the required volume of metal can also be removed from the inner region and each component of the decorative bell capital (Figure 4 *b*) can be compared with the cross-section of the decorative bell capital, as proposed in Figure 2 *b*.

Utilizing the computer-modelled design, the weight of the components was determined. This was estimated from the calculated volume and the average specific gravity of the pillar material (7682 kg/cubic m), based on three available specific gravity data (namely 7810, 7622–7747 and 7500 kg/cubic m)[3]. Table 1 provides the weights of the seven components of the decorative bell capital, while Table 2 lists the weights estimated for the decorative bell capital and the main body of the pillar.

The total weight of the pillar has been estimated in the present study as 6511 kg using the average specific gra-

Table 1. Computed weight of the components of the decorative bell capital of the Delhi Iron Pillar

Part	Volume (cubic m)	Mass (kg)
1	0.009	73.810
2	0.001	11.382
3	0.005	39.531
4	0.016	128.442
5	0.009	71.873
6	0.004	27.812
7	0.031	245.516
Hollow cylinder	0.006	47.848
Total	0.081	646.1414

Table 2. Computed weight of the main body and decorative bell capital of the Delhi Iron Pillar

Part	Volume (cubic m)	Mass (kg)
Bell capital	0.081	646.1414
Column	0.745	5865.6860
Total	0.827	6511.8274

vity of 7682 kg/cubic m. In this study, the weight of the Delhi Iron Pillar has been estimated accurately taking into account current information about the pillar. This can be compared with published literature[2] estimates, which generally mention the weight of the pillar as 6 t. It is clear that the results of this study are in agreement with the published data. The main advantage with the current approach is that the computer model of the Delhi Iron Pillar can be utilized for a wide variety of purposes, e.g. modelling the thermomechanical deformation of an object, a subject that will be taken up in the future.

The CATIA V5R16 software was used to prepare component drawings of the Delhi Iron Pillar. Based on estimated dimensions, the weight of various components of the pillar was determined. The total weight of the pillar has been precisely estimated as 6511 kg, which is comparable to estimates available in the literature. This study also explains how computer modelling can be usefully employed to determine precise weights of historical objects.

1. Anantharaman, T. R., *The Rustless Wonder – A Study of the Iron Pillar at Delhi*, Vigyan Prasar, New Delhi, 1996.
2. Balasubramaniam, R., *Delhi Iron Pillar: New Insights*, Aryan Books International, New Delhi, 2002.
3. Balasubramaniam, R. and Dass, M., On the astronomical significance of the Delhi Iron Pillar. *Curr. Sci.*, 2004, **86**, 1135–1139.
4. Dass, M. and Balasubramaniam, R., Estimation of the original erection site of the Delhi Iron Pillar at Udayagiri. *Indian J. Hist. Sci.*, 2004, **39**, 51–74.
5. Ghosh, M. K., Delhi Iron Pillar and its iron. *Nat. Metall. Lab. Tech. J.*, 1963, **5**, 31–45.
6. Balasubramaniam, R., The decorative bell capital of the Delhi Iron Pillar. *J. Met.*, 1998, **50**, 40–47.
7. Balasubramaniam, R., Dass, M. I. and Raven, E. M., On the original image atop the Delhi Iron Pillar. *Indian J. Hist. Sci.*, 2004, **39**, 177–203.
8. Balasubramaniam, R., Some aspects of lead presence in the Delhi Iron Pillar. *Curr. Sci.*, 1999, **77**, 681–686.
9. Tickoo, S. and Maini, D., *CATIA V5 R16 for Engineers and Designers*, Dream Tech Press, New Delhi, 2006.

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Berthierine-rich ooidal ironstone from the Late Palaeocene–Middle Eocene Subathu Formation, Dogadda area, NW Himalaya and its stratigraphic significance

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Berthierine-rich ooidal ironstone occurs within carbonaceous shale in the lower part of the Late Palaeocene–Middle Eocene Subathu Formation in Dogadda, Uttarakhand Himalaya. Berthierine/chamosite occurs both as ooids and as matrix. Ooids are spherical with 1–2 mm diameter and have concentric layer structure around a nucleus. Quartz is coarse-grained and occurs as embayed grains. Carbonate phase is absent in the ooids. Berthierine and chamosite assemblage indicates a temperature of ~130–160°C of burial diagenesis for Dogadda ironstone. The lithological association, distinct mineralogy and texture suggest that the mineralogy of the Dogadda ooidal ironstone is *in situ*, formed in a shallow-marine environment under conditions of low net sediment accumulation. Dogadda ooidal ironstones, along with coeval ash beds in the foreland basin are useful in stratigraphic correlation.

Keywords: Berthierine, ooidal ironstone, Palaeocene–Eocene, Subathu Formation.

MUCH attention is being paid in recent years in examining the Maastrichtian to Early Eocene sedimentary sequences the world over, as this interval encompasses events of global significance such as Mid-Maastrichtian deep ocean circulation reversals, the Cretaceous–Tertiary (K/T) boundary mass extinction, Palaeocene–Eocene Thermal Maximum (PETM), extensive Cenozoic volcanism, and collision of the Indian plate with Eurasia. In this context, the Subathu Formation in the foothills of NW Himalaya, by virtue of its stratigraphic age (Late Palaeocene–Middle Eocene), shallow marine sediments and/or conditions, abundant fauna with excellent preservation, along with ample outcrops of almost complete and continuous sequence (Figure 1), forms an ideal field laboratory to obtain insights into events of global and regional importance. During the course of a systematic investigation on the lithological make-up of the Subathu Formation in Dogadda area, Uttarakhand, aimed to trace mineralogical variation across Late Palaeocene–Eocene transition in a shallow marine setting, the author found a prominent unit of berthierine-rich ooidal ironstone in the lower part of the Subathu Formation. The stratigraphic position of the

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