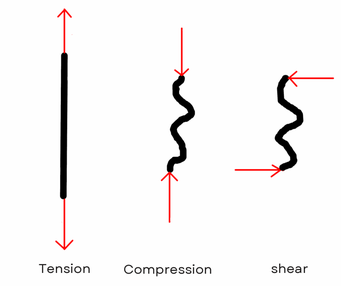
Main propreties of cables

Tectonics of cable - analytical part - Martin Cornille

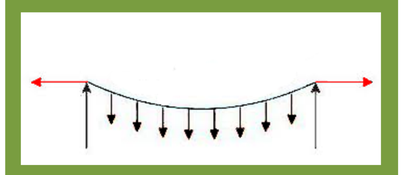
Physics of cables

Cable works in **tension**, they cannot work in compression so there is no bending either.



Not only they work in tension but they have a high tensile strenght. Thanks to the efficiency of simple tension, the fact that cable are light and their strenght, cables are a great way to **cover long distance.**

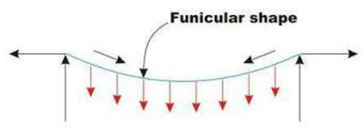
Horizontal reactions



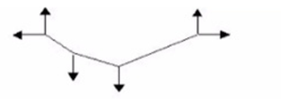
As they work in tension, **anchorage** is really important when used horizontally because their structural load will be transferred horizontaly where they are attached.

Shape

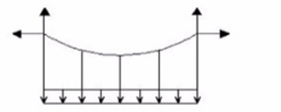
In his most basic arrangment, with only his own weight or with a continuous load all along the cable, a cable will have a **funicular shape.** (this shape can be attenueted if the cable is prestressed)



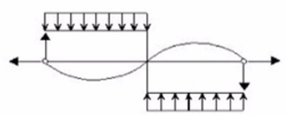
Due to a diversity of other possibles way to attach weight to a cable, it's shape varies too:



Concentrated loads (polygonal form)



Uniformly distributed vertical load (square parabolic form)



Asymetric loading with uplift

Materials

Modern cables are in differents type of **steel** and sometimes polyester and aramid fibres.

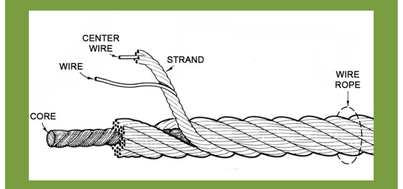


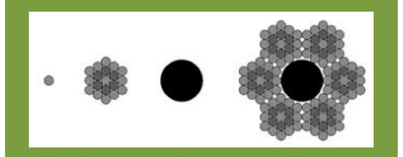


Historically, ropes and chains where used too.

Details of cable

Those drawing shows the composant of a modern cable, it's very similar to ropes but with a stronger material.





Wire Strand Core Rope

Tensegrity

Tensegrity is an unusual way to use cables. Instead of hanging cable to compressive part connected to the ground, it is the compressive part that are connected trough a tensile part (cables).

This way of building goes a little bit against the normal way to use cable. It's unusual because not super logical and very hard to use in buildings because of the need of an original external force to put it all together.

Because of it's instability and difficulty to build, tensegrity is rarly used in real building. Still, it's an interesting way to use cables and a lot of people experiment with this type of structure.

The various **experiment** goes to some kind of bridge, tower, sphere shaped assembly of tensegrity part and even a chair. The experiments are sometimes exposed as sculptures.



Experiment



tensegrity bridge: atelier architecture 64



Toy using tensegrity

This is the most common exemple of tensegrity. As we can see, it's the cable in the middle that make everything hold together. This kind of structure seems very disturbing and conter intuitive.

Small scale

The main qualities of cable make them perfect for large scale bridge and roof but they are also used in other ways.

Unfortunatly, using them come with some complex arrangement that is too much of a burden for smaller constructions. There is also a lot of other and easier way to build smaller construction. That's why they are less used in those

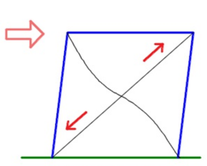
But, even if they are not used as main structure for smaller buildings, we can still find some **common use** of them in the structures.

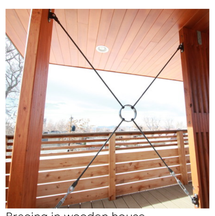
We can also find other ways outside structures, such as in chairs, handrails, hamacs, curtains, shelves, ... and even find some similarities in nature.

Bracing

One of the main use of cable in smaller scale is to help with horizontal forces. For exemple they can be used to complete a framed structure that is not strong enough against horizontal forces, such as wind, car mouvement, ...

They are used quite often thanks to their strenght and ability to be **almost invisble** thanks to their size. If used in front of a window you will not even notice them.





Bracing in wooden house

Overhang

One other great use for cable is to support little overhangs in a building. The most frequent use is for **terraces**.



housing tower: "white tree", Montepellier

Cables are perfect for terraces because once again they are almost invisible and don't stand in the view. They lighten the structure and don't make big hole in the thermal envellope.

One of the main default of a cable for overhang or bracing is that it needs to be in **diagonale** and so can be in the way. Fortunatly it is not a problem in most of the case

Cable supported

The bigger scale buildings can be divided in two categories: cable supported and cable stayed structures. Both categories are mainly used for bridges and roof or floors.

The first one, cable supported structure is where the cable are **effective members** of the structure. They are the main load carryer and transfer the loads they are supporting directly to their anchor.

The cable supported structures can also be divided in two sub-categories: simple suspension and cable net.

Pros

First as we have seen they are an easy solution for covering long distances in a very strong way. They are also kind of cheap.

They are easy to build and easy to unbuild.

Cons

Unfortunatly, they need regular maintenance, and are not good against wind and sismic activity because of their constitution.

One other major inconvenient is that those kind of structure create a lot of horizontal loads that need to be taken care of.

Biggest distance between 2 anchors

Basic materials

Glued laminated wood -> 45m (beam)

Reinforced Concrete -> 90m (beam)

Steel -> 60m (beam)

Cable -> 270m (Ponte tibetano: Sellano)

Simple suspension

Simple suspension structures, as the name let it know are structures where only one suspension is used. The cable is pulled between two anchoring points. Then you can attach the rest of the structure to it.

As this method is mainly between two points, they are an easy solution to build bridges. So much that this kind of structure is the first one that used cable in large scale in history. Even if thanks to the improvent of technologies, simple suspension bridge can now cover way bigger distances.



Han dynasty Bridge: China

The **linearity** of this method makes it difficult to build roofs from it, as roofs needs to cover more a surface than a line. But some exist anyway.



Ponte tibetano: Sellano



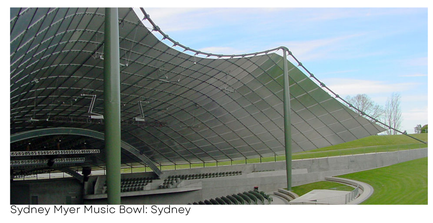
Football stadium: Braga

Cable net

Once again, the name tells everything. A cable net is a **network of cable** criscrossed and combined with other surfaces to protect from the rain or the sun.

This kind of structure is mainly used for roofs because on the contrary of simple suspension, this kind of structure is more of a surface and is not very pratical to connect two points as is supposed to do a bridge. We can even add that as the cables have a funicular shape, using a surface shaped like this is not very useful exept as a roof.

A roof this scale is not so usual, that's why most of these constructions are stadiums or concert hall.



Sydney Myer Music Bowl: Sydney



Olympic stadium: Munich

As we can see they can also take various shapes. Because of the various loads as seen before but also because of the building shape. They can also take other shape like cable truss to be more resistant to loads. A cable net is also a shape that makes structure with cable more resistant

Cable stayed

This second type of big scale structure with cable, the cable stayed structure is different than the first one. This structure support horizontal plane such as the bridge deck or roofs and floor **from above** instead of being part of it.

Thus, the cable are used as tensile structure to transfer the loads from the horizontal plane to the anchorage.

The cable stayed structures can be divided in two sub-categories, the cable stayed and the cable suspended.

Pros

Once again, cable are light, cheap and flexible and strong enough for covering very big distances.

This is why it is often used for big scale roof and nearly always for bridge. They are most often used in bridge because a bridge have most of the time less anchorage on the ground making it the best way to be build.

Thanks to being symmetrical, horizontal loads take care of themselves without need for big reinforcment.

Cons

Unfortunatly they also need regular maintenace and are still not good against wind and sismic activity.

For roofs, another incovenient arise as the cable needs to go trough the etencheity to hold the structure making it more difficult to avoid water infiltration and to insulate.

Biggest distance between 2 anchors

Complex structures

Glued laminated wood -> 107m (ribbed dome)
Reinforced Concrete -> 900m (Huanghe River Bridge)
Truss -> 204m (Schwedler triangulated dome)
Cable -> 2023m (Çanakkale bridge: Turkish)

Cable stayed

A cable stayed structure is a structure that **directly connects** the anchorage and the loads. Thus a lot of cable go from the anchorage to the number of points that needs to be.

Doing this unsymettricaly would result in a very big horizontal load, fortunatly most of the time it is symetrical. Thanks to this, one cable go from one side of the anchor to another and nullify the load.

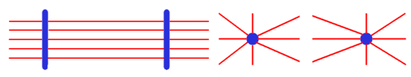


Guadana international bridge: between Spain and Portugal



Daxter Laboratory: Illinois

The system is easy to apply to bridges because they are linear and they can be used for roof in parallel or radial system with the anchorage in the middle to support all the surface.



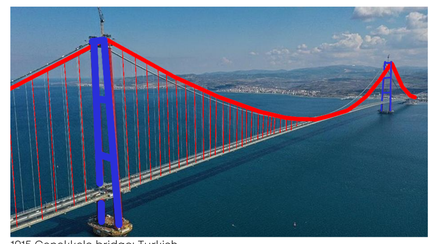
Parallel Radial

Cable suspended

Cable suspended structure on the other hand, Have **one main cable** coming from one anchorage to another and then secondary ones connecting the main one to the horizontal plane.

The main cable is horizontal so he has a funicular shape and the secondary one are vertical so they are linear.

The horizontal loads are also an issue here, but thanks to the way the loads are connected and once again the symettricality, the horizontal loads are minimal.



1915 Çanakkale bridge: Turkish

As this system needs at least two connected anchorage to work, using it for roof is once again a little bit more complicated. But it was used quite often in a parallel system.



Papeterie Burgo: Mantoue

Cables (tension)

Anchor (compression)

Research of tensegrity

Tectonics of cable - Pratical part - Martin Cornille

After analysing how cables works, in my point of view, one thing standed out and I wanted to go deeper and expermitent it. This thing is the **tensegrity.**

This feels so **unnatural and unconventionnal** I wanted to see what it can do. As tensegrity is a structural concept there is multipe ways to explore it. I have divided this structural concept in two main parts and started experimenting

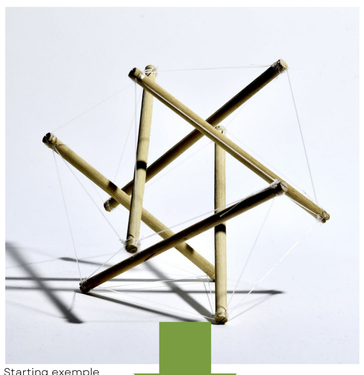
"Simple" compression shape

The first one is simple compression shape, this is not an official name but the way I see it.

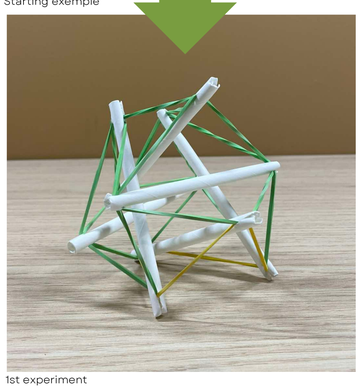
What it means is that the compression part of the tensegrity is only composed of one linear block. And those linear bloc are attached to one another using tensile force.

What is interesting with this is the way to assemble everything and making a complex shape with only simple elements.

As we can see it looks almost like art even tough it's possible to use this type of structure to make actual architecture such as bridge as we have seen in the analytical part.



Starting exemple



1st experiment

"Complex" compression shape

The second one is complex compression shape. Once again this name is not official but felt right to describe this way of using tensegrity.

This time, instead of using a lots of simple element for compression, few big ones are used. Those big elements are most of the time very complex as we can see in the picture at the right.

The main issue with this is that the compression elements are also complex to build as we have strange shapes. And it's also almost impossible to bring this to an actual building scale.

What is interesting is that only few elements are used and the impression of unnatural is very visible.

At the end of these two first experiment I could already drew some **conclusions.**

Firstly, the simple compression shape I build worked immediatly following the steps I found on internet and the result was very strong. To take it further the challenge would be to **expand it** and try different combinaisons.

Secondly, the complex compression shape did not work as exepted and building such complex shape is indeed complex. The challenge here is already to make it work with an unconventional material to use in compression: **paper**.



Starting exemple



1st try of using paper in compression



1st experiment (failure)

From then I wanted to **choose** one of the two possibilities to take it the further I could. I chose the second one as the possibilities of improvement and of research where the most interesting. Especially when I haven't found anywhere this kind of combinaison.

1. Paper in compression

There is multiple enginering offices that are researching paper and origamis because this way of folding a simple piece of paper that is not strong and transforming it into a strong one. This is a very interesting propreties for multiple domain such as spatial exploration and quick and cheap but strong emergency housing.

What we need to achieve in this first part is to turn a flat piece of paper into the strong but complex compression shape we struggled to make in the first experiment.

2. Tries

With these shapes, we can now **assemble** them into tensegrity. Indeed this is the first objective.

Assemble these shapes once again face new challenges. It's hard to even make it work and a final shape that can summarize everything is still not achieved.

3. Final

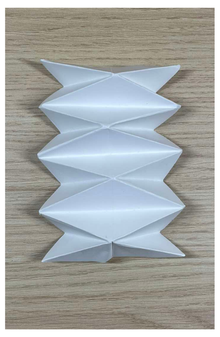
With the experience of the experiment I have now a clear idea of what my final work should lool like.

I believe that this combinaison of elements highlight very well the experiment with the paper as well as the qualities of tensegrity.

Triangles

It's well known that triangles are interesting shapes specially structurally speaking. Thus this was my first thought that ended up in the shape we have seen in the first experiment.

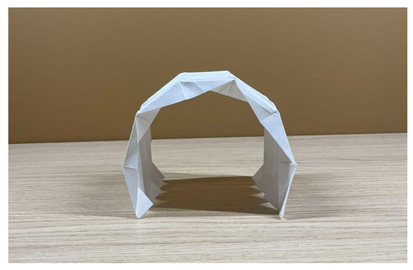




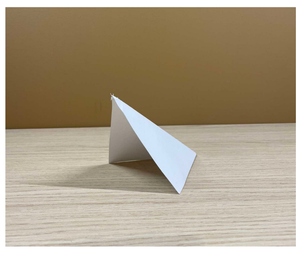
By looking deeper into it, we can **combine** triangles instead of working with one or two. In the pictures above we can see simple combinaison of triangles but this easy combinaison is already making paper way stronger against compression.

3D

Now the challenge is to transform what we just learned into a big complex shape. The way of folding paper can transform a flat piece of paper into a kind of demi-cylender type of shape that once against work very nicely in compression.

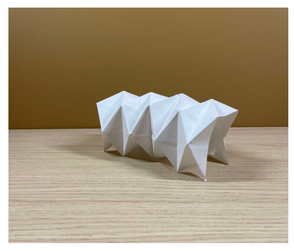


This shape is perfect for what we are trying to achieve, so from there I've tried multiple sizes of paper and triangles to figure out what which one would be the best.









Folding



To make such 3D shape you must start folding in colomns, row and diagonales.

The proportion between base and high of the triangles define the angle in wich the final shape will be folded into (in the Z axis).

It's interesting to see the way a flat piece of paper can turn into a 3D shape.

For this first experiment with the combinaison of all elements, I tried to stay simple with not too many part and tried to make it the strongest possible.



This model is still very lacky as the model did not reach the qualities expected. The lightness of paper made it hard to work as a conter-lever. The cables where also difficult to work with at this scale.

At this point, I believe that the only difficulties are human factor and I just need to be more precise and plan a bit more thanks to the experience I gain to make it work.

At first I wanted to use another quality of paper and make the whole experiment easily foldable and unfoldable. Unfortunatly it's probably manageable but i did not suceed in that task.

Even tough, The whole model was made from 4 pieces of paper and some srtrings. Those materials can take very little place and their expension is very impressive. The whole can still be assembled and dissassembled with just a little more work.

The final shape try to highlight the fact that the different pieces of paper **do not touch** and can still go up in an uninstinctive way.

I believe that the experiment is a succes but could have been taken even further. The model show the strentghs of the experiment but also some weaknesses.

Conclusion

The research about paper was very successfull and I believe there is a lot more to learn. This material can do so many thing and take so many shapes.

On the other hand the starting point of this research is still lacking, as I had a lot of difficulties to make the model work together and it even broke afterwards making me change my plan for something a little smaller for the final model.

The picture shown at the left worked but somehow some changes made the balance break and I struggled to build it again. Thus, the smaller model is gonna show the qualities as well and be stronger but is also the proof that these kind of tensegrity is very fragile. (or is so complex that it's so hard to make it work).