64-Meter Antenna Pedestal Tilt at DSS 43, Tidbinbilla, Australia

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It was discovered in 1973, that the 64-meter antenna pedestal at DSS 43 had settled causing a level reference plane to be tilted. This article discusses the tilt of the pedestal, its amplitude, rate of change, method of measurement, and the degree of confidence in the measurements. The effect of the tilt and a prognosis for the future effect on tilt are discussed along with recommendations.

I. Background

A foundation investigation was performed in May 1967 at the proposed 64-meter antenna site DSS 43 at Tidbinbilla, Australia. In addition, a geophysical study, consisting of several seismic refraction survey lines, was also conducted to supplement the information obtained from three borings made as part of the foundation investigation. The borings were 18 m (60 ft) from the center of the antenna site on radials of 120 degrees and extended to depths of 24, 27, and 28 m (78, 90, and 91 ft).

The soil and bedrock profiles revealed by the borings consisted of a thin surface layer of topsoil underlain by alluvium consisting of mixtures of clay, sand, and gravel which, in turn, was underlain by granite bedrock at depths between 15 and 18 feet and which extended to the depths of the borings. The alluvium was firm-to-stiff, porous in the upper 5 feet, becoming stiff-to-hard and dense with depth. The bedrock was observed to be very decomposed (weathered) in the upper 3 m (10 ft), becoming less weathered (more crystalline in appearance) with depth and finally merging into relatively fresh granite bedrock at depths in excess of 21 m (70 ft). Ground water, as observed in the borings, was on the order of 4 m (12 ft) below existing grades. The uniformity of the subsurface profile was substantiated by the seismic refraction study.

Footings for the pedestal and base of the instrument tower were both designed to obtain bearing on the very weathered, but dense granite. The pedestal obtained bearing at a depth of 6 m (20 ft) and the instrument tower at 8.75 m (28.5 ft). During construction, a visual appraisal of the full site excavation substantiated the uniformity of the founding material as revealed by the borings and laboratory test results. It is believed that the observed pedestal tilt is not caused by variation in the compressibility of the supporting bedrock materials.

II. Foundation Analysis

When the pedestal tilt was first discovered, as a result of the January 1973 level survey of the DSS 43 azimuth bull gear, informal inquiries were made through the Network Support Facility (Australia) to determine if any regional tilts were being observed at local Australian Government facilities. The Snowy Mountain Authority, which is in charge of the large hydroelectric development centered some 96 km (60 miles) south of DSS 42/43, stated that elevations over their project area had been monitored for several years but that the effort had been discontinued when no changes were detected.

Closer to DSS 43 (approximately 24 km, 15 miles) is the Mount Strombo Astronomical Observatory, which is operated by the Australian National University at Canberra. No tilt was observed at the observatory during the period that the DSS 43 tilt occurred.

Bench marks placed on the 26-meter antenna footings at DSS 42 were resurveyed after the 64-meter DSS 43 antenna tilt was noted, but no change in relative elevations was found to have occurred during the period of concern.

An investigation of the hydrostatic bearing loads was accomplished in mid-1974 to determine if the observed pedestal tilt might have been caused by an imbalance in the hydrostatic bearing loads. The pressures in the bearing recesses were determined and it was reported that the bearing pads were carrying the following loads:

Pad 1	7.918×10^5 newtons	(178 kips)
Pad 2	7.873×10^5 newtons	(177 kips)
Pad 3	9.208×10^5 newtons	(207 kips)

The above indicated imbalance in pad loads causes an imbalance in bearing pressure under the pedestal ring footing.

A settlement analysis using the results of consolidation tests run on samples obtained as part of the 1967 foundation investigation and the above nonuniform bearing pad loads indicates that differential settlement across the antenna pedestal on the order of 3.175 mm (1/8 in.) could result from the imbalance.

Pad 3, the most heavily loaded, is the pad located on the "back" or rear side of the antenna (Fig. 1). As the antenna generally looks northerly during tracking operations, Pad 3 is bearing over the southerly half of the pedestal, which is the portion experiencing settlements relative to the north side.

III. Reference Surface

The top surface of the azimuth drive bull gear is used as a reference surface by the hydrostatic bearing instrumentation in process of determining the flatness of the hydrostatic bearing runner surface. Any deviation from a gravity level plane by the top surface of the bull gear, unless compensated for, will reflect as errors in the runner flatness determination. Therefore, frequent measurements are made of this surface to assure that the proper corrections are made in the hydrostatic bearing determinations.

A survey was made of the level of the top surface of the bull gear at the time it was installed in 1967. A record was kept of the deviation from a true gravity plane at 10-deg intervals around the 360 deg of the bull gear. This record serves as the starting reference.

The reference plane is a gravity-level plane through the mean elevation of the original bull-gear data taken when the bull gear was installed. Since then, the heights of the 10-deg intervals have changed and plots of the data resemble sine curves indicating a tilt in the plane of the top surface of the bull gear (Fig. 2).

The concept of the sine curve can be best explained by the following example. If a circle is inscribed on a plane and the plane is tilted with respect to a gravity-level plane through the axis of rotation, a plot of the ordinate values vs angular position around the circle will be a sine curve. The amplitude of the curve is proportional to the tilt of the plane, and the phase angle will indicate the direction of the tilt. The ordinate values h may be expressed by the equation $h = A \sin(\beta + \varphi)$, where A is the amplitude and φ is the phase angle. The amplitude A and phase angle φ can be determined for a "best-fit plane" (sine wave) by applying a Fourier series approximation to the raw data h and angle in the following manner:

Let the curve through the data points be described as

$$P_1 \sin\beta + P_2 \sin 2\beta + \cdots + Q_1 \cos\beta + Q_2 \cos 2\beta + \cdots$$

If only the fundamental is considered, neglecting the harmonic components, the function can be reduced to $P \sin\beta + Q \cos\beta$, where

$$P = \frac{2}{n} \sum_{1}^{n} h_n \times \sin\beta_n \text{ and } Q = \frac{2}{n} \sum_{1}^{n} \cos\beta_n$$

where n is 36, the number of equally spaced 10-deg points, and h_n is the height at angle β_n. The amplitude then is $A = \sqrt{P^2 + Q^2}$ and the phase angle $\varphi = \tan^{-1} Q/P$.

By applying this type of analysis to the data from the second survey made in January 1973, the "best fit plane" indicated that the top surface of the bull gear had tilted approximately 26 seconds from the "best fit plane" through the 1971 data taken just after the installation of the gear. Subsequent measurements made between 1973 and 1976 indicate that the angle of tilt is increasing at a rate of approximately 3.6 seconds per year. In 1976, the total tilt was 34 seconds (Fig. 3).

IV. Error Analysis

Eleven surveys have been made since January 1971. Each survey usually contains three traverses around the bull gear. Each traverse is a series of measurements of the incremental differences in heights between successive 10-deg intervals. The sum of the 36 increments in any set of measurements must be equal to 0.000 ± 0.25 mm (±0.010 in.) (closing error). If the closing error is greater than 0.25 mm (0.010 in.) that set of data is invalid. If the closing error is less than 0.25 mm (0.010 in.), the closing error is equally distributed through the 36 incremental measurements. The average of the three sets is used as the value for the height of the bull gear relative to a gravity plane.

The probable error of individual observations was determined from the data taken for 11 surveys made since 1971. A point on the bull gear which showed very little change in height since installations was selected. The probable error r of a single observation was computed using the formula

$$r = 0.6745 \, (n - 1)^{-1/2} \left[\sum_{1}^{n} h_1^2 \right]^{1/2}$$

Here n is the number of observations and h the heights above the gravity level reference plane. The probable error of a single observation based upon the 11 surveys was computed to be 0.023 mm (±0.0009 in.). This tolerance includes the accumulation of the individual incremental tolerances.

The probable error of the incremental observations was similarly determined to be 0.005 mm (+0.0002 in.). A comparison with 15 surveys taken at Goldstone over the same period of time indicates that at Goldstone the probable error of a single height observation is 0.020 mm (+0.0008 in.) and of the incremental observations 0.00025 mm (+0.00001 in.).

The diameter of the measurement circle on the top of the bull gear is 21.2 m (835 in.). A tolerance of 0.023 mm (0.0009 in.) at this diameter represents +0.22 arc-sec. Therefore, the probable error in the determination of the pedestal tilt is approximately +1/4 arc-sec.

V. Effects of Tilt

The major effect of the tilt is upon the hydrostatic bearing instrument (HBI). Since the HBI reference plane is determined from the top of the bull gear and the top of the bull gear tilts as the pedestal tilts, new corrections must be fed into the HBI every three to six months. It takes a crew of four men 8 to 10 hours to make a complete bull gear/HBI survey and program change. Frequent surveys will cause high maintenance cost.

The instrument tower, located in the center of the pedestal, is totally isolated from and independent of the pedestal. Observations made with a theodolite located at the top of the instrument tower looking at a gravity mirror located in the base of the tower indicate that the instrument tower has not tilted since placement of the Master Equatorial. There has not been any effect upon the pointing accuracy of the antenna.

Another area of concern is the effect upon the clearances between the windshield and instrument tower. Neither the insulation on the instrument tower nor the windshield is perfectly round, and some interferences were corrected during construction. The pedestal tilt affects the alignment of the windshield but is such that the tilt will improve the clearance at the closest point. The total clearance at the closest point between the floor of the ME room and the windshield now is in excess of 2.54 cm (1 in.). The rate of change at this elevation due to the pedestal tilt is only 0.66 mm (0.026 in.) per year.

The pedestal tilt will change the preload on the radial bearing by approximately the vertical component of the weight of the rotating structure or 4528 N (1018 lb), which is negligible compared to the 1.468×10^6N (330-kip) preload. The tilt will also change the elevations of the truck trace on the wearstrip by 0.79 mm (0.031 in.), where 1.27 cm (0.5 in.) can be tolerated before the radial bearing trucks would have to be readjusted.

VI. Risk Assessment

Table 1 summarizes the amount of the change at DSS 43 to date and the rate of change per year at the critical areas on the antenna caused by the pedestal tilt. The maximum change before corrective action must be taken is shown, and the time before corrective action is estimated based on the current rate of change. There is no effect upon the antenna pointing accuracy.

VII. Conclusion

DSN Engineering is of the opinion that the tilt (differential settlement) of the pedestal is due to the nonuniform loading on the pedestal. The unbalanced load thesis can be tested by simply parking the heavier Pad 3 on the "high" or northern side of the pedestal when the antenna is not tracking and monitoring the tilt to determine if the tilt lessens proportionally to the amount of time the nonuniform load condition is reversed. The tilt does not affect the operation or the expected life of the antenna.

Table 1. Summary of antenna pedestal tilt at DSS 43

Location	Change since installation	Change per year	Maximum change allowable	Time before corrective action
Bull gear HBI reference	35 $\widehat{\text{sec}}$ 3.6 mm (.142")	3.6 $\widehat{\text{sec}}$ 0.381 mm (.015")	0.381 mm (.015")	1 year[a] requires update of HBI digital cam program
Cables between instrument tower and windshield	35 $\widehat{\text{sec}}$ 5 mm @ 30.5M (.195 @ 1200)	3.6 $\widehat{\text{sec}}$ 0.533 mm (.021")	12.7 mm (.500")	14.5 yrs
ME room floor joint	3.5 $\widehat{\text{sec}}$ 6.5 mm (.255")	3.6 $\widehat{\text{sec}}$ 0.66 mm (.026")	63.5 mm (2.5")	86 yrs
Radial bearing	3.5 $\widehat{\text{sec}}$ ±0.79 mm (±.031")	3.6 $\widehat{\text{sec}}$ 0.076 mm (.003")	12.7 mm (.5") ±6.35 mm (±.25")	150+ yrs

[a]The periodic corrective action to the hydrostatic bearing instrumentation digital cam program is minor. It takes approximately 8 hours to survey the level of the top surface of the bull gear and enter the corrective data into the digital cam computer program.

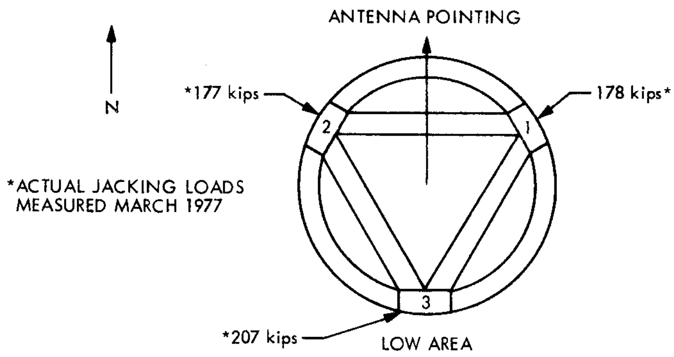

Fig. 1. DSS 43 bearing pad load

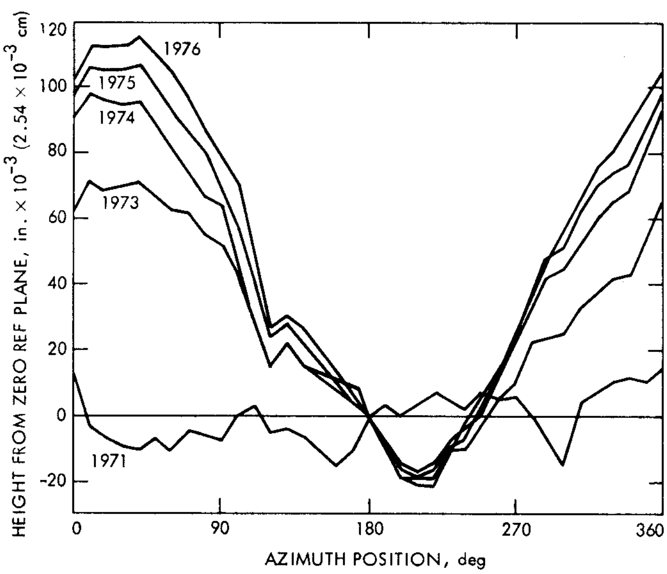

Fig. 2. Change in bull gear elevation since 1971

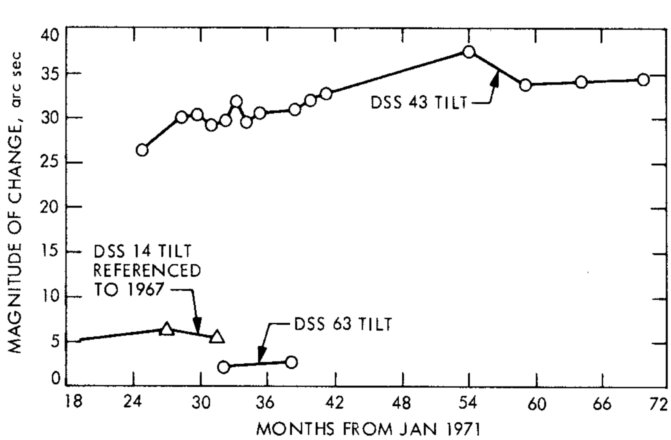

Fig. 3. DSS 43 bull gear plane tilt