Concept for lightweight structures using climbing/caving equipment

Davor Andrić*, Zorana Protić†, Dunja Mandić§

* University of Zagreb
Faculty of Architecture
Kačićeva 26
10000, Zagreb, Croatia
e-mail: dandric@arhitekt.hr, web page: http://www.arhitekt.unizg.hr

† University of Zagreb
Faculty of Architecture
Kačićeva 26
10000, Zagreb, Croatia
e-mail: zprotic@arhitekt.hr, web page: http://www.arhitekt.unizg.hr

§ University of Zagreb
Faculty of Architecture
Kačićeva 26
10000, Zagreb, Croatia
e-mail: dmandic@arhitekt.hr, web page: http://www.arhitekt.unizg.hr

Key words: lightweight structures, extreme conditions, caving/climbing equipment.

Summary

Speleologists explore many underground objects in remote, wild and karst areas of Croatia. Approach to some of the most important objects, like the ones in the Crnopac area (Mt. Velebit range), is very difficult. Camp locations can be equipped with structures that serve for resting, crossing or working. Same applies to some underground locations. In order to form such spaces for outdoor activities one must use materials found on sight and ones brought on foot. Structures should be collapsible and mobile so that they can be easily stored or moved to another location. Materials carried on foot need to be lightweight. inflatable tubes can be used as compression elements for the structure and ropes as tension elements. Structure should be adaptable to various site configurations. Concept is based on pneumatic tubes, ropes, meshes, tent wings, hooks, spits, and other similar caving and climbing equipment. Geometry of the structure and the amount of used material depend on the type of used equipment, knots and anchorage.
1 INTRODUCTION

Crnopac, an area on the southern part of Velebit mountain range, is one of the most important locations in Croatia for speleological exploration. The biggest pit system of Kita Gacešina - Draženova puha jka is the main underground object for speleological research. Many other objects like Muda Labudova pit and Munžaba pit are also being explored. Plethora of large and small objects scattered across wild karst terrain of Crnopac is usually hard and difficult to approach.

Authors of this article were intrigued by the idea and possibility of organizing a speleology camp open to non speleologists as well. In order to envision this idea, different concepts for contemporary, temporary and semi-permanent structures are to be considered.

Article investigates possibilities of combining a contemporary pneumatic lightweight structural element with caving/climbing equipment.

2 CONTEXT

Crnopac is a vast area with irregular terrain morphology. Location is extremely inaccessible. It is rich with augmented karst forms (cliffs, vertical rocks, sinkholes...) and has two different climatic regions. Southern side has less vegetation more sunny days with less snow and rainfall while northern and central parts are covered with beech and coniferous forests with less sunny days and more snow and rainfall. Winters are harsh with Bura wind blowing with great intensity. Summers are hot and dry while Jugo wind that blows from south can get very strong. There is almost no drinking water, except rainwater or drain water in some sinkholes.

Crnopac massif covers an area of approximately 35 km2. It is a morphologically fragmented plateau which extends to the average height of 900-1100 m while some parts are even higher. Croatian cavers in the Crnopac area have found and explored more than 150 caves. Most of the Crnopac massif is built of carbonate breccias dating from Tertiary age. [1]

This area is mostly covered with fir and beech forests and belongs to the so called Dinaric fir-beech forests. [2] Fir (Abies pectinata) can reach up to 40 meters high and 1.5 meter trunk diameter. It is an evergreen tree with narrow tree top and straight branches which grow in whorls around the tree’s trunk to form a pyramid-like shape. It is light and soft, low on flexural strength and torsion. Beech (Fagus sylvatica) grows up to 40 meters in height and has a long and clean trunk which can be over 1 meter in diameter at breast height. It is hard and elastic, resistant to tension, bending, pressure and impact. It is a deciduous tree with rounded tree top.

Speleological activities on Crnopac can be divided into 3 categories: stay, work and infrastructure. Stay needs are mostly met by sleeping in tents or in the open and resting and gathering around the fire under the tent wing. Many forms of structures can be created by using tent wings and ropes. For widening the spectrum of possible structures for forming a protective space for outdoor stay an introduction of a new element is needed. Work is usually done underground or on vertical rocks. A person needs to be minimally loaded in order to operate
optimally. Infrastructure implies some crossing structures, rainfall collection devices, platforms for storing food... Since some places are narrow and difficult to cross a passage mitigating structure might come in handy.

![Image](image1.jpg)

**Figure 1:** Topology, underground objects and speleologist carrying equipment. (Foto: Ante Sušić, Dalibor Jirkal)

One of the main problems for erecting temporary structures in Crnopac is transport. Transport is mainly done on foot. Therefore, the structure needs to be as lightweight as possible.

In general, elements for generating temporary structures could be divided into three categories:

- natural structural elements
- structurally applicable equipment
- nonstructural elements and equipment.

Natural structural elements are mainly rocks and trees. They serve as part of structure or as natural anchorage. Load bearing capacity of a natural anchorage can not be reliably determined on the spot, but just assumed as fit or unreliable. Branches should be used with care as an anchorage. Artificial anchorage is formed by drilling the spit into a rock. It has a load bearing capacity of about 2 Tons. Structurally applicable equipment gurt/slings serve for connecting parts, and connecting the structure to a natural anchorage.

![Image](image2.jpg)

**Figure 2:** Equipment: ropes, gurts, carabiners, bags... (Foto: Dalibor Jirkal, Ante Sušić)
Carabiners serve as connecting parts. They have certified load bearing capacity of about 2 Tons longitudinally and about 1 Ton transversally. Ropes serve as tension members for the structure. They also stabilise the structure by restraining its deformations. Since static ropes are used for speleological purposes they will be used for structure as well. Ropes are made of polyamide and they have two layers: core and protective skin. It is sensitive to mechanical damaging but if used correctly it can withstand high loads. Minimal nominal load capacity for static ropes is 1,5 Tones. Real capacity falls drastically when using climbing devices (sometime down to 600 kilos).[3] They are usually 9-11,5 mm thick and 30+ m long. In relation to rope lengths our tube should be shorter. Thinner ropes are used as well but they are usually 6 mm in diameter and 5 m in length. There are several knots that can be used for forming the structure. Nets, though rarely used by speleologists, can be used as infill supporting layer... Parts for the structure are of different qualities and capacities which is shown in table 1.

<table>
<thead>
<tr>
<th>NATURAL</th>
<th>Capacity</th>
<th>Reliability</th>
<th>Adaptability</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>rock</td>
<td>high</td>
<td>high</td>
<td>low</td>
<td>none</td>
</tr>
<tr>
<td>tree (beech)</td>
<td>high</td>
<td>high</td>
<td>low</td>
<td>none</td>
</tr>
<tr>
<td>branch (beech)</td>
<td>middle</td>
<td>middle</td>
<td>middle</td>
<td>none</td>
</tr>
<tr>
<td>EQUIPMENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gurt</td>
<td>middle</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>rope</td>
<td>middle</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>carabiner</td>
<td>middle</td>
<td>high</td>
<td>middle</td>
<td>high</td>
</tr>
<tr>
<td>OTHER</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>net</td>
<td>low</td>
<td>low</td>
<td>middle</td>
<td>high</td>
</tr>
<tr>
<td>tarpaulin</td>
<td>low</td>
<td>low</td>
<td>middle</td>
<td>high</td>
</tr>
<tr>
<td>tent wing</td>
<td>low</td>
<td>low</td>
<td>middle</td>
<td>high</td>
</tr>
</tbody>
</table>

Table 1: Structural elements and their assumed properties

In terms of capacity, levels are determined in relation to certified load bearing capacities of standard caving equipment which is around 2 Tons of weight that could be applied to an element. Most of the equipment parts are products certified to this load capacity. In relation to this, beech tree trunks and rocks are of greater capacity.

Reliability is given in relation to some usual scenarios of failure. By far, nets, tarpaulin and tent wings are the least reliable to human and wind actions.

Adaptability is a property of geometry and form customisation, while mobility factor is related to ease of transport.
3 THE TUBE

Most inflatable structures that are used for shelters, rafts, boats, load bearing arches or lightweight plane wings etc. usually consist of tubes (in this case) or other inflatable shapes made with membranes composed of one, two or several layers. Choice of layers depends on the type of their usage, possible damage and other factors. Recently more studies have been done for developing lighter materials and inflatable structures for spaceflight but these materials may not be commercially available yet.

Simple structures with no complex requirements mostly use one layer membranes. Whenever high strength and high resistance inflatable elements are needed additional inner and outer coatings are added. Characteristics of each membrane derive from combination of these layers. The basis of an inflatable load bearing tube will usually be a fabric or a foil with an inside bladder. Bladder expands while fabric holds. Outer coating is added to protect against UV rays, moisture, fire, chemicals, abrasion, tearing, ripping etc. Depending on the coating material, bladder can be omitted if the outer coating provides airtightness.

Woven or braided fabrics serve as reinforcement for inflatable tubes. Yarn is made of continuous fibers mostly made of nylon, polyester, taffeta as well as high performance fibers such as liquid crystal polymer, para-aramid synthetic fiber or other synthetic fiber materials alone or in blends with cotton or other natural fibers. Neoprene is mostly used as inner coating when the outer coating is omitted or when fabric membrane can’t provide sufficient airtightness.
Protective outside coating is chosen depending on the usage of an inflatable tube. Materials such as polyethylene synthetic rubber (as a lighter and stronger alternative to some other materials), PVC, polyurethane or vinyl are used. [5]

Tube membrane and net material selection for this inflatable tube will mostly depend on its weight, elasticity, warp and weft strength, tear, rip and abrasion resistance as well as pliability and flexibility to prevent damage during packing, storage and handling.

In relation to the groups of structural elements mentioned in table 1, inflatable tube of medium to low capacity and high adaptability and mobility is proposed.

<table>
<thead>
<tr>
<th></th>
<th>Capacity</th>
<th>Reliability</th>
<th>Adaptability</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>TUBE</td>
<td>low/middle</td>
<td>middle</td>
<td>high</td>
<td>middle/high</td>
</tr>
</tbody>
</table>

Table 2: Target properties of the Tube element in relation to elements in table 1

Tube has a layered structure with an addition of perforated layer or net to provide attachment places for connecting other elements. Additional local protection of the tube against tear and puncture is gained by putting ends in a transport bag or attaching a transport bag as a damage protective layer - technique similar to protecting ropes from rubbing against a sharp rock.

Proposed introduced structural element is a pneumatic tube made 25 cm in diameter and 15 meters in length. By attaching various elements like ropes, carabiners, or sticks and rods variety of forms can be made and additional local rigidity and stability assured. Level of inflation regulates the rigidity and geometry of the structural element.

**Morphogenic potential**

Concept is examined in context of needs, micro locations and use provided by its morphogenic possibilities as a part of structure made as a combination of various elements. By folding a tube on the ground and laying over a net or tarpaulin sleeping above the ground is achieved which is useful if the ground is uneven or prickly. If a tube is suspended on a tree trunk it can form a tent in the air for places that don’t have enough flat surface for raising tents. If there are no trees around, tube can be bent and twisted to form a supporting arch or series of arches or spatial pretzel like structure to carry the roof cover made of flexible membrane. Furthermore, crossings can be formed by suspending one or a series of tubes on tyrolean ropes. Almost an infinite field of possible combinations using the tube with other natural elements and equipment.
Figure 4: Structural schemes using proposed pneumatic tube: planar, spatial and linear. (Renderings: D. Andrić)

4 CONCLUSION

Caving equipment is made of smart and robust materials with good load bearing capacity and reliability. In difficult terrains their weight to load capacity ratio is of great importance. A lightweight multipurpose structural element like pneumatic tube with high flexibility and durability ensures higher quality of structural forms for hosting a large spectrum of activities in the open as well as underground. Tube has a high morphogenic potential in terms of possible geometries that can be formed by folding, curving, and suspending and combining it with natural elements and caving equipment.

This is a topic for future research, analysis and design. Precise geometry, and material composition as well as fabrication and field tests of the prototype are yet to be evaluated.
REFERENCES


