Cave Survey – Using Tape / Disto and Instruments

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Overview

This document was originally (and still is) intended for those new to cave survey, but has also evolved into a fairly comprehensive reference of best-in-class practices and tips & tricks for international cave survey. As always, theoretical knowledge is not complete without actual practice and feedback from experienced cavers, and no claim is made as to completeness or this being the only way of doing things right. For feedback or questions, contact David Ochel at mailto:do@ochel.net.

When surveying a cave, you always measure between two established (and somehow marked/flagged) survey stations, in order to create a basic line plot. This is a *survey shot*. It involves choosing and labeling stations (*setting points* or *being on point*) and measuring the distance between those stations, as well as measuring the compass direction (*azimuth*) and vertical angle (*inclination*) from one to the next station. The primary objective of this work is to support a *sketcher*, who will take your measurements, plot them in a survey book (*the book*), and make a scaled drawing of the passage around it. This can then be taken out of the cave to generate an accurate map (and other information).

Assignments in a survey team may vary. Typically, one person *does tape* (also referred to as *lead tape*) – setting points and having one end of the tape – while a second person reads instruments and measures azimuth and inclination for each shot. A third person is the sketcher on a team, which requires training and practice (and, in larger projects, meeting specified criteria) going beyond what is being described in this text. It is possible to do a survey with only two people, in which case one person will both *do book* and hold one end of the tape, and the second person *does instruments*. More variations are possible, and larger projects often have additional tasks (such as, conducting a cave resource inventory) going beyond what is covered here.

Setting stations and measuring distance

As the person on point, you are in charge of choosing suitable survey stations. That means that you are also responsible for knowing enough about the cave ahead of you to choose the best place for the next station, for being aware of any possible side-leads that might hide behind a boulder or in the ceiling, or for finding a way through a breakdown maze. (There is a nuanced balance, though, between checking ahead in order to be able to set stations, and *scooping passage* – exploring it without surveying it.) Some projects will have specific standards for how to set stations best in order to represent passage in a certain way, but apart from that, the following points should be observed:

- A free line of sight between two stations is required. Measuring *through* obstacles or bending the tape around obstacles between two stations should be a VERY rare exception. And if you do it more than once a year, dark clouds will follow you around.

- If you are having trouble finding a new station with line of sight to the last one, have the instrument person place their main light on the old station and wiggle it around toward the area where you want to place the new station. Any surface illuminated by their light will have line of sight.
- Long shots are not always the best. Put stations at intersections, so that the survey can continue down all passages. If you shoot past intersections, don't be surprised if the sketcher calls you back to re-do the shot. If in doubt, ask: "There is a small side-lead to the left over here that pinches out after 2 meters, do you want me to set a station here?"
- Put stations in places that the instrument person can reach and read from. Consider the size of the instrument reader, setting a station too tall for them to reach, or in too small of a hole for them to access, will cause discourse in your friendship with them. Likewise, avoid putting stations on the floor or high point of the ceiling, as it's difficult to get accurate clino readings from these positions.
- If you are on a two person survey team, it helps to set stations on rocks or ledges where the sketcher can put their station light down and have their hands free to continue sketching while you are reading instruments to that station.
- Marking stations: Most larger projects have standards on how to mark stations. For example, with flagging tape close to the station, and a dot of marker or fingernail polish on the rock for the exact spot. Other projects don't (permanently) mark stations because of conservation concerns. In general, not permanently marking stations in larger caves and cave systems seems a bad idea, since it will be hard to tie in later discoveries into the existing survey. In wet caves, if your project permanently marks stations, try to set stations above the flood level so they will still be there after the next (big) rain event. In extreme cases, you may want to drill a hole at important stations to mark them permanently.

The basic devices to measure the distance between survey stations are measuring tapes, often on spools with a length of 30 or 50 meters (or the equivalent in feet), and more recently in environments that don't require lots of swimming, laser range finders (*distos*). Here are some tips about using them:

- Be sure you are using the right units. If in doubt, ask: "Are we surveying in metric or feet today?"
- When surveying in metric: Read meters and centimeters.
    - Correct: 2.21 m is "two point two one meters".
    - Wrong: 2.01 is not "two point one" (it's "two point zero one"), and 2.20 is not "two point two" (it's "two point two zero").
- When using a tape:
    - Check where the tape begins, every time. Usually, the end of the metallic tip, not the beginning of the actual tape, is zero. This is not always the case, especially with cheap tapes.
    - Make sure the tape is pulled taut and doesn't touch any obstacles, see above. (Don't overextend it or pull it apart either, though.)
    - Be careful about tapes that have metric readings on one and English ones on the other side of the tape – don't mix them up during the survey.
    - If the tape is not long enough, set an intermediary station. Being creative in extending it is sometimes an option if you can be sure that it won't degrade the accuracy, such as using a piece of accessory cord or rope and measuring its distance.
- When using a disto:

- Be aware that their distance is limited, often about 15 m, unless you pay more money for longer-reaching ones.
- Before taking a disto caving, compare a couple of disto readings with an actual tape measurement before relying on the disto's accuracy.
- Note that "zero" typically starts at the end of the disto, not at the top where the laser sits. (Some distos can be configured either way!)
- Some distos provide readings to the millimeter (the third digit). There is usually no point in recording millimeters in cave surveys - round them up or down when providing the number to the sketcher. (1.114 becomes 1.11; 1.117 becomes 1.12.)
- Do NOT point the disto at another person without warning, the laser can cause permanent eye damage. It is good practice to announce it to the group before you turn it on, so that they can be sure not to look in your direction: "Laser!" (Which is best done in a super-evil voice. ;-))
- It is more accurate and a bit faster if you have a target to shoot – for example, the instrument person's hand next to the station, an inventory book, etc. It also helps to illuminate the target a little bit. (But not so much that the laser point can't be seen on it anymore.)
- Measure distances at least twice when using a disto in the cave survey. It is very fast, and prevents errors from shaky hands. Brace the disto against the wall for stability, then take a deep breath and hold it to be less shaky.

Left-right-up-downs (LRUDs)

Some cartographers and/or projects (and/or sketchers) expect the survey team to record LRUDs – left-right-up-down readings – for every survey station. Often, it is the tape person that provides these readings, but sometimes somebody else in the team will do it.

Always clarify what the exact expectations are; typically, this means looking from the current station toward the general direction of the survey (or toward the next station) and then providing the size of the passage from that perspective, either perpendicular to the station, or at a line that bisects the from and to station angle. But does that mean that if you are reading from the top of a one-meter stalagmite in the middle of the passage, the "down" reading should be zero or one meter?

General Notes on Instruments

Cave surveys require precision survey instruments – compass and inclinometer (*clino*). Most often, you will run into instruments made by Suunto or Brunton. You need instruments with an eyepiece – non-precision instruments (such as backpacking compasses) do not usually meet the accuracy needs of a cave survey.

Here are some general points on using instruments, and the following sections will deal with particular aspects of compasses and clinos, respectively. Let's start with some notes on scales:

- Survey instruments typically have multiple scales. Always make sure you are using the right one – there is nothing shameful about taking a moment to double-check, unless you are using instruments 365 days a year. Compasses usually have a *foresight* and *backsight* scale. (See below for more on the concept of backsights.) Clinos often provide percentage gradients in addition to the inclination in degrees that is useful to cave surveyors.

- If you buy any instruments, make sure you buy them with the correct scales. Not all are the same! Compass should be 0 to 360 degrees, not in 90 degree quadrants. Clino should have a scale that reads from -90 to +90 degrees.
- Precision instruments can/should be read to the half (.5) degree.

When shooting stations, you should be aware of these aspects:

- Although the manufacturer instructions tell you to use both eyes when reading an instrument (one looking through the eyepiece to read the scale, the other focusing on the target), many cavers use one eye (other eye closed) in order to avoid parallax issues, which can introduce errors especially over shorter distances.

  Here is what the Suunto manuals say about this: "The axes of the eyes of some people are not parallel, a condition called heterophoria. This can even vary in time and be dependent on different factors too. Therefore, in order to be sure that said phenomenon does not affect the accuracy of readings, it is suggested that the operator checks this possibility before taking the actual readings as follows: Take a reading with both eyes open and then close the free eye. If the reading does not change appreciably there is no disalignment of the eye axes, and both eyes can be kept open. Should there be a difference in the readings, one has to keep the other eye closed and to sight partly past the instrument body making use of the optical illusions whereby the hairline continues past the instrument body and is seen against the target."

  Also, tilting your head to sight along awkward stations can induce errors when using both eyes. Be consistent whether using one eye or both.
- In dark environments (caves), the person at the target point will typically put a *station light* on the station to allow the person reading instruments to focus on the target. Not blinding the latter by directing bright lights toward their face while they read instruments also helps. A different color LED will help the instrument reader to distinguish the station light from your headlamp; alternatively, turn your headlamp off to avoid confusion.
- The instrument person will also need a light in order to illuminate the scale of the instrument. It is often helpful to have a light that is separate from your regular headlamp, many people carry a station light that serves the double-purpose of being their instrument light as well.
- When reading a compass or clino, you will ideally line up three points with each other: the hairline in the instrument, and the two stations you are reading to and from. You then read the degrees off your scale at the hairline. As you can imagine, that requires being behind the station. Depending on how well the stations are set, this may sometimes turn out to be awkward – you may have to lay down in the mud, cling to a rock, or whatever else it requires. Such is the life of a cave surveyor.
- If you have difficulties getting a free line of sight from your station to the target station, you can move the instrument above or below, or to the right or left of, the station and ask the person holding the station light to move the station light for the same distance in the same direction. Doing this (and setting stations that require doing this) should be an exception and not the rule, though.
- Reading instruments both forward and backward (reading *backsights* in addition to *foresights*) is often used to increase a survey's accuracy. Usually, this involves having two persons equipped with instruments, and one of them reading from the previous to the next station (foresights), and the other person shooting the backsights the other way. Some projects or sketchers will define the deviation they are willing to accept between foresights and backsights, for example a maximum of two degrees difference. Some projects will also require the *calibration* of instruments (technically, of the combination of instruments and the cavers reading them ;-)) before each survey – reading foresights

and backsights between two fixed points in both directions by both instrument persons and recording the results on a cover sheet provided for that purpose.

- Even if a survey doesn't require both foresights and backsights, backsight shots are a possibility. If it is easier to read from the "new" station to the "old" station, do it – it will increase the accuracy of your numbers! Make sure to tell your sketcher that you are reading backwards, and/or ask them whether they want you to give them the corrected numbers. (In case of inclination, correcting numbers means a plus instead of a minus and vice versa; in case of the azimuth – at least when using Suunto compasses – that means using the small top numbers instead of the large bottom numbers on the scale).

Instrument Troubleshooting:

- If the scale appears out of focus, instruments sometimes have an adjustable "eye piece" that can be screwed out or in a little to adjust focus. (It can also be completely taken off the instrument in order to let it dry.)
- Any instrument can get damaged. Water leaks inside can make them too foggy to read, or they might begin to stick with age and/or get an air bubble that interferes with reading them accurately. If it is obvious that an instrument is not functioning correctly, stop the survey.

Compass Readings

The amount of horizontal degrees from one to another station read on a compass is called an azimuth.

- The azimuth is ideally read standing behind the station so you can line both stations up with the hairline in your compass. A less preferred alternative is to read it from somewhere exactly above or below the station. The worst option is to line up in front of the "from" station, but it's better than nothing. In any case, think a virtual line going through the two stations and read the compass either in front of or behind your stations **on** (or exactly above or below) this virtual line. For those that are geometrically inclined, all you have to do is make sure that you are in the same vertical plane as is created by drawing a line through both points and extending it infinitely up and down. However, the farther you get from the station, the harder it is to estimate that you are in the correct position. Try to stay close to the station. (For example, don't stand above a station on the floor.) To attain some survey standards, you need to read from within 10cm of the station. A backsight shot is always an alternative, if that gets you in a better position.
- The compass must always be held level in order for the dial to be able to rotate. This makes high angle shots difficult to read. In that case, it sometimes helps to pull the tape between the stations and then line the compass up with the tape and read that. (See also the section on Minus Ninety below.)
- Human pitfall #1: As just pointed out, the compass dial **must** rotate freely. If the compass body is held at an angle, the compass dial will jam and give bogus numbers. How to avoid this: Measure twice, and wiggle the compass in between measurements. Turn your head back and forth while sighting and see that the compass dial moves freely back and forth.
- Magnetic pitfall #1: Your headlamp (or any separate light you use for reading the instrument), when turned on, may create a magnetic field that causes the compass needle to deviate from the magnetic north. Check this before starting the survey! To do so, place the compass on a level surface. Place your light close to the compass and slowly move it back and forth, watching to see if the capsule moves. Try it with the light on and with the light off.
- Magnetic pitfall #2: Metal near your station (such as bolts or your rappel rack) may deflect the compass needle.

Clino Readings

The inclination between two stations represents the vertical angle of a line going through those two stations. Here are some tips on how to use your clino to read it:

- Inclination is ideally read by standing immediately behind the station. If that's not possible, be careful to not only maintain the same height as the station, but also the same distance to the target as if you were exactly at the station. As above, try to stay within 10 cm of the station, as the farther you get from it the harder it is to gauge your relative position. Or consider a backsight shot (see above).
- Inclination is always positive or negative. An inclination of +32° is "plus thirty two", not "thirty two".
- Instruments sometimes have one of various "other" scales in addition to the 0-90 degree scale that you want. The degree scale is usually on the left, but if in doubt, check before you start the survey or when reading numbers. If you forget, point the clino straight down and use the side that reads -90.
- When having a small degree of inclination, always double-check whether you are reading a positive or negative inclination. The easiest way to check this is to look at the numbers on the right and see if the negative or plus sign is there.
- It's in the nature of inclination that when you are reading negative inclination (target station is lower than your station) and you are close to (like three tick marks above) the 20° mark, the inclination is **minus** 23°, and when you are reading positive inclination and you are three tick marks above the 20° mark**,** it's **plus** 17°. Or is it the other way around? ;-) Always be aware of this.

Minus Ninety

Reading a compass on a steep inclination (think a pit or steep slope in a cave) is a pain, since you have to keep the compass dial level to allow it to freely rotate. As a result, those readings are often inaccurate.

In the case of steep angles, it is always favorable to find two stations that are exactly on top of each other, and shooting a *Minus Ninety*:

- The inclination from the higher to the lower station in this case is always, who would have thought, minus 90°, and the azimuth is always, surprisingly, somewhere between 0° and 360° (recorded as 0°). No need to read instruments, just measure the distance! Use the tape, weighting the end with a carabiner (or some such) as a plum, to ensure that you have a straight vertical line between the two points.
- In this situation, we have a problem with distos! You can't be sure of your plumb line without a guideline, such as a tape with a karabiner clipped to it to pull it straight. Of course, if you are carrying a tape as a backup, you can use that.
- Do not use rope length when measuring a plumb. Rope stretches and it will give an inaccurate length. For pits that are much deeper than your survey tape, you can use fishing line or kite string.

Special Cases

Swimming Passage

- The upstream surveyor should hold the tape reel in case the end of the tape is dropped. In fast flowing water (cascades, not canals), once the instrument reader lets go of the end of the tape, it will be swept quickly downstream faster than it can be reeled in. If the tape reel is upstream, then this is not a problem. If the tape reel is downstream, the tape can get wrapped around stuff under water.

Sometimes it will get stuck too deep underwater to fix, or in dangerous areas of rapids, and you'll have to cut the tape.

- For long lakes, it's not necessary to take a clino reading. Survey to a fixed distance above the water surface at the start and end of the lake, then assume that the water surface is level.
- For canals, choose stations with nearby handholds – you will need something to hold onto when pulling the survey tape out of the water.
- A loop of bungee on your helmet can be used to keep the instruments out of the water while you swim.
- Be careful to avoid tangling the survey tape around your legs while swimming. Be prepared to drop/cut the tape if this happens.

Vertical Caves

- When reading the compass, make sure you are far enough away from any metal such as bolts and your SRT kit.
- The upper surveyor should keep the tape reel in case the end of the tape is dropped.
- Plumbs (minus nineties) are preferable to high-angle legs, but sometimes it's not quite possible to get two stations to line up exactly vertically on the wall. In these cases, if the shaft is slightly overhung, first do a plumb from the upper station to a point in space near the wall. Then have the lower surveyor do a very short horizontal leg from the point in space to a point on the wall, taking compass and clino readings, and using the free end of the tape to measure the distance. This only works if the lower surveyor can reach both the wall and the bottom of the plumb at the same time.

Survey Organization

Here are some notes on streamlining the organization of a survey team:

- The sketcher is the person "in charge" of the survey. You will usually learn quickly (or can always ask) if they want to go into a specific direction, prefer *long* over *short shots*, expect you to go and explore or wait for instructions, etc. Don't be offended or ashamed if they ask you to check out certain things, re-read your instruments because the original readings seem wrong on their line plot, etc. Errors happen in a survey, inevitably, and it is much better to catch them in the cave rather than later on.
- The sketcher is usually also the slowest person on the team, because they have a lot to do. Help the sketcher by giving them information about the passage, such as: "There are 2 leads at station 10 – one is a horizontal crawl that goes at least 2 meters, the other is a dome that pinches out after 4 meters." Always tell your sketcher the stations that you are reading and the order (for example, "station AB twenty to AB twenty-one"). If you are reading instruments and your memory allows, it also helps to read both azimuth and inclination before giving the numbers to the sketcher as one piece of information, instead of distracting the sketcher twice to record those two numbers. Likewise, give all the LRUDS at once. Lastly, it helps to always give the data to the sketcher in the same order, such as distance – azimuth – inclination (and left – up – right – down for LRUDs).
- Sketchers should always read your numbers back to you – listen and make sure it matches what you measured. Do NOT take the next measurement until the sketcher has confirmed your last set of numbers, as they may not have heard you, or may have twisted them in their mind while writing them down (321 instead of 231, for example).
- Think about the order in which you do things. For example, if you are setting point it may be more efficient to hold the light on the station for the instrument reader before reeling in the tape. That way

the sketcher can plot the leg sooner rather than later – don't keep the sketcher waiting for numbers. Likewise, if you are waiting for your turn to read backsights, get ready by taking off your gloves, getting the instruments out, etc.

- Some sketchers like to leave the survey tape on the ground between stations as an aid to orienting their sketch. Ask your sketcher what they prefer and don't reel in the tape until they're ready.
- The whole team is responsible for safety, just like normal caving. If someone is cold or tired, it may be time to end the survey for the day.

Caring for Survey Equipment

- If your instruments fog up due to changes in temperature, place them down your shirt to warm up.
- If your instruments get very wet use body heat (put them in your sleeping bag overnight) or desiccants (e.g., place them in a container with rice) to help dry them out.
- It is easy to puncture the glass over the capsule on many survey instruments. Be particularly careful when going through squeezes, crawls, and popcorn. Either pass the instruments, or put them inside your cave suit with the glass side facing your chest.
- In very muddy passages, mud may clog the rollers of your survey tape. Abrasion may destroy the tape rollers or even wear off the numbers. Clean the rollers regularly while waiting for other members of your team to do their jobs.

References

- BCRA Survey Grades – http://bcra.org.uk/surveying/index.html