“Anchor Analyzer” Simulation Software

Presented by:

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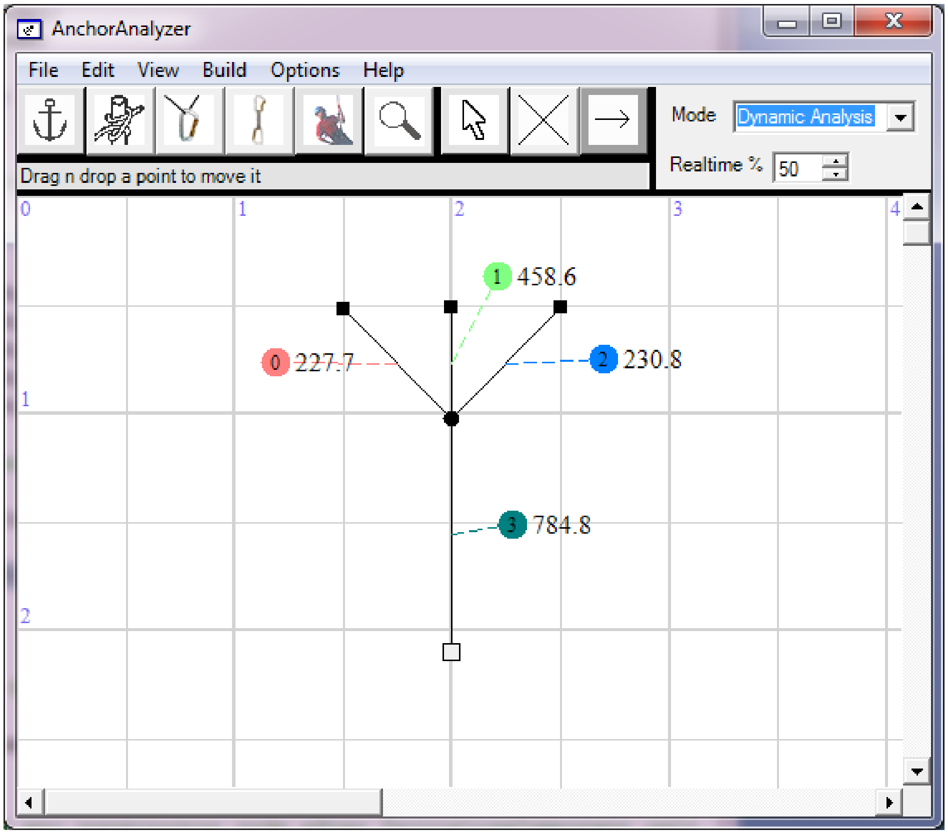


Drag n drop a point to move it

Mode Dynamic Analysis

Realtime % 50

Inland Northwest Search and Rescue

Introduction

AnchorAnalyzer is a PC based software application that simulates the static and dynamic behavior of protection systems used in technical rescue and recreational climbing. It can be used as an effective visualization tool in the hands of a qualified instructor, but it should not be used to design anchor systems due to inaccuracies introduced by its simplified models.

The user draws the topology of a protection system on a graphical user interface (GUI), and specifies the materials used. The mouse is then used to alter the direction of pull in static simulations, or to raise and drop a load in dynamic simulations. Force vs. time on all tethers can be displayed graphically.

How to Specify an Anchor System

Anchor systems are typically composed of a wide variety of tether materials, carabiners, protection, etc. You need to boil that down to the primitive elements supported by this program. Any rope, accessory cord, sling, or webbing should be modeled as a *tether*. Protection should be modeled as *anchor points* since they should never move due to a load. Carabiners and pulleys that slide on tethers should be modeled as *sliding points*. Other hardware and knots that tie tethers together should be modeled as *tie points*. A load is oddly enough a *load point*.

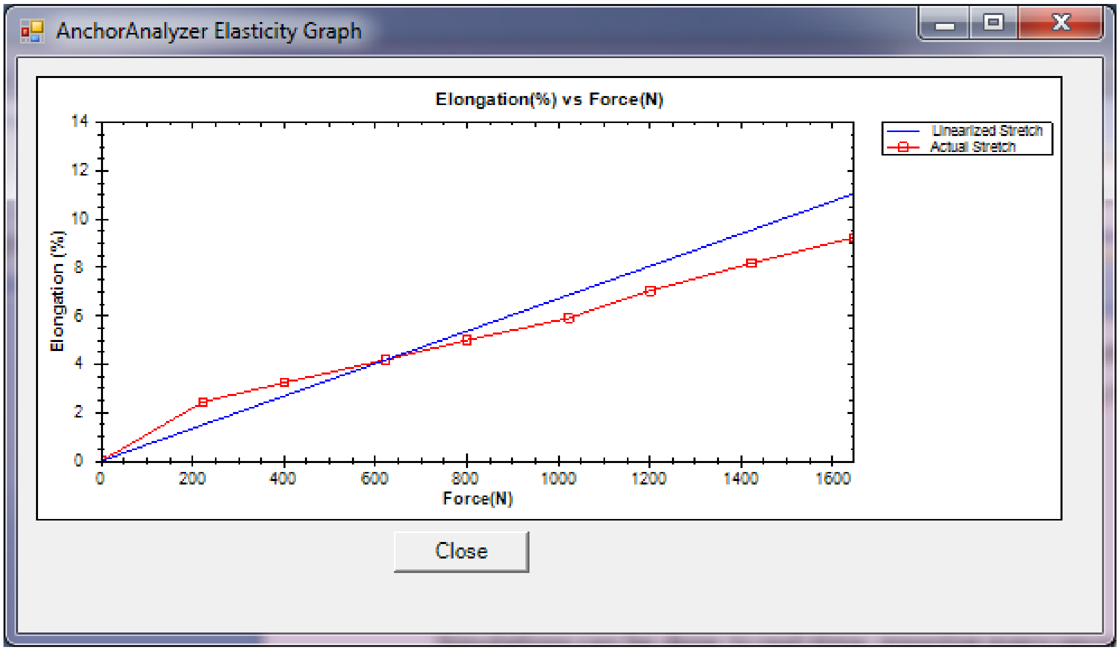
The specifics of any primitive element are configurable after the element is placed on the screen. For example, you can specify that a tether is composed of 7mm perlon, a sliding point has a particular coefficient of friction, or a load point has a certain mass.

The actual mechanics of how to enter this information using the GUI will not be included in this paper. This will be covered in the presentation, and a help system is available if you are interested in using the tool.

Features

Elasticity Models

The elasticities of tether materials typically used in recreational climbing and technical rescues are not linear. Here is a plot of the elasticity of 7 mm perlon. Both the actual measured stretch is shown, as well as a linearized estimation.

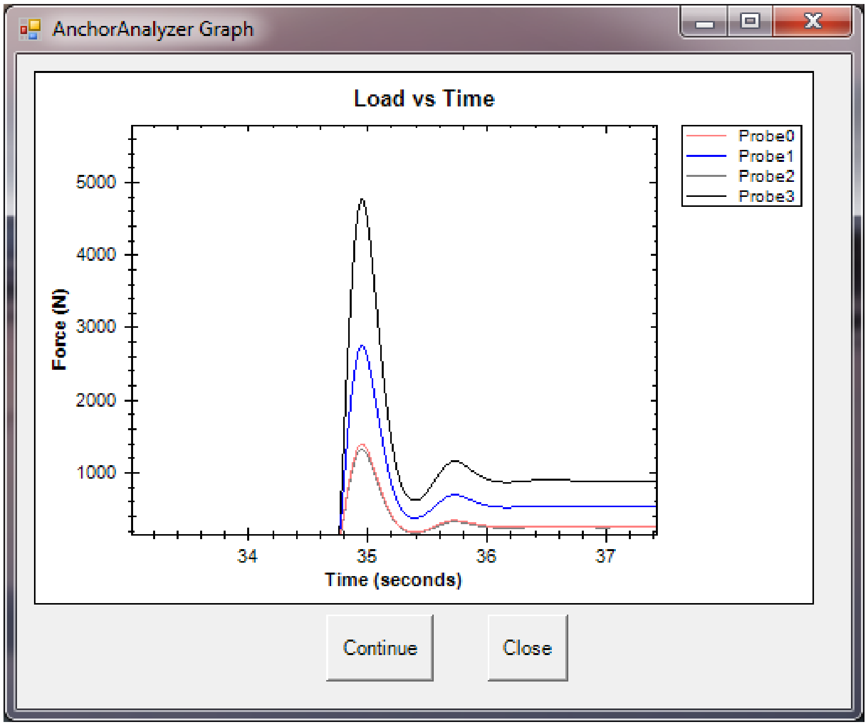


The most accurate simulations should be obtained when you use actual measurements of elasticity.

The linearized estimation can be used to demonstrate the effects of the topology on an anchor system. For example, the screen dump on page 1 is of an anchor system simulated using a linearized elasticity model. The ~2:1 ratio of forces on the center vs. outer legs reflects only the effects of the legs’ angles and lengths in this topology. It should be stressed that use of a linearized elasticity model can lead to very large errors in the simulated forces from what would be expected in the actual anchor system.

Graphing

Any set of tethers can be added to a graph showing tension over time. Here is an example graph of the cordelette anchor system shown on page 1 undergoing a fall factor 1 fall, simulated using a linearized elasticity model. This is constructed using 7 mm perlon for the legs of the anchor system, and 10.5mm dynamic rope. The user specifies the color of each probe when it is placed, and this color is also used in the graph.



Warped Time

Simulations can be done in real-time, meaning every second of simulation corresponds to a second in the life of the anchor system. However, this is often too fast to see what's happening, so the user can warp time by slowing down the simulation up to 10x.

Pre-tensioning

AnchorAnalzyer allows you to change the length of tethers after the system has been constructed. This allows you to effectively pre-tension one leg of a system, or add slack to it.

Evaluating the Behavior of Anchor Failures

At any point in time the user can delete an anchor point and watch what happens to the system.

Algorithms Used

You can learn a lot from even the simplest model. AnchorAnalyzer ignores some of the 2nd and 3rd order contributors including for example knot slippage, mass of the tethers, etc. Instead it focuses on the primary contributors: mass of the load, elasticity of the tethers, and friction of the sliding points.

The Physics

Simple physics is employed:

- Newton's First Law: every body remains in a state of rest or uniform motion (constant velocity) unless it is acted upon by an external unbalanced force.
- Newton's Second Law: a body of mass *m* subject to a force *F* undergoes an acceleration *a* that has the same direction as the force and a magnitude that is directly proportional to the force and inversely proportional to the mass, i.e., ***F*** = *m**a***.
- Capstan Equation: A sliding point won't slide until $T_1/T_2 > e^{\mu\beta}$. This is used in the simulation of sliding points.

The trick is to determine with acceptable accuracy the forces on each point created by gravity, friction, and the tension of each tether connected to it.

Dampening

When a tether is stretched under tension it does not necessarily return to its original length when the tension is released. Most tether materials used in anchor systems display this hysteresis due to the slippage of its individual fibers across each other as the rope is stretched, and the friction between the fibers keeps them from sliding back to their original position once tension is released [1]. This hysteresis converts the stored energy into heat, which dampens out the oscillations that would otherwise be present. AnchorAnalyzer does not currently simulate hysteresis in a tether's elasticity. Instead, dampening elements are used on each tether to absorb energy, but they are applied only when a tether's elongation is shrinking. This means that the behaviors of the initial fall, and hence the maximum force experienced by the system, are not affected.

Accuracy Analysis

No claims are made regarding the accuracy of AnchorAnalyzer.

No testing has been done to verify its accuracy.

AnchorAnalyzer does seem to be fairly representative, though. A simulated FF1 fall on the dynamic rope in its database results in a UIAA impact force of 7 kN compared to the typical UIAA rating of around 8. This error is not unreasonable since its elasticities are extrapolated from crudely measured data.

Sensitivity of the Impact Force Due to Errors in the Modulus of Elasticity

Fortunately, the impact force isn't nearly as sensitive to errors in the modulus of elasticity as one might assume.

The equation for the impact force of a fall assuming a linear spring model [2], is

$$(1)\quad F = mg + \sqrt{(mg)^2 + 2kmgR}$$

where m is the mass of the load, g is the acceleration of gravity, k is the modulus of elasticity of the rope, and R is the fall factor.

Differentiating over k,

$$(2)\quad \frac{dF}{dk} = \frac{mgR}{\sqrt{(mg)^2 + 2kmgR}}$$

And the percentage error in F due to a percentage error in k would then be

$$(3)\quad \frac{\%\ error\ in\ F}{\%\ error\ in\ k} = \frac{dF}{dk} \times \frac{k}{F}$$

Assuming a typical impact force UIAA specification ($R = 1.78$, $m = 80\ kg$) of 8 kN for dynamic ropes, equation (1) requires that $k \cong 18.4$. Therefore,

$$\frac{dF}{dk} \cong 0.194$$

$$\frac{\%error\ in\ F}{\%error\ in\ k} \cong 0.446$$

The percent error of the impact force should be a little less than half the percentage error in our estimate of the modulus of elasticity of the dynamic rope.

If we instead use a material with a high modulus of elasticity such as a dyneema sling, the results are similar. Based on a recent report from DMM [3], a FF1 fall on an open dyneema sling produced an impact force of approximately 22 kN, resulting in

$$\frac{\%error\ in\ F}{\%error\ in\ k} \cong 0.426$$

It should also be noted that the user can customize the materials database used by AnchorAnalyzer by editing the config.xml file. The web is full of instructions on how to edit XML files, and the format is quite simple. See the embedded help capability for more information.

Potential Uses of Anchor Analyzer

Education

AnchorAnalyzer can be a very effective educational tool in the hands of a qualified instructor. Its graphing features, static and dynamic simulation, linearized vs. actual elasticity models, and ability to warp time can help students visualize an anchor system's behavior.

Research

Why did the research community believe for so long that the cordelette was a good equalizing anchor? I would suggest that the effects of a tether's non-linearity were not obvious. Running random experiments takes way too much time and money, so AnchorAnalyzer could be used to help identify experiments with more interesting potential.

Limitations and Opportunities for Further Work

Hysteresis Instead of Artificial Dampeners

Artificial dampeners are used instead of hysteresis, but they can cause instabilities with short tether lengths. Simulation of the actual hysteresis would hopefully eliminate this issue.

Dynamics of Sliding Points

The capstan equation, $T_1/T_2 > e^{\mu\beta}$, defines when a sliding point starts to slide. It does not tell us the dynamics of the slide, though. The author is currently looking for help to understand the physics behind this motion.

Fuse Elements

It would be very nice to be able to specify the force that would cause a particular anchor point to fail. When this force occurs, the component would be deleted, and the rest of the anchor system would take the load. This would help determine if the other components truly are redundant, or if the failure of one could potentially result in the failure of another. Furthermore, this would enable the simulation of the energy absorption that occurs when one or more anchor points fail. This would be a simple addition to AnchorAnalyzer.

Belay Slip

Belay slip could be added to AnchorAnalyzer to simulate its effects on impact forces.

Additions to the Materials Database

Although the user can add materials to the database by editing the config.xml file, it would handy to have more built into the tool. Data from manufacturers would be very much appreciated.

Availability

There are no plans to offer AnchorAnalyzer commercially. It will hopefully be available from the MRA’s website, http://www.mra.org, in the members-only section by the time ITRS 2010 occurs.

Other means of providing the program with limited liability will be seriously entertained.

References

[1] Banfield, S., and Flory, J, “Computer Modeling of Large, High-Performance Fiber Rope Properties”, *Oceans '95*, San Diego, October 9-12, 1995.

[2] Goldstone, R., “The Standard Equation for Impact Force”, pulled from http://www.rockclimbing.com/cgi-bin/forum/gforum.cgi?do=post_attachment;postatt_id=746 on Sept 21, 2010.

[3] DMM, “How to Break Nylon & Dyneema® Slings”, pulled from http://www.dmmclimbing.com/news.asp?nid=293&ngroup=1 on Sept 21, 2010.

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