Designing a rig for load-testing 3D-printed truss structures

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Abstract — When simulating real-world environments, there are several physical attributes to consider. Being able to test simulated shapes' durability in real-world scenarios would be a useful tool when investigating the reality gap between simulation and the real world. We design a test rig to investigate the vertical strength of a 3D-printed truss. We discuss the accuracy of the load-testing rig regarding the application of the 3D-printed truss structures.

Load-testing | Truss | 3D-Modelling| Generative Design

1. Introduction. There is significant unrealized efficiency potential in today's industry. Parts in machinery, vehicles, tools, and everyday objects can be optimized to be lighter and stronger. The intention with a Generative Design (GD) algorithm is to optimize the shape of an object. We can optimize several physical attributes with a GD algorithm, including weight, strength, shape complexity, et cetera. The amount of material per unit in mass production might be reduced drastically with shape optimization. The industry can speed up production, save money, and the environment by minimizing objects' masses with shape optimization.

The engineer constructs a simulated environment that mimics the properties of real-world applications. Optimizing shapes in simulated environments is an efficient way to design new objects at a low cost. Ensuring that the simulation corresponds sufficiently with the given real-world application is a crucial part of the design process. We want to produce a test that coincides with the final application of a designed shape. In this paper, we explore the durability-comparison of different 3D-printed truss structures using a customized load-testing rig.

The load-testing rig shall fix each truss' position to apply an external, vertical force. The load can be applied from underneath as a pulling force, or from above as a pushing force.

The main issue with stress testing is to ensure that all shapes test on the same standard. The rig should test each truss structure in accordance with its application (in this case, the vertical strength of the truss). Identical copies of each truss should be tested on the rig to investigate the accuracy of the load test.

2. The Rig Setup. The load-testing rig consists of three aluminum components. The parts are 3D-modelled in Fusion360 (1) and milled using a Datron CNC-miller (2).

From the bottom up, the rig consists of one 400 x 200 x 10 mm aluminum plate with two 10 mm protruding stakes and a centered square cavity with dimensions of 100 x 100 mm.

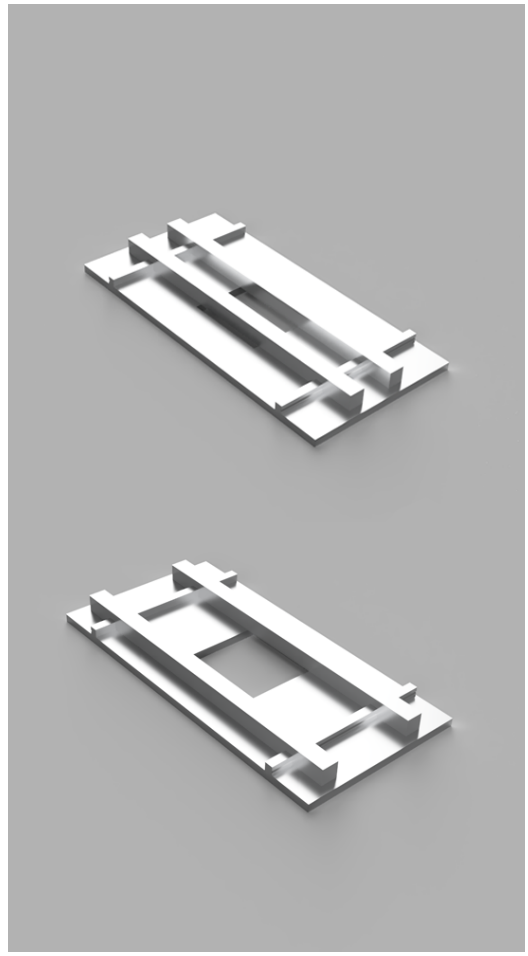

Fig. 1. Stress-Test Rig Illustration of the customizable configurations of the rig.

The protruding stakes are parallel, 300 mm apart and serve the purpose of fastening two movable sticks, see Figures 1 and 2. The two 200 x 10 x 10 aluminum sticks are used as an attachment for fixing the orientation of the object to be load-tested. The sticks are slid across the stakes, as illustrated in Figure 1. The complete stress-test rig can be placed on two additional aluminum blocks to elevate the rig from its surface, if necessary.

The cavity in the 400 x 200 mm plate allows for truss designs with a little-to-no disparity in height to be stress-tested adequately without vertical counterforce from the rig itself.

Aluminum is deemed a sufficiently durable material for testing truss structures in PLA, see table 1. A force is applied to the truss as a vertical force using a DYNAMIXEL actuator (3). The actuator is configured with an attachment to push or pull on the truss. The force is applied to the truss incrementally until fracture, see Figure 5.

Lastly, we position a tripod mounted camera at level with the configured truss. The camera records every step of the load testing. The recorded video is a tool to accurately find the point of plastic deformation.

3. The Truss. Various truss structures are 3D-printed for testing on the rig. The different trusses are 3D-printed on a Creality Ender-3. Today, the Ender-3 is an affordable 3D-printer at 200-300 USD (4). The Ender-3's bed measures 220 x 220 x 250mm, and these measures define the upper dimension limits for the trusses. We use Polylactic Acid (PLA) for 3D-printing the trusses. Today, PLA is the most commonly used material for 3D-printing (5), due to its low cost (primarily, but not exclusively (6)).

	Polylactic Acid (PLA)	Aluminum
Density	**1.210–1.430 g/cm^3**	**2.70 g/cm3 g/cm^3**
Young's modulus	**0.35 - 2.80 GPa**	**69 GPa**
Tensile strength	**10 - 60 MPa**	**110 MPa**

Table 1. PLA properties (7) (8)

4. Configuring the Truss. A truss (as illustrated in Figure 3) is 3D-printed and placed on the test rig, at the center of the cavity. The minimum length of the 3D-printed truss is 100+ mm, to fully bridge the cavity.

The movable blocks are slid to touch the truss from the left and right side before clasps are applied to grip the whole configuration sufficiently. We fix the truss on the rig to begin load-testing.

We strain each truss on a fixed point, with a vertical load. We apply the load in incremental steps until fracture. Load-testing a truss structure on the rig consists of
(a) Recording the elastic limit
(b) Recording the point of fracture
(c) Tuning the force-increments applied with the actuator for optimal accuracy. If a truss fractures before signs of plastic deformation, lower pressure increments can be applied for more accurate measurement of the elastic limit.

5. Source of error. Three measures are taken to report the accuracy of the test rig:

1. We level the load testing rig and the actuator with sufficient accuracy concerning the application of the truss.

2. A tripod-mounted camera records the truss configured on the rig. After load-testing, the recordings can be inspected to determine the elastic limit and the point of plastic deformation. We can more accurately distinguish the elastic limit by inspecting the video recordings. A camera with a higher resolution may increase accuracy.

3. Multiple truss structures were 3D-printed. When load-testing the trusses, fluctuation might indicate inaccuracies in the Ender-3 3D-printer, uneven load-application or reality gaps between simulation and reality, or a combination of the mentioned.

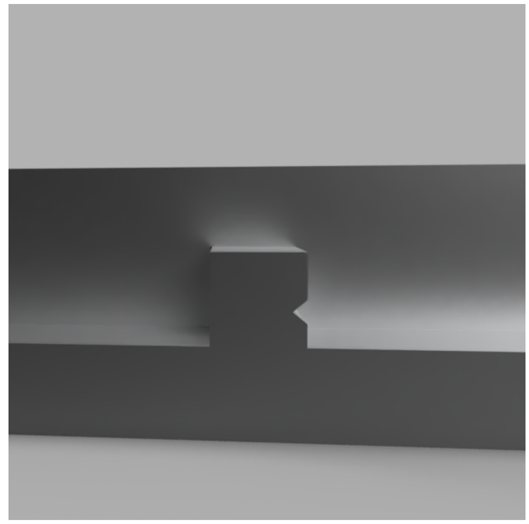

Fig. 2. Side-View of the Stress-Test Rig The triangle slot keeps the sliding components in place.

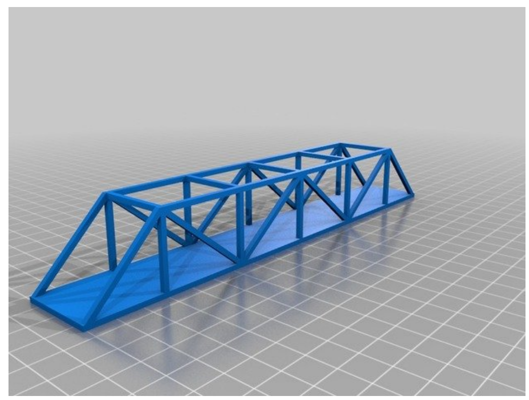

Fig. 3. 3D model of a general truss (9)

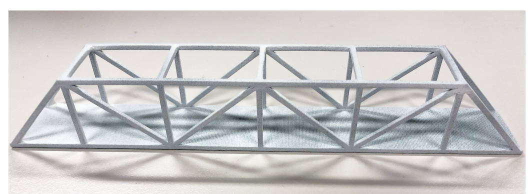

Fig. 4. 3D-Printed truss (9)

6. Further Work. We propose three points when customizing a new test-rig:

1. When creating a test-rig of any sort, it should suit the application sufficiently. The application of the test object, as well as accuracy requirements for the test, must be well defined before designing the rig. The accuracy- and application measure underlies the final design of the test-rig.

2. In the case of this load-testing rig, we are testing material with a stiffness more than 30 times softer the rig itself. The pressure applied is never enough to elastically nor plas-

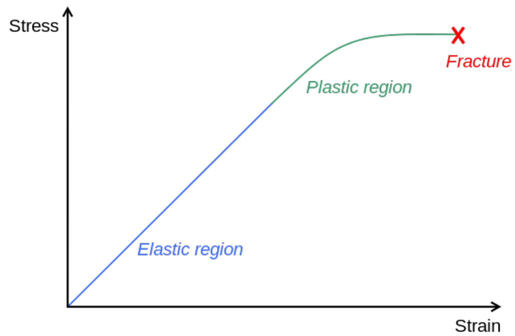

Fig. 5. Elastic vs. plastic deformation (10)

tically deform the rig during testing of the trusses.

3. All sources of error should be investigated to determine likely foreseen inaccuracies. When taking all sources of error into account, an accurate measure of the reality gap can be found.

Furthermore, the rig can be expanded on in several ways. Customizable legs can be applied to elevate and level the rig. Note that the rig always should be leveled for optimal accuracy.

A frame can be built on top of the rig to hold the actuator at a fixed distance from the truss. A frame is a helpful tool, highly recommended for enabling efficient load-testing.

For accurate measuring of the load in Newton (N), a compression load cell in combination with a strain gauge converter should be attached to the actuator, see Figure 6.

7. Conclusion. A load-testing rig was 3D-modelled, for manufacturing in aluminum. The rig fixes the position of a truss to be load-tested before a DYNAMIXEL actuator configuration (load application) applies a vertical force on the truss. The trusses were 3D-printed using the same printer-settings on a Creality Ender3. The trusses are placed and fixed on the load-testing rig one by one.

We note that the aluminum test-rig should have sufficient strength and functionality for load-testing the trusses 3D-printed using PLA material.

Further work consists of attaching a fixed frame to the rig for keeping the actuator configuration at a fixed distance and position.

Fig. 6. Tedea Huntleigh Compression Load Cell (2kg), with a Wachendorff Strain Gauge Converter (11) (12).

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