2013 AFRL University Design Challenge

MECH 4240 Preliminary Design Review- Part 2

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Abstract:

The Air Force Bridge Project is a simple problem with unlimited solutions. The objectives of this project include the designing, testing, and manufacturing of a lightweight, portable device that allows military personnel to safely traverse a horizontal void (ravine, river, stream, gap between rooftops, etc.) Para-rescue men are United States Air Force Special Operations Command operatives tasked with the recovery and, in certain cases, the medical treatment of personnel and important equipment. The missions charge members of these with saving the lives of aircrews involved in aircraft disasters, accidents, or crash landings away from an air base, meaning that they are required to traverse a multitude of different environments to do so. These environments have the potential to be relatively smooth, allowing for straightforward transition of the teams from point A to point B, but that is often not the case.

Situations arise in which relatively large cavities (ravines, rivers, steep ditches, building-to-building gap, etc.) within the geography of a region must be crossed. In order to resolve this issue, the design team has rendered multiple concepts for Air Force Special Operations teams to allow them to traverse themselves, along with their equipment, across a gap spanning 20ft. These concepts are lightweight in design, easily packaged occupying less than 5 ft^3, quickly deployable and retrievable taking less than 5 min. These devices will not only allow the teams to traverse the gap, but to do so quickly, quietly, and in an effective manner as to add proficiency to the task of mission completeness.

Introduction:

United States Air Force Special Tactics Battlefield Airmen executing rescue and assault operations around the world have experienced difficulty traversing many different types of gaps. Some forms of these gaps include irrigation canals, moving from one rooftop to another, crossing minefields, fast flowing mountain streams, snow and glacier crevasses, desert rock formations, unstable/collapsed structures, and compound walls. These obstacles typically range from one to twenty feet in width, and often have landings at different elevations. Ground forces need an easily portable, lightweight, multipurpose tool to negotiate these obstacles.

Battlefield Airmen often have to wear body armor and carry a lot of gear for their missions, along with any heavy equipment or injured soldiers they may have to carry or assist. This makes it impossible to simply jump over every obstacle. Fording canals and streams is often undesirable while loaded with gear and/or injured personnel. Canals and streams often can have heavy currents with unknown depths.

Pre-mission intelligence reports may advise soldiers of the terrain that lies before them. Currently, they bring large aluminum ladders with them for missions that include large gap crossings. These prove to be bulky, heavy, and cumbersome additions to what they already have to carry.

These airmen need a more reliable way to cross canals, get from rooftop to rooftop, and cross any aforementioned gap encountered on a mission. Solutions to this problem should be lightweight, have a multipurpose role (could be used for something other than a bridge), be easy to deploy (i.e. while wearing winter or tactical gloves), reusable, and easy to maintain (e.g. field repairable). It needs to be reliable, strong, and stable, so a soldier weighted down with gear or possibly carrying an injured person (i.e. total weight of 350 lbs.) can safely traverse the obstacle.

Mission Objective:

Design a compact, lightweight, portable system that enables military ground forces to safely traverse a 20 ft. gap with their equipment and rescued personnel.

Customer:

Air Force Pararescuemen, also known as PJ's, are highly trained special forces personnel whose main tasks are to:

- conduct combat search and rescue operations
- recover downed aircrews and aerospace hardware
- provide medical treatment when needed (emergency paramedic qualified)

Often times, these missions are conducted behind enemy lines in groups as little as two PJ's. Therefore, their missions are often done as quietly, and quickly as possible. In a mission, they can come across a vast number of situations and conditions. Some of their working environments include: arctic, jungle, mountains, desert, urban, and wet environments.

Obstacles they could face include large gaps, steep inclines, large objects/structures and many more.

Currently, PJ's are rather limited with conquering some of these obstacles, mostly due to the fact that they are limited to using only what they can carry with them. Due to their many job functions, PJ's carry a lot of weight in/on their rucksacks yet must maintain required agility and mobility.

Final Concept Phase:

It was decided that the final concept would be based off of Concept IIA, the tension cable supported I-beam. There are still, however, many attributes that must be changed for this concept before it is considered the final design. A full piece-by-piece analysis of this concept and the changes that needed to be made are conducted in the following.

First, there were a few attributes of some of the losing concepts that were desirable, and that are utilized in the final design. Concept IID, the telescoping square truss developed a telescoping method that turns out to be an optimal way of storing a device with minimal volume. Concept IIC had the desirable attribute of the supporting force being distributed through multiple cables. This enabled the span itself to be relatively small and lightweight. Last of all, Concept IIB had the desirable trait of a wide walking surface for the soldiers to walk on. This enables them to concentrate on simply getting across, and not so much on having to keep their balance in a straight line.

The tension cable supported I-beam concept had a few key characteristics that greatly affected its appeal. The cable structure with the vertical support beam was probably the most crucial working principle that it benefitted from. This enables the beam that spans the gap to be much smaller and lighter because it only has to support about half of the moment that it would without the cable Figure 37. Another key trait of the cable supported I-beam structure was its use of pins to connect each section. This is an advantageous design because it allows for quick and easy assembly. This method of connection also requires minimal parts and no special tools for assembly.

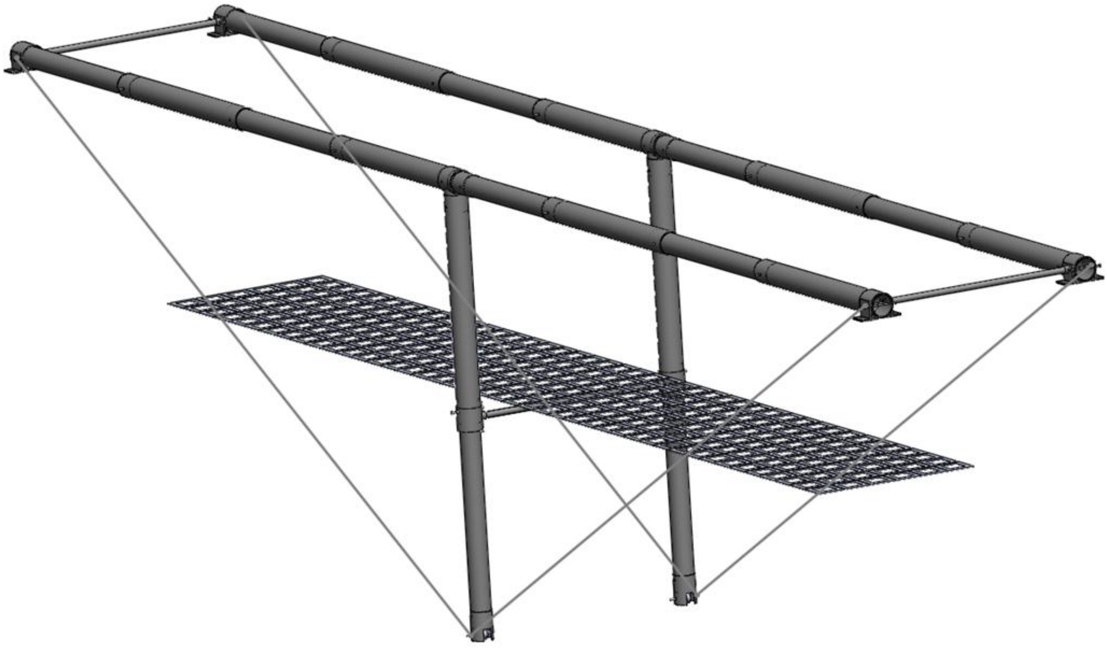


Figure 19: Final Concept

The key elements of the final design are:

Versatile Walking Surface:

- A stiff nylon net walking surface that is lightweight.
- Surface disperses the load more evenly across each of the beams for minimal stress concentrations.
- Non-slippery surface that is safe no matter what the environment.

Transformable Telescoping Sections:

- Telescoping beams limit the stored volume.
- Telescoping sections can be separated to customize lengths more closely to fit any circumstances.
- Span is effective for gaps of any distance up to 20ft. Lengths are customizable to within 2.5ft of any gap distance. (See Fig. 36)
- All telescoping sections are identical.

Quick Assembly:

- If span is less than 12.5ft. , than vertical supports and tensioned cable are no longer necessary. Therefore, with shorter lengths, assembly time can be reduced.
- All 10 telescoping sections (including vertical supports) are interchangeable with one another making assembly easier.
- Pins connecting each section that make assembly and disassembly quick and easy.
- Parachute cord is utilized for suspending the walking structure from the crossing beams. Parachute cord is something the soldiers already carry with them, so this is an effective use of materials the soldier already has on hand.

Strength in Structure:

- Tensioned cable with vertical support that helps reduce the bending moment on the beam.
- Utilizes Carbon fiber that has a great weight to strength ratio.
- Dual crossing beam design adds redundancy and balance to structure. This design also provides superior stability, ensuring no sudden shifts of the device.

Adaptability to difficult Environments:

- Vertical post is usually 5.3ft., but can be reduced to 2.6ft. if a minimum clearance is available underneath the span.
- Surface forming footings for the crossing beams that hold the structure in place while in use no matter what the surface it is resting on.
- Tight nylon mesh surface enables soldiers to climb across steep elevation changes across any gap.

Stealth:

- Soft footing allows for quiet deployment as well as silence while in use.
- Soft walking structure enables soundless transition across a gap.
- Design from a side view is rather transparent.
- Structure can be painted and color matched to the surrounding environment.

Multiple Usages of Device:

- Device could be used to traverse large vertical distances as well as horizontal distance.
- Nylon netting walking surface could also be used as general netting to strap and hold things down if needed.

Safe Design:

- Structure deflection is minimal, giving soldier peace of mind while crossing.
- Lowered walking section that enables the soldier to be encased by the crossing beams that can be utilized as handrails.
- Handrails enable soldier to use free hand to secure an injured soldier or delicate technology with confidence.

In the end, the final concept ended up being close to each of our desired values for our engineering requirements.

Meeting Engineering Requirement Goals:

- Total weight it can support
    - Supports 700lb dynamic load. This should meet and exceed the goal set of being able to support a 350lb. load.
- Horizontal crossing distance
    - Spans 20 feet with excess for mounting. This meets the goal set of being able to span a 20ft. gap
- Total weight of device
    - Weighs approximately 25 pounds. This is right in the middle of the delighted to disappointed range.
- Packed Volume
    - Occupies ~3 cubic feet. This exceeds the set goal by going below the volume that was desired of 5 cubic feet.
- Total Process Time
    - The total time for the crossing process to occur should be less that the desired time of 10min, exceeding the time expectations.
- Number of people required for transport
    - The total people to transport this device is1 person meeting the goal. This device could also be carried between multiple people though.

Concept of Operations:

The following are the steps to deploy this device.

*Steps that only need to be done if span is greater than 2.5 sections in length (12.5ft)

1. Unstrap the device from the rucksack
2. Get a single telescoping section, and extend it outwards to its full length of 5ft. Place a pin in the hole in the middle of the two sections to set them in place.
3. Add additional half or full telescoping sections until you get the desired length of span. Reference Figure 36 for the number of sections required for a desired gap.
4. Repeat steps 2-3 to get the second parallel beam
5. *Repeat step 2 again twice. This will form the two vertical supports. Install the pulley two pulley assemblies into the end of the smaller radius tube. This assembly simply fits into the end of the tube and is pinned in.
6. Add anchors/footings to each end of each of the two complete beams. Each one is simply added to its designated hole at each end.
7. *At hole just inside each of the anchors, pin in each of the four cable attachment points
8. Install the cross members to join each of the parallel beams. This is done by simple pinning them into their mounting points
9. Put all of the loops on each end of the crossing net around each of the respective beams. Pull the net across the length of the entire span and lock it in on the opposite side.
10. *Install each of the vertical supports at the mid-span. These will be simply pinned into the mid-span joint that accepts the perpendicular vertical support.
11. *Run cable underneath vertical supports and clip the cable into the four attachment points with winch attached.
12. *Tie rope to the cross member on the opposite side of the device. Line up span to cross the gap. With the close side of the span sitting in its final resting spot, use the rope to slowly lower the span across the gap until it is resting on the opposite side.
13. *Tighten each of the cables with the ratchet to the specified tension of 350 lbf. This tension will be marked on the rope to the specified length that creates this tension.

Revised Final Concept:

Mock-up:

In order to demonstrate the concept behind the vertical support, a mock-up primarily made out of PVC was constructed. The mock-up is full scale and has been tested under multiple loadings. With both bars extended over a 12 foot distance, it is capable of supporting at least 400 pounds at the middle. A 20 foot section was also made in order to get a realistic feel for how long the distance actually is. The structure deployed at 20 feet is much larger than previously envisioned.

Validate and Verify:

In order to validate two small walls will be built out of wood that can be used to simulate the course at competition. The walls will be free standing and mobile enough to setup multiple configurations. Marks will be made where to place the walls at 5, 10, 15, and 20 feet in order to test the system at all of these distances. This will also be timed in order to figure out which sections are the easiest to deploy and which are the most time consuming.

In order to validate that the correct design was built, the results from the verification must be evaluated against the criteria stated in the design objectives.

Interfaces and ICD:

At this point, the system is free of electronics for simplicity. The mechanical interfaces are where the cable is tensioned. The ratcheting device used for this will interact with the main structure via a pin. All of the telescoping sections are connected using pins. The end pieces that attach the two spanning poles will interact with the ground, acting as our base. Further details on these interactions will be discussed in final report once more detailed drawings are created.

Technical Resource Budget Tracking:

It is important to optimize the design for scoring points and choose places to take hits in order to produce a better result in order categories. Carbon fiber has proven to be the best resource as far as raw materials are concerned. Every other material is too light or not strong enough. David Branscomb has provided carbon fiber materials at no charge. Based on the calculations that were provided there should be enough carbon fiber to finish the design without having to purchase more. Depending on the remaining budget at the end of the semester he has requested replacements for what is used.

The design will occupy less than one cubic foot of space which meets the requirement. The structure will be adaptable to any span, and will meet the twenty foot requirement. It will weigh more than the upper maximum but that is a necessary evil. According to the discussion with the competition leaders, they are more concerned with a working product, and engineering judgment should be used in order to evaluate which design requirements are more important than others.

Risk Management:

The risk analysis process reflected within the risk analysis report uses probabilistic failure points in each conceptual design. The risk analysis results are intended to serve several functions, being able to establish the points of failure in order to reinforce the area, allowing for contingencies to be created in the circumstance that an area should fail, and allowing insight into force distribution as to provide a venue for the load to be redistributed. Furthermore, the scope of the report includes the identification and communication of important steps, logic, key assumptions, limitations, and decisions to help ensure that risk analysis results can be appropriately interpreted.

Table 1: Sample Risk Assessment for Conceptual Design

Concept	Failure Location	Failure Mode	Resulting Action	Risk Level	Protective Measures/ Alternative Methods
1	Pin Joints	Shearing of pins due to significant forces being applied by weight of cargo	Failure in Wire: results in loss of tension throughout base frame	High	Outer Sleeve to assist in tensioning
			Failure in Rigid Piece: results in structure to collapse on respective side	Very High	Supply an anchor to prevent collapsing
2	Pin Joints	Shearing of pins due to significant forces being applied by weight of cargo	Failure at Every Joint: Results in immediate collapse	Very High	Supply an anchor to assist in bending
					Apply an outer sleeve to center cross section to prevent bending at most sensitive area
3	Deck Failure	Due to fabrication of lightweight materials, deck is not meant to be load bearing	A tear will manifest itself. Potential for cargo to plummet	Moderate to High	Use lightweight high strength material (may add to overall weight of structure)
	Failure of Corner Legs	Significant amount of stress on ends	Causes device to fold into itself and collapse to ground	High	Adding additional points in which to anchor supports

Post Midterm COD's:

Cable Attachment for Tension Cable:

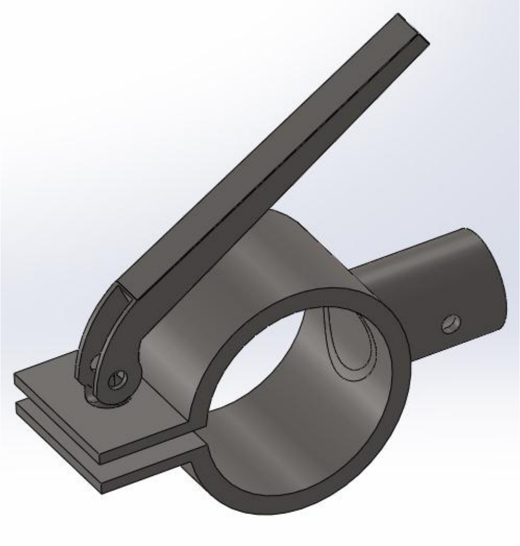
One of the key structural points for this design is the ability to apply a vertical load in the middle of the structure in order to oppose the maximum moment. This reduces the deflection at the middle of the beam; therefore, increasing the rigidity of the structure. This force is needed when the structure is at a working length of 12.5-20 feet. Another design obstacle is the attachment of this cable, the structure has multiple configurations of working distances and it is advantageous for the final design to have fully adjustable attachment points.

The first design concept uses a hinged pipe clamp with a tightening clasp and a high friction material on the interior of the clamp to prevent sliding. The pros for this design are the mobility of the attachment point. The cons outweigh the pros because the durability of the friction material depends on the tolerances of the clamp in relation to the tube. The tube used for this project will not have a universal diameter so a clamp of this type will be impossible to find in the correct size. The manufacturing process for the tube is not exact; therefore, contact around the circumference of the material is uncontrollable. Also, tightening the device requires some sort of tool in order to achieve the proper clamping strength. Weight is another con for this design since the clamp will need to be made from metal.

Another concept is a semicircular solid metal piece with a set screw through it and a rubber interior to reduce slipping. This design can achieve a high enough resistance to slipping horizontally along the tube, but puts a stress concentration on the tube where the set screw contacts the tube. This design minimizes the weight compared to the aforementioned design, but is not as mechanically sound. This design has many of the same cons as the one above; the only improvements are lower weight and adaptability to imprecisely manufactured parts. Additionally, this design would have to be slid onto the pipe from the end.

The tensioning cable will be made out of 550 parachute cord, thus a loop can be added to both ends of this rope in order to create the same design as the one below, a choke strap. The main con for this design is lateral slipping along the length of the pipe, but a lock on clamp can be added in order to provide a surface that will not allow horizontal slipping. The lock-on clamp can be similar to the one mentioned above, and this idea further reduces the weight since there are no clips used for attaching. Another design could be to purchase a quick locking clamp that is rubber to reduce the possibility of slipping.

The chosen concept uses a strap with loops at both ends. The strap will be wrapped around the carbon fiber tube in the correct location and one end will be fed through the other making a choking strap around the exterior of the pipe. An anti-clip coating will be sprayed onto the surface of the strap in order to keep it from sliding down the pipe. This, along with a 3” width of the strap will maintain enough surface area contact and high enough coefficient of friction to remain static. The end of the ratchet strap will be looped into the bottom loop as shown in the picture below.



Carbon Fiber Manufacturing

1. Yarn Components
    a. The yarn properties were determined using various criteria including jacket coverage, bending strength, and yarn diameter
    b. Axials (for large and small diameter structures)
        i. 0.14 in diameter
        ii. Vectran jacket TBD
        iii. Carbon fiber: 10 spools of 12k fiber expected
        iv. Waiting on shipment of more spools of carbon fiber to arrive
    c. Braiding (for large and small diameter structures)
        i. Yarn #13 – Tested by moon buggy team
            1. 0.07 in diameter
            2. Front: 16 bobbins with small vectran (orange springs)
            3. Back: 8 bobbins with small vectran (orange springs)
            4. Carbon Fiber: 2 spools of 12k fiber

2. Open Structure
    a. The open structure properties were determined based on bending, torsion, tension, and compression tests
    b. Section A (small diameter)
        i. 2.175 in diameter (nominal)
        ii. Carbon fiber internal sleeve
        iii. Carbon fiber external sleeve
    c. Section B (large diameter)
        i. 2.9 in diameter (nominal)
        ii. Carbon fiber internal sleeve
        iii. Carbon fiber external sleeve

3. Vectran Spools
    a. For 38 in length
    b. Section A (small diameter)
        i. Open structure braiding
            1. Braiding for yarn
                a. 16 spools of 42.4 m thin Vectran
            2. Axials for yarn
                a. 8 spools of 21.1 m thin Vectran
        ii. Open structure axials
            1. Braiding for yarn
                a. TBD after carbon fiber spools arrive
            2. Axials for yarn
                a. TBD after carbon fiber spools arrive

- c. Section B (large diameter)
  - i. Open structure braiding
    - 1. Braiding for yarn
      - a. 16 spools of 53.2 m thin Vectran
    - 2. Axials for yarn
      - a. 8 spools of 21.1 m thin Vectran
  - ii. Open structure axials
    - 1. Braiding for yarn
      - a. TBD after carbon fiber spools arrive
    - 2. Axials for yarn
      - a. TBD after carbon fiber spools arrive

4. Open Structure Manufacturing
   - a. Section A
     - i. 1.9 in OD mandrel- http://www.onlinemetals.com/merchant.cfm?pid=1223&step=4&showunits=inches&id=73&top_cat=60
     - ii. Apply carbon fiber inner sleeve to mandrel
     - iii. Braid carbon fiber structure over inner sleeve
     - iv. Add carbon fiber outer sleeve
     - v. OD of carbon fiber structure = 2.45 in
     - vi. $OD = OD_{mandrel} + 2*(T_{sleeve} + T_{web} + T_{axial} + T_{sleeve})$
     - vii. $OD = 1.9 + 2*(0.03 + 0.075 + 0.14 + 0.03)$
     - viii. Replace mandrel with bicycle inner tube
     - ix. Slide assembly into 2.5 in aluminum pipe mold (2.469 ID)
     - x. Pressurize and place in oven to cure
   - b. Section B
     - i. 2.625 in OD mandrel- http://eagletube.thomasnet.com/viewitems/all-categories/standard-fractional-tubing?&pagenum=14
     - ii. Gives 0.156 in gap between sections A and B
     - iii. Apply carbon fiber inner sleeve to mandrel
     - iv. Braid carbon fiber structure over inner sleeve
     - v. Add carbon fiber outer sleeve
     - vi. OD of carbon fiber structure = 3.17 in
     - vii. $OD = OD_{mandrel} + 2*(T_{sleeve} + T_{web} + T_{axial} + T_{sleeve})$
     - viii. $OD = 2.625 + 2*(0.03 + 0.075 + 0.14 + 0.03)$

Mock-up:

From the initial stages of prototype conception, the following issues were discovered and evaluated for correction and/or improvement for future implementation:

Uniformity of Tubes/Telescoping Ability

PVC piping was the material used for prototype development. All of the tubes were cut from a homogeneous blend of PVC material with the only variation being the differences in diameter between the interior and exterior tubes. This is comparable to the final concept in the idea that both the inner and outer tubes will be made out of the same carbon fiber material. All tubes were cut to the dimension of 37” in length as to simulate the telescoping concept.

Results:

-A slight increase in length to the interior tube may provide for an ease in expansion of the telescoping tubes.

- Homogenous materials work seamlessly together.

Pin Connection Placement:

A set of cut tubes (Interior tube within Exterior tube) were drilled as a unit to ensure that hole placement would align to establish a suitable pin connection site. In result, this created a mirroring type effect meaning that either the interior or exterior tube would have to have a reverse orientation to allow for proper connection.

Results:

-Extremely difficult to slide pins through both ends.

-Pins will have to be tapered on the inserting end to allow for ease of user to fully connect pin to both ends of tubing system.

-For the finalized concept there needs to be a stopper housed within the exterior tube and on the outer surface of the interior tube that will act as a damping system for the telescoping tubes.

-Mirroring Effect can be neglected if accounted for in manufacturing.

Dimensionality

As previously stated, the dimensions, length wise, were created in a manner to be similar to that of Corp1’s conceptual finalized design. This allowed for a realistic view of how the system will be transported.

Results:

-Allowing for tighter tolerances between Exterior and Interior tube diameters will better support bending moments when the system is placed in tension.

-The PVC prototype was cut in 37” segments as to give a representation of the length that Corp 1 has established for the carbon fiber tubes. This length, in addition to the ruck sack provided by Mr. Cahil gives a very reasonable estimate for the conditions that our spanning system will be housed while being carried.

-Placement of pieces throughout the housing on the ruck sack will be an issue. Due to the heavy stature of the ruck and the rough manner that the user will remove the sack from their person this limits the areas of placement on the ruck sack itself.

-This is will be an important issue in the area of package ability for the system.

T Connection

In the construction of the PVC prototype a "T" Connection was the simplest of the viable choices in connecting the vertical support to the horizontal tubes that span the gap. This "T" Connection was purchased of the same PVC material as to represent a custom coupling system to be created in manufacturing.

Results:

-Creating a T joint for the final concept will work, but it will create an additional amount of volume to the system that will have to be factored in.

-Pin connections will be the simplest form of connection between this coupling piece and the vertical and horizontal connections that will be interfacing with it.

-Due to the force coming through the Coupling due to the tensioned Vertical support bar, high yielding strength will be a definite requirement in design of the coupling piece.

Support Rope Vertical Attachment

At the base of the vertical support column, notches were cut to create spacing for the ratchet straps to be placed. Following these pieces being removed, these holes were then taped over to ensure that wear of the straps would not take place due to sharpened edges.

Results:

-There must be a groove, notch, or housing set in place as to prevent the movement of the tensioning cord from sliding off of the edge.

-The area must be smooth as to not cut away at the cord causing the system to fail.

-The creation of a system to inform the user that the cord is at a maximal tension may be vital in failure prevention.

-A system to inform the user that the system has been tensioned enough.

Placement of Ratchet

The ratchet systems were placed on the ends of the tubes and in conjunction with the vertical tube applied force to the system that will reduce, if not prevent, the moment placed by the user when using the system.

Results:

-Proved the concept that the vertical support would drastically assist in moment prevention.

-The attachment sites of the ratchet will be a very challenge design aspect

-If attached to the outer most side of the tube, tensioning will place a massive moment in the horizontal direction which may cause undue catastrophic failure.

-If attached to the very ends of the tubes then the tensioning tube will reside on the top of the banks. It is not guaranteed that the banks will be evenly distributed, suitable for placement of a tightened cord, or sustainable for the cord as to not cut into the cord's infrastructure reducing its reliability.

-An adjustable ratchet site is now in the works that will allow for ratchet placement to be easily adaptable to the environment.

Stress Concentrations (Snaking/Bending)

After placing the system in tension the connection points throughout the horizontal members went into bending as expected.

Results:

-Following the full construction of the system the connection joint bent at varying directions.

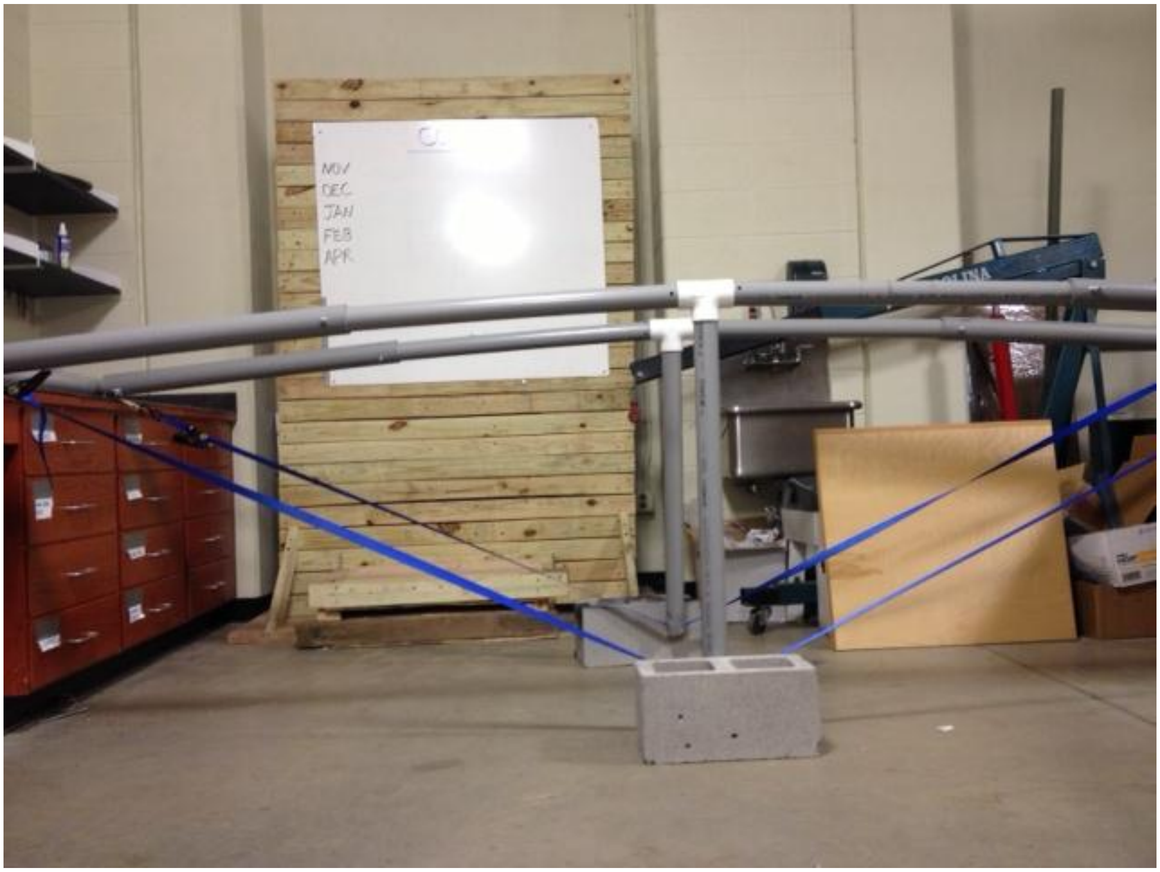
-This created moments in directions that were not accounted for in previous calculations

-To account for these moments all of the pin connection sites were re-drilled to be completely uniform which corrected the "extra" moments.

-The final design will allow for the telescoping members as well as pin connections to be completely uniform to account for this design aspect.

Overall Assessment

Overall, the PVC prototype provided a vast amount of information that will increase and improve the overall efficiency and integrity of the system. This prototype will provide a solid foundation for future development of the finalized system.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Mock-up Materials:

Materials were purchased from The Home Depot and taken to the senior design room where construction of the prototype was performed. A minimum of two team members were required to be present and working together during any and all construction phases.

Three 10ft x 2” and three 10ft x 2.5” schedule 80 PVC pipes were first cut to the desired length of 37” using a miter saw. An Expo marker was used to mark a point in the center of each 2.5” pipe at a distance 2” from the end. A 37” section of the 2” pipe was then slid into a section of 2.5” pipe. A hole was then drilled through both the 2” and 2.5” pipes at the marked point using a 7/16” drill bit via drill press.

Prototype pins were produced by cutting 3’ sections of 3/8” threaded rod into 4” lengths using a hacksaw. A 2” pipe was aligned axially with a 2.5” pipe and then inserted so that the holes drilled in both were aligned. A pin (4” length of threaded rod) was inserted through both pipes and wing nuts were screwed on either side to secure the pipes together. This produced a 4” overlap between the 2” and 2.5” pipes. The process was repeated three more times to produce 4 sections of connected 2” and 2.5” pipe for a total length of 70” each.

Two of the 70” pipe assemblies were then connected using a 2” schedule 40 tee joint which produced a 140” assembly section (in order: 37” x 2” pipe + 37” x 2.5” pipe + tee + 37”x2.5” pipe + 37”x2” pipe, 4” overlap between each 2” and 2.5” connection). This process was then repeated to produce two 140” sections.

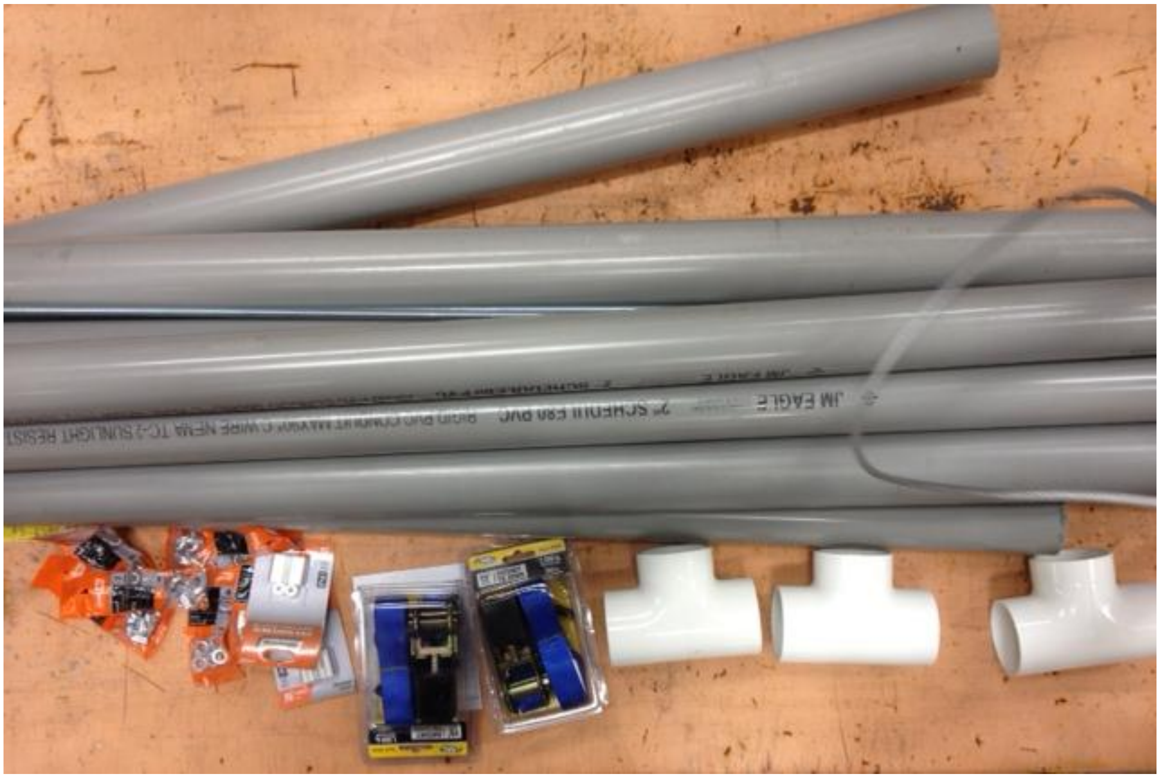
A 1.5” wide and 1” deep groove was then cut in one end of two 37”x2” pipe section using a jig saw. These sections were then inserted with the groove side out in the remaining open slot of the tee joint.

A ratchet strap was then connected to either end of one of the 140” pipe assemblies. The strap was placed in the groove of the 2” pipe in the tee. The ratchet was then tensioned to approximately 35lbs.

The above process was then repeated for the other 140” pipe assembly. The assemblies were placed side by side (each end resting on a table) to form the completed prototype bridge.

This prototype was instrumental in revealing many manufacturing problems including: difficulty in drilling the center of the pipes, difficulty in the use of pins, difficulty in tensioning the strap using the ratchet, difficulty in extending the bridge over a “gap”, as well as other issues. The prototype was successful in also revealing stress concentrations and force vectors.

Overall, the prototype served as an excellent proof of concept, as it supported approximately 300lbs over a gap of 10 feet successfully with minimum deflection. As carbon fiber rods are on the order of ten times stronger than PVC, the actually bridge performance is exceptionally promising.


JM EAGLE
2" SCHEDULE 80 PVC

Research for Segment Joining Method:

The first concept for uniting the telescoping support tube is through the use of interlocking joint. The interlocking joint is composed of two members a male and female. This joint has two possible design approaches; the first would integrate an end cap, which is combined to the existing carbon fiber tube segment with resign. The second would be to integrate the male component on the exterior of the small diameter segment while the female component of the joint is on the interior of the larger diameter segment. These two joints would inhabit the telescoping ability of the tubes by the length of the joint. This interlock joint would also be the bending moment concentration. The interlocking joint without an integrated end cap would add minimal weight ~ 5oz per joint, if the male and female components were both manufactured from carbon fiber. The alternation of including metal end caps to incase the male and female segments of the interlocking joint would add~1lb per joint.

The second concept for joining the telescoping members entails expanding the telescoping sections to a predetermined length, at this length hole in each segment are aligned; a quick release pin, as shown in figure 1, is inserted into these holes, joining the two tube segments as shown in figure two.

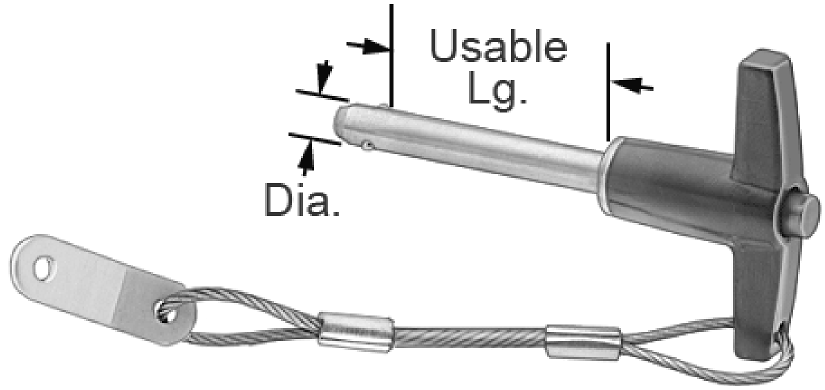


Figure 1: Quick Release Pin

Figure 2: Expanded Telescoping Support with Pin Joint

In the pin joint there are three areas of concern, the shearing force on the pin, the stress concentration on the support tube segments, and bending moment support provided by the joint. The selected pin from McMaster is rated to support 9,200 lbs, this is sufficient to eliminate the concert on the pin failing. The second concern would require addition support to the tube structure to support the stress concentration surrounding the pin. The third concern is best addressed by this configuration, because the telescoping sections overlap 2 inches, which proves a larger region to distribute the bending moment. The added material need to support the pin joint is negligible ~4oz total, the pin itself adds the majority of the weight~.5lbs a joint.

The final concept for joining the telescoping members is a cam lock as show in figure 3. A cam lock consist of two individually machines components, a male and a female. These components are attached to the end of the telescoping segments using resign.

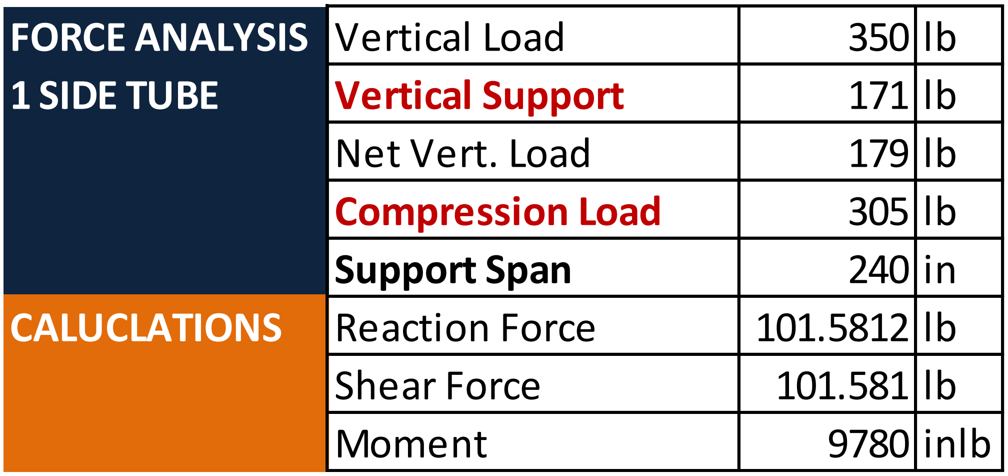
Figure 3: Cam Lock

These cam locks can be prefabricated and purchased through McMaster. The cam lock design offer a quick and easy way to combine segment, that consist of inserting the male component into the female component, then securing the locking arms to hold the joint in place. The cam lock components have a weight of ~2lb for both the male and female component, which adds a total of ~40lb to the total weight.

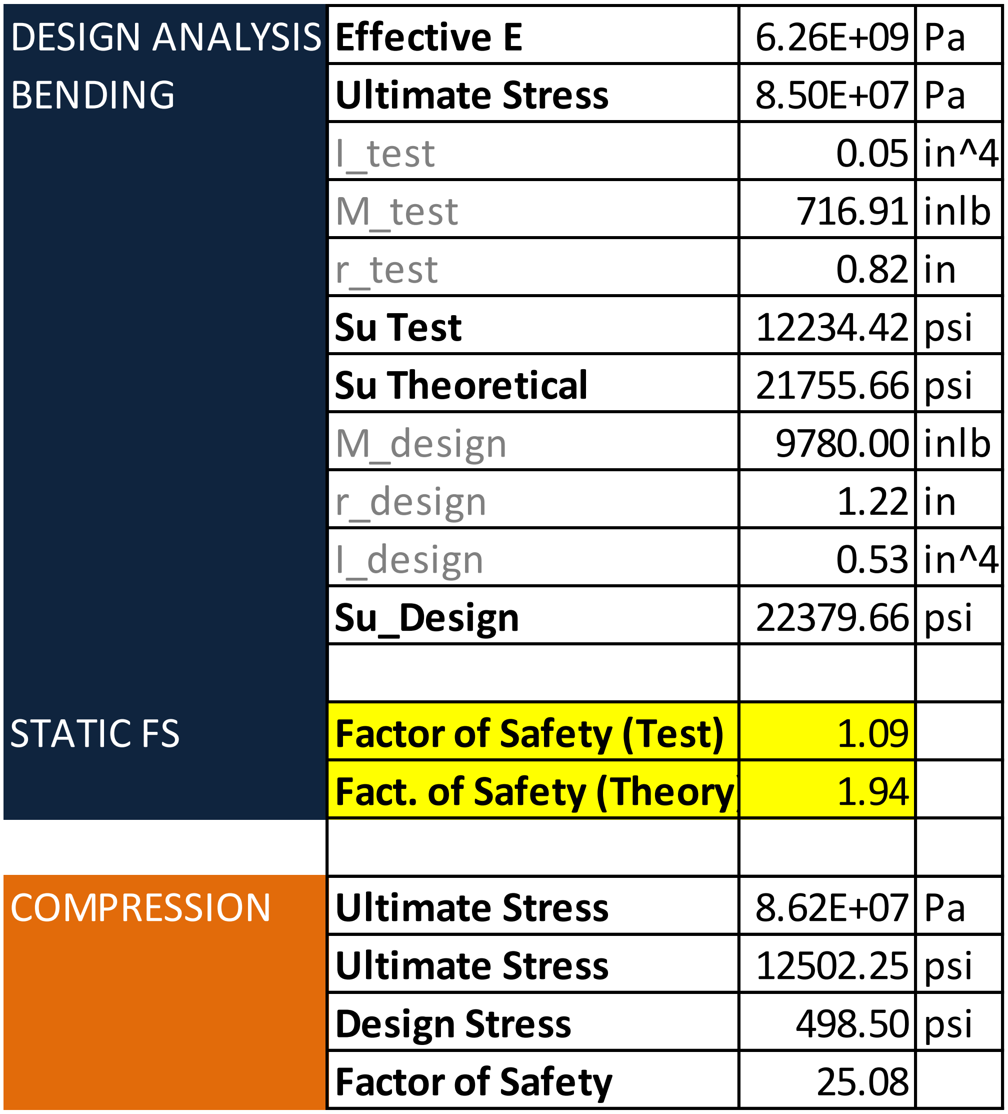
For the purpose of achieving or mission objective, the most practical solution is the pin joint; this joint adds the least weight to the overall project while completing still completing the task. The three concerns previous addressed are factored into the decision but can be easily addressed to prevent failure. The pin joint is also adds the least weight to the net weight of the device, since the only added material is the pin and carbon fiber reinforcement.

Concerns that need to be focused on for the pin joint arose from the development of the prototype-bridging device. The first is the difficultly to align the pinholes, this occurs when the telescoping devices are not exactly at the appropriate length, this can be corrected by a stop. The second problem is if the tolerances of the hole and pin are large the bridge is allowed to flex which decreases structurally integrity.

Dimensional Analysis:



FORCE ANALYSIS	Vertical Load	350	lb
1 SIDE TUBE	**Vertical Support**	171	lb
	Net Vert. Load	179	lb
	Compression Load	305	lb
	Support Span	240	in
CALUCLATIONS	Reaction Force	101.5812	lb
	Shear Force	101.581	lb
	Moment	9780	inlb



DESIGN ANALYSIS	**Effective E**	6.26E+09	Pa
BENDING	**Ultimate Stress**	8.50E+07	Pa
	I_test	0.05	in^4
	M_test	716.91	inlb
	r_test	0.82	in
	Su Test	12234.42	psi
	Su Theoretical	21755.66	psi
	M_design	9780.00	inlb
	r_design	1.22	in
	I_design	0.53	in^4
	Su_Design	22379.66	psi
STATIC FS	**Factor of Safety (Test)**	1.09	
	Fact. of Safety (Theory	1.94	
COMPRESSION	**Ultimate Stress**	8.62E+07	Pa
	Ultimate Stress	12502.25	psi
	Design Stress	498.50	psi
	Factor of Safety	25.08	

The end cap (vertical support/cable interface) must:

- Support the vertical load(~175lb)
- Keep the cord straight and in line
  - Through the prototype, it is evident that the cord be slightly off center can induce a large twisting force on the structure.
- Must ensure that the cord does not slip or come off, completely eliminating its usefulness
  - Having the cord slip off the vertical support would be catastrophic. Therefore, this needs to be ensured to not happen.
- The design needs to be simple and light weight. Quick and easy to put on.

An added additional requirement:

- Indicating when enough tension is in the cord.

Midterm interpretation for end cap:

For the midterm, the end cap was simple. It simply fit around the end of the vertical support, and had a pulley on the end that the cable would rest on. The pulley was utilized so there would be low friction, and in turn would not cause the vertical support to deflect sideways.

What was learned:

It would be optimal to utilize a design that is simpler than using a pulley. A pulley could require more regular maintenance, and in general could cause reliability issues. It is also more difficult to keep the cord on the pulley. As an alternative, it was decided to use a smooth, rounded, metal surface. It was found that a coating could be added to the metal surface that would reduce its coefficient of friction to as low as 0.05. These coatings are also very durable, possibly outlasting the life of the product. A surface like this would also be able to distribute the load around the rim of the end of the vertical support instead of concentrating the force at the pin hole in the vertical support.

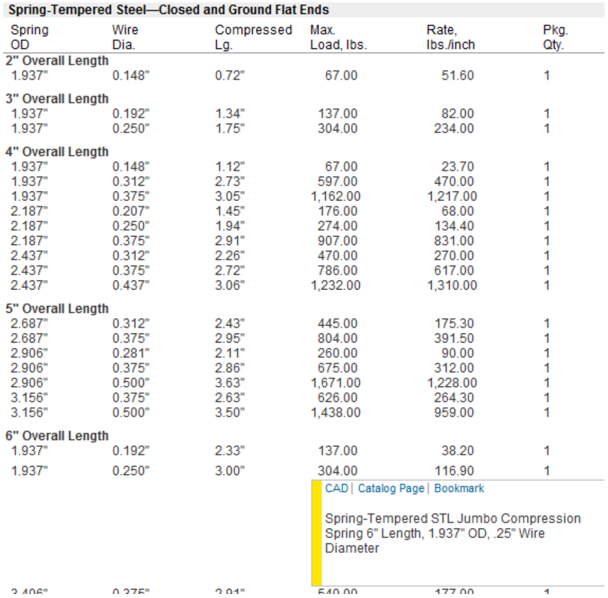
As stated above, it was found that having the cable centered is very important. Therefore, the tolerance of the guide for the cord on each side should be minimal.

In the group, there was brainstorming on how we could indicate the amount of tension in the cord. Springs, torque wrenches, etc. where brainstormed. The idea came out to utilize a spring in the end cap. This spring would have a known deflection under the required mid-span vertical force of ~175lbs. This spring would resist the upward movement of the cap. As the cord is tensioned under the end cap, the cable pushes up on the cap. This in turn compresses the spring at the bottom of the vertical support. When the cap deflects by a predetermined amount, the user will then know that the appropriate tension has been applied to the cord to get the correct amount of upward force on the vertical support.

Final interpretation:

It is unsure whether to follow the idea of using a smooth surface for the cord to rest on opposed to a pulley at this point. A smooth surface rest is preferable due to its simplicity and reliability, but availability and time for certain manufacturing techniques may be limited. It might prove difficult to machine a metal piece with that sort of curvature and geometry. Some design elements, like using L-brackets can simplify forming this design. Still, expertise and some additional thought must be sought out on what would be a manageable design for manufacturing capabilities and limitations of the group. Some research was done on possible low coefficient of friction coatings. Many are available. A Teflon like coating seems like would be a good, reliable choice of coating.

For the spring mechanism, careful consideration was taken on choosing a spring. The spring had to be able to fit into its limited space (about 1.9in) from the vertical support cylinder, and not be too long to create a large and bulky end cap. Also, the spring rate must be large enough to cause only limited deflection, allowing a smaller spring to be used. It also must have a small enough spring rate to give a noticeable amount of deflection for visual detection of the end cap seating. This proved to be rather difficult. A spring was however found off of McMaster-Carr that would fit our requirements. It would however, have to be slightly modified. The spring found is listed below:

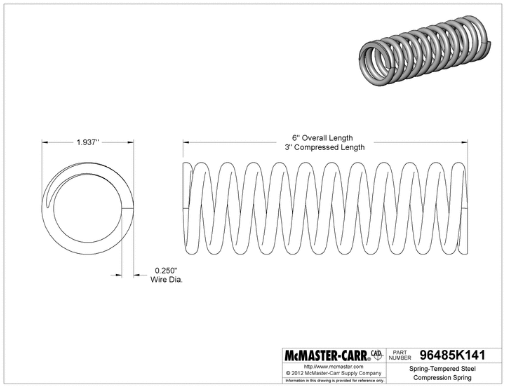


Spring-Tempered Steel—Closed and Ground Flat Ends

Spring OD	Wire Dia.	Compressed Lg.	Max. Load, lbs.	Rate, lbs./inch	Pkg. Qty.
2" Overall Length					
1.937"	0.148"	0.72"	67.00	51.60	1
3" Overall Length					
1.937"	0.192"	1.34"	137.00	82.00	1
1.937"	0.250"	1.75"	304.00	234.00	1
4" Overall Length					
1.937"	0.148"	1.12"	67.00	23.70	1
1.937"	0.312"	2.73"	597.00	470.00	1
1.937"	0.375"	3.05"	1,162.00	1,217.00	1
2.187"	0.207"	1.45"	176.00	68.00	1
2.187"	0.250"	1.94"	274.00	134.40	1
2.187"	0.375"	2.91"	907.00	831.00	1
2.437"	0.312"	2.26"	470.00	270.00	1
2.437"	0.375"	2.72"	786.00	617.00	1
2.437"	0.437"	3.06"	1,232.00	1,310.00	1
5" Overall Length					
2.687"	0.312"	2.43"	445.00	175.30	1
2.687"	0.375"	2.95"	804.00	391.50	1
2.906"	0.281"	2.11"	260.00	90.00	1
2.906"	0.375"	2.86"	675.00	312.00	1
2.906"	0.500"	3.63"	1,671.00	1,228.00	1
3.156"	0.375"	2.63"	626.00	264.30	1
3.156"	0.500"	3.50"	1,438.00	959.00	1
6" Overall Length					
1.937"	0.192"	2.33"	137.00	38.20	1
1.937"	0.250"	3.00"	304.00	116.90	1
3.406"	0.375"	2.91"	540.00	177.00	1

CAD | Catalog Page | Bookmark

Spring-Tempered STL Jumbo Compression Spring 6" Length, 1.937" OD, .25" Wire Diameter

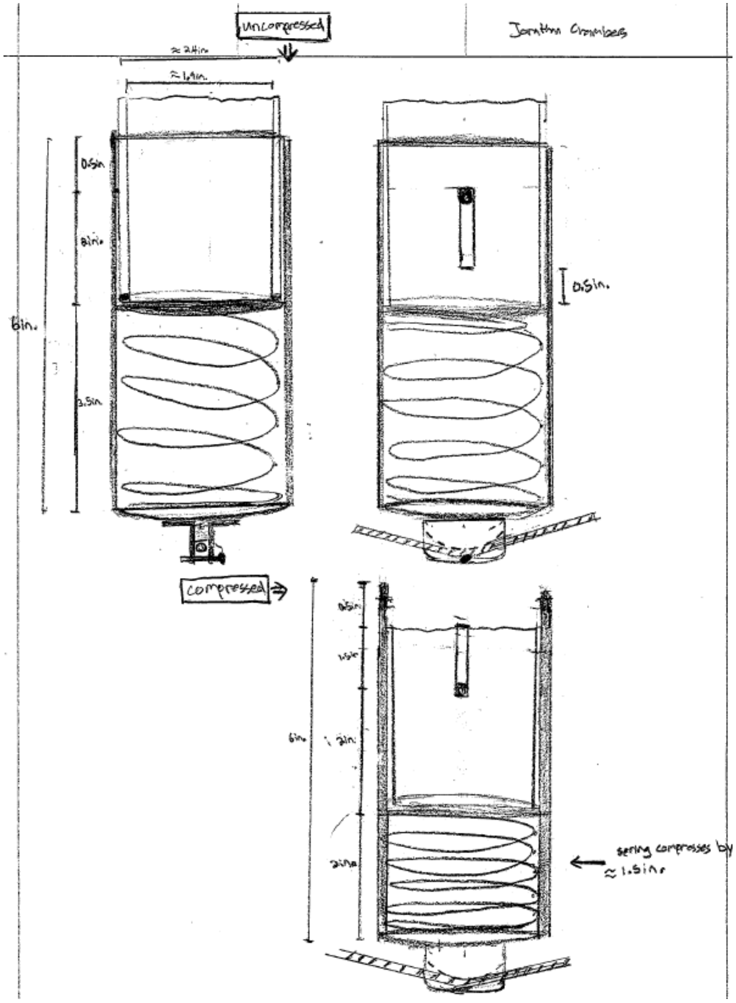


http://www.mcmaster.com/#cadinlnord/96485k141/=kdgupf

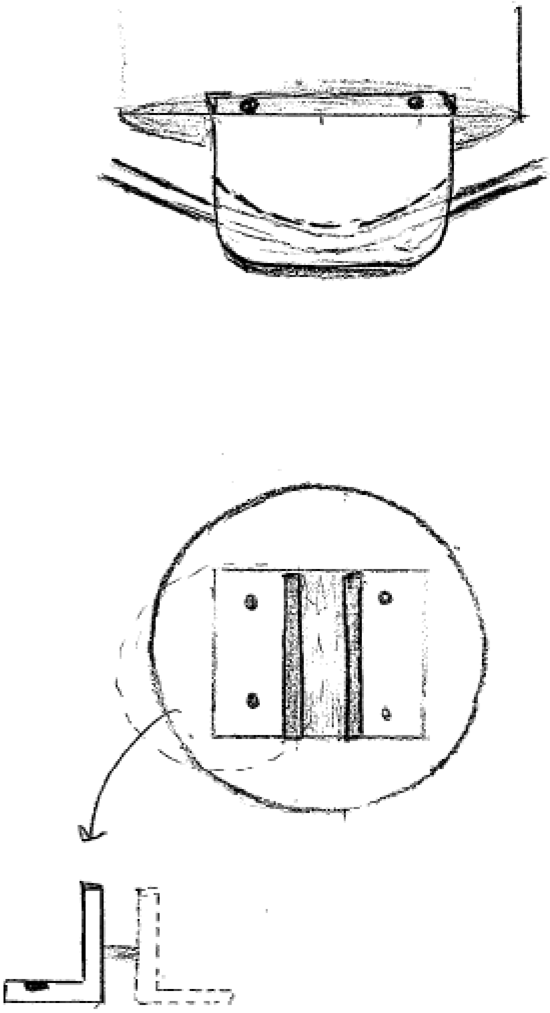
The spring rate of 116lb/in would allow the spring to deflect 1.5 inches under the load of 175lb., which would be a visible deflection. To reduce the size while keeping all of the desirable traits, the spring will be cut down in size. No spring could be found to perfectly match this spring rate and size/shape characteristics. Therefore, this is a necessary, and rather simple, modification. The diameter of this spring is perfect size to fit under the circumference of the end of the vertical support.

The end cap will be put in place with a pin using the standard pin hole available on each tubular structure. The pin will be stuck through a 1.5 in. slot. The end cap can then travel up and down through this slot, while not twisting or changing its directional orientation. When the pin reaches the bottom of the slot, it is known that the 175lb load is then being applied by the tensioned cable.

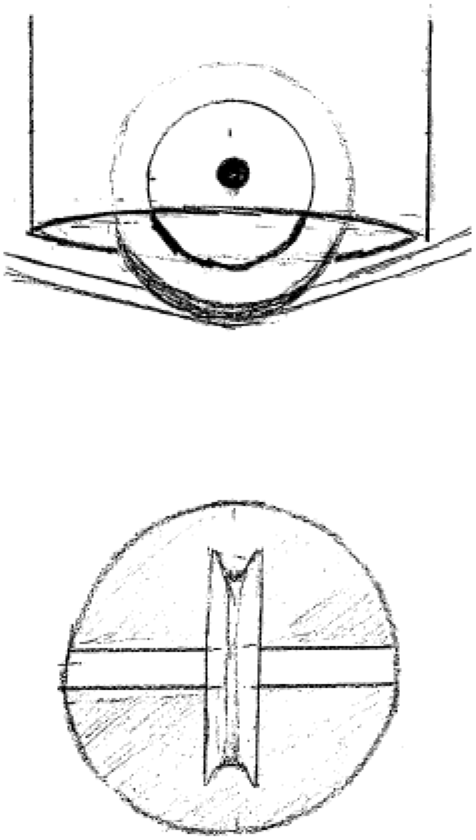
In the end, it will be attempted to find a way to utilize the curved surface for the rope to rest on as opposed to a pulley. This will only be done however if manufacturing methods permit. Otherwise, a pulley design will have to be used. The spring design seems like it should be a simple and easy way to determine the correct tension is being supplied. Testing will need to be done to test this method.



cable rest 1:



cable rest 2:



Appendix

Project Management:

Due to the level of complexity of the problem, most of the tasks had multiple people working in tandem on them. Most people had a primary focus as far as research topics were concerned but all consulted one another based on prior experience. The structure of this semester was odd because there were no known tasks. Concept development and testing are the only things that can be done at this point in the competition.

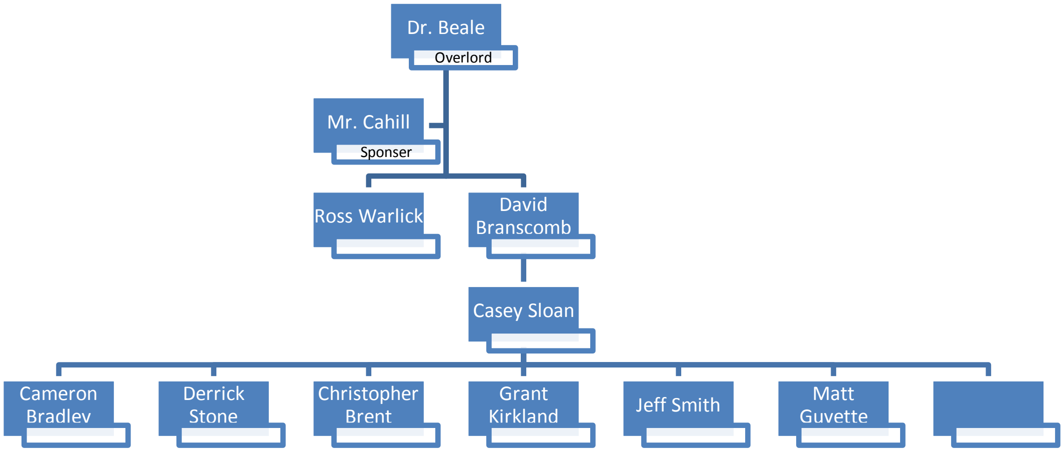


Figure 21: Management Diagram

Engineering Analysis

Vertical Support Suspension System Design

A MATLAB Code was utilized to expedite the analysis of a given suspension system parameters as follows:

Input

Attach point to Tube

Tension in Cable

Output

Maximum Moment

Vertical Support Force

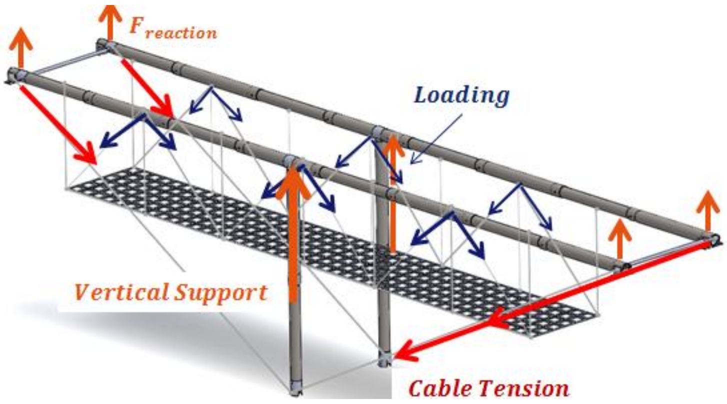


Figure 22: Force Analysis on Tube Structure

Compressive Load

The chosen suspension design provides a 171 pound force center vertical support which reduces the maximum moment on the structure by a factor of two.

Axial Compression Test / Verification of Design in Compression due to Vertical Support System

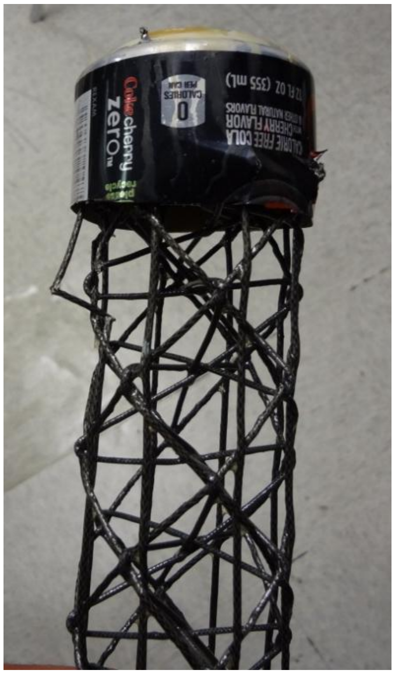


Figure 23: Axial Compression Test

Based on testing an un-sleeved carbon fiber tube with z supports to compressive failure the following information was found:
Ultimate Compressive Stress: $S_{uc} = 86.2$ MPa

The current design's compressive stress is: 5.90 MPa.
The estimated factor of safety is 14.6

Moment and Deflection Analysis:

The following is results from code written to find the bending moment in the beam, and in turn the vertical deflection of the whole beam. The code is based off of general equations for deflection and moments in a beam from mechanics of materials. A loop is run to plot the reactions at each point on the beam. In most circumstances, a distance step across of the beam of 1ft. was sufficient.

Constants unless otherwise specified:

- Load of 350lb.(for each beam. 700 overall)
- Rope Tension of 350lb.
- Position of load at mid-span(where max moment always is)
- Length of span of 22ft.
- Connecting points of 1.5ft in from each side
- 5.333 ft. vertical support beam

*The max bending moment for the beam span is at 1111 ft.-lbs. which is what the beam experiences with our set constant values above. Therefore, a moment above 1111ft-lbs. is not acceptable.

Base Set-Up for 20ft. Gap:

The following is what is designed to for the maximum gap of 20ft. It follows all of the above requirements.

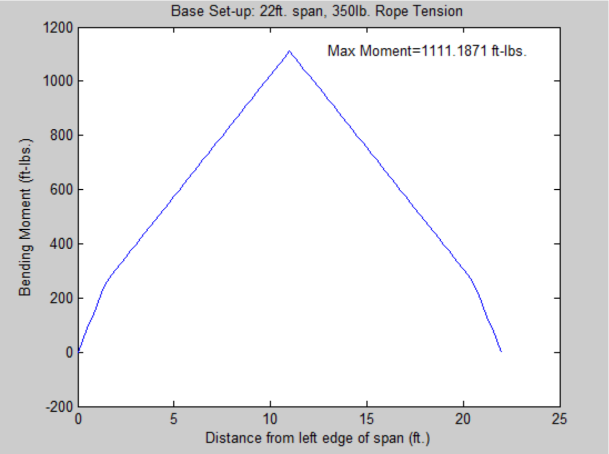


Figure 35: Deflection with Load at 7ft

Carbon Fiber Tube Design

Bending Analysis

From experimental analysis of an un-sleeved carbon fiber tube with internal z supports, the following information was found.

Ultimate Bending Stress: $S_u = 57\ MPa$

Effective Elastic Modulus: $E_{eff} = 6.26\ Gpa$

Assuming these same values for the designed sleeved carbon fiber tube with no internal supports the minimum moment of inertia required for the design may be determined as follows. Where the max stress at failure in the sample structure is given by:

$\sigma_{\mathrm{test\ failure}} = \mathrm{S_u} = \frac{\mathrm{M_{test}\, r_{test}}}{\mathrm{I_{test}}}$ *then*

$$\mathrm{S_u} = \frac{\mathrm{M_{test}}\left\{\frac{\mathrm{M_{design}}}{\mathrm{M_{test}}}\right\}\mathrm{r_{test}}\left\{\frac{\mathrm{r_{design}}}{\mathrm{r_{test}}}\right\}}{\mathrm{I_{test}}\left\{\frac{\mathrm{M_{design}}}{\mathrm{M_{test}}}\right\}\left\{\frac{\mathrm{r_{design}}}{\mathrm{r_{test}}}\right\}} = \frac{\mathrm{M_{design}\, r_{design}}}{\mathrm{I_{design}}},\ \text{then}$$

$$\mathrm{I_{design}} = \mathrm{I_{test}}\left\{\frac{\mathrm{M_{design}}}{\mathrm{M_{test}}}\right\}\left\{\frac{\mathrm{r_{design}}}{\mathrm{r_{test}}}\right\}$$

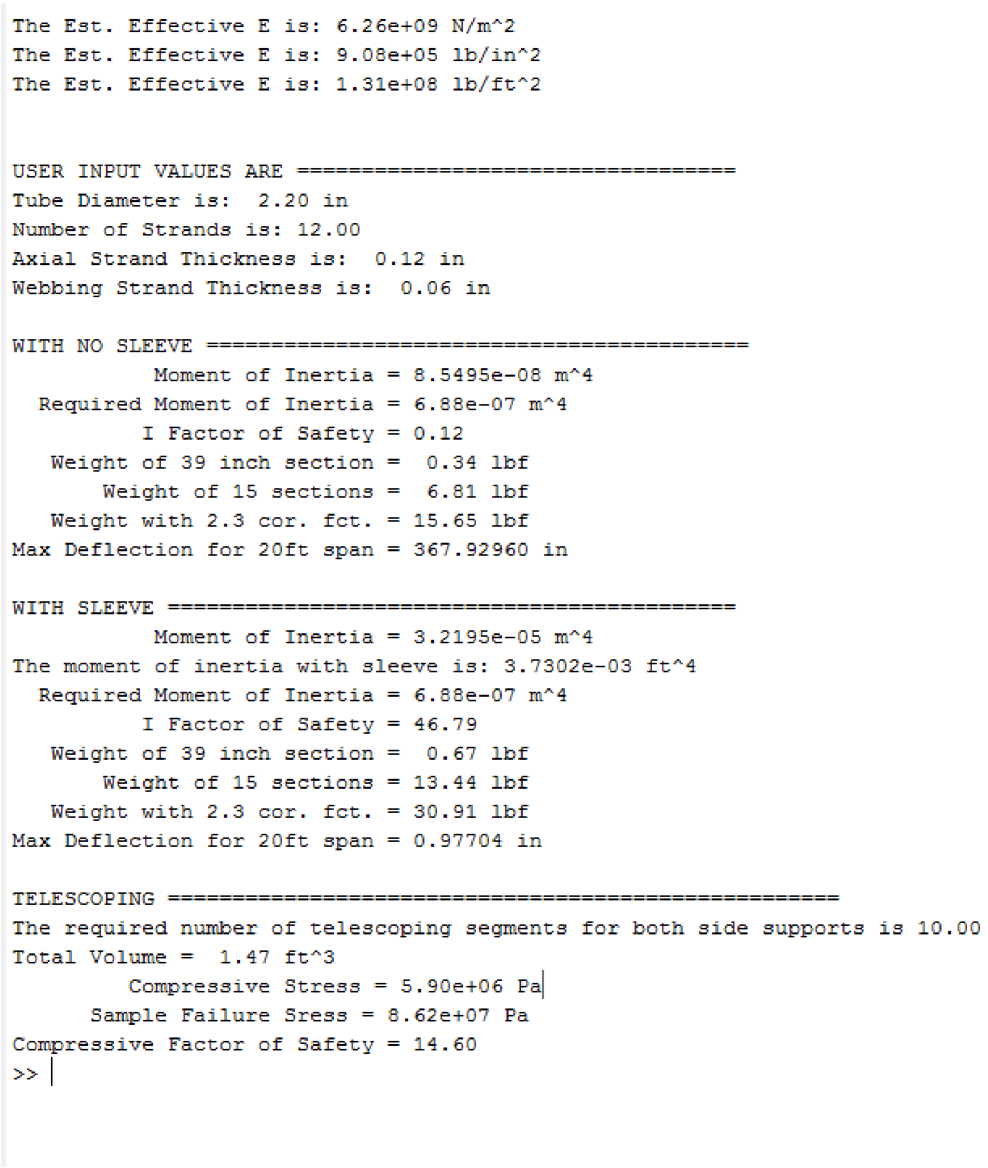
With the reduced load on the beam due to the vertical support suspension system the deflection may be determined as follows:

```
y = (Force_max*(Length^3))/(48*E_mod*M_Inertia);
```

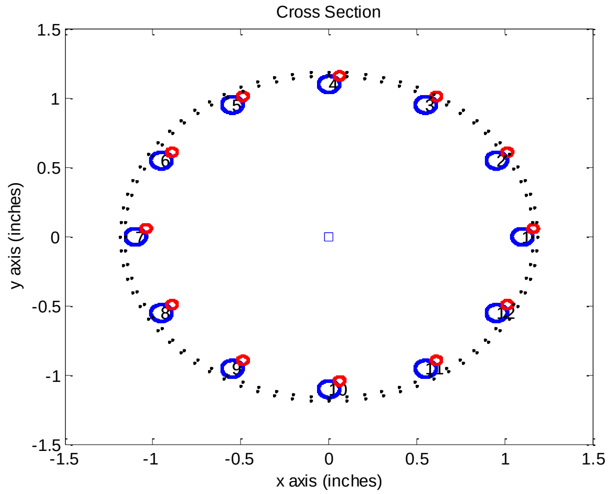
A MATLAB code was created to expedite the design process by taking the following inputs and calculating the following outputs.

CODE INPUT	CODE OUTPUT
Vertical Support	Moment of Inertia (I)
Compressive Force	Required I
Effective E	Bending Factor of Safety
Tube Diameter	Total Weight of Horizontal Supports
Thickness of Axial Yarns	Max Deflection Over 20ft
Thickness of Web Yarns	Package Volume of Horizontal Segments
Number of Yarns	Compressive Stress and Factor of Safety
Length of Segment	
Overlap of Segments	

REF: See COD_Brent (MATLAB Code)

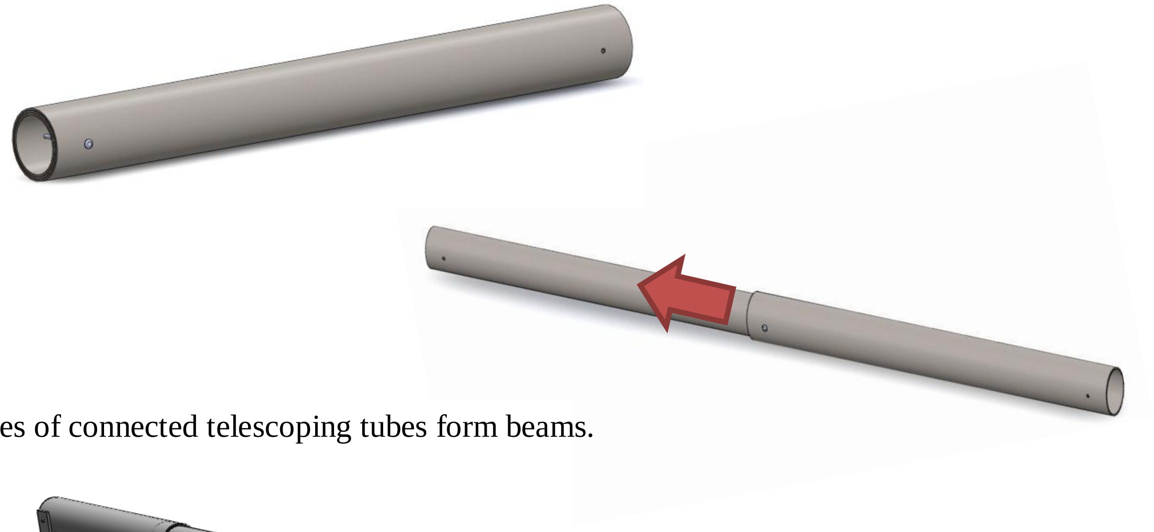


```
The Est. Effective E is: 6.26e+09 N/m^2
The Est. Effective E is: 9.08e+05 lb/in^2
The Est. Effective E is: 1.31e+08 lb/ft^2


USER INPUT VALUES ARE ==================================
Tube Diameter is:  2.20 in
Number of Strands is: 12.00
Axial Strand Thickness is:  0.12 in
Webbing Strand Thickness is:  0.06 in

WITH NO SLEEVE ==========================================
           Moment of Inertia = 8.5495e-08 m^4
  Required Moment of Inertia = 6.88e-07 m^4
          I Factor of Safety = 0.12
   Weight of 39 inch section =  0.34 lbf
       Weight of 15 sections =  6.81 lbf
   Weight with 2.3 cor. fct. = 15.65 lbf
Max Deflection for 20ft span = 367.92960 in

WITH SLEEVE =============================================
           Moment of Inertia = 3.2195e-05 m^4
The moment of inertia with sleeve is: 3.7302e-03 ft^4
  Required Moment of Inertia = 6.88e-07 m^4
          I Factor of Safety = 46.79
   Weight of 39 inch section =  0.67 lbf
       Weight of 15 sections = 13.44 lbf
   Weight with 2.3 cor. fct. = 30.91 lbf
Max Deflection for 20ft span = 0.97704 in

TELESCOPING ===================================================
The required number of telescoping segments for both side supports is 10.00
Total Volume =  1.47 ft^3
         Compressive Stress = 5.90e+06 Pa
      Sample Failure Sress = 8.62e+07 Pa
Compressive Factor of Safety = 14.60
>> 
```

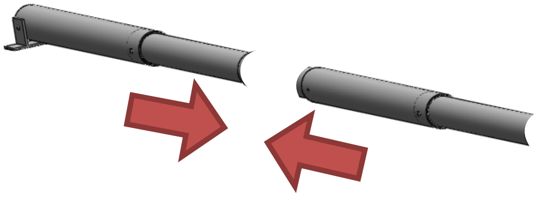


Physical Decomposition:

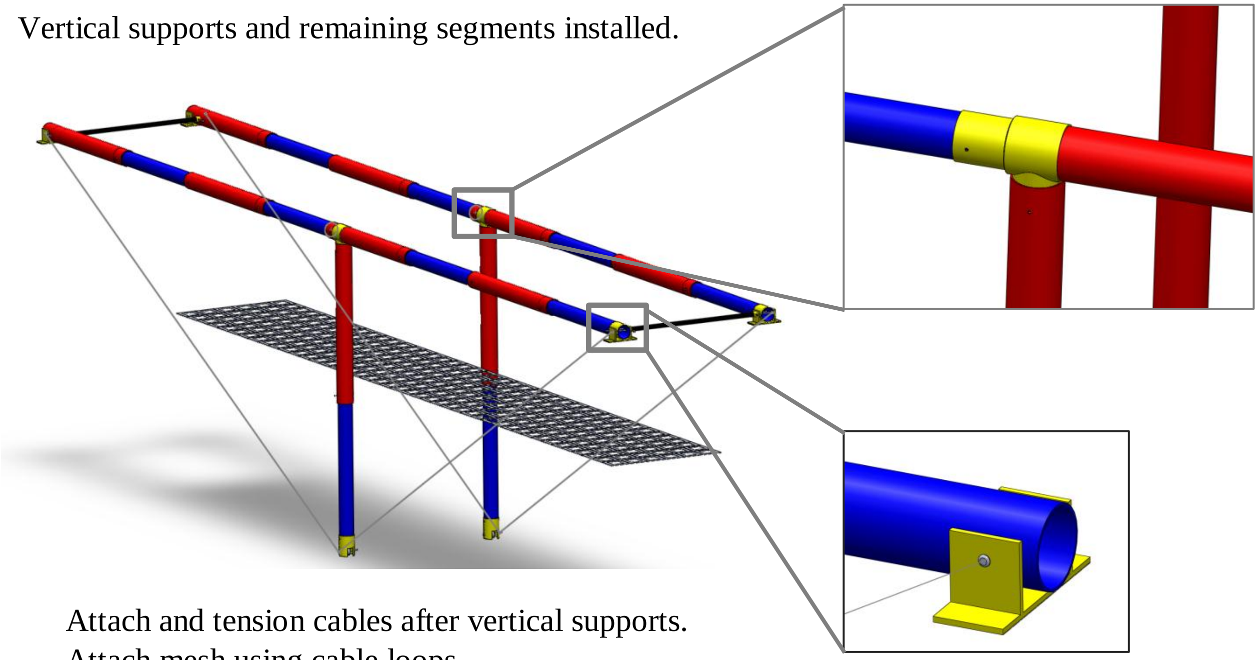
Telescoped tube segment contracted and extended.



Series of connected telescoping tubes form beams.



Vertical supports and remaining segments installed.



Attach and tension cables after vertical supports.
Attach mesh using cable loops.

Figure 36: Telescoping Extension User’s Guide

Number of Telescoping Sections	Overall Length of Span	Capatible With Gap Distance of:	Extra distance on each end for sitting on ledge
1	5'8"	5' or less	4"
1.5	8'4"	7.5'-5'	5"
2	11'	10'-7.5'	6"
2.5	13'8"	12.5'-10'	7"
3	16'4"	15'-12.5'	8"
3.5	19'	17.5'-15'	9"
4	21'8"	20'-17.5'	10"

*With gap distances less than 12.5’, the tension cable and vertical supports are not necessary. This is proven by the figure below that shows the maximum moment remains below the 1111ft-lbf threshold that has been set. By the beam having a moment of 1093 ft-lbf with no tension support cable, this proves that lengths under 12.5’ can do without the support structure.

Figure 37: Moment of 12.5ft long beam without cable support

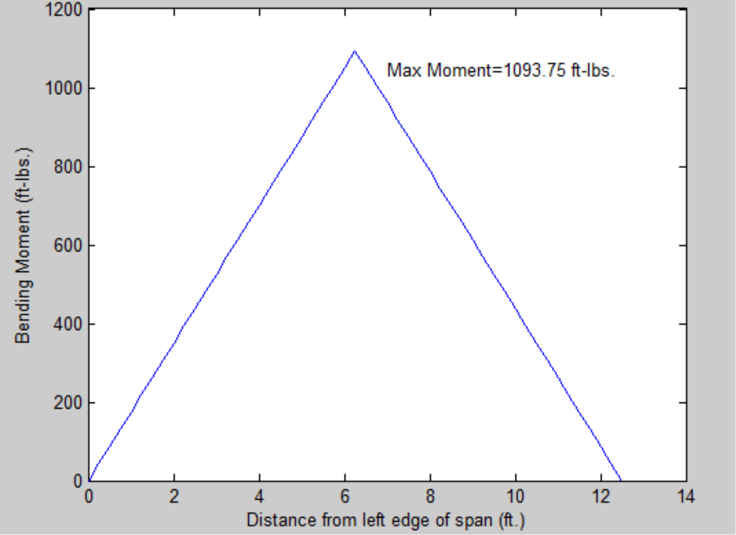
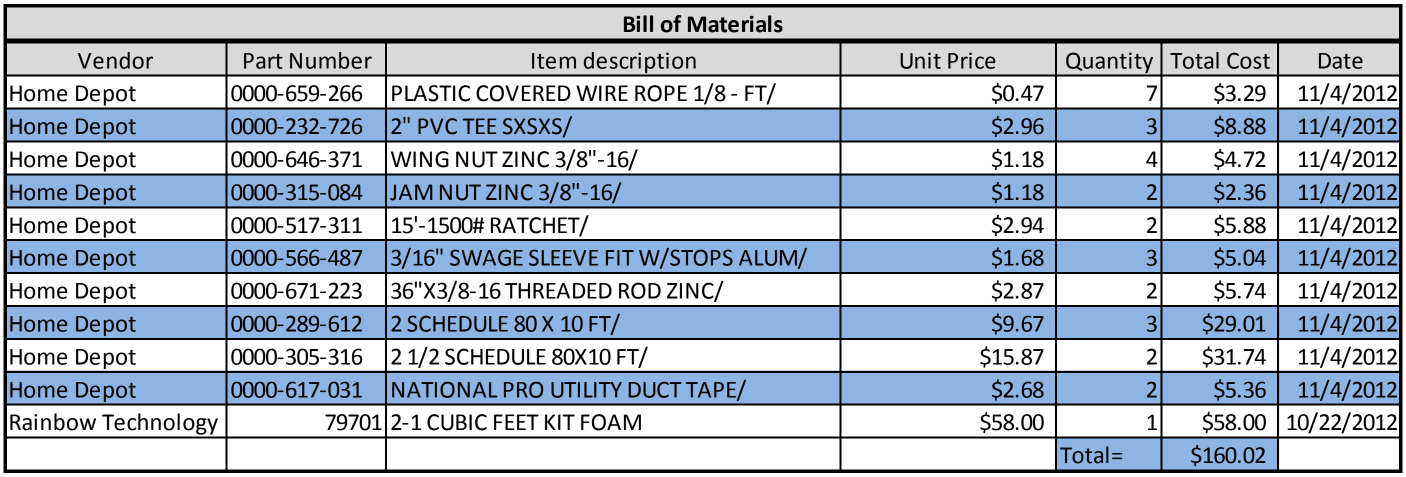


Table 2: First-Cut B.O.M.



Bill of Materials						
Vendor	Part Number	Item description	Unit Price	Quantity	Total Cost	Date
Home Depot	0000-659-266	PLASTIC COVERED WIRE ROPE 1/8 - FT/	$0.47	7	$3.29	11/4/2012
Home Depot	0000-232-726	2" PVC TEE SXSXS/	$2.96	3	$8.88	11/4/2012
Home Depot	0000-646-371	WING NUT ZINC 3/8"-16/	$1.18	4	$4.72	11/4/2012
Home Depot	0000-315-084	JAM NUT ZINC 3/8"-16/	$1.18	2	$2.36	11/4/2012
Home Depot	0000-517-311	15'-1500# RATCHET/	$2.94	2	$5.88	11/4/2012
Home Depot	0000-566-487	3/16" SWAGE SLEEVE FIT W/STOPS ALUM/	$1.68	3	$5.04	11/4/2012
Home Depot	0000-671-223	36"X3/8-16 THREADED ROD ZINC/	$2.87	2	$5.74	11/4/2012
Home Depot	0000-289-612	2 SCHEDULE 80 X 10 FT/	$9.67	3	$29.01	11/4/2012
Home Depot	0000-305-316	2 1/2 SCHEDULE 80X10 FT/	$15.87	2	$31.74	11/4/2012
Home Depot	0000-617-031	NATIONAL PRO UTILITY DUCT TAPE/	$2.68	2	$5.36	11/4/2012
Rainbow Technology	79701	2-1 CUBIC FEET KIT FOAM	$58.00	1	$58.00	10/22/2012
				Total=	$160.02	

Disruption on the Environment:

The impact on the environment for the final design is negligible.