Submillimeter Array Technical Memorandum

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Testing of Completed Antenna Foundations on Mauna Kea

Introduction

A large number of the completed antenna foundations were tested on December 12 and 13, 1995 for their ability to resist the overturning moments of the antenna. The test was done by placing two electronic levels on the top of the concrete foundations and observing the tilt produced by placing a 1878 Kg (4150 pound) block on the opposite side. The moment induced by this block is about 21100 NM (15,562 foot pounds), almost exactly the moment produced on the antenna by a 14 m/sec wind.

Detecting sub arc second motions is difficult in any circumstances and the environment for making this test is not ideal. The air temperature was close to freezing on both days and accompanied by a brisk wind on the second day. The sun, wind and air temperature combination causes any surface, including the levels, to vary greatly in temperature depending on whether or not even the slightest shadow falls on the device. This can wreak havoc with the readings, as the levels will show a thermal drift in their zero point of about 0.3 arc sec per C. In order to improve the confidence in the data, both levels were always covered and used in parallel so that fictitious readings could be eliminated.

The two-channel data from the electronic levels was read by a lap top computer with an A-D card. The A-D was set to a resolution of 1.2 millivolts and the channels sequentially loaded to memory at a rate of 3 Hz each channel. Since the level calibration is 20.9 arc seconds/volt, this gave us a resolution of about 25 milliarcseconds, although the actual sensitivity was not that high. The fundamental noise in the level readings was of the order of 0.1 arc seconds at the 3 Hz rate, but did smooth to better values over short periods of time roughly consistent with the number of channels averaged. The ability to reliably detect tilts in this condition appeared to be about 0.1 arc seconds, based on repeat tests on the same position and comparisons between the two level readings of the same event. On one occasion it was possible to get a clear reading at better than 0.1 arc sec accuracy, but large temperature drifts in the levels, which occurred many times, could usually have masked a tilt to about this magnitude.

Twelve of the most suspect foundations were tested over the two day period. A list of the results is shown in the following table. All foundations easily exceeded the specification of 0.4 arc seconds tilt and most were below our effective detectivity.

Tabulation of the Results

Foundation #	Direction of loading	Summary of the results
7	E (see p. 4)	no detected movement with excellent noise levels, see following graph
8	E	no detected movement except momentary shock when block dropped
9	N	no detected movement
10	S	no detected movement with excellent noise levels
11	S	no detected movement, see following graph
13	E,S,W,N	Data shows a hint of some rotation of the order of 0.1 to 0.15 arc sec, see graphs
14	E,S,W,N	the foundation is stiff toward the west but shows rotations of the order of 0.2 arc sec in the other three directions, see graphs
15	N, E	no detectable rotation, however noise levels where higher than at most sites, see graph
17	N	no detectable rotation until weight deliberately dropped, see graph
18	S	type II pad, very stable even to dropping the weight, see graph
19	E	no detectable motion
21	E	good noise level with a detection of ~0.08 arcsec tilt, see graph

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Comments

The more interesting records are shown in the following plots. Both the raw 3 Hz readings as well as a running 6 point or 2 second average are often plotted . The raw readings are important because on the more stable pads the brief transient when the block is lowered or lifted is the only way to tell the loading and unloading cycles. The six point smoothing appeared to best bring out the resulting rotation. On the more stable pads we usually set down the weight quickly at least once to be sure we could later identify the two cases. In one instance, foundation 17, this drop was quite hard and actually appeared to shift the entire pad by about 0.4 - 0.5 arc seconds. We cannot rule out that this shift was only in the levels, but since they both agree it seems likely that we observed a permanent solid body rotation. The drop did point out the obvious sensitivity of the levels to a motion about as large as the specification. We decided to abandon this exercise on other pads since the impact chipped one of the pad edges.

- Foundations 10 and 11 are of some note, since they are in the same soil conditions as pad 23, as yet to be built. Both were very stable and beyond our ability to reliably detect any rotation.

- Of all the foundations, the weakest according to the surface conditions would be foundation 13. This foundation is on the slope of Puu Poliahu where the fine and light material has collected for generations. As expected, we were able to measure some tilt at this site, although only about 0.1 - 0.15 arc seconds, still much better than specification. The tilt was detected at more than one azimuth, but is so close to our threshold detection level it is difficult to say whether or not the foundation has any preferred direction.

- Foundation 14 produced some interesting results. Motion was detected on two quadrants on the first day and in three of the four quadrants on the second day. After discussing foundation 14 with the staff at the site it is clear that this is probably not a random event. The foundations are of three types: a) the 31 foot original design used for foundations 12 and 16; b) the smaller 12 foot foundations poured directly onto solid rock (20 and 18); and c) the newer 20 foot design used for all the others. Of the new design, all of the foundations except one were excavated to about 15 cm below grade and recompacted using water with fine granular material to 95% optimum compaction. Foundation 14 was the only foundation of the new design where this was not practical due to lava outcroppings at the base of the excavation. The crew distinctly remembers a harder section in the northwest or west quadrant but did not record the azimuth. While we likely never know for certain, the data is consistent with a hard obstruction to the west side and softer material in the other directions.

- Foundation 18 was tested, although we were certain ahead of time that this rock-mounted foundation would be very stiff. The data confirms the stiffness, in that even the drops of the weight are indistinguishable in the measurements.

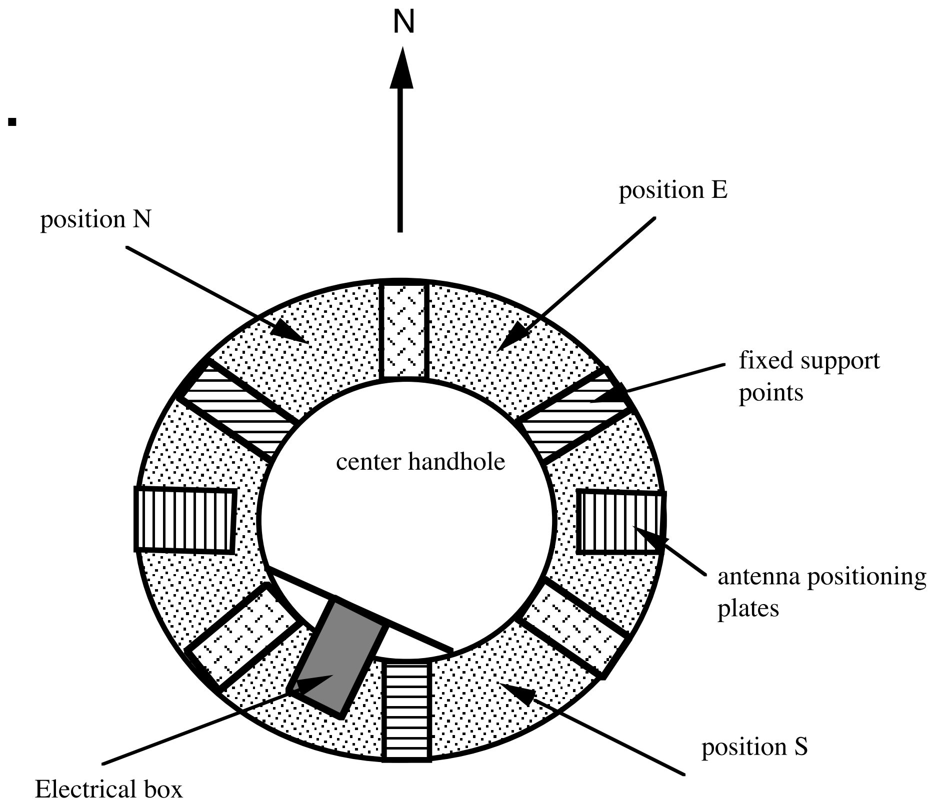
- The foundations not yet measured with the most recent experimental method are 1-6, 12, 16, and 20. Foundations 1-6 are in the smallest ring and are not yet backfilled. They are likely to be very close in character to foundation 7 which was exceptionally stiff. Foundations 12 and 16 are of the 31 foot size and, with stability increasing roughly at the cube of the diameter, will be very unlikely to show any motions. Foundation 20 has been poured into solid rock and should mimic foundation 18 which was very stiff.

Discussion

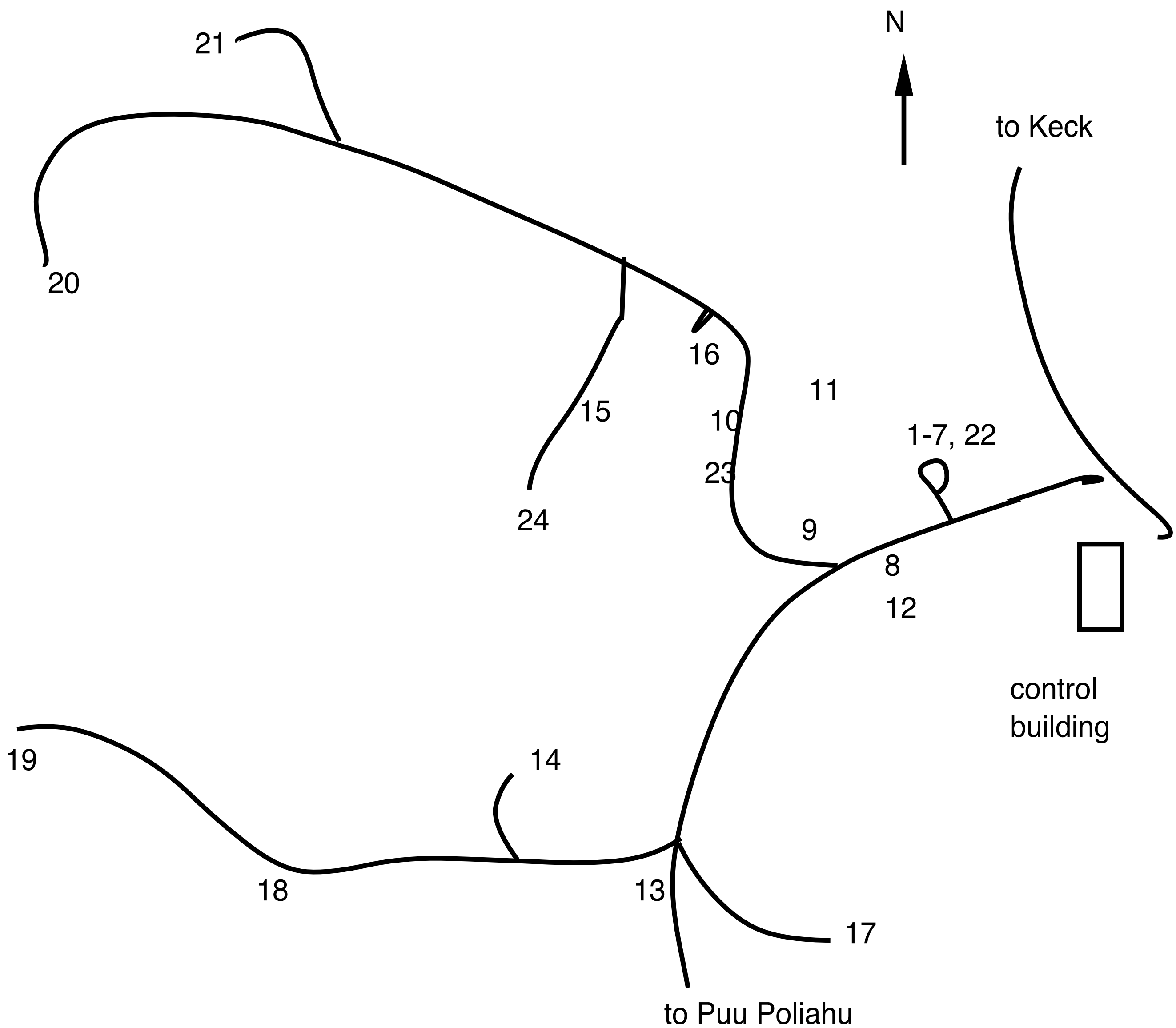
It is clear that the effective stability of the foundations is well above that predicted by the geotechnical engineers. We had already observed that the culture of this industry is very conservative, since serious consequences occur if bridges and skyscrapers are not stable to the values predicted. Also, the new 20 foot foundation design is much stiffer than the old, due to the better geometry of the structure, effectively eliminating any chance of flexure in the concrete. However, it would seem that these foundations are even more stable than the most optimistic of engineers would have predicted.

The answer to the unusual stiffness is probably in the unusually light loads and the sub surface preparation.   The loads on the base of the antenna are less than 2400 Kg per sq meter (4 pounds per square inch), well below almost any structural foundation. A load this small will not be transferred beyond the 15 cm depth which was compacted by the contractor (unlike the normal loaded column). You can see the effect of this compaction method merely by looking at the access roads, where previously soft soil has been hardened to the point where vehicles hardly leave a mark. It is likely, therefore, that the effective modulus of the soil, as measured by our foundations, has been increased many times by the construction method. Furthermore, as additional settling takes place and the weight and torque of the antenna are added, most of the foundations will compact their base more and become even stiffer. Foundation 14 suffered relative to its peers by having a subbase which could not be similarly prepared.

The Mauna Kea foundations have, in the aggregate, greatly exceed their required stiffness and should provide an unexpectedly good base for the antennas.



Top view of a foundation with the normal load positions indicated.
The two electronic levels were typically placed on the rim at the
opposite edge of the foundation.



A schematic view of the SMA site roads and foundation numbering on Mauna Kea.