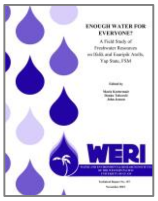

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IFALIK ATOLL

Elevation Measurement 2015

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Benchmark

First of all we tried to find the benchmark reported by Tracey *et al*. (1961). Failing to identify the exact location of the previously established benchmark, a new benchmark was established in front of the island's main Man's House, right on the spot where the benchmark described by Tracey *et al*. (1961) was supposed to be, *i.e*. on a limestone block embedded in the ground ca. 5 m west from the southern frontal post of the Men's House. The flattest part of the block was further leveled with a chisel and a cement ca. 8 cm x 12 cm platform was made on top. Until the elevation relative with the mean sea level would be established (after the tide measurements finished), the arbitrary elevation "0" was designated to this benchmark.

Location (in WGS 1984): 144.454498177º E, 7.24953218131º N

Methodology

Differential leveling was used to measure the elevation of the selected points. A measuring staff is first placed on the point with the known elevation ("backsight") and the level instrument is placed at the midpoint between the point with the known elevation and the point with the unknown elevation to be measured ("foresight)". The level instrument is then leveled so that its level of sight (laser beam in our case) is perfectly horizontal. The reading of the value on the staff at the level of sight is then recorded. Next, the staff is placed on the point to be measured. The level instrument is rotated towards the staff so that it stays leveled at the same horizontal level, and the value on the staff at the instrument's level of sight is recorded. The difference between the two recorded values on the staff is the elevation difference between the two measured points.

Laser differential level with an auto-leveling system ("Margie's level")

For the purpose of measuring the elevations of the observation wells, a borrowed laser differential level with an auto-leveling system and a laser reader was firstly used. The level instrument has two sets of specially designed rechargeable Ni-MH batteries and its mounted on a robust tripod. After turning it on, the instruments levels itself automatically into a perfectly horizontal level and a laser beam starts spinning at high speed covering the whole 360° area (searching for the target, *i.e*. the laser reader). The laser reader mounted on the measuring staff needs to be slid up and down the staff until it is in the level of sight of the level instrument; when hit by the laser beam it makes a signal. The value on the staff at which the laser reader is hit by the laser is then recorded. The specified precision of the instrument is ±3 mm, but needs to be checked and the instrument calibrated if necessary.

Self-assembled leveling setup

As an alternative to the laser differential level, an attempt was made to use a conventional pocket-size laser meter (Tuirel T100) as a laser source mounted on a camera tripod. Both were equipped with a spirit level (bubble level) and thus allowing leveling of the laser meter into horizontal position. The tripod had a rotable mount, which permitted pointing the laser from “backsight” to “foresight” station. Once leveled, the laser was pointed towards the measuring staff and the value hit by the laser beam recorded.

Considerable problems were encountered with the compatibility of the tripod with the laser meter and needed to be solved in the field. Wobbling as well as keeping the laser meter horizontal while rotating were the major challenges. Washers and silicon were used to fix the wobbling.

Measurement

Using laser differential level with an auto-leveling system (“Margie’s level”)

Firstly, the observational well closest to the coast was measured. The level, however, ceased to function immediately after the measurement. The cause seemed to be an old and weak battery set of which one would not respond to the charger at all. After an 8-hour charging period (as suggested by the manual), the battery fully charged although its power dropped rather quickly after the level being used. However, even with the battery fully charged, the laser beam did not work. During consecutive trials of resetting the level’s computer and switching the level off an back on after longer spans of time, the laser occasionally turned on for short periods. Not enough, however, for performing measurements.

Measuring-accuracy testing of the self-assembled leveling setup and the attempted measurement

The accuracy of the provisional differential leveling setup was tested by using it to measure the elevation of the observational well previously measured by the laser differential level. The difference between the measurements was 4 cm, way to high for the required and aimed sub-centimeter accuracy.

Because the actual accuracy of the laser differential level was not actually tested and just assumed, the resulting 4 cm difference in measurement could have been also due to the inaccuracy of the laser differential level. Hence, the accuracy of the provisional level was rechecked independently. Initially, we would try to measure two points on the presumably flat concrete floor surrounding the school building. If the measurement was accurate, there should be no difference between the two points. The floor, however, proved to be fairly uneven or pending. Therefore a more time-consuming test method that involves reverse measuring the elevation difference of two distant points in several steps. Such method gives not only an estimate of the error of a single measurement but a resulting total error of several measurements.

For the purpose, we measured the elevation difference between the benchmark in front of the Men’s House and the school concrete platform surrounding the school and also did the reverse measurement (between the school to the benchmark). Since the school is located half-way to one of the observational wells, the measured elevation of the measuring could be continued from the measured school's concrete platform in case the accuracy had proven to be good enough.

The distance between the level and the measuring staff of individual measurements was between ca. 7-10 m as measured by the distance laser meter. If the method and the surveying were accurate, the arbitrarily established elevation of the initial point (benchmark) measured from the end point (school platform) should be the same. Instead, the measured elevation differed by 4.5 cm (Attachment A).

In spite of the low estimated accuracy, it was still valuable to try to measure the elevation difference between the tide gauge and the closest well. Given the short distance between the well and the gauge, the error summing would be theoretically avoided and the measurement would give a rough estimate of the water elevation in the well in respect with the sea level. Although with the given accuracy, negative values could have been obtained. Nevertheless, an attempt was made. Due to sunny weather and the measuring area being out of the canopy (*i.e.,* the coast), the major problem resulted to be finding the laser spot on the measuring staff. With several attempts to walk along the laser beam trajectory in order to properly adjust it to hit the measuring staff, the efforts were finally abandoned and the measurement postponed to twilight time. During the transport of the equipment however, the laser meter got detached from the tripod mount and fell into seawater and got permanently broken.

Concluding Remarks

Comparison of the used equipment

Auto-leveling laser differential level:
Advantages:
- auto-leveling system assures:
  - rapid measurements;
  - high precision/accuracy;
  - the precision/accuracy is constant (*e.g.*, does not depend on level of tiredness of the surveyor);
- laser reader makes measurements possible in all light conditions.

Disadvantages:
- bulky and heavy;
- high maintenance;
- requires the possibility to charge the batteries of the leveling instrument;
- expensive.

Self-assembled leveling setup:
Advantages:
- light and small (pocket size leveling device);
- standard batteries are easy to replace and extra power supply for charging batteries is hence not required
- cheap

Disadvantages:

a) General for the method:

- time-consuming measurements mainly due to manual leveling (regardless the tripod);
- lower accuracy;
- measurements strongly depend on the surveyor(s) and have hence a relatively high accuracy uncertainty;
- necessity to eye-spot the laser beam dot on the staff limits measurements to low light conditions (dawn/dusk, cloudy weather, areas covered with canopy).

b) Specific for the used setup:

- due to the inadequate tripod it was not possible to keep the leveling device (laser meter) in a horizontal position when rotating the device for 180°, which required re-leveling resulting in decreased accuracy and increased time consumption;
- difficult to precisely level the instrument (tripod issue), which also decreased the accuracy and slowed down the measurements;
- the leveling instrument and tripod mount did not match well, which was the main reason why the instrument detached from the mount and fell into the sea.

Remarks and suggestions

During the survey with the self-assembled leveling setup, a great weakness proved to be the inability to accurately level the laser meter with the given tripod (the rotating mount was the actual problem). The two performed tests suggest an accuracy limit of the method of about ±5 cm. A tripod with a better mount could considerably improve the accuracy of the measurements. The accuracy should be, however, tested between points with well-known elevations (*e.g.*, two high-precision benchmarks or a known perfectly flat surface).

Even though measuring instruments can have high-specified precision, possibly high inaccuracies may result due to multiple intermediate measurements between a benchmark and the point of interest, terrain, and operators. Hence, an accuracy test is still recommended when highly accurate measurements are needed. Suggested would be an elevation measurement between two points of known elevation difference, *e.g.,* two high precision benchmarks. In this regard, it should be noted that most of the benchmarks on Guam have an accuracy of ±10 cm. A set of benchmarks between Pago Bay and WERI have a millimeter accuracy.

The atoll freshwater lens is expected to be really thin and hosted in a highly permeable aquifer, which would result in very small differences in groundwater level compared to the sea level. Consequently, very high elevation accuracy is needed and, therefore, an appropriate surveying equipment and accuracy test measurements are strongly recommended. Taken into consideration the often-rainy weather and in generally wet environment, water-resistant equipment is suggested.

And last but not least, because in areas with a scarce or absent benchmark network, or target points to be measured are possibly quite far apart from each-other and from the existing benchmark(s) or set-up tide gauge, the elevation measurement can be very time consuming. Hence, time constraints on expeditions should be considered when choosing the measuring method. Techniques with self-leveling systems or techniques that do not require leveling would thus be favored (referring also to techniques not mentioned here).

The used laser meter (Tuirel T100) had an inbuilt Pythagorean Theorem mode that would enable vertical measurements. The tests on a vertical wall, however, showed that the measurements were off by 2-3 cm on a short distance such as 2-3 m. Hence, the laser meter was not used for vertical measurements. The reason for such a big error could be the inability to precisely rotate the laser meter from a horizontal to the desired oblique position without a designated tripod mount. The horizontal measurements proved to be within the specified accuracy (± 3 mm).

Literature Cited

Tracey, J.I., Abbott, D.P., Arnow, T., 1961. Natural history of Ifaluk Atoll: Physical environment. Bernice P. Bishop Musem Bulletin 222, 77 p. Honolulu, HI.

Attachment A

Elevation measurement log of the accuracy test

FORWARD				REVERSE		
Station	Staff reading (mm)	**Station elevation (mm)**		**Station**	Staff reading (mm)	**Station elevation (mm)**
Benchmark 0	1315	**0**		**School 5**	1325	215
1	1355	-40		4'	1485	55
Difference	-40			Difference	-160	
1	1635			4'	1400	
2	1345	250		3'	1250	205
Difference	290			Difference	150	
2	1495			3'	1360	
3	1490	255		2'	1335	230
Difference	5			Difference	25	
3	1260			2'	1315	
4	1455	60		1'	1480	65
Difference	-195			Difference	-165	
4	1400			1'	1245	
School 5	1245	215		**Benchmark 0**	1355	**-45**
Difference	155			Difference	-110	

Chart explanation:

Forward – the measurements from the benchmark in front of the main Man's House to the concrete platform surrounding the school.
Reverse – elevation measurements from the concrete platform surrounding the school to the benchmark in front of the main Men's House.
Station – measuring point.
Staff reading – the read value on the staff at the sight level of the level instrument.
Station elevation – the measured elevation of the station, the sum of the elevation of the previous station (grey field) and the *difference* (blue field) .
Difference – the difference between the read value on the staff above the station with the known elevation (backsight) and the read value on the staff above the station with the unknown elevation (foresight); the resulting difference is the difference in elevation between the two stations.
Station elevation – the measured elevation of the station obtained by adding the "*Difference*" to the previous (known) station elevation.

The elevation 0 of the benchmark station is arbitrary.