

Ice Lubrication for Transporting Heavy Stones to the Forbidden City in 15th – 16th Century China

Jiang Li¹, Haosheng Chen^{2*}, Howard A. Stone³

¹ School of Mechanical Engineering, University of Science and Technology Beijing, Beijing 100083, China

² State Key Laboratory of Tribology, Tsinghua University, Beijing 100084, China

³ Department of Mechanical and Aerospace Engineering, Princeton University, NJ 08544, USA

*Corresponding author for chenhs@tsinghua.edu.cn

1. Introduction

When introducing the history of tribology, typically two milestone cases are summarized: Transportation of the colossal status of Ti at Saqqara Egypt *c.* 2400 B.C., where water was used as lubricant, and transportation of a huge human-headed bull at Kouyunjik Assyria *c.* 700 B.C., where the aid of rollers was used to take advantage of rolling motion over sliding [1].

It is thought that “the haulage of colossal statues by masses of men does not appear in any kind of ancient Chinese representation”, because spoked wheels appeared in China about 1500 B.C. [1]. However, we discovered that in the 15th – 16th Century A.D. huge stones (over 100 tons) were transported to the Forbidden City in Beijing by sledges hauled by men from a quarry over 70 km away (Fig. 1). In contrast to the wood-on-wood sliding used by the Egyptians, wood-on-ice sliding was adopted by the Chinese, where an ice path was created in the winter by pouring water on the frozen soil [2]. We first discuss the practicality of the approach using documented information, and then discuss the features of ice lubrication in the heavy-load low-speed regime.

2. Analysis and Discussion

Large numbers of stones had been mined and transported for the construction of the Forbidden City in the 15th – 16th century, and wheeled carts were widely used for large stones < 18 tons [2]. However, for the huge stones weighing 60 tons and above, which was beyond the load capacity of the wheeled carts, sledges pulled by men could be a practical and reliable method, where lubrication played a significant role.

We calculated the number of men needed to haul the sledge with a 123-ton stone for 70 km within 28 days in 1557 [2] under different lubrication conditions. The results are shown in Table 1, where the mean effort of a man was estimated with two methods: a mean tractive force of 800 N [1] and an average power of 64 W during the greatest day’s work over a long time [3]. The results match well with each other, and the results of an ice surface lubricated with a water film, Condition 4 in Table 1, are more practical and reasonable than those of the other three conditions listed. The historical description that wells were dug every 0.5 km for the supply of water for pouring to drag the sledge also supports the lubrication condition.

Ice is a nature material of two significant merits:

improved strength and the smoothness of the surface to reduce friction. A 1200-ton building was successfully moved 240 m in 22 days with the aids of 4 hydraulic jacks by this technique in Harbin China in Jan. 2013.

Table 1 Number of men needed to haul the sledge

Conditions	μ	800 N/man ^[1]	64 W/man ^[3]
1. Dry road	1.71 ^[4]	2629 men	2685 men
2. Log rollers	0.21 ^[4]	323 men	330 men
3. Ice road	0.36 ^[5]	554 men	565 men
4. Ice with water film	0.03 ^[5]	46 men	47 men

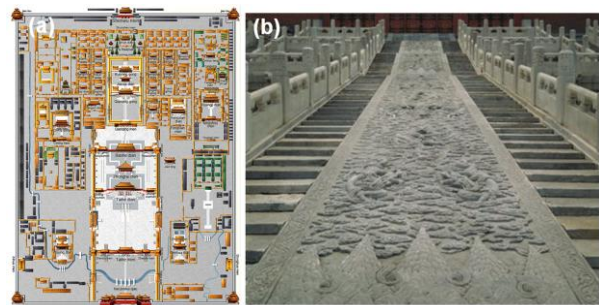


Fig. 1 The Forbidden City in Beijing. (a) A map of the 753 m x 961 m area. (b) The existing heaviest stone. The Huge Stone Caving weighs more than 200 tons.

3. Summary

The exploration of the historical case provides a good example for the study of the heavy-load low-speed regime of the friction of ice.

4. References

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