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A3_9 Driving up the Eiffel Tower

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Abstract

This paper discusses how far up the Eiffel Tower a car is able to drive, depending on the friction force that the car is able to generate. With a coefficient of static friction between rubber and solids given as between 1 and 4 it is calculated that the angle for which a car would no longer be able to drive up the tower is between 45° and 76°. It is then calculated that for the Eiffel Tower these gradients occur at heights of

Introduction

In many films cars, bikes and other various types of transport are seen to be driving along or up buildings. If these buildings have vertical surfaces then a car cannot drive on or up the surface as the normal force which creates the friction would simply push the car off the surface straight away. However if there was some slant or gradient to the surface, then the problem becomes more interesting. Therefore this paper will investigate whether it would be possible for a car to drive up one of Paris' most famous landmarks: the Eiffel Tower.

The Tower…

The Eiffel Tower was chosen as a special case because the gradient changes as the height increases. The authors have taken the height and horizontal distance from the centre of the tower for the base, first platform, second platform and top of the tower. The values for these are given in table 1 [1].

	Height (m)	Distance from central axis
Base	0	62.5
1st platform	57	33
2nd platform	118	19
Top	324	0

Assuming the gradient is constant between each measurement, the gradient of the line is described by

$$m = (h_2 - h_1)/(w_1 - w_2), \qquad (1)$$

where m is the gradient, h is the height, w is the horizontal distance from the central axis and the subscripts refer to the initial and final positions (1 being the lower of the two points) Therefore the gradient between the base and the edge of the first platform is 1.93, that between the edges of the first and second platforms is 4.36 and the gradient between the edge of the second platform and the top is 10.84.

Coefficient of Friction

When a car is moving each point on a tyre comes in contact with the road for a short amount of time. For the time that it is in contact the tyre and road do not move with respect to one another, therefore it is the coefficient of static friction which must be used in this case.

The authors were unable to obtain a good value of the coefficient of friction between rubber and iron (the material from which the Eiffel Tower is made). The best estimate for this value is that given for between a solid and rubber, a value given by many sources as between 1.0 and 4.0 [2]. We have therefore assumed that one side of the Eiffel Tower is a continuous surface of substance will give the coefficient of friction of 1.0 and another side is that of 4.0

Friction

The force due to friction on an object [3] is given by

$$F_{f,max} = \mu_s N, \qquad (2)$$

where $F_{f,max}$ is the maximum force of friction on an object, μ_s is the coefficient of static friction and N is the normal force on the object. For an object on a slope N is defined as,

$$N = m\, g \cos(\vartheta), \qquad (3)$$

where m is the mass of the object, g is the acceleration due to gravity and θ is the angle that the slope makes with the horizontal.

$F_{f,max}$ can also be described in terms of trigonometric functions as shown in equation 4.

$$F_{f,max} = m\, g \sin(\vartheta). \qquad (4)$$

Substituting equations 3 and 4 into equation 2 and cancelling like terms equation 5 is found,

$$\sin(\vartheta) = \mu_s \cos(\vartheta). \qquad (5)$$

From this μ_s can be given as

$$\mu_s = \tan(\vartheta), \qquad (6)$$

and θ can be given as,

$$\vartheta = \tan^{-1} \mu_s. \qquad (7)$$

Using the limits of the coefficient of friction for rubber (1.0 – 4.0) then θ is found to be,

$$\theta = 45° - 76°.$$

At 45° the gradient of the slope is 1 and at 76° it is 4. This means that the coefficient of friction is equal to the increase in height over one unit length.

Conclusions

The absolute maximum gradient that a car may climb is 4. This means that, using the assumptions above, on the side with $\mu_s = 4.0$ (under perfect conditions) the car would not be able to make it above the first platform at a height of 57m. However the assumptions used are not physically correct and the gradient increases with height throughout. In reality the car possibly would be able to make it a little way above the first platform.

For the side with μ_s =1.0 the car would not be able to drive up this at all.

References

[1] http://www.ce.jhu.edu/perspectives/studies/Eiffel%20Tower%20Files/ET_Geometry.htm

[2] http://www.engineershandbook.com/Tables/frictioncoefficients.htm

[3] P Tipler, *Physics for scientists and engineers*, (Freeman Worth, New York, 1999), 4th ed., p115