Investigation into the Strength of Lego Technic Liftarms and Brick Beams, and of Liftarm Pin Connections

Contents

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1.0 Introduction

"Studless" Lego Technic Liftarms have been in use since the early 2000s while "Studded" Lego Technic Bricks have been in use since the late 1970s. This report is to further investigate the strength of these Liftarms and Brick Beams to clarify what the theoretical maximum weight limit is. It is often said that you can do almost anything with Lego but limits have been reached. The goal is to quantify those limits for the AFOL (Adult Fans Of Lego) community in a similar way to Philo and his work on Lego Motors. My previous report back in July 2011 was quite well received even though there were some criticisms.

With the help of David Luders, I am privileged to be able to repeat this experiment. While similar in its goals, this report will hopefully address some of the criticism and further the knowledge in this area.

For the purposes of this report **Liftarms** will refer to the "Studless" Lego Technic Liftarms; **Brick Beams** will refer to "Studded" Lego Technic Bricks; **Beams** will refer to either Liftarms or Brick Beams; **Pins** will refer to Lego Technic Pins.

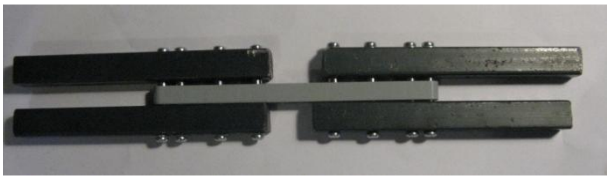
2.0 Method

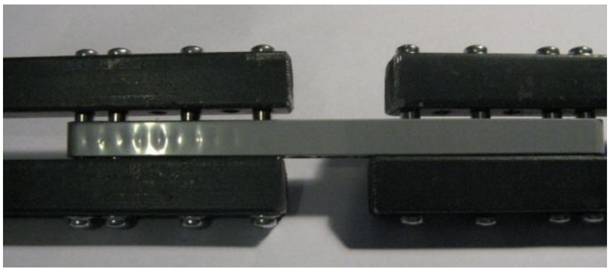
The tension tests were done with a Material Test System and the transverse tests with a Hounsfield Bench top Materials Testing Machine. These are show below. These machines are the same as used in the first report.

All Lego used is new and only used once.

Following feedback on my July 2011 Experiment; there was a request for two major changes. First is a larger sample size. Thanks to David Luders donating parts, I was able to perform 3 runs for each combination. Second was the crushing of the Beams affected the result. I was able to manufacture a rig that would hold the Liftarms in a more realistic way. It is important to note that the rig was only used for the Beam tension tests.

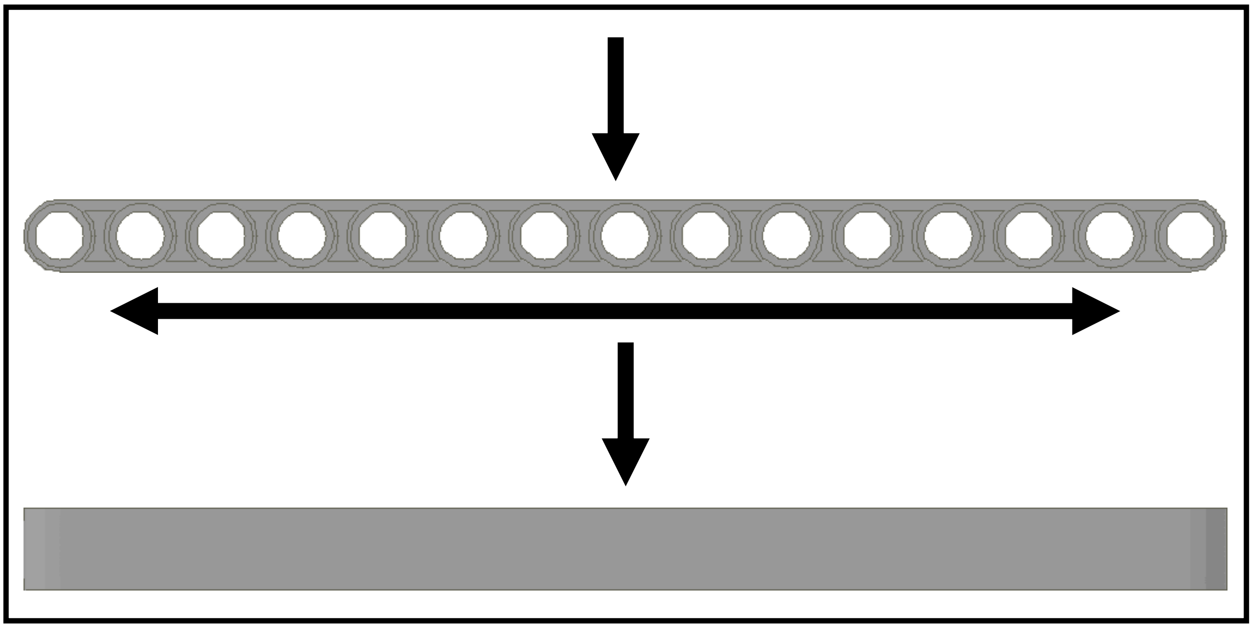
The first category of tests involved testing the Liftarms and Brick Beams in 3 areas. The first is the tension test. This used the new rig. The four silver cylinders held each end of the Liftarm. The jaws of the MTS gripped the steel sides. This ensured the Beam remained intact during the test.





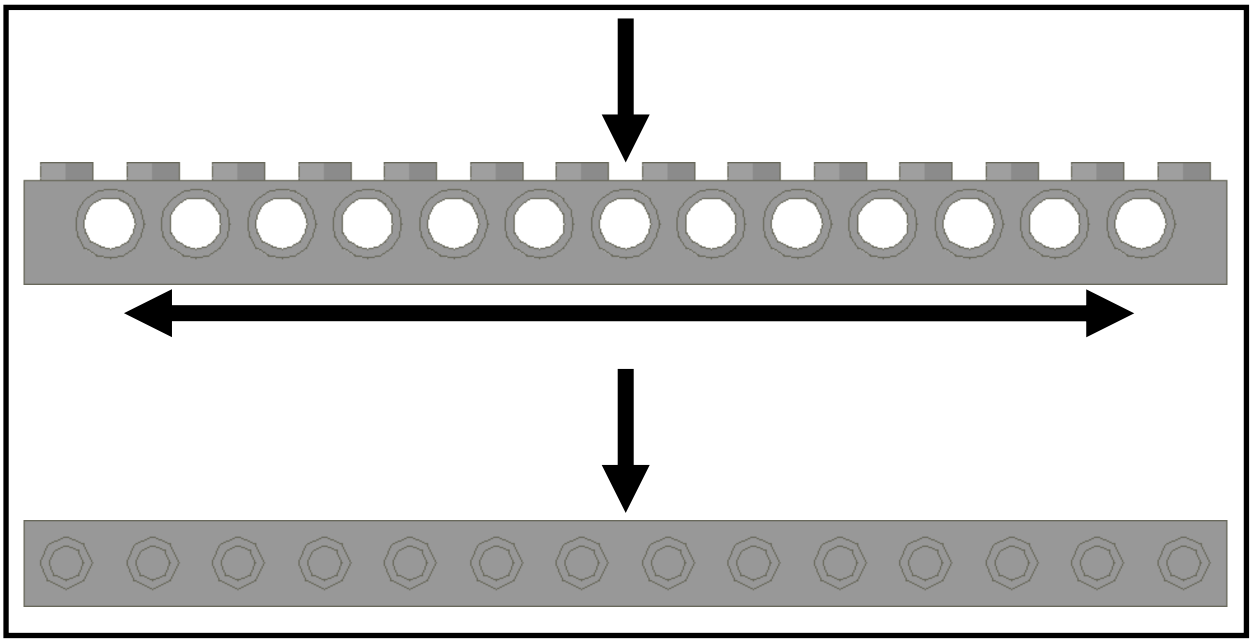
The second and third tests were the transverse tests with the force applied to the Liftarms and Beams with the pin holes perpendicular to the force and parallel to the force. These were performed in the same way as previously.

Technic Liftarm



The black arrows indicate the application of Force.

Technic Brick Beam

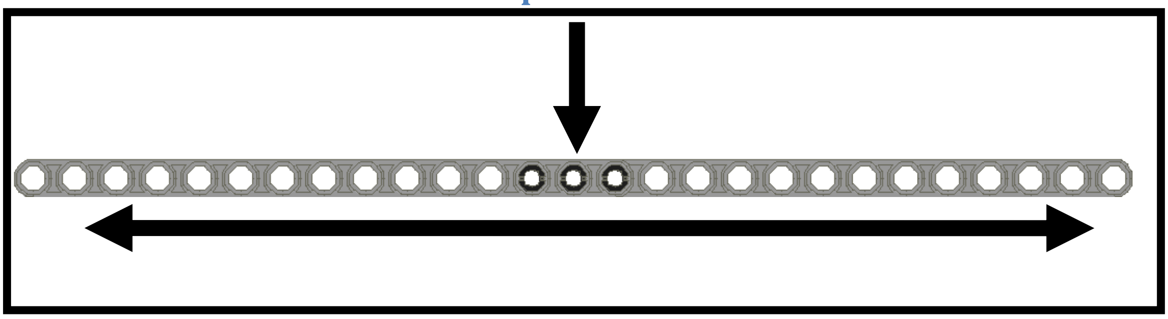


The black arrows indicate the application of Force.

The Technic Pin tension tests were performed with the jaws directly holding the Liftarm. I consider this acceptable as I was not trying to find if the Liftarm breaks, but if/when the connection fails. The third change was the addition of zip ties to the pin connection tests. The zip ties held the connection together. This prevented the connection parting during the tests. This worked quite well and produced interesting results.

The second category tests the shear strength of pin connections in Liftarms. There are 5 different configurations tested fully with 1 extra as an aside. These tests were also performed with tension and transverse forces. The transverse tests were performed the same as the Beam transverse tests. The tension tests had the Liftarms directly clamped in the jaws like the July 2011 Experiment.

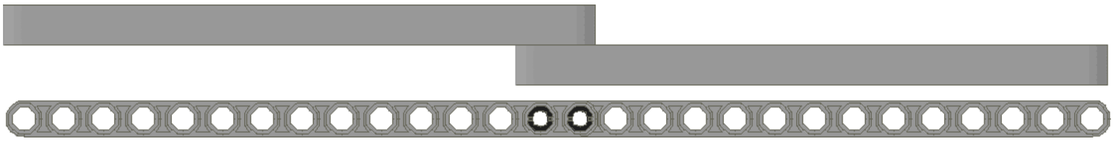
Liftarm Pin Connection Force Representation



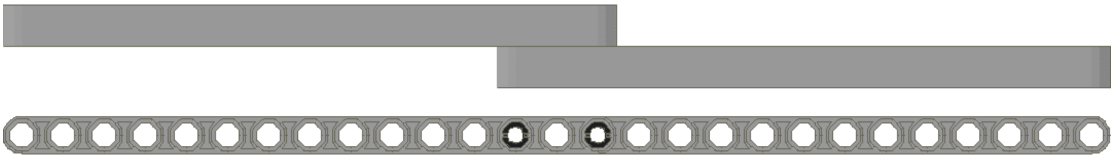
The black arrows indicate the application of Force.

Liftarm Test Specimens

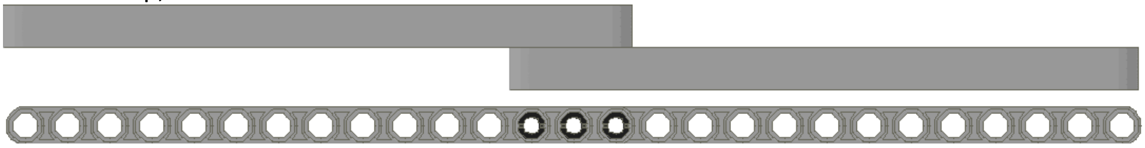
- 2 Pin Overlap, 2 Pins Used



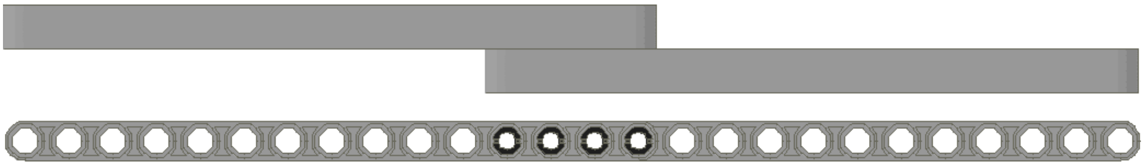
- 3 Pin Overlap, 2 Pins Used



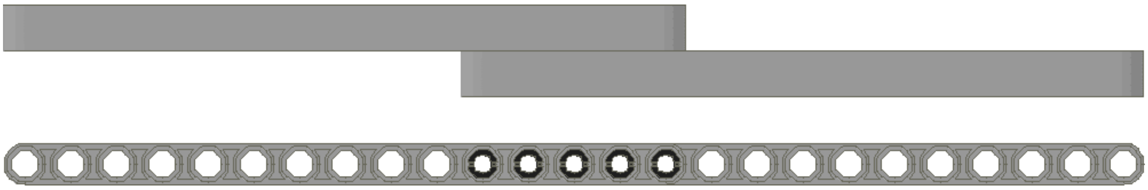
- 3 Pin Overlap, 3 Pins Used



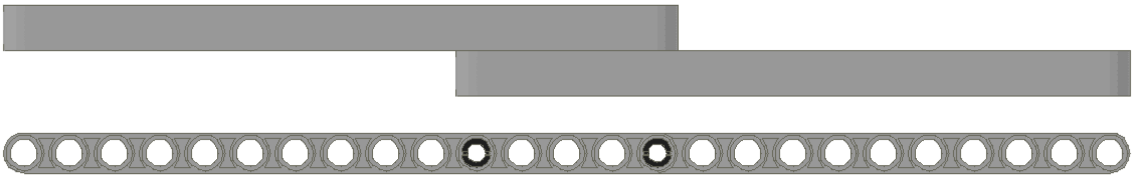
- 4 Pin Overlap, 4 Pins Used



- 5 Pin Overlap, 5 Pins Used



- 5 Pin Overlap, 2 Pins Used



3.0 Results

Test	Force (N)	Comments
Base Line		
Liftarm, Tension	1. 715 2. 795 3. 809 4. 816	Liftarm broke, Result to be ignored
Liftarm, Transverse, Pin holes Top	1. 98 2. 100 3. 99	
Liftarm, Transverse, Pin holes Side	1. 158 2. 162 3. 157	
Brick Beam, Transverse, Pin holes Top	1. 140 2. 137 3. 141	
Brick Beam, Transverse, Pin holes Side	1. 218 2. 215 3. 213	
Brick Beam, Tension	1. 843 2. 853 3. 856	
Liftarm Pin Tension		
Liftarm 2 Pin Overlap, 2 Pins Used	1. 253 2. 257 3. 301	
Liftarm 3 Pin Overlap, 2 Pins Used	1. 305 2. 305 3. 314	
Liftarm 3 Pin Overlap, 3 Pins Used	1. 376 2. 387 3. 379	
Liftarm 4 Pin Overlap, 4 Pins Used	1. 426 2. 436 3. 455	
Liftarm 5 Pin Overlap, 5 Pins Used	1. 487 2. 496 3. 477	

Liftarm 5 Pin Overlap, 2 Pins Used	1. 253	
Liftarm Pin Transverse		
Liftarm 2 Pin Overlap, 2 Pins Used	1. 123 2. 122 3. 113	
Liftarm 3 Pin Overlap, 2 Pins Used	1. 162 2. 160 3. 165	
Liftarm 3 Pin Overlap, 3 Pins Used	1. 166 2. 171 3. 169	
Liftarm 4 Pin Overlap, 4 Pins Used	1. 214 2. 216 3. 203	
Liftarm 5 Pin Overlap, 5 Pins Used	1. 248 2. 247 3. 255	

4.0 Discussion and Conclusions

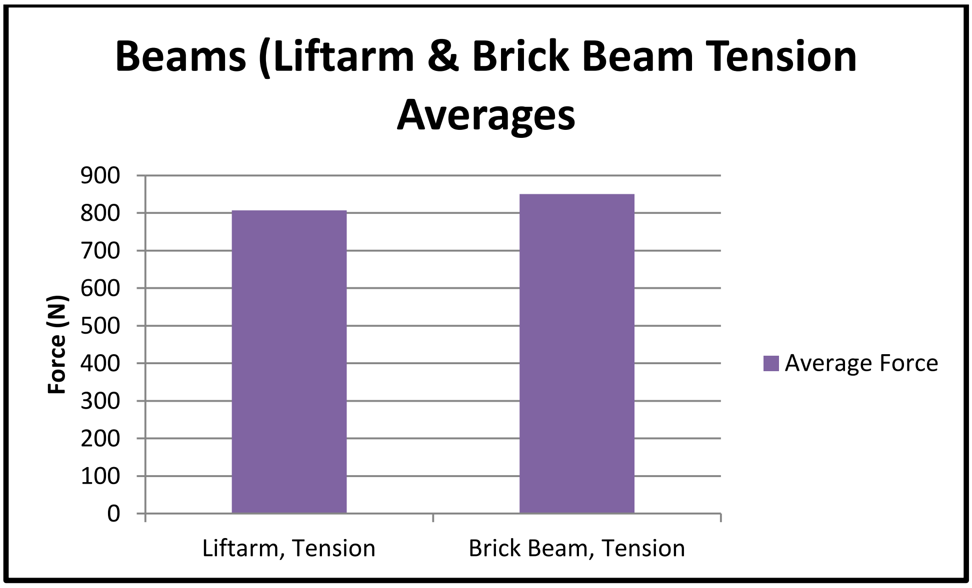
This set of tests really does highlight the strength of Lego. Unlike my first report, this will focus much more on the numbers rather than the physical results. This is twofold. First is that the numbers can be trusted. While not a large sample size, there is still enough to see that the results are consistent. The second reason is that the physical results are still quite similar to the first test.

A number of readers have probably seen the HispaBrick Magazine 12 article, *Efficient LEGO structures: Technic mechanical measurements & tips* by Oton Ribic (2011). Although our testing methods and the goals are quite different, our results are quite similar. This is an important sanity check for my report and his article. Hopefully this will give increased confidence in the results obtained.

With the Technic Pin connections, the usage of zip ties greatly changed the performance of the connections. The goal of the zip tie was to simulate a tight packed reinforced connection. These are common in tight situations but less common for trusses or towers. The stretching of the zip ties was a concern. As such each tie was only used twice and retightened after the test. In all cases the zip tie only stretched/slips one or two notches. This is quite a good result considering the strain on the ties.

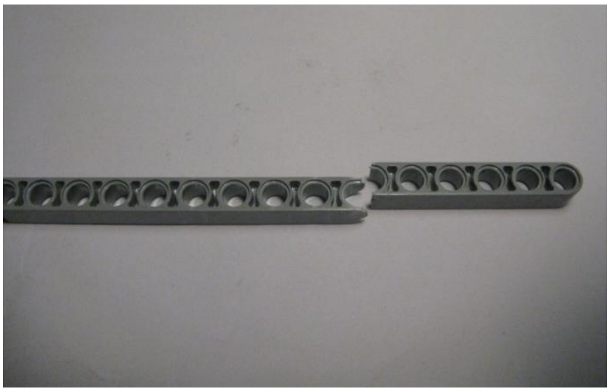
For those interested in using zip ties to strengthen their MOCs (My Own Creations), they work best in numbers (I only used two for each test, but more would be better) and they provide the best support when directly over the pins or aligned in between the pins. Aligning the zip ties near the edges or over blank pin holes is not the best solution. This not going to fix all connection problems, but it does provide up to a 150% increase in strength over pin-only connections (Increase calculated from the tension results of the July 2011 report and this current report).

With the addition of multiple data sets, these graphs provide a very clear trend of the strength of the Liftarms and Pin connections. The Appendices provide further graphs that may be of interest to some readers.



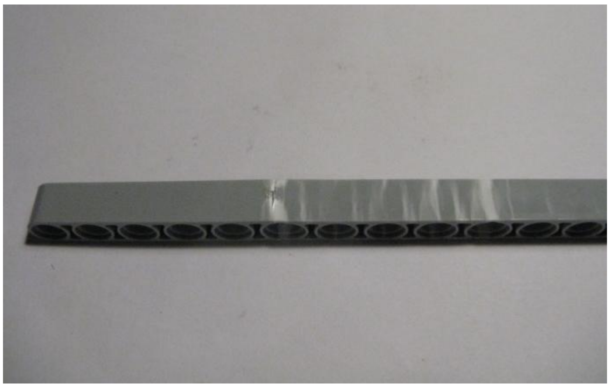
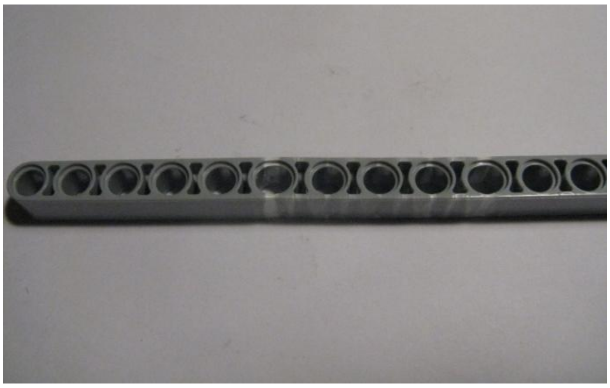
Although not very clear, overall the Brick Beam is marginally stronger than the Liftarm. The difference is about 40N which is ~5% of the overall strength. To put this into more meaningful units, the average force of a Beam is about 84.5kg on Earth. That's a grown man (on the light side though, not a football player). I should point out that this is the ultimate breaking strength; the force at which plastic deformation is obtained is much less.

These tests also disprove my July 2011 report. Then I claimed that the Liftarms were much stronger than the Brick Beams. This is not the case and it is clear that the rig here made a big difference. So overall, criticism on that issue was quite well justified.

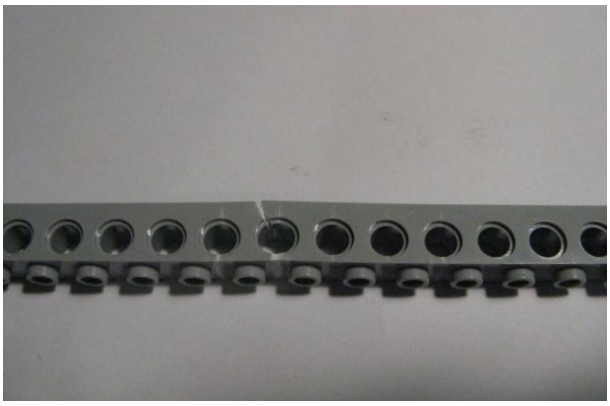



This first specimum was misaligned when tested. As such, the force required before it broke is much less than those of the next tests. Because of this misalignment, it was concered best to remove the test from the results.

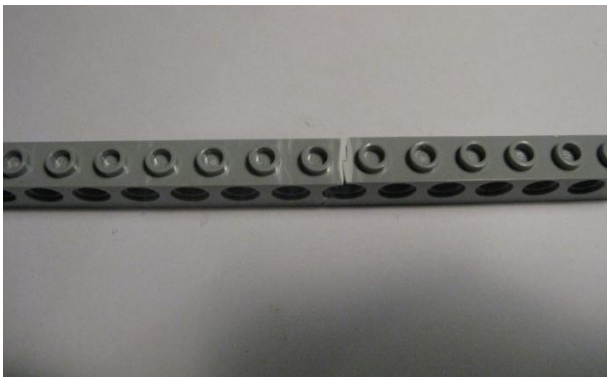
All Beams were supported from the endmost 6 pin holes (Only 4 simple supports on each end was used though). The image above clearly shows that the greatest force is on the last supportive pin hole. This is also what I hypothesised in July 2011. It is good that even though the values are wrong, the principle was not.

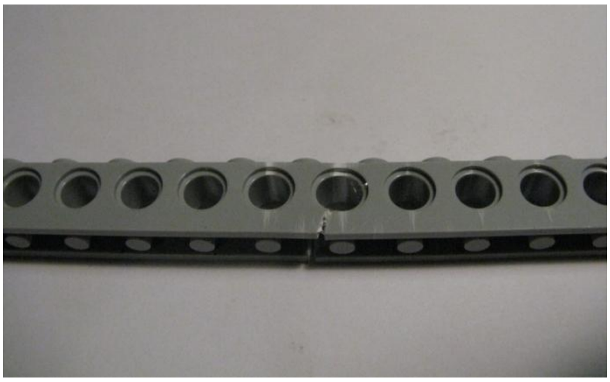



This is the first respectable result from the Liftarms. As you can see, there is no stress or fractures except from the middle 5 pin holes. The greatest fracture is at the first support pin hole. Unlike the first Liftarm, this one did not fracture. This highlights the importance of maintaining the alignment of the force. The other two specimens are all similar in appearance.

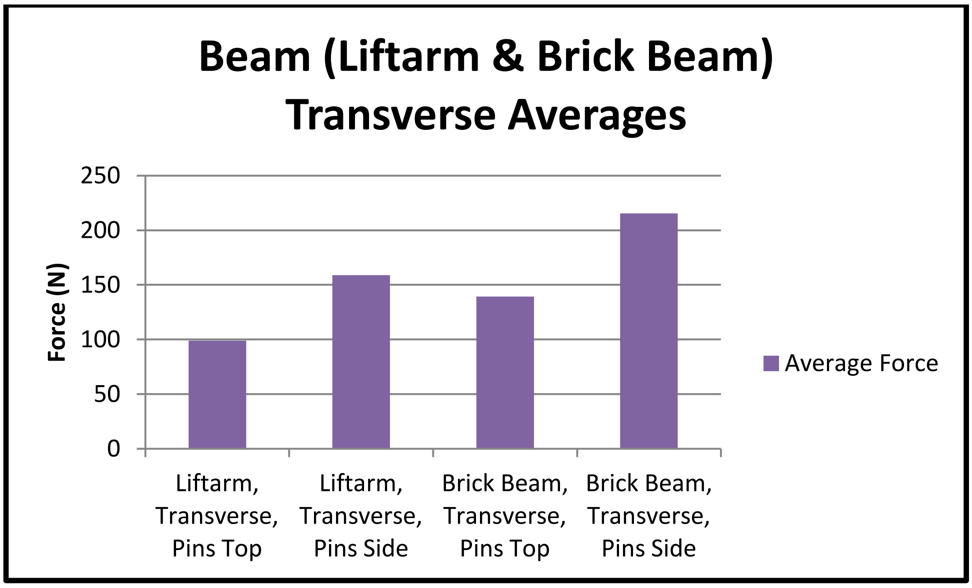


The Brick Beams behaved in a similar way to the Liftarms. There was no damage observed on the support pin holes, but the centre span had creases and stress points located throughout. This is much the same as the Liftarms so although the Brick Beam is stronger, the damage sustained is the same.

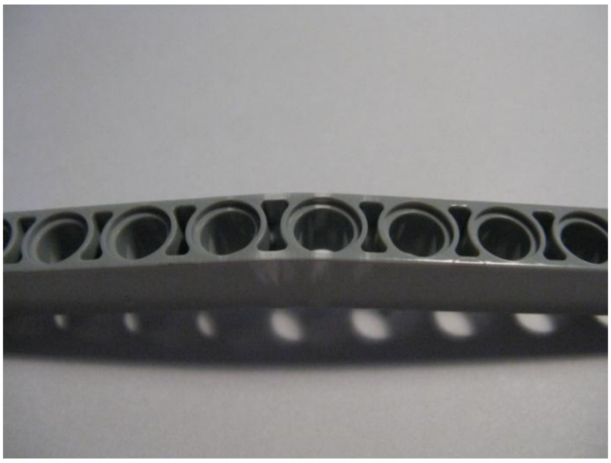




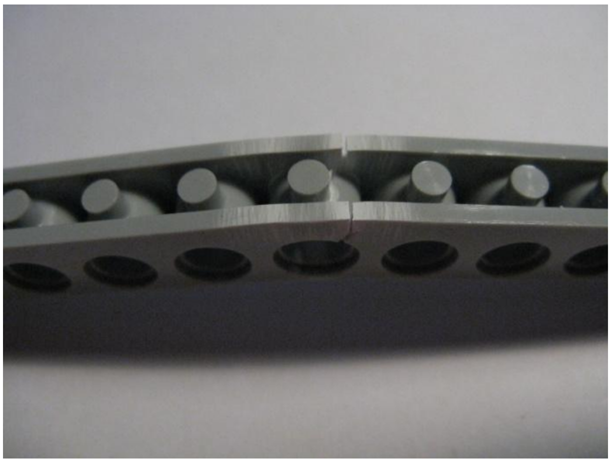
These are from two different tests however both show signs of fracture. The left image was the closest Brick Beam to complete separation, while the right image only has the bottom of the Beam fractured. It is interesting to note that there is some damage beyond the first (6th) support pin hole. This is unusual as no other Beams had such damage.



With this graph, the transverse strength of the Beams is varied. The rotation of the Beam matters greatly as does the style of Beam chosen. In a transverse situation a Brick Beam is superior in every way. This makes a lot of sense as there is more plastic per Beam.

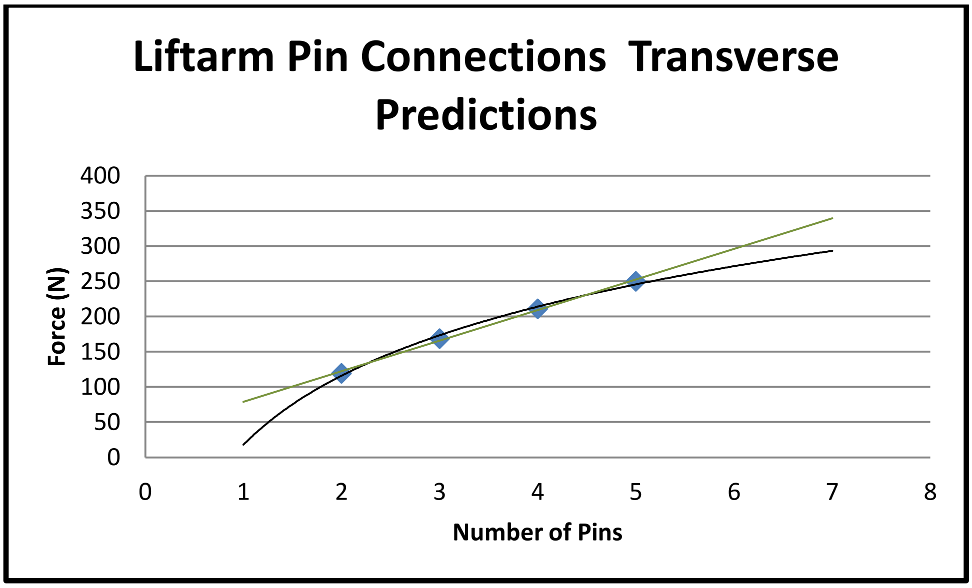



These pictures show a comparison in damage to the Beams. It is quite clear that the Brick Beam has sustained more damage than the Liftarm. It is unclear if the plastics used are different. It would appear that the Brick Beam is more brittle. More likely however, the structure of the Brick Beam makes the whole thing more rigid and more brittle. This is quite a big difference, especially if bending is expected in the MOC. If the Brick Beam is bent too far, while it may take more force, the Beam is more likely to fracture. This is in direct contrast to the Liftarm which will bend a lot more before it starts fracturing.




These images show the propagation of the fractures. It is off to the side of the application of the force. This possibly could be from the clutch pin. This then highlights a key weak point in the Brick Beam. It is also interesting to see that the crack went through the edge of the pin hole. The fracturing here is very much like the fracturing seen in the pin connection tension tests. Therefore it is not too bold to predict that there will be more problems with pin holes fracturing rather than the rest of the Beam.

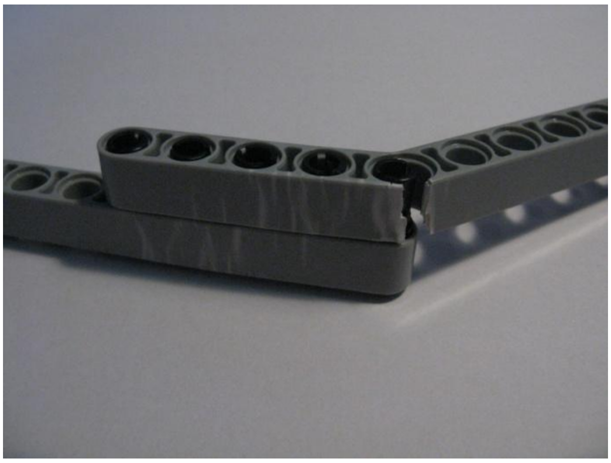
This final image shows the formation of the above fracture. This was however from a different test. This reinforces my last point. It is quite interesting to see that the base of the Beam is flat. Even though the force was applied to the center, the force is manipulated outwards to beside the pin holes. This then implies that the support for such a Beam should probably be centered on the clutch pin rather than the stud gap (i.e. Support Beams should be aligned with the Technic pin holes rather than the 'traditional' studs). Hopefully with this information MOC builders can build stronger bases.

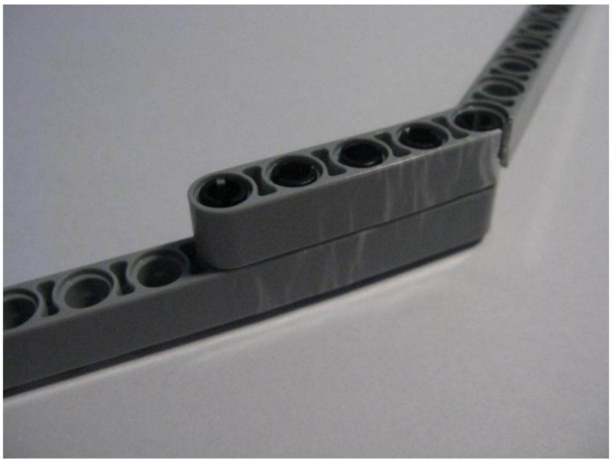


This graph shows the average force for each connection. The black line is a logarithmic trend line. When compared to a linear tread line (green), the logarithmic is a better fit. This then implies that after a certain number, there will be no big increase in strength from the connection.

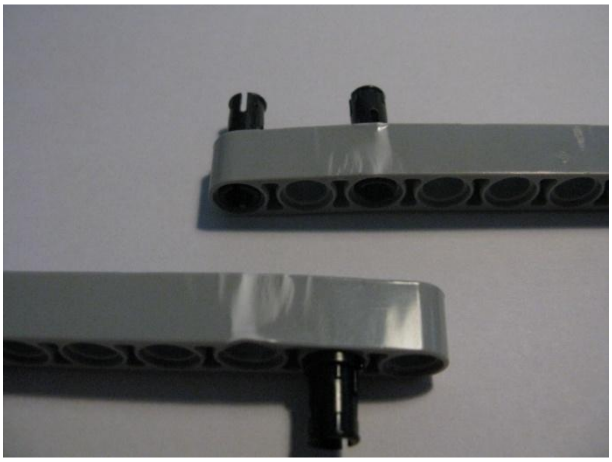
If the pin connection results are compared to the Beam results, we see that a connected Liftarms is much stronger than just a basic Liftarm. This makes a fair amount of sense. At the point of application of the force is the joint, there is an overlap of the Liftarms. This means that the force is being dissipated by two Liftarms rather than one.

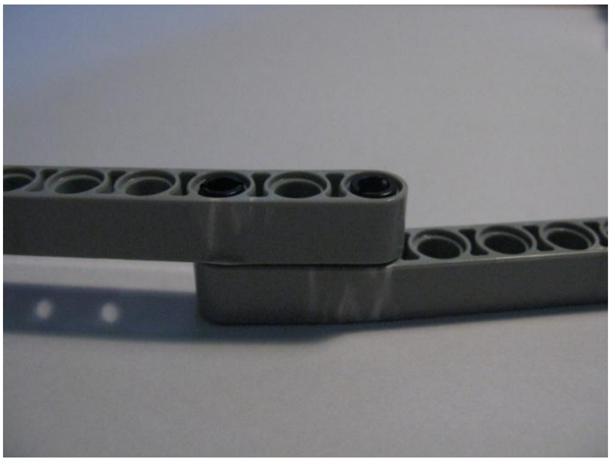
From these transverse tests, there is a clear result. If more pins are used, the stronger the connection. It is important to note that the amount of bending is not recorded. Visually, the 2-pin connection moved a lot more than the 5 pin connection even though the force was a lot less. So we can hypothesise that the stronger the connection, the less it will move. This is an important observation; what displacement would break a 2-pin connection is quite different to that of a 3-pin connection.



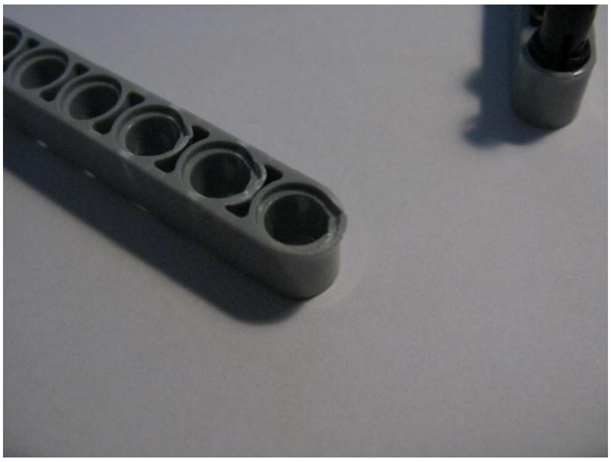
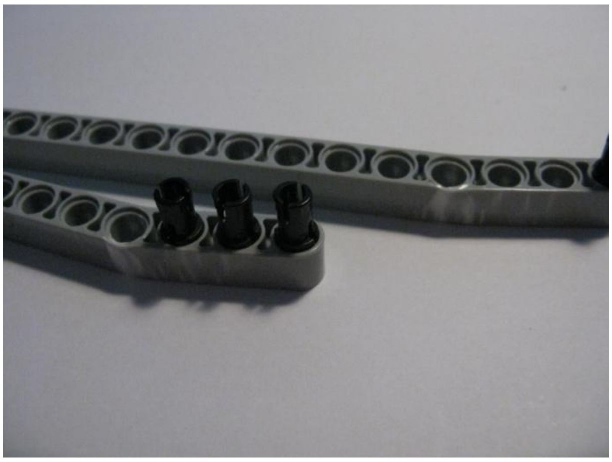


These images clearly show the failure of the Liftarm. The location of the break is most interesting. Unlike most of the other breaks, it is in the centre of the pin hole. It is also clear that the other Liftarm did not break nor bend as much. No other Liftarm fractured at that location so there may have been a defect on the Liftarm. Ultimately it did not have an effect on the strength and not much can really be learned as it was unusual.

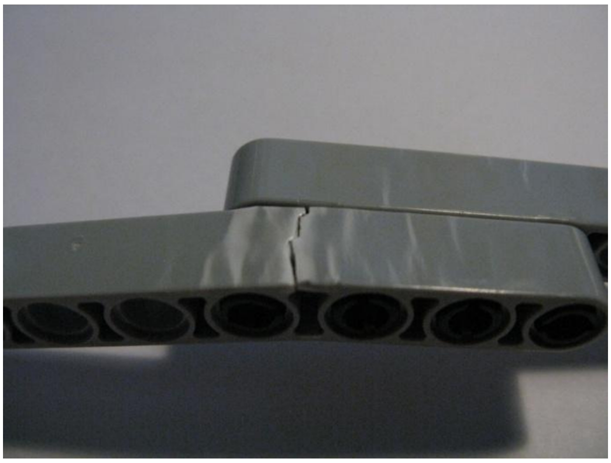
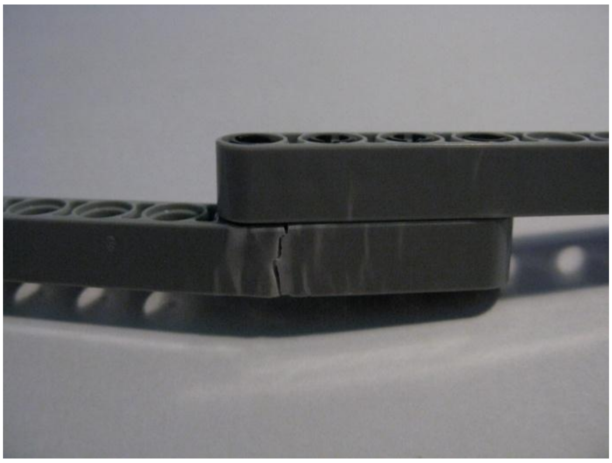




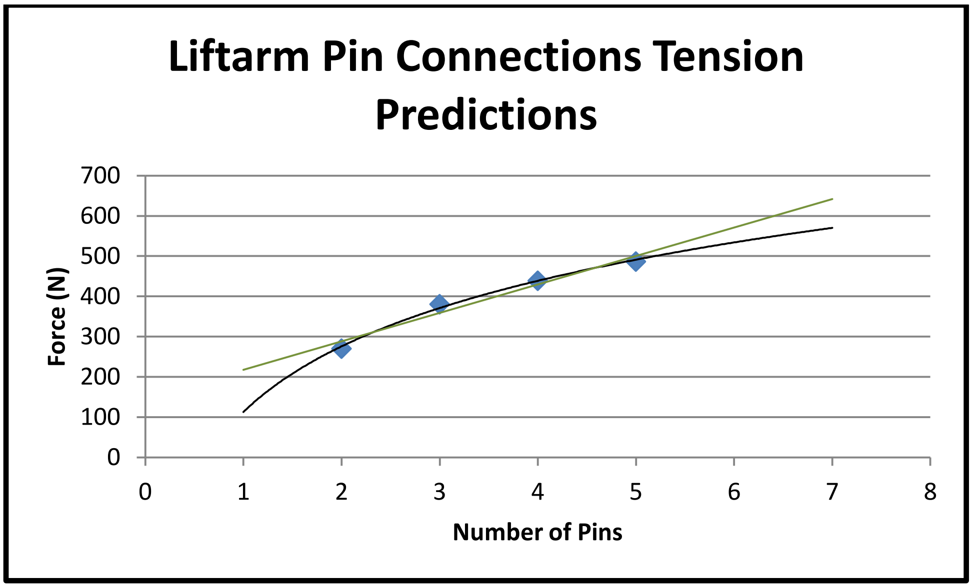
Both these specimens were similar (as they had a 3 pin overlap) but the results are quite different. One we see has only severe bending at the edges. However, the other (with only 2 pins) has the start of a fracture forming. All 3 pin overlap, 2 pins used have this same phenomenon. The combination of the gap and only 2 pins seems to magnify the force and fracture the Liftarms. This is a particularly important result. Many MOCs would use the 3/2 connection but although it can withstand more force, the chance of a catastrophic failure is much higher.

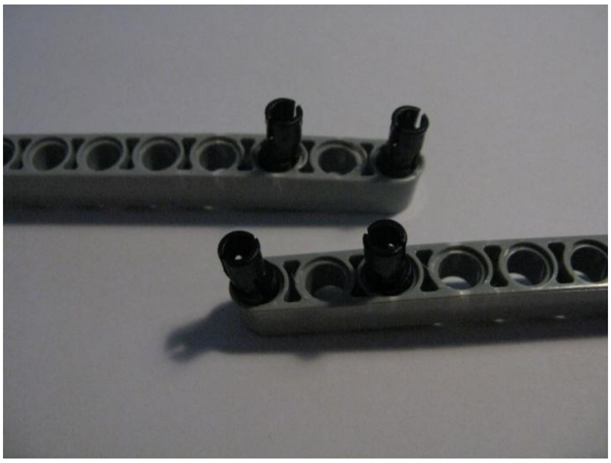
These images show the most common result of the transverse tests. There is substantial damage to the edge of the pin holes. This would basically render them useless. The other image shows both Liftarms with bends in them. Most Liftarms bent but some didn't. The results in this experiment are much closer to the 5 pin transverse test in the July experiment.

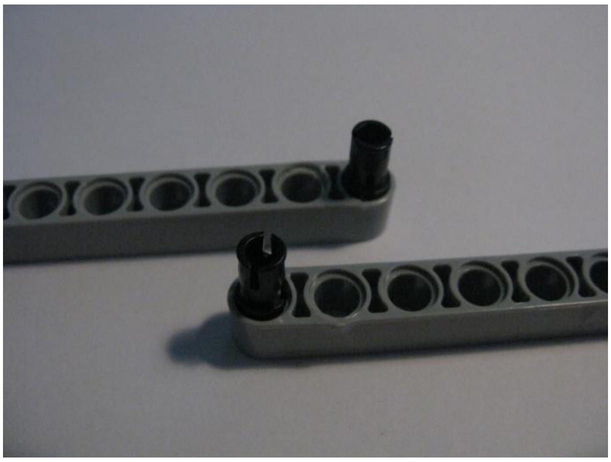
This specimen behaved quite unusually. Most of the transverse specimens did not fracture. It is quite clear that this one did. The location of the fracture is quite similar to the location of the fractures from the transverse Brick Beams. This is clearly highlighting a trend. It is also important to see that the bend is very asymmetric. Only one Beam is fractured. I am not able to explain this but it does show that even in controlled testing, inconsistent results are still possible.



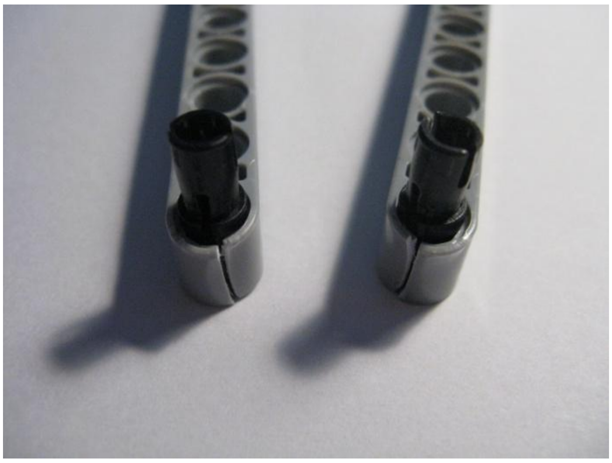
The results from the tension tests reflected those of the transverse tests. The logarithmic trend line is again the best fit. It is interesting that the shapes of the lines are quite similar. This implies that the difference in strength is fixed, i.e. the ratio is the same regardless. It is quite clear that pin connections are much better in tension than transverse. It would be interesting to see if using Brick Beams would change the result. This however is outside the scope of the testing and would have to be completed by other people.



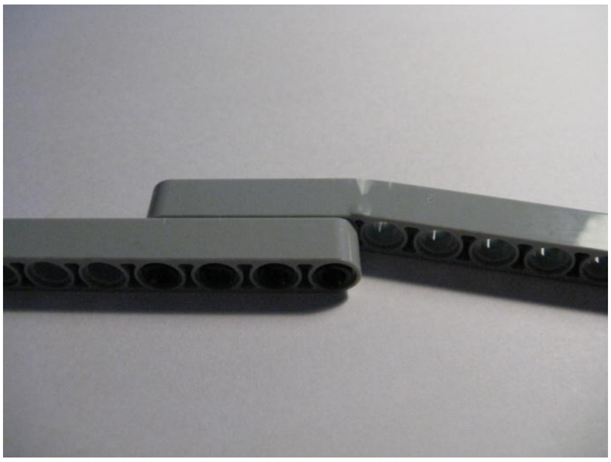
One observation is that even with zip ties it was not possible to actually break a pin. The closest was some doubly bent pins from a 4 pin test. There were two bends halfway on each side. No visible fractures were seen although the clutch action was severely compromised. The Liftarm itself sustained the most damage.




All the Liftarms used in the tension pin tests were all ruined after one test. This was quite surprising. In every case the holes were deformed around the edges. The two images above clearly show this problem. Also observed, the angles that the Liftarms and pins were at were quite substantial. Certainly the perceived limits of the pin connections are quite a lot higher than any normal builder would consider ‘safe’ (i.e. no damage to the Liftarms). This is almost certainly in the design of the Liftarms and pins. The Lego Group would much prefer a deformed Liftarm than the chance of the flying projectile. It is a good learning experience to see the absolute limits of the material.

One of the more unusual results and really un-expected is the Liftarms failing. As the image shows, both Liftarms have failed at the pins. Again the pins themselves are not deformed however the clutch mechanism has weakened. This is surprising because on two of the three tests (that being the 3 pin space with 2 pins used) the Liftarms failed. The third was starting to fracture. No other connection failed like this. It does however partially confirm the hypothesis I made in June 2011. The end of each Liftarm seems to have concentrated the force to a small area. As there is no middle pin to share some of the force, the force on the end of each Liftarm may have breached the limit of the material.



This final image is a specimen from a failed test. While adjusting the vertical position, the jaws moved too far. The result is the bent Liftarm. This is quite different to the other tests as it was the only compressive force applied to the connection. As this was not a controlled test, there was no force reading available. However, it still shows what should happen when a large compressive load is applied.

In summary there are two key points to note. The more pins that are used, the stronger the connection and Brick Beams are stronger than Liftarms. These are definitive results and come from the numbers. The other conclusion is that at failure, the Beams will fracture near the pin hole. If the pin hole has support, then it will be the narrowest part of the Beam that will fracture, if it is freestanding, then the fracture will be off to one side. This is important for designing the support for Beams as the stresses. These conclusions, while quite broad, really do sum up the results from the experiment and explains most things seen from the specimens.

After concluding all these experiments, I have come to appreciate Lego Technic's strength. I understand the limits of Lego Technic and hopefully this knowledge will be useful to other people. When I first set out to test Technic, I was not sure what I would get. By doing two independent reports I think that I have learnt a lot about testing materials. While not very useful directly, it has given some insight into other engineering disciplines (As a Computer Systems student, I don't get a lot of exposure to the Mechanical side). I am very happy about the final results and the substantial knowledge I have gained.

As I don't plan on conducting further research into the strength of Lego Technic, I am not able to directly influence any further work. However for people who wish to conduct more tests and experiments I do have a short list of suggested areas. This builds on my work but is still independent and should allow flexibility.

- Using Technic Axles instead of Technic Pins
- Using other pin type connectors (e.g. Pin with bush, Light Gray pins without friction, 3L pins)
- Find the strength of normal Lego Brick Beams (i.e. without pin holes)
- Find the strength of Technic Axles
- Find the compressive strength of the Beams and Pin connections

Hopefully these ideas will spur further research in this area. I am quite willing to offer advice to any person that wishes to conduct their own test.

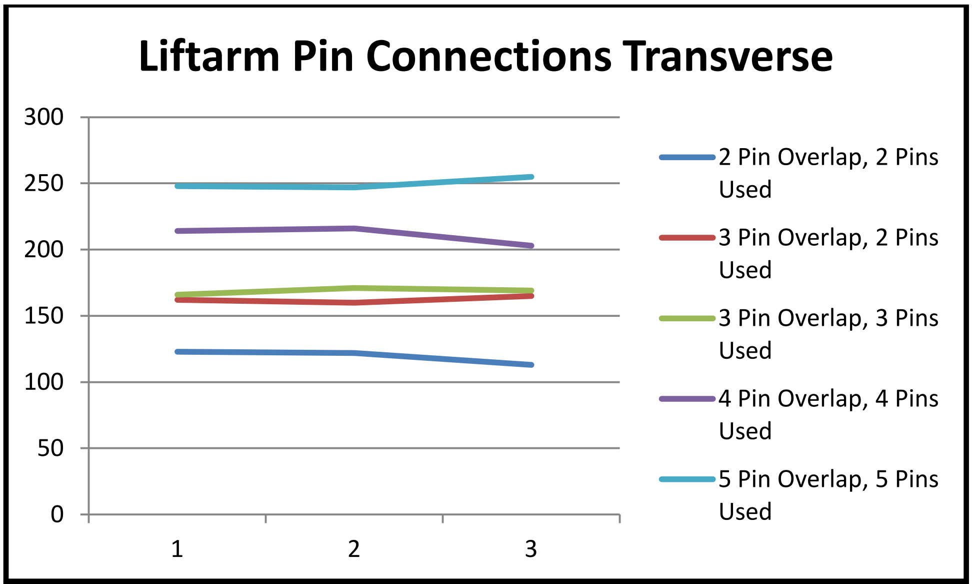
Finally, I would like to thank The University of Southern Queensland Faculty of Engineering and Surveying for the use of the lab. Specifically I would also like to thank Mohan Trada and Selvan Panther. For donating the supplies to run this experiment, I would like to thank David Luders.

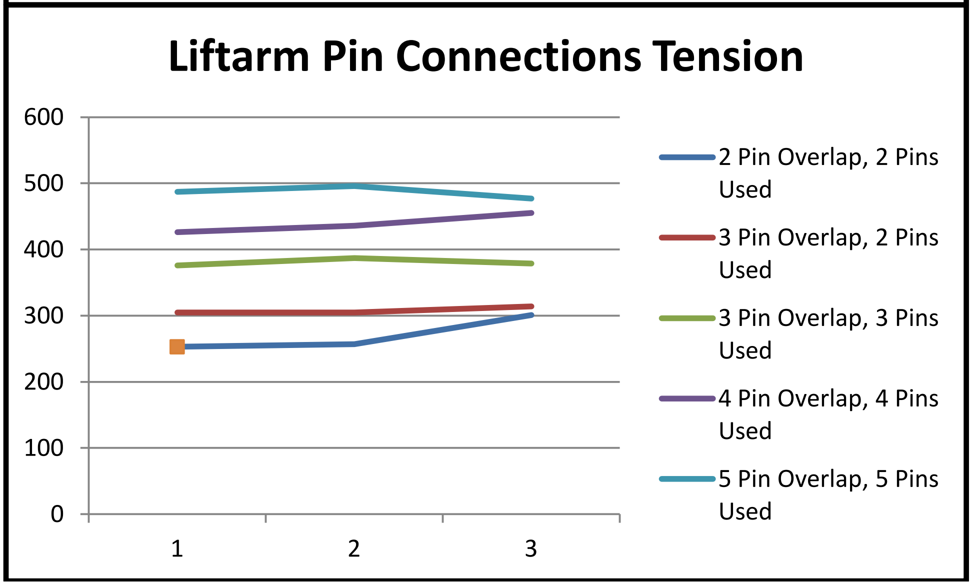
I hope you have found this report useful and worth your time.

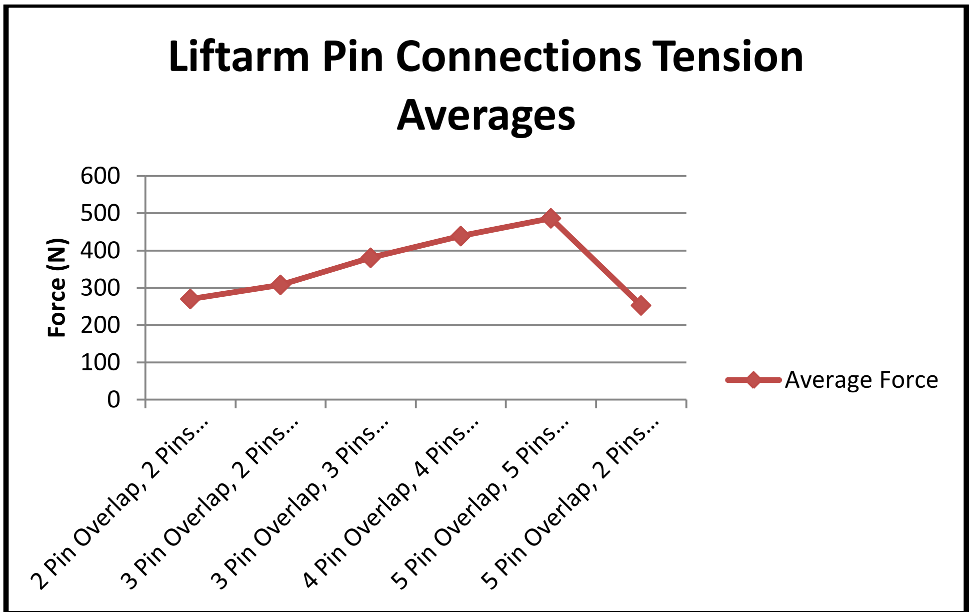
Happy Building!

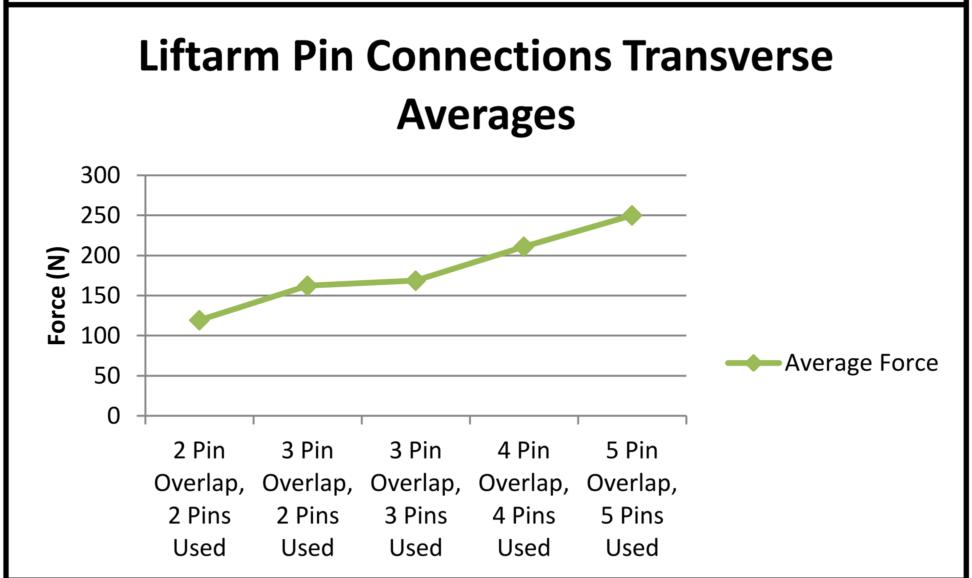
5.0 Appendices

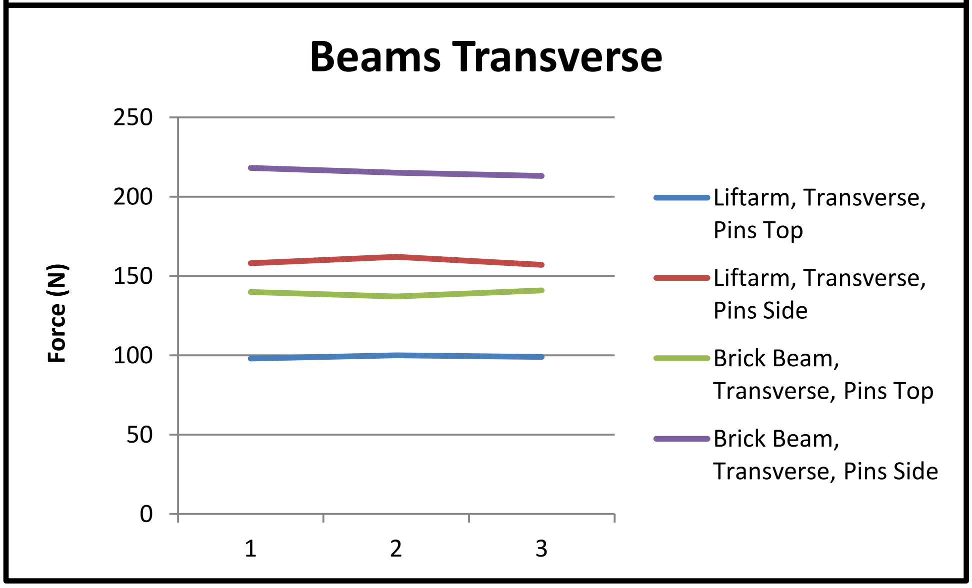
Further Graphs






Liftarm Pin Connections Tension Averages
Force (N)
600
500
400
300
200
100
0
2 Pin Overlap, 2 Pins...
3 Pin Overlap, 2 Pins...
3 Pin Overlap, 3 Pins...
4 Pin Overlap, 4 Pins...
5 Pin Overlap, 5 Pins...
5 Pin Overlap, 2 Pins...
Average Force


Liftarm Pin Connections Transverse Averages
Force (N)
300
250
200
150
100
50
0
2 Pin Overlap, 2 Pins Used
3 Pin Overlap, 2 Pins Used
3 Pin Overlap, 3 Pins Used
4 Pin Overlap, 4 Pins Used
5 Pin Overlap, 5 Pins Used
Average Force


Beams Transverse
Force (N)
250
200
150
100
50
0
1
2
3
Liftarm, Transverse, Pins Top
Liftarm, Transverse, Pins Side
Brick Beam, Transverse, Pins Top
Brick Beam, Transverse, Pins Side

Results, Discussion and Conclusions from July 2011 Report

Results

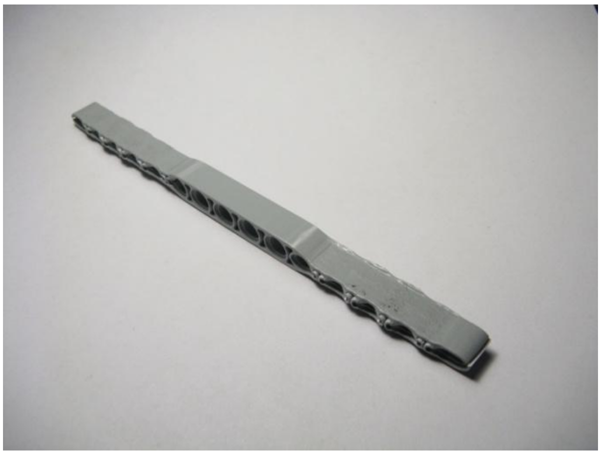
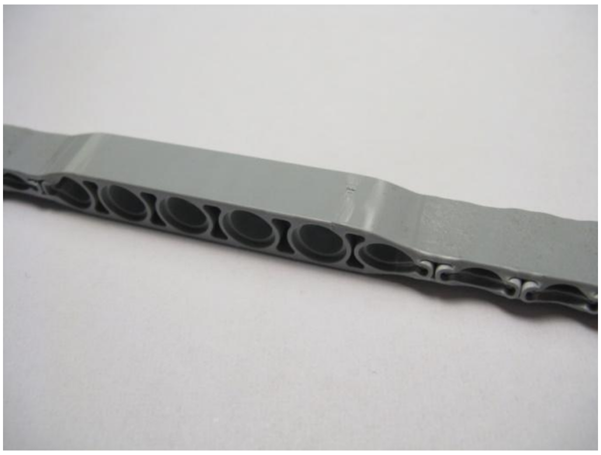
Test	Force (N)	Comments
Base Line		
Liftarm, Tension	658 642	≡1.26mm dia steel wire
Liftarm, Transverse, Pins Top	97	
Liftarm, Transverse, Pins Side	185 153	
Brick Beam, Transverse, Pins Top	243	
Brick Beam, Tension	534	
Pin Tension		
2 Pin Overlap, 2 Pins Used	101 131	Pins Popped Out Pins Popped Out
3 Pin Overlap, 2 Pins Used	121	Pins Popped Out
3 Pin Overlap, 3 Pins Used	176	Pins Popped Out
4 Pin Overlap, 4 Pins Used	195	Pins Popped Out
5 Pin Overlap, 5 Pins Used	228	Pins Popped Out
Pin Transverse		
2 Pin Overlap, 2 Pins Used	58	Pins Popped Out
3 Pin Overlap, 2 Pins Used	96	Pins Popped Out
3 Pin Overlap, 3 Pins Used	112	Pins Popped Out
4 Pin Overlap, 4 Pins Used	177	Pins Popped Out

5 Pin Overlap, 5 Pins Used	252	Permanent Bend in lift arm, Pins did not pop out

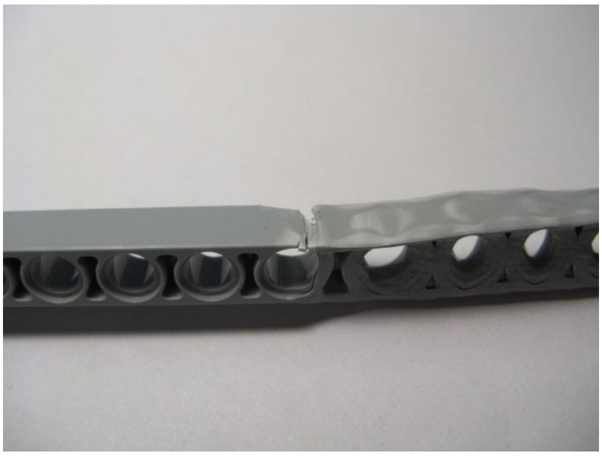
Discussion and Conclusions

The first observation is the effect of the machine on the Liftarms. In all tension cases, the Liftarms were crushed by the grippers. Obviously as the machine normally tests metal the design of the grippers has to allow for that. It is not obvious but the more the machine pulls; the more force the grippers exert. Unfortunately this force is not measurable so no useful data can be gained from it, other than what happens when you crush a Lego Liftarm.

The first tension test is unusual in that there is no detectable fracture present, which is the case. The fracture is actually the stress line shown below.

The fracture is more visible in the second test of the Liftarm here.

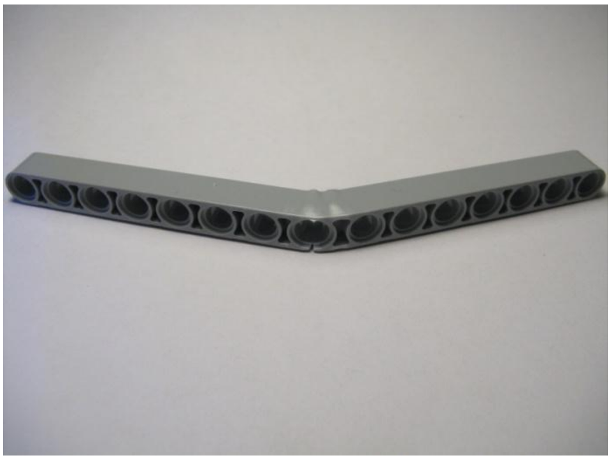



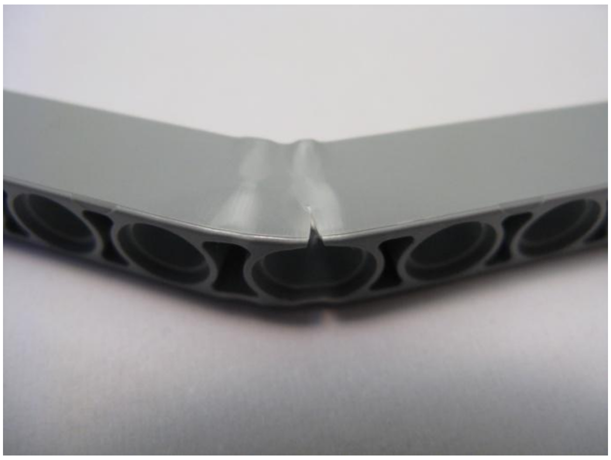
The location of the fracture is quite interesting. In both cases, the failure point is on the boundary between the hole and the outer covering. The acute angle between the hole and the flat outer covering probably has made a big difference to the strength of the Liftarm. It also highlights the major weak point of the Liftarm. If this was in a real life situation, it is likely that the Liftarm will fail not in the middle and not at the joints to other Liftarms but in between the joints and the middle of the Liftarm.

This makes a lot of sense, the joints have the stress distributed evenly and the middle can rout the stress easily but the interface between the two have all the force over a very narrow part of the Liftarm and produce very large localized stresses.

The transverse tests on the Liftarms also produce interesting results. The pictures below show the difference and they do not seem to follow the numeric results.

The third test involved a transverse force on the Liftarm with the pins facing to the top. It makes logical sense that this would be the strongest direction as there is more structure for the stresses to pass.

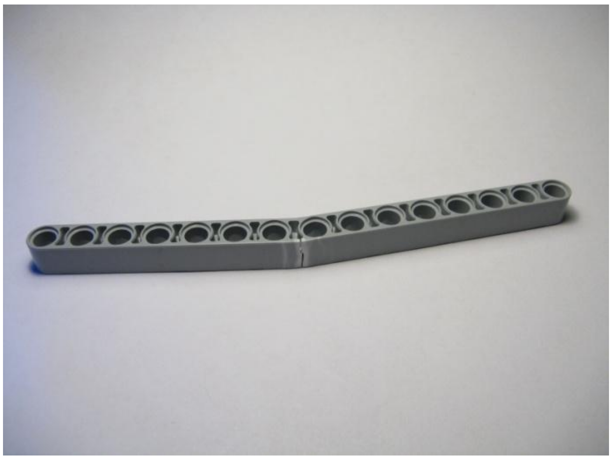




The numrical results show it is the weaker of the 2 directionswith it only able to support 97N before failure. It appears in the expected location and there are clear and visible signs of buckling.

The following 2 tests were transverse forces on the Liftarm with the pins facing the side. This puts it in a very similar situation as the tension tests.

This fouth set of images show the first test which involved a pause during the application of the force.

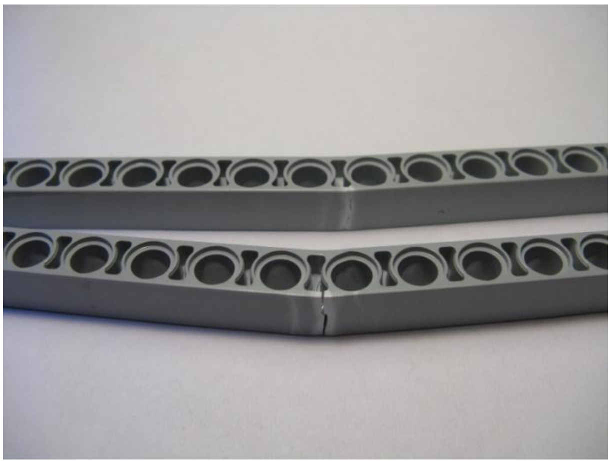


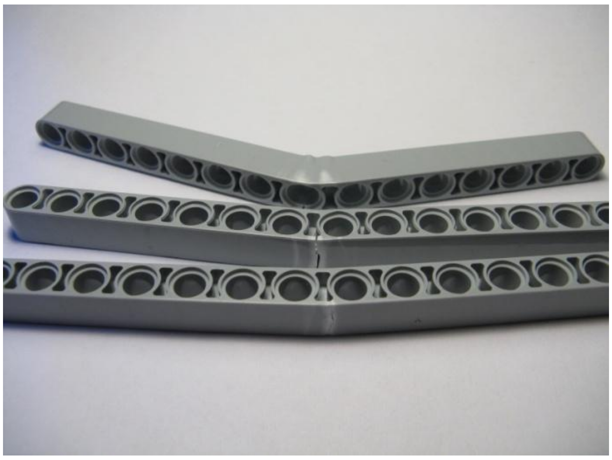
As we can see, the fracture is quite large and occurs on the joint between the hole and the outer covering. This is quite simlar to the tensions tests in the location. It highlights the weak point of the Liftarm.

The fifth set of pictures show the same test above except that there was no pause.

It is clear than the pause had a small effect on the maximum force. The fracture is also a lot smaller. Again the fracture is in the same place further higlighting the weakpoint.

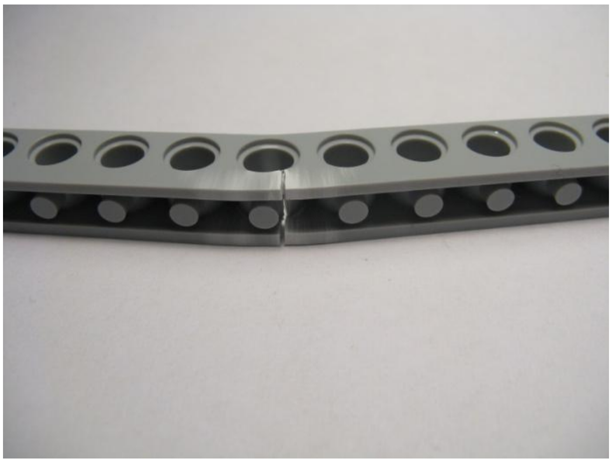
These next images show the Liftarms in the same image to compare displacment.





By comparing the displacement of the Liftarms to the force required, we come to the conclusion that the more force required to break the Liftarm, the less displacement required. It logically makes no sense at all. Overall it can also be said that the Liftarm is strongest in transverse when the pins are on the side when the force is applied on top.

The seventh test was a Brick Beam in transverse.

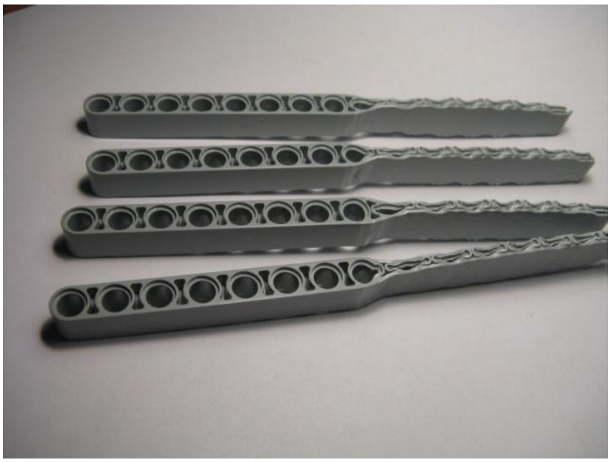
As the raw numbers show, the Brick Beam is much stronger in transverse. The failure is also in the expected location, where there is little material in the cross section. The displacement is similar to the fourth test.

The eighth test was the Brick Beam in a tension environment.

The point of failure is again similar to the transverse test, and most interesting, similar to the point of failure of the Liftarms. It is quite clear to see the pin hole pulling away from the rest of Brick Beam. This reinforces the fact that the edge of the connection area will fail before the middle of the Brick Beam. We can also see that the strength is about 20% less than the Liftarm. This quite significant as the Brick Beam is much stronger than the Liftarm in the transverse test.

Most of the following tests were not destructive (bar one that is shown later).



These Liftarms were used in multiple tests as it was observed that it would be a waste as the crushing had no visible effect on the strength. The transverse tests were performed with different Liftarms, but they were unaffected apart from some marks from the plunger.

The tension tests were all very similar. In all cases, the pins were pulled apart. In all except the first test, the pins seemed undamaged. In no cases did the pins fracture or fracture. There is a correlation between the number of pins and their strength. There are two possible reasons but either can be confirmed or denied in this test. First the strength of the clips that hold the pin in the Liftarm or second the leverage applied to the Liftarm. These theories were partly tested by the inclusion of the 3 pin distance, 2 pins inserted. This ended up being middle of the road and not statistically significant. This test still does show the expected behavior, (More pins means a stronger connection) just the reasoning behind the behavior is still unknown.

The transverse tests were a lot clearer. The first four tests all ended up with the pins popping out. The fifth was quite unusual and is discussed later. The results show a clear trend and the reasoning behind it. The bigger the distance the joint covers, the stronger in transverse the joint is. The 3x2 test also shows that it is possible to use a lower number of pins and still have a strong joint. Of course, the more pins you have, the stiffer the joint will be and hence stronger.

The last test perform was the 5 pin transverse test. It was definitely the most interesting.

It is quite clear that the whole Liftarm has been bent. The pins did not pop out. It appears that the Liftarm and pins holes have bent at the same time. It is also interesting as it is a permanent bend. The only other times this happened was when the Liftarm fractured. In this case, no fracture is visible and the Liftarm appears to have maintained it strength. As the transverse tests did not exert a large sideways force, this result leads to the conclusion that it is possible to have the Liftarm 'fail' before the join does though it should be noted that it didn't happen in any other tested and might just be a fluke.

There are many alterations to the tests and testing procedure that could be changed. I would certainly be willing to do more tests if I was given assistance with resources. It would also be good to increase the number of tests and the sample size to get more accurate results. As the tests are destructive, it is necessary to have a large amount of materials. Now I understand the equipment a lot better, it is possible for me to design the tests so that the desired result is achieved. Rigs could be designed to only test certain parts and be more specific. As I said above, outside assistance will be accepted to further the data and conclusions.

The results of the experiment were definitely unexpected. But still make a lot of sense. It is entirely possible for the below conclusions to be irrelevant in real life. The tests are not as thorough as I would have liked and have many artificial element in them. However they can be used as a guide for both future testing and creations. The conclusions from the experiment are as follows:

- Liftarms are better in tension than studded
- Brick Beams are better in transverse than studless
- Liftarms are stronger in transverse with the pins on the side
- Connections to other components will fail before the Beam (Either connections themselves or the connection area of the Liftarm)(IE the (unstressed) centre of the Liftarm will not fail)
- Pin connections will probably pull apart before they fail catastrophically
- The more pins, the stronger the connection
- In transverse 3 pin overlap, with 2 pins used is almost as strong as 3 pin overlap and 3 pins used
- Liftarms in transverse conditions won't fail (but will bend) if the pivot points match the end of the connection
- Lego is quite strong for its weight

Finally a big thank you is needed for the Mechanical Department of the University of Southern Queensland, Faculty of Engineering. Mohan Trada and Selvan Pather have been very helpful with their time, knowledge and resources. Without your help, this testing could not have happened.