Efficient LEGO structures: Technic mechanical measurements & tips

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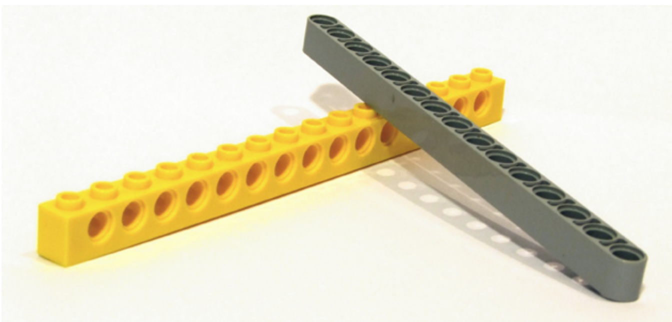
One of the common problems designing Technic models regards judging the adequate amount of structural reinforcements. Too little and the model will bend and twist, or even collapse; too much and the model will have less available space for functions, possibly be compromised aesthetically, and heavier — again, perhaps requiring further reinforcements. Though this problem of balance arises in every at least medium-sized model (in fact, not only in LEGO® but mechanical engineering in general), one way of minimizing it is to ensure the reinforcements being maximally utilized in the first place. The aim of this article is exactly to provide the measurements and resulting guidelines for Technic structural efficiency.

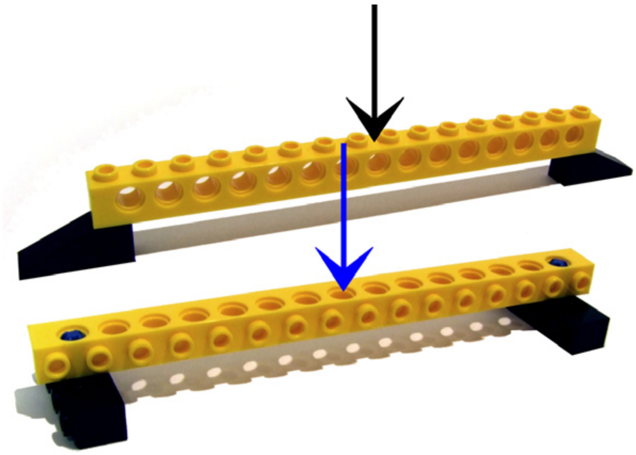
Let us begin by addressing one very common discussion topic among Technic builders: difference in strength between studded and studless beams — our elementary structural parts. We can safely assume that both types of beams, and most other LEGO parts for that matter, have more than sufficient strength when subjected to compression or tension, i.e. pushed or pulled lengthwise. It is bending that causes most problems in practice. There are two basic planes of bending regarding to the orientation of their holes — let's call them vertical (perpendicular to the holes), and horizontal (parallel, along the holes).

There is little doubt in studded beams being noticeably stronger than their studless counterparts, but they are significantly heavier as well. How much exactly, and which offer a better deal? For the measuring purpose we can build a simple bridge that secures the beams' ends, provide simple downward force on their center, and measure the displacement.

Using the 16L studded and 15L studless beams which are roughly equivalent, the results get quite interesting. Subjected to a force of 25 N (weight of 2.5 kg), the studless beam bends 1.5 mm, while the studded only about half as much: 0.8 mm. Under the identical force but horizontally ("sideways"), both give a little more — studded 1.5 mm, and studless 2.5 mm. The ratio is smaller sideways, which can be attributed to the two beams being of similar width, but rather different in height.



Let us analyze these numbers considering the beams' masses — they amount to 4.1 g and 3.1 g. The studless beam is less than one quarter lighter than the studded, however it barely manages providing half the strength vertically, and not even two thirds horizontally. Studded beams therefore bear much better strength-to-weight ratio, and are subsequently a better building material for the heavily strained main structural parts — a vehicle chassis, a robot's skeleton, etc.

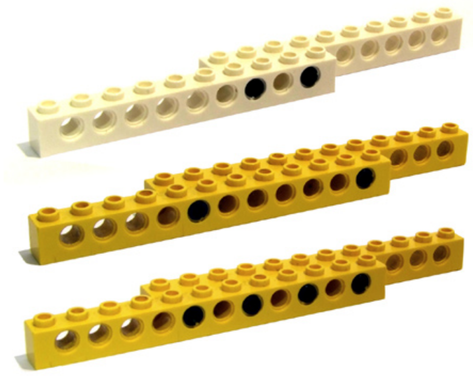


However, the structural strength does not rest on beams alone; the pins connecting them need to be taken in account as well. So let us "split" the 16L beam into two 10L studded beams connected by two friction pins, with a joint section of 4L to get a total length of 16 studs, and subject it to the identical vertical force as before. (Horizontal force would easily disconnect the beams of this structure, so there is little sense in measuring it — it is rather the matter of clever design to avoid the force being applied parallel to the pins.)

Such composite beam loses plenty of its strength — it bends as much as 2 mm vertically. In other words, this connection reduces the strength in comparison to a compact beam as much as four times, making it significantly weaker than the comparable studless beam, too.

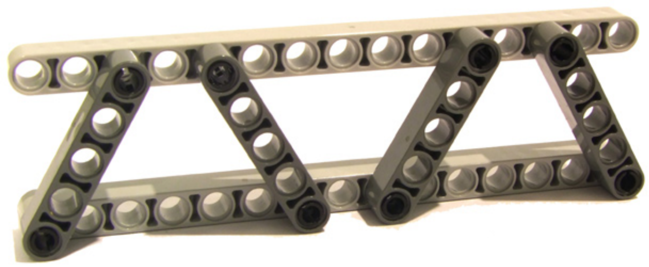
Increasing the joint section should improve the strength: let's replace two 10L beams by a pair of 12L beams, having a joint 8L section connected with four friction pins for a total length of 16L again. Remarkably, it deflects only 0.7 mm in the center, meaning that this type of structure is even stronger than a single compact 16L beam! However, the number of pins connecting the beams is important: removing the two inner pins from this structure increases the bending displacement to 1.5 mm — just like a 15L studless beam. Not troublesome, except for the heaviest models.

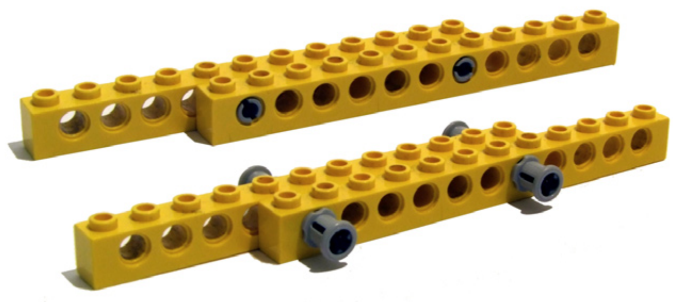
When possible, prefer friction pins for maximum strength, as replacing the two friction beams in this latest structure with two 4L axles with bushings or a pair of frictionless pins increases the displacement by 0.2 mm, that is, reduces the overall strength by about 15%.



For instance, we can compare a “classic” Technic frame composed of three studded beams separated by plates and reinforced by two vertical beams at its ends, to a simple triangular frame built with only 6 studless beams. The first instinct perhaps tells us that the studded structure is massively stronger, and in some respects it is, but subjected to a heavy load from above which will be its typical usage, it all rests on bending of the top 16L beam. The studless structure is in fact several times stronger from above, thanks to its triangular form, and yet almost half as light. In a wider picture, positioning beams wisely is at least as important as their own strength.

The overall strength of a beam structure is, of course, defined by its structural configuration as well. Though there are far too many possible forms to even consider focusing on them specifically, the previous measurements offer useful guidelines. For instance, all the significant forces should ideally act lengthwise along the beams — but if the construction disallows it, a studded beam mounted so that the main force acts vertically upon it, should be a next best solution.





All these facts can be summarized into a few simple conclusions which can serve as building guidelines, which you can read about in the separate frame.

Of course, there are various other measurements that could be done regarding the mechanical properties of Technic parts (such as beam torsion strength, chain drive limits, axle friction and flexibility, etc.) to improve the constructions even further. Thsi time we have focused on beams as the basic Technic building material — but watch this space for further measurement projects!
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This is the reason why triangular and cross-braced structures are so important and useful in Technic, and mechanical engineering in general. Almost any external force acting on such structures will directly or indirectly subject one or more of its beams to compression, resulting in particularly high rigidity.

Technic Beam Construction Facts:

• In comparison to their studless counterparts, studded beams are approximately double as strong vertically and 2/3 stronger horizontally, yet only 1/3 heavier.
• The overall structural strength is affected much more by the beam connections than the beams’ inherent strengths.
• Important load-bearing beams should be connected by long common sections (e.g. 6L or more). Short common sections dramatically decrease overall strength.
• Higher pin density in a common section (e.g. 4 instead of 2 friction pins) noticeably increases overall joint strength, possibly to even more than that of compact beams.
• Using frictionless pins or axles as beam connectors reduces the strength about 15% in comparison to the friction pins.
• Cross-braced and triangular structures massively increase rigidity, often to higher levels than classic stacked compact beams, yet are significantly lighter.