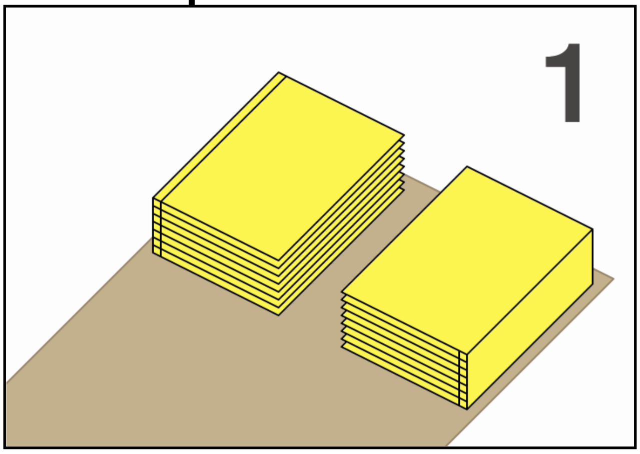
Inseparable phone books, science fact or science friction?

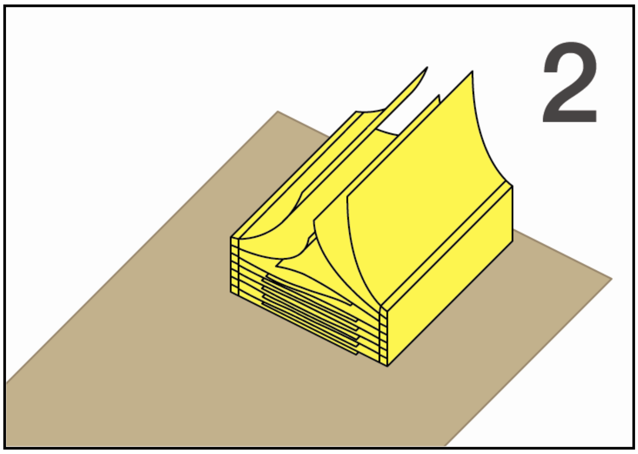
The Question

Think of two sheets of paper laid atop of one another, how much force is required to separate these two sheets by sliding them apart? In other words, how much force is required to overcome the friction between these two sheets of paper? Very little, you'd think? The **question** is what happens when you multiply this situation several times over in the form of two interwoven phone books?

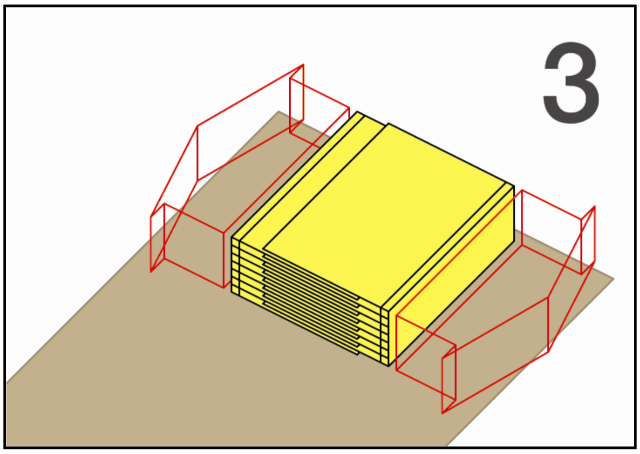
The Setup



Get hold of two phone books, preferably of equal thickness, page number and without insulting redirections from Civil Engineering (:see Boring).



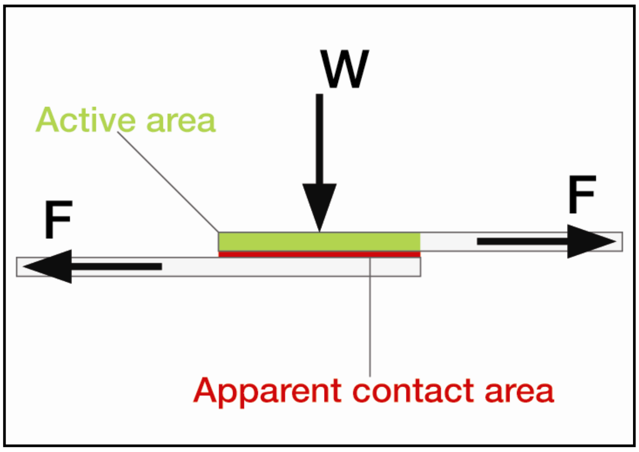
'Weave' the two phone books together by placing a single leaf of one book upon another, alternating the process from one book to another. Imagine it like putting the teeth of a pair of combs together. In order to stop the pages unravelling and falling open during testing, apply a little tape to the cover pages, sticking them to the pages that are securely woven – 4 lengths of 3cm should be enough.



With all the pages correctly woven the phone books are now fused and ready for testing. To test, apply a force to each spine-end by pulling the two books into tension, this is more easily done with two people, one each end. You will soon realise your force is no match for the phone books' strength. So how much force is necessary to separate these two phone books?

The Science

Static friction describes the friction force opposing the direction of motion when the sliding velocity is zero, static friction is defined as:



$\mathbf{F = \mu R}$

Where,
F = Friction force
μ = Coefficient of Friction (COF)
R = |**W**| = Reaction force due to the applied load **W**

Note the applied load is assumed to be given by the mass above the contact area only (active area, coloured green in the diagram).

FRICTION FOR TWO

Using the initial example of two sheets of paper, by applying the above formula to some convenient values we can calculate the friction force necessary to separate two sheets of paper.

μ = 1 (reasonable assumption for paper-paper COF)
R = |**W**| = 2grams * 9.81m/s^2 = 0.002 kg * 9.81m/s^2 = 0.01962N
F = 1 * 0.01962N = 0.01962N

Two sheets of paper can be separated easily.

SCALING UP

Let us assume that each telephone book has 500 sheets and weighs 1kg. As the pages are stacked upon one another, the average normal force is used to calculate the total friction force. The number of friction contact surfaces – sheet surfaces or pages – defined as N, is directly proportional to the friction force, giving,

$\mathbf{F = N\mu R_{av}}$

Inputting the values, we get,
μ = 1
$\mathbf{R_{av}}$ = |$\mathbf{W_{av}}$| = 0.5 * (1 + 1)kg * 9.81m/s^2 = 9.81N
N = Number of Contact Surfaces = Number of Sheets - 1 = (500 + 500) – 1 = 999
F = 999 * 1 * 9.81N = **9800.2N**

From the above calculation, the friction force required to separate two phone books is approximately **one tonne-force** (9.81kN). Not inseparable, but not far from it.

CASE CLOSED/IS THAT 'NORMAL'?

Interestingly, using only two sheets but with the same contact area as all the sheets in the phone book would give a friction force of **F = 1 * 1 * 9.81N = 9.8N**, 1000 times smaller. Increasing the contact area between *two sheets* decreases the pressure (reaction force/area). Increasing the contact area of *stacked sheets* (by adding sheets) does not decrease the pressure (reaction force/area). When stacking, this creates a positive, direct relationship between contact area and Coefficient of Friction. More sheets = higher COD = higher **F**.

Reference/More Information: http://www.youtube.com/watch?v=6sIB2kL-BWc, physicsforums