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Anchoring emergency lightweight shelters

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Abstract

Field tests have been conducted to address the question: 'what are the major aspects to consider using anchors in the humanitarian sector?'. Influence of soil, weather, type and combination of anchors, installation, orientation, inclination, depth, displacement and price have been measured. An extensive study of anchor usage, practice recommendations with step by step checklists and a handout for humanitarian field practitioners is provided to identify the best anchoring option for their context of intervention.

Keywords: soil anchors, emergency shelters, tents

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1. Introduction

Anchors and foundations play an essential role in the structure of emergency shelters. A failure of the anchors can be the first in a series of dramatic ones. Its undesirable consequences are either the shelter being blown away by the wind as ground resistance is lost or the shelter collapses due to loss of structural stability. Good anchoring is a prerequisite to reach the effective shelter lifetime, and it is relevant to economic and effective material usage, because within the family tent ridge-2015 it accounts for a significant percentage of the total mass.

Soil anchors have been extensively investigated and documented for permanent and heavy applications. They involve frequently the consumption of concrete and, therefore, cannot be considered light, neither recoverable nor sustainable. On the other hand, available data on anchors for emergency shelters and tents is commercial, scarce, dispersed and insufficient.

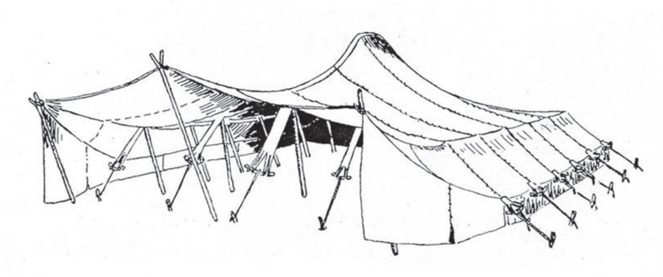
This anchoring study starts from the specific requirements of emergency lightweight shelters and tents formulated by the International Federation of Red Cross and Red Crescent Societies - Shelter Research Unit (IFRC-SRU), with the overall objective of contributing to the reduction of shelter related vulnerabilities that put the inhabitants' lives at risks.

Field tests on 18 commercial anchors of three types (pegs, screws and buried anchors) have been conducted in five different soils measuring forces and displacements. The anchors were selected according to their appropriateness for emergency shelters and availability. A total of 66 suppliers were contacted, 37 anchors were received, out of which 18 were finally chosen.

2. Antecedents

Antecedents of passive anchors can be found in Nature. Roots feed plants and provide uplift resistance against the wind **involving a volume of soil** (fig.01). Stakes have been used for anchoring tents like the Bedouin tent (fig.02), the Tabernacle, the military tents or the circus tent.

Sea anchors attach the ships to the sea bed. A high efficiency ratio is needed in order to withstand heavy loads with minimum self-weight. Metal flukes bury themselves in the soft bottom or hook on to rocks. They are installed from a long distance through the chain that attaches it to the mooring vessel. They are recoverable breaking them out of the bottom by shortening the rode until the vessel is directly above the anchor.

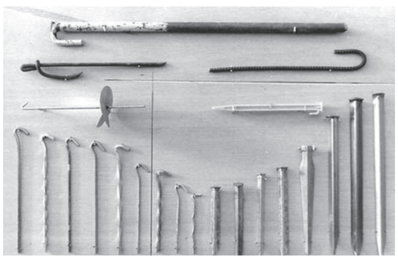


Figures 1,2: Antecedents of anchoring shelters can be found in Nature and vernacular architecture.

More recent examples are the anchors for bridges, mobile homes, antennas, poles, transmission towers, pipelines, buried tanks, equipment, runways, agricultural installations and cattle.

3. Typology

Soil anchors can be active or passive. Active anchors are prestressed by initially tensioning against a steel bearing plate. The level of prestress is a percentage of the design-working load. When the prestressed anchor is externally loaded, it behaves as a much stiffer member than a dead anchor. Passive anchors act only against the soil when loaded. They move more than active anchors, but they are simpler and involve fewer problems of relaxation and durability. They can be subdivided into two main groups according to whether they reach the surface of the ground or are buried.



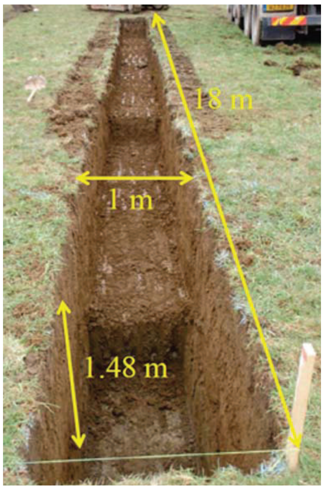
Figures 3, 4, 5: Pegs, screw anchor and arrowhead anchor (percussion-driven).

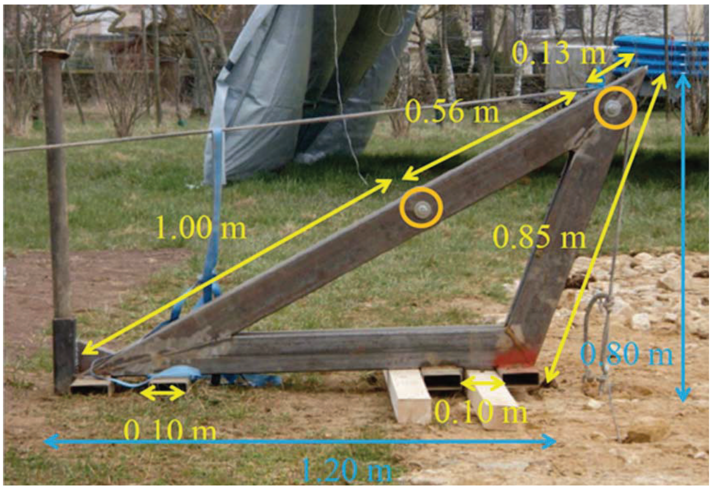
Anchors reaching the surface are mostly pegs (fig.03), also called stakes: various profiles include round, flat, V-shaped or T-shaped. Most common materials are metal, plastic and wood. Force is essentially transferred by compressing the soil. Another type of anchor that can reach the surface or be buried is the ballast anchor. It is generally made of a heavy material such as concrete, earth or water and uses its own weight. If the ballast anchor is buried, the friction surface is bigger and the anchor is stronger.

Two other types of buried anchors are the screw anchors (fig.04) or helical anchors and the percussion-driven anchor (fig.05). The screw anchor consists of a rod with a helix straddling or in some cases of a body in the form of a helix itself. It is inserted into the soil just as a screw and use the surfaces of the helix in order to create resistance by compression of the soil above. The percussion-driven anchor (or mechanical anchors) is composed of a base attached to a cable called tendon. Similarly to the screw anchor, it uses the surface of the buried and armed base to create resistance by compression.

4. Field tests. Equipment

In order to obtain useful data inputs for the identification of important aspects, a series of test was conducted. The materials used include:





Figures 6: Soil trench. Figure 7: Pulling system

a) Pulling system composed of a steel cable, a motorized winch and a triangular steel construction to control the angle of pull (fig.07).

b) Measuring system: dynamometer.

c) Four soil trenches, dimensions ℓ=18, w=0.8 and h=0.6 to 1.5m were filled with different kinds of soils, compacted in layers of 30cm (fig.06). These soils were chosen in order to create a representative diversity (sand, silt, rocky sand and clay rocky sand). A fifth sample was provided by the original natural soil (clay + sand).

d) 18 Anchors belonging to three categories: 8 pegs, 3 screws and 7 percussion-driven ones (see annex for more details). A total of 66 suppliers were contacted, 37 anchors were received, out of which 18 were finally selected for the final test sets.

5. Field tests. Procedure

Similarly, to wind loads applying punctually, the test was conducted by activating the winch step by step, hereby pulling each time a bit more on the anchor. Each time, the displacement of the anchor in the direction of the pull and the forces were measured and written down. The obtained data resulted in two outputs: the maximum performance for a displacement lower or equal to 5 cm (+/- 1) and the absolute maximum performance measured independently from the displacement. Preliminary tests were carried out to determine the relevant effects of inclination and position. The reference IFRC-SRU 2018 includes a complete description.

6. Field tests. Results

A detailed exposition can be found at IFRC-SRU, 2018. Most important findings concern to:

- **Weather** exists under the ground too. Different performances have been measured depending on temperature and precipitation.

- **Limit states**. Two outputs were obtained with the tests: the overall peak performance without constraints and the peak performance reached with a constraint, a displacement limit of 5 cm (+/-1). Big differences between the values, were sometimes observed. Pegs and screws show a difference smaller than 3 times while percussion-driven anchors can reach as much as 8. Thus, percussion-driven anchors can need substantially more displacement before reaching their maximum capacity.

- **Maximum resistance**. The highest resistances were observed for percussion-driven anchors. Independently of the soil, the strongest anchors always reach 6 kN and in some cases the output was higher than 12 kN. For the case of screw anchors, forces measured were considerably lower: for all compatible soils, the most performing anchor reaches 3 kN in all of them. For pegs, only one model in one soil reaches the 3 kN threshold.

- **Incompatibilities**. Observed incompatibilities were screw anchors in ‘Gravel-Sand’ and ‘Silt’ and the biggest percussion-driven anchors in ‘silt’ and ‘rocky-sand’ soil.

- Ease of use. Pegs and screw anchors are relatively easy to set up. The only drawback which applies, especially for pegs is the hazard risk once installed (for instance with children playing). Therefore, sharp ends should be removed in pegs design. For percussion-driven anchors, the situation is clearly different: the arming process is a fundamental step which needs special skills. As it takes place invisibly, skilled experience is needed to correctly estimate whether the correct position is reached.

- Removability, reusability. For pegs and screw anchors, removal is rather easy. For pegs, pulling on the axis is generally sufficient as resistance is weaker in that setting. For screws, repeating the set-up instructions in the opposite order is sufficient and if the anchor is not damaged, it can be reused for future endeavors. For percussion-driven anchors, removal is only possible using a shovel if the soil allows burying but it is very time-intensive. Therefore, percussion-driven anchors should be perceived as single-use. A wrong placed percussion-driven anchor becomes a spilled anchor. (Percussion-driven anchors with a second rope for disarming and removal are not recommended for use in the humanitarian sector as inverting the ropes can have dramatic consequences).

- Warning indicators. In the case of screw and peg anchors, upward movements have a clear and strong visual impact, even if the displacement is only of a few centimeters. Strengthening measures must be taken urgently if anchors slide out. For percussion-driven anchors, the indicator is much subtler as only the distance between the eye-loop and the soil can serve as such. Regular measuring and recording is necessary.

- Price is not a reliable indicator. The ratio between price and performance is not stable. Two anchors of the same type and with the same price can show significant differences in terms of performance.

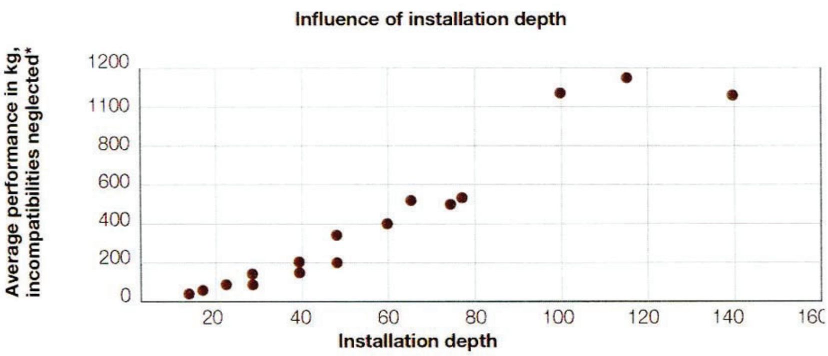


Figure 8: Depth increases performance independently of the type. In opposition to the unit price, a clear link does exist between the average performance and the depth of the 18 tested anchors.

- **X-crossing pegs is a limited improvement**. The resistance of three anchors, one being the peg itself and the other two creating additional resistance, is 10% higher than the one of a single peg.

- **Combination of pegs**. In order to increase forces, pegs can be combined by connecting several of them to the same guy rope. As, the same soil might be compressed twice, the force transferred per peg decreases.

- **Combination of percussion-driven anchors**. The resistance of combined percussion-driven anchors increases but the ratio overall peak performance without constraints / peak performance reached with a displacement limit of 5 cm is unstable.

7. Recommendations, observations and comments

1 Don't take any risks if shelters cannot be strengthened. The consequences of dismounting for a few days are much smaller than the ones of unusable or blown away shelters.
2 Forces applying to the shelter are highly dependent on the exact situation and shelter.
3 Wind speed is different from wind pressure, one of the forces impacting buildings.
4 Even after completion, weather conditions need to be monitored. If those ones become higher than the one structures are designed for, measures need to be taken.
5 The differences between the types of anchors are fairly big and need to be taken into account.
6 Instructions about how to use the anchors should always be distributed with the products.
7 If percussion-driven anchors are chosen, special attention should be paid to the arming process.
8 If the force is pulling in a different direction than the axis of resistance, the anchor might loosen the guy rope by moving. This is a risk to be considered beforehand.
9 Pegs use compression to transfer horizontal forces and friction to transfer vertical ones.
10 Screws and percussion driven anchors use both friction and compression in the same axis.
11 Always attach the rope as close as possible to the ground as this reduces the force applying to the anchor.
12 An anchor which is difficult to insert into the ground indicates a ground which is more difficult to compact and finally, a bigger resistance.
13 Anchors which do not reach their intended implementation depth are considerably weaker.
14 Check regularly anchors after installation and correct them if necessary. If an anchor cannot be fully inserted, attach the rope at the bottom, close to the soil.
15 Two types of soil are never 100% identical: different contexts = different soils = different anchor performances.

16 Don't trust previous experiences when using pegs. A peg which worked in the same location a few years ago will not necessarily work in that location again.
17 When identifying a location, cross-checking at different depths and at different points is necessary. A few meters are sufficient to change the type of soil.
18 Even once identified, the performance of an anchor can change as it is impacted by external influences (i.e. humidity variations).
19 Screw anchors are better suited for vertical than for diagonal pull.
20 Pegs were observed working best when implemented vertically into the soil. However, a guy rope pulling in the axis of the peg should always be avoided. Therefore, if the angle between the guy rope and the soil is smaller than 45°, the angle should always be installed vertically. Correct installation increases the performance by approximately 20%.
21 V and T-sections showed best performances when used with the sharp side pointing in the direction of the tent/guy rope. Correct usage increases the performance by approximately 20%. Together with the correct inclination, approximately 45% more resistance can be obtained.
22 The climatic context has a major impact on the anchor performances. Depending on the day, the performances of an anchor in a given soil can be different.
23 Depending on the type of anchors and soils, displacements bigger than 5 cm (+/- 1) might be required before reaching the full potential of the anchor (the maximum resistance). This is especially the case for percussion-driven anchors.
24 The best test performances are reached by percussion-driven anchors, followed by screw ones and pegs.
25 Pegs were found compatible with all tested soils and show best results in 'clay sand' and 'rock sand'.
26 All tested screw anchors and some big percussion-driven anchors cannot be installed with human force in 'silt' and 'rocky sand' soils.
27 All tested screw anchors loose resistance in sand soils.
28 Tested percussion-driven anchors which can be implemented with human force in 'Silt' and 'Rocky sand' show best performances in this type of soil.
29 Percussion-driven are the most complicated to install. Especially the arming process which takes place invisibly requires trained people.
30 Percussion-driven anchors are generally of single use as removal is very time-intensive if not impossible (need to dig). Therefore, an implemented anchor cannot be corrected (i.e. moved).
31 Pegs and screw anchors are easier to set up and to reuse. Also, displacements which should warn people are easier to perceive.
32 Hazard risk for beneficiaries (i.e. playing children) should be minimized by avoiding sharp ends.

33 The price of an anchor is not a reliable indicator. Performance is clearly influenced by other factors.
34 Depth is a reliable indicator: independently of the type of anchor, performance will increase with increasing depth.
35 Pegs perform better if combined as active ones rather than as x-crossing.
36 Combining percussion-driven anchors is also an option to increase resistance.
37 When choosing an anchor, one should not only bear the soil and weather conditions but also the installation procedure in mind. Who is going to install the anchors in the soil? If the answer to this question is unsure, choose an anchor which is easy to install. Otherwise, the risk of wrong installation increases.
38 Furthermore, it was noticed that one can increase the performance of anchors by either combining them or using longer models. However, simply buying a more expensive anchor is not recommended.
39 Many other alternative approaches exist. The ones discussed in this part are only examples to illustrate possible strategies.
40 Sometimes, alternatives require extensive research before becoming applicable. Examples are the durability of buried wood and textiles. The lifetime of anchors should in fact exceed the one of the building itself.
41 Inspiration can often be gathered from related fields. For instance, sheet piling within earth engineering can give ideas for combinable anchors.

8. Alternative approaches

1 Appropriate tools of other uses. This first approach was tested during the test sets. It is a screw tool (hand auger) used by gardeners to make holes. This one was inserted into the soil and reached a considerable maximum value of 512 kg for a displacement of 5cm(+/-1) and an absolute maximum resistance of 1500kg. This shows that product being designed for a different purpose can very effectively be used as anchors, sometimes even showing better results than specifically designed anchors themselves.

2 Local practices. Vernacular architecture. Nomad populations exist or existed in many regions of the world. As their buildings are lightweight and temporary, they have been confronted to similar challenges. In fact, some groups use interesting alternatives. Bedouins for instance use local bush vegetation which they dig into the sand before attaching the guy rope. This shows that knowledge of local and nomad populations can be of major interest. Means to identify those practices include not only members of the practicing groups but also local populations, publications, archives, etc.

3 Use local resources. Textile earth bags, **rocks, refilled oil barrels, cars, trucks, car tires, wheels, etc**. Before using this method, further studies concerning its influence on the soil and the environment are needed (influence on vegetation, humidity and textiles). Also, the durability of several types of textile should be explored to choose the most appropriate one.

9. Conclusion table

Comparison of the different anchor options considering technical and practical aspects.

		Pegs	**Screws**	**Percussion driven**	**Ballast anchor (*)**
					
Technical aspects	**Resistances observed**	Low	Medium	High	
	Difficult soils	None	Hard and compact soils		None
	Combinations	Possible	With a reduction of performance per unit		Possible
Practical aspects	**Extra material**	Hammer	Bar	Hammer and bar	Bag or container
	Instructions	Instruction manual		Skilled people	Instruction manual
	Time of installation	Very little time	Little time	Some more time	Little time
	Monitoring	Visual inspection		Inspection + measuring + recording	Visual inspection
Balance	**Performance**	Limited resistance		Highest resistances	
	Complexity	Ease of installation		Complex	Easy

(*) Ballast anchors were not tested. They are included as a reference due to their simplicity, compatibility and performance.

10 Annex. Tested anchors.

Supplier	Model	Family	Weight (N)	Dimension (mm)	Installation depth (cm)	Unit price(*)
Delta Ground Anchors	Plastic stake	Peg	0,48	155	15	1.86
IFRC catalogue	Family tent stake	Peg	1,43	220	18	0.39
	Family tent stake	Peg	2,82	280	24	0.6
	Family tent stake	Peg	4,00	350	30	1.06
	Multipurpose tent stake	Peg	4,85	510	50	1.55
SRU	Prototype	Peg	3,15	350	30	1.3
Toughstake	Sand/Snow stake 3	Peg	1,98	444	40	40
Vortex	Yard anchor	Peg	0,20	150	15	1.75
Anchor System	Auger 40	Screw	13,10	600	50	Not provided
Shelter Logic	Shelter auger 30	Screw	7,00	762	60	5
Vortex	Spiral anchor 16	Screw	7,75	400	40	13.97
Duckbill	68-D8D	Percussion driven	0,92	68	75	5.72
	MR4	Percussion driven	5,00	138	140	20.7
Milspec Anchors	Arrowhead 3	Percussion driven	2,38	75	78	3.1
	Arrowhead 6	Percussion driven	7,07	150	115	18.2
Platipus	Platipus S2	Percussion driven	0,50	70	50	2.96
	Platipus S4	Percussion driven	1,80	121	67.5	4.75
	Platipus S6	Percussion driven	5,30	171	100	9.87

(*) US $ - Nov.2016

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