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A Simple Type 2 Lever for Lifting and Moving Monoliths

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Abstract

Many investigations into how ancient humans quarried, moved, and placed very large stones have resulted in a high level of uncertainty regarding likely methods used. Some suggested methods include using flotation (boats) in rivers and canals, simply dragging on top of the ground, sliding on logs, moving on rolling logs, and even giant wheels fixed to the ends of massive, quarried stones. Each of these methods (which may have been used, as well as others proposed) have advantages and disadvantages. Instead of reviewing these methods, in this paper the authors investigate the potential of using a simple type 2 lever in an unconventional way to achieve lift and horizontal movement simultaneously. The focus is upon mechanical advantage as opposed to in-depth analysis of operational logistics. Estimates of potential productivity and required resources, are included for comparison to some proposed dragging methods. The authors conclude that ancient people could have used this method, which only requires expertise in carpentry (timbers) and rigging (with ropes) to implement the technique, reduce labor, and increase productivity compared to dragging methods.

1. Introduction and Design

There has been much debate about the devices used by ancient peoples to transport monoliths. [1]The materials and technology greatly restricted the options available to the builders of those times. However, the physics of the human body and mechanical structures remain unchanged. By analyzing the properties of four bar mechanisms, type two levers, and the physical restrictions of a laborer, we will demonstrate that the peoples of that time conceivably used the device proposed by Boles and Morris [3]. In Figure 1 the device proposed by Boles and Morris takes advantage of the Second Class's ability to position the pivot against the ground. By doing this, the friction between the support timber and the ground serves as a stable pivot position [4]. A rope attached to the furthest point of the timber will transfer the force applied by the operator to the effort position of the lever. The position of the load determines the point at which the monoliths section of rope attached to the A-frame timber applies force to the device. One major advantage of this system is the operator must only provide effort for the first half of the whole movement, the second half of the monoliths movement is the result of gravity pulling the monolith back to the ground.

The overall design of this system is essentially a four-bar mechanism. Furthermore, from international 'The World's Strongest Man' pulling competitions, authors observed that the movement of the laborer pulling the rope starts from a low position relative to the ground. As the laborer builds momentum, they will also raise their height [2, 6]. This, in combination with given restraints from Boles and Morris in Table 1 of the length of the timber, pull height of laborer, length of pull rope, represents a four bar with a crank-rocker build seen in Figure 2. Given any angle, and in our case, it will be θ_4, and the lengths of each bar, we calculate the positional analysis of the four-bar mechanism using the Formula 1 As shown below.

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$$\theta_3 = 2\tan^{-1}\frac{\left(-E \pm \sqrt{E^2 - 4DF}\right)}{2D}$$

$$\theta_4 = 2\tan^{-1}\frac{\left(A \pm \sqrt{A^2 + B^2 - C^2}\right)}{B + C}$$

$A = \sin\theta_2,$

$B = \cos\theta_2 - K_2,$

$C = K_1\cos\theta_2 - K_3,$

$D = \cos\theta_2 - K_1 + K_4\cos\theta_2 + K_5,$

$E = -2\sin\theta_2,$

$$F = K_1 + (K_4 - 1)\cos\theta_2 + K_5$$

$$K_1 = \frac{d}{a}, \qquad K_1 = \frac{d}{c}, \qquad K_3 = \frac{a^2 - b^2 + c^2 + d^2}{2ac}, \qquad K_4 = \frac{d}{b}, \qquad K_5 = \frac{c^2 - d^2 - a^2 - b^2}{2ab}$$

For the four-bar mechanism, each of the angles can be determined given at least one angle and all lengths of the bars. These formulas can be arranged for any given input angle [7].

2. Methodology

For this study, we have restricted several aspects of the experiment. First, the amount of force that a male of weight ranging from 120 to 198 pounds can pull a rope with a force from 90.6 to 187.7 pounds [1]. For the purposes of this report, the pull force supplied by the person is restricted to 100 pounds (3). Secondly, the structural limitations for the A-Frame were predetermined from the work of Boles and Morris per Table 1.

The movement begins with the monolith on the ground and the timber A-Frame to start with θ_4 of 80° from the ground. [5] When the laborer pulls on the rope, the monolith moves vertically and horizontally. After the monolith passes 90°, the force of gravity will finish the movement. The total change of angle in the A-Frame is 20°.The objective is to determine the maximum force a laborer could generate upon the monolith to have movement, the change in horizontal displacement, and the maximum lift height achieved. Additionally, we measured the difference in movements and forces between the two attached heights of the lift rope.

Using the Four Bar linkage calculations in Formula 1 and the parameters from Table 1, we used MATLAB to perform the calculations, simulate the movement, and plot the data output. We calculate the measurements for the first half of the movement, because the laborer is only required to apply force during from the 80° to 90° section of the stroke. Freudenstein published approximate synthesis of four bar linkages using kinematics of joint structures and their interdependence with kinematic equations. [8] Acharyya and Mandal presented performances of evolutionary algorithms for four bar linkage mechanisms. [9]

3. Results and Discussion

Figure 3 shows the maximum force that a single laborer generates a maximum force of 100 lbs. The amount of lift force this device can generate is dependent upon the height where the lift rope connects to the monolith. The data generated from Results one (10 feet lift height) and two (20 feet lift height) demonstrate how the maximum force for each case is dependent upon both the height of the lift rope and the angle of movement. In our case, we choose to keep the change in angle of movement constant from 80° to 120°. This restricts the maximum force to the point of initial movement. Therefore, the difference in lift force between the two results is only dependent on the lift rope height. The data demonstrates that increasing the height from 10 feet to 20 feet reduces the maximum lifting force to 51%.

Figure 4 shows the horizontal movement of the monolith and Figure 5shows the change in height as a function of angle θ_4 from horizontal. The height of the lift rope directly corresponds to the distance the monolith will move horizontally and to the maximum vertical lift height. By increasing the height from 10 feet to 20 feet, the monoliths horizontal movement and the vertical maximum lift height doubled. As expected, the vertical height and horizontal movements are directly proportional to each other due to the properties of levers.

When compared to other suggested methods such as raft, roller/sled, or crane methods of moving monoliths, this simple type two lever has several advantages. The raft and roller/sled methods offer no vertical lift. They only offer horizontal movement of the monolith. Furthermore, the raft method requires the construction of waterways and a device capable of floating the monolith. On the other hand, the crane method provides vertical lift and no horizontal lift. Additionally, due to a crane being a type one lever, the pivot would be required to withstand up to double the force of the monolith as a shear force. Whereas the type two lever used in the system proposed here, distributes the shear force along both the horizontal and vertical component of the lifting timber. Also, a crane would require three or more points of contact with the ground to be stable. This would require additional resources to manufacture. In terms of productivity, the mechanism proposed here has three timbers in a two-dimensional configuration that make up the A-frame and can be easily stacked on a cart during transport. Unlike the crane alternative, which would have to be broken down, transported, then reassembled.

To move a two-ton monolith using this method, it would take three laborers using Result one and five laborers using Result two to perform one movement of the device. With an objective of moving a great distance at the fastest possible rate, then the operator would set the device at the 20-foot position to achieve a longer stroke. However, if the objective were to maneuver the monolith slightly to position it, the operator would use the 10-foot setting.

4. Conclusion

We conclude that people with limited technology and access to raw materials and laborers, conceivably used the device proposed by Boles and Morris in order to transport monoliths. Our research of four bar mechanisms, type two levers, and the physical restrictions of a laborer, demonstrated that this device is adjustable to handle different load sizes. Furthermore, the device is capable of maneuvering horizontally and vertically along with precision at the cost of reset rate of the device. Therefore, this device would still be a preferred choice to the alternatives, considering numerus advantages of the method.

Figure Captions

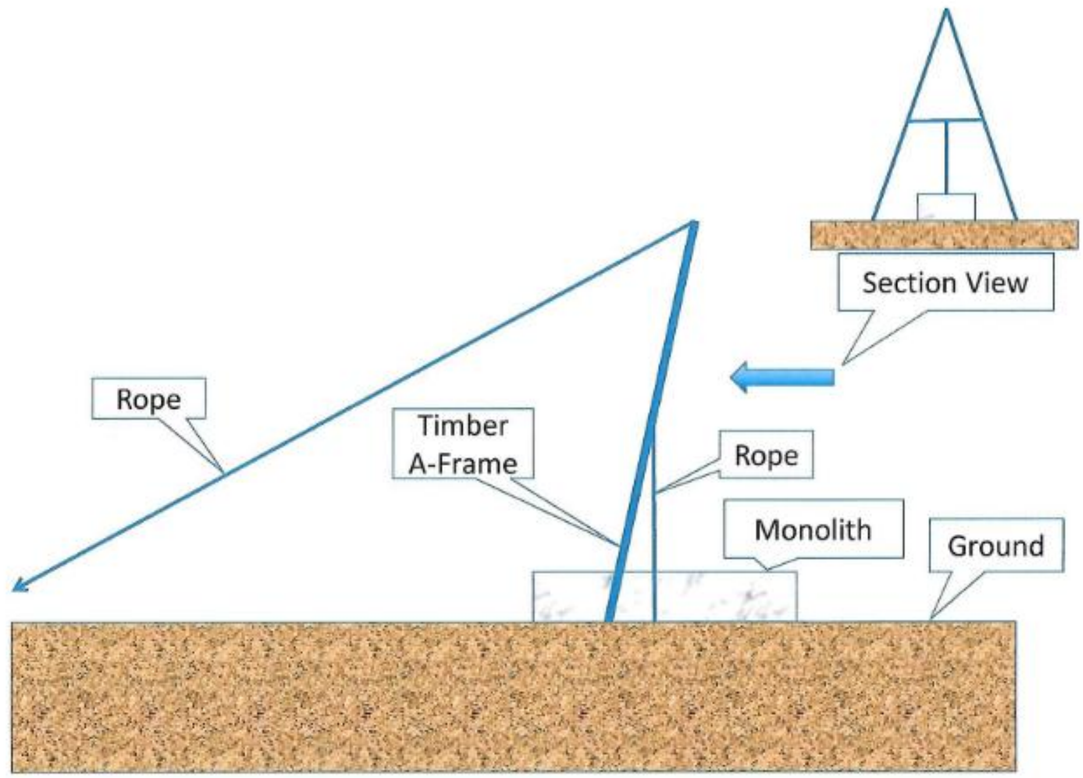
FIGURE 1. Boles and Morris design of structure to transport monolith. The rope extending from the top of the Timber A-Frame will experience the 100 lbs. pull force from the laborer [3].

FIGURE 2: Four bar mechanism. R2 represents the position of the laborers' hands holding the rope. R3 represents the rope extending from the operator to the timber. R4 represents the timber. R1 represents the ground [7].

FIGURE 3: Maximum Force of Lift for Result one (the 10-ft. lift height) shows the max force the laborer will be able to generate is 1900 lbs. Maximum Force of Lift for Result two (the 20-ft. lift height) shows the max force the laborer will be able to generate is 960 lbs.

FIGURE 4: Horizontal movement of the monolith. For the 10-ft. height, the horizontal displacement from the ground to the 90°point of the monolith is 1.755 feet. Therefore, the total displacement of the monolith per action would be 3.5112 feet for Result one. For the 20-ft. height, the horizontal displacement from the ground to the 90°point of the monolith is 3.522 feet. The total displacement of the monolith per action would be 7.044 feet for Result two.

FIGURE 5: Vertical movement of the monolith. The vertical displacement from ground to the 90° point of the monolith is .1543 feet for the 10-ft. height. This is also the maximum height achieved by the monolith for Result one. For the 20-ft. height, the maximum height and vertical displacement is .3085 feet.



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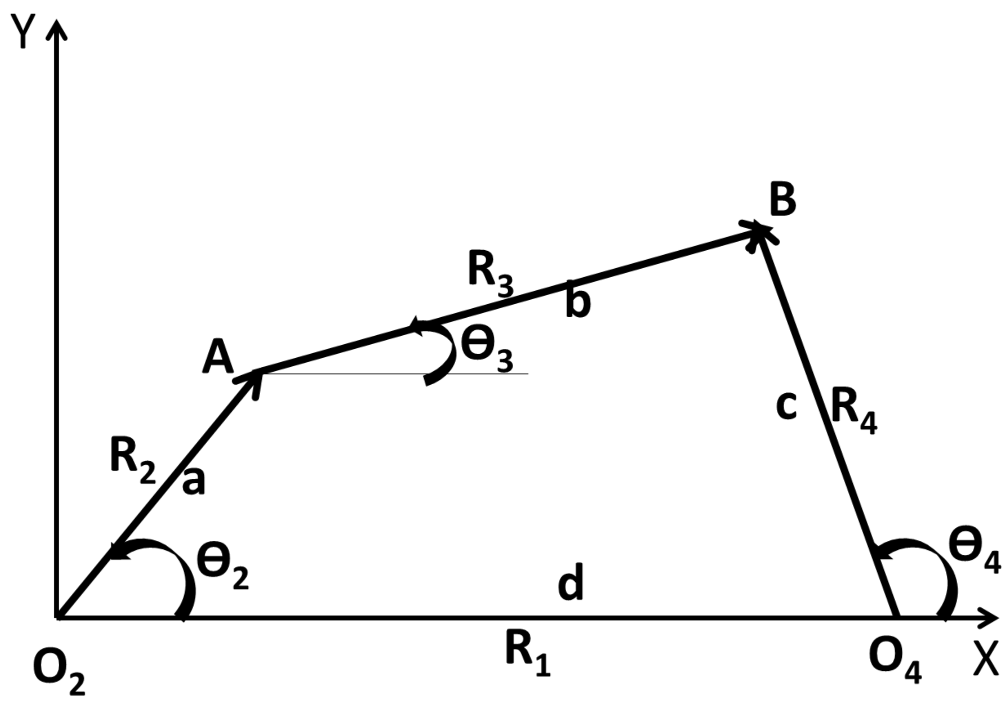

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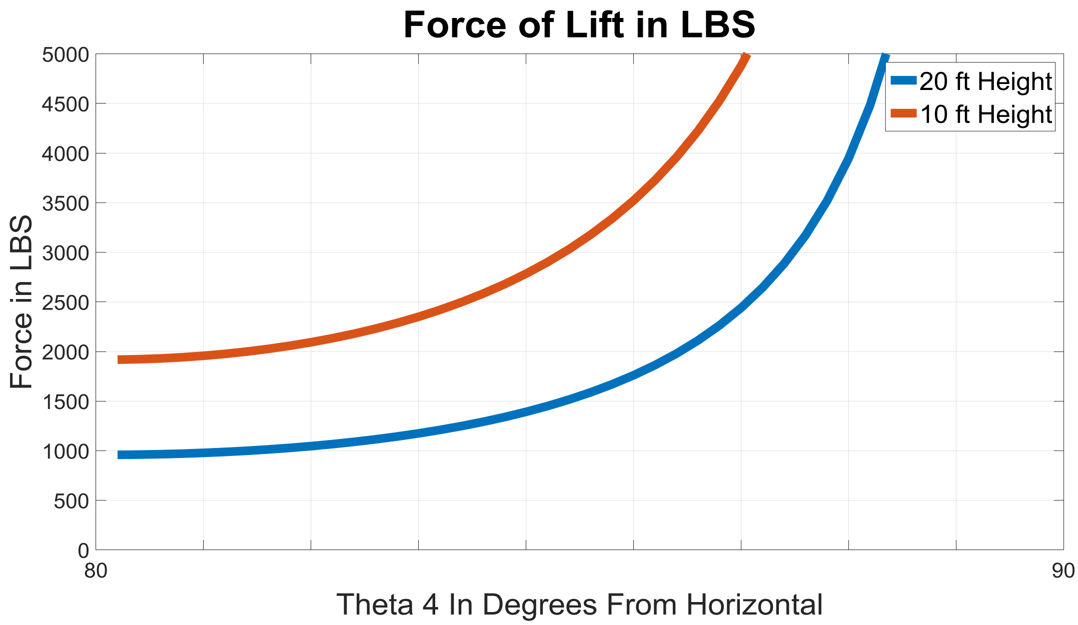

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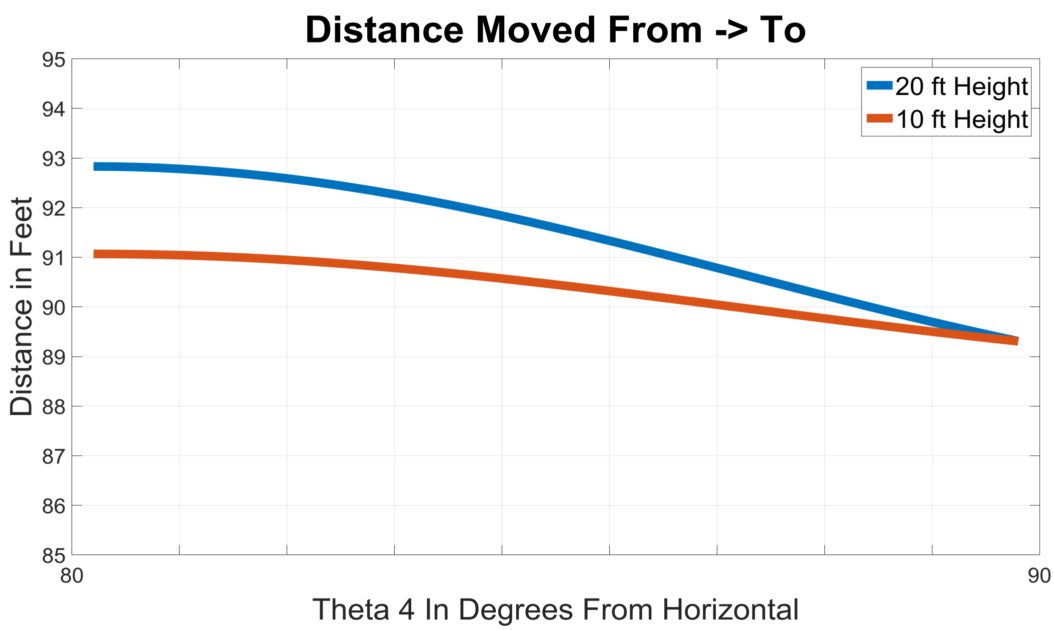

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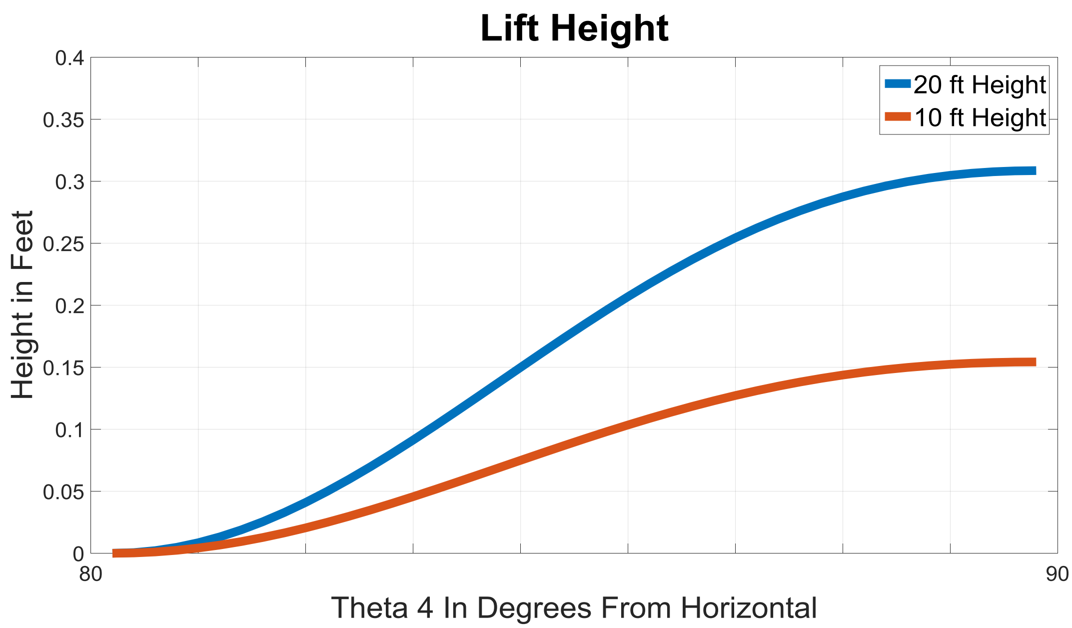

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Variable	Result one	Result two
Pull Rope length	100 feet	100 feet
A frame height	40 feet	40 feet
Lift rope attacked to frame	10 feet	20 feet
Maximum tilt angle	10 degrees	10 degrees
Force of person	100 lbs.	100 lbs.

TABLE 1. The predetermined restraints from Boles and Morris. The two different results are from the variation in attached height of the lift rope to monolith. Maximum tilt angle refers to the change in angle +/- of the A-Frame from its vertical position[3].

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