MISCELLANEOUS PAPER S-68-14

PROJECT ALTAIR
KWAJALEIN, MARSHALL ISLANDS
STATIC AND DYNAMIC RESPONSE OF A RING-BEAM ANTENNA FOUNDATION

by

D. R. Casagrande

July 1968

Sponsored by

Advanced Research Projects Agency

through

U. S. Army Sentinel System Command, SENSC-RC

and

U. S. Army Engineer District
Mobile

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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FOREWORD

The investigation reported herein was sponsored by the Advanced Research Projects Agency (ARPA) through the U. S. Army Sentinel System Command, SENSC-RC, and the U. S. Army Engineer District, Mobile, under ARPA Order 6-68. The authorization was transmitted by the U. S. Army Engineer District, Mobile, in DA Form 2544, No. 67-34, dated 17 November 1966. This authorization was for static and dynamic response measurements of the ALTAIR radar foundation. The static response measurements were made during the period February 1967 through April 1968, and the dynamic response was recorded during February 1968.

Personnel of the U. S. Army Engineer Waterways Experiment Station (WES) who were actively engaged in the data acquisition, analysis, and report phases of this investigation were Messrs. R. W. Cunny, Z. B. Fry, and D. R. Casagrande of the Soil Dynamics Branch and Mr. M. B. Savage, Jr., of the Instrumentation Branch. This report was prepared by Mr. Casagrande.

The work was performed under the general supervision of Messrs. W. J. Turnbull and A. A. Maxwell, Chief and Assistant Chief, respectively, of the Soils Division.

COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE, were Directors of the WES during the conduct of the investigation and publication of this report. Mr. J. B. Tiffany was Technical Director.

Acknowledgment is made to personnel of the U. S. Army Engineer District, Honolulu, and personnel of the ALTAIR construction contractors for their assistance and general cooperation during the data acquisition phase of the investigation. Acknowledgment is also made to the Mobile District for their assistance during the initial gage installation.

Special acknowledgment is made to the late LTC Joseph M. Kiernan, Jr., CE. LTC Kiernan was ALTAIR program manager during initial developments. This investigation was initiated mainly due to LTC Kiernan's foresight in recognizing the advantage of recording data contained herein.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
pounds	0.454	kilograms
pounds per square foot	4.88243	kilograms per square meter

SUMMARY

ALTAIR is an experimental radar installation. Its 150-ft-diam antenna dish is supported by a four-legged frame that rotates on a 118-ft circular track. The track is centrally located on a 9-ft-wide ring-beam foundation. Four radial ribs and a cable tunnel connect to the beam and act as stiffeners. The subsurface materials in the area consist of coral sand and rock.

The antenna dish operates in two modes: elevation (vertical) and azimuth (horizontal). The elevation is changed by rotating the dish about a horizontal axis passing through the base of the dish, and the azimuth of the dish is varied by rotating the entire support frame.

The accuracy of a radar installation is sensitive to the antenna foundation response under both static and dynamic loadings. Due to the unique design of the ALTAIR structure, it was decided to monitor the static and dynamic responses of its ring-beam foundation to ascertain if the foundation met operational specifications.

The settlement of the beam was monitored from February 1967 through April 1968 during the period of dead load application resulting from construction of the antenna superstructure. By 10 April 1968, the foundation had settled an average of 0.049 in. and had tilted almost as a plane toward the adjacent operations building. This tilt was 0.026 in. for the 118-ft track. The rate of settlement, which was almost constant at 0.0037 in. per month during the dead load application, started decreasing in January 1968, at which time the rate of dead load application was reduced.

The dynamic foundation response, consisting of transient (elastic) deflections and vibration frequency and amplitude, was recorded in February 1968 during the initial antenna testing program. The maximum transient (elastic) deflection of the beam was 0.0088 in. at a point halfway between two of the ribs, and the minimum elastic deflection was 0.0044 in. at the cable tunnel connection. The data indicated that the beam was bending outward as any of the four bogies supporting the frame passed any of the points monitored. The angle of this bending at any location was independent of which bogie passed the point and was a maximum of about 8 sec halfway between two of the ribs. At this angle of twist, the outside edge of the beam was deflected about 0.004 in. more than the inside edge.

The foundation vibration was monitored in three modes: radially, tangentially, and vertically to the circular foundation. The main frequency of response in all three modes was 21 Hz (cps). Frequencies as low as 10 Hz were recorded in the tangential mode, but these vibrations usually lasted for only a few cycles. The stiffening effect of the cable tunnel increased the tangential frequency at this point to an average of 30 Hz. Very high-frequency vibrations (130 to 170 Hz) of relatively minor amplitude were superimposed on the lower frequencies at azimuth rotation rates greater than about half the design rate. The rate at which the azimuth drive gear was engaging the drive-rail teeth was occasionally the same as the recorded foundation frequency when this rate was less than 21 Hz.

The maximum amplitude of foundation vibration was in the vertical mode. The maximum recorded vibration was 0.0007 in. peak to peak, which was caused by maximum azimuth deceleration from a rotation rate slightly greater than design rate. The amplitude of vibration was generally less than 0.0001 in. peak to peak except during acceleration, deceleration, or at azimuth rotation rates greater than about half the design rate. During constant-rate azimuth rotation with constant elevation, the maximum foundation vibration occurred at a rotation rate slightly less than design rate. Operation in the elevation mode only (constant azimuth), although this mode was not fully operational at the time of these tests, created foundation vibrations of relatively minor amplitude with respect to those resulting from azimuth rotation.

PROJECT ALTAIR

KWAJALEIN, MARSHALL ISLANDS

STATIC AND DYNAMIC RESPONSE OF A RING-BEAM ANTENNA FOUNDATION

PART I: BACKGROUND, PURPOSE, AND SCOPE OF INVESTIGATION

1. ALTAIR is a new experimental radar installation. The criteria relative to settlement and deflection of the concrete ring-beam antenna foundation necessitated very small allowable movements under both static and transient loading conditions. The unique design of the antenna superstructure and its foundation made it difficult to accurately predict the response of the foundation to the various expected dead and live loads. It was therefore suggested by the designers and consultants that provisions be made in the construction plans for installing test equipment to determine the response of the ring under actual loading conditions. Planning for such measurements at this early stage of the project, rather than following the usual procedure of attempting to instrument the structure after completion, facilitated the installation of the gages and permitted the design of a simple and accurate gage. Also, the gages could be located in the foundation instead of on it, thereby reducing the danger of damage from construction operations.

2. A proposal outlining a system for monitoring the settlement and dynamic response of the ring-beam foundation was subsequently submitted by the U. S. Army Engineer Waterways Experiment Station (WES) to the U. S. Army Engineer District, Mobile. The proposed system, consisting of eight gages located in sets of two at four positions around the foundation, would determine the total and differential settlement of the foundation and monitor the transient response of the various sections of the foundation.

3. The settlement gages were installed under the direction of WES personnel during February 1967 immediately after construction of the foundation had been completed. Construction of the superstructure was initiated during March 1967 and was completed in March 1968. The

settlement of the foundation during this period was recorded at intervals of one to seven weeks by personnel of the U. S. Army Engineer District, Honolulu, and Sylvania Electronics Systems-East (antenna superstructure design and construction contractor). The transient response of the foundation was monitored by WES personnel during February 1968, at which time the antenna testing program was initiated.

4. Static and dynamic properties of the subsurface materials at the site are presented in previously published reports.* The static properties were determined from field and laboratory tests consisting of standard penetration resistance, plate bearing, consolidation, shear, density, water content, and classification tests. The elastic dynamic properties were determined from field tests and consisted of refraction seismic velocities and dynamic shear and compression moduli. Obtaining these data was necessary in order that a foundation with high stability requirements under static and dynamic loads could be designed.

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* U. S. Army Engineer District, Mobile, CE, "Foundation Investigation for Design of Structures for ALTAIR Project," Oct 1965, Mobile, Ala., and R. F. Ballard, Jr. and D. R. Casagrande, "Dynamic Foundation Investigation, Roi-Namur, Kwajalein Atoll, Marshall Islands," Miscellaneous Paper No. 4-858, Nov 1966, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

PART II: THE INVESTIGATION

Location and Description

5. The ALTAIR installation is located on Roi-Namur Island, Kwajalein Atoll, Marshall Islands. The coordinates of the island are approximately latitude N9°24' and longitude E167°28'. A location sketch is presented in plate 1.

6. The radar superstructure consists of a 150-ft-diam* antenna dish mounted on a four-legged support frame (photographs 1 and 2). Each leg of the support frame is attached to a two-wheeled bogie (photograph 3). The frame rotates on a 118-ft-diam circular steel track, which is supported by a concrete ring-beam foundation with cross-sectional dimensions of 9 ft wide by 6 ft high (plates 2 and 3).

7. The total dead load of the superstructure is approximately 765,000 lb. This load is transmitted vertically to the center of the foundation beam in the proportion of 55 percent through the two back bogies and 45 percent through the two front bogies (plate 2). The horizontal-drive mechanisms attached at one of the back and one of the front bogies increase the dead load slightly at these bogies. Each horizontal-drive motor also exerts an outward force component of approximately 20,000 lb on the inside of the ring-beam foundation. Because the antenna dish is counterbalanced, its elevation should not vary the dead loads transmitted by the bogies. However, wind load can substantially alter the loading scheme as explained in the electronics system support criteria report.**

Antenna Operation

8. The antenna operates in two modes: elevation (vertical) and

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* A table of factors for converting British units of measurement to metric units is presented on page ix.

** Sylvania Electronics Systems-East, "Design Criteria for ALTAIR Facilities as Required for Support of Sylvania Supplied Equipment," March 1966.

azimuth (horizontal). The elevation is changed by rotating the dish about a horizontal axis passing through the base of the dish, and the azimuth of the dish is varied by rotating the entire support frame. At 0-deg elevation and 0-deg azimuth, the antenna dish is pointing horizontally in a compass direction of N50°E. The azimuth rotation has a full 360-deg range, and the elevation range is 90 deg (straight up). Azimuth rotation is effected by two drive motors attached to the superstructure and located at diametrically opposite bogies, and the dish is elevated by a single drive motor supported by a truss cantilevered from the center of the structure (see plate 2 and photograph 4). The operational rates in both azimuth and elevation are classified at this time; however, the upper limits in each mode are the same and will be designated as M deg per sec in this report. Other rates will be designated as a function of M ; e.g., 0.2M.

PART III: PROCEDURE

Location of Gages

9. The various sections of the ring-beam foundation designed for the ALTAIR antenna will have different magnitudes of vertical reaction to the static and dynamic loadings; i.e., the section over the cable tunnel will react differently than a section at a rib connection, which, in turn, will be less flexible than a section between the ribs. For this reason, vertical-response monitoring gages were to be installed at the cable tunnel, at a rib connection, and halfway between two ribs. A fourth location, diametrically opposite the between-ribs location, was selected to give a better indication of the relative settlement of the ring. Two gages were placed at each location, one inside and one outside the azimuth wheel track, as an insurance measure in case one of the gages became inoperable and to indicate any twist (cross-sectional tilt) of the beam. The eight gages were located as shown in plates 3 and 4.

10. The vibratory response of the circular foundation was monitored in the vertical, radial, and tangential modes at an azimuth location of 270 deg (between two ribs) and in the radial and tangential modes at an azimuth of 180 deg (cable tunnel). These locations were thought to represent the most flexible and the stiffest parts of the foundation. The pickups at each location were installed at the deflection gage located on the outside of the azimuth wheel track (gages 6 and 8, see plate 3).

Installation of Bench Marks

11. In order to obtain accurate measurements of settlement and transient vertical deflection, a good reference point independent of the foundation is essential. A 26-ft-long steel pipe was installed at each gage location during February 1967, prior to construction of the superstructure, to serve as a reference for static and transient measurements. This 1-1/2-in.-diam bench-mark pipe with a plate welded to the bottom was grouted in at a depth of about 26 ft below the surface of the

foundation and was isolated from the surrounding soil by a 4-in.-diam steel casing. A stainless steel pipe cap was epoxied to the top to act as a bench mark. The system is shown in plate 4. Details of the installation are documented in a "Memorandum for Record" prepared by the author in March 1966.

Measurements

Static

12. Settlement of the foundation was recorded by monitoring the movement of the foundation relative to the bench mark at the eight gage locations. A consistent reference plane from which to measure to the bench mark was obtained by epoxying steel support blocks to two opposing walls of the gage well and resting a steel bar on the knife edges of these blocks. The measurement was made by using a depth micrometer with an accuracy of ±0.0001 in. The micrometer stem was placed through a hole in the center of the reference bar, and the distance from the surface of the bar to a punch mark on the bench-mark pipe cap was recorded. The system is shown in plate 4 and photograph 5.

Dynamic

13. Transient (elastic) vertical deflection measurements were made using the bench-mark and reference-bar system established for the settlement readings. For dynamic measurements, the micrometer was replaced by a linear position transducer having an electrical stroke of ±0.050 in. (G. L. Collins Corporation Model No. SS-101). The gage principally converts the mechanical motion of its probe assembly relative to its case assembly (see plate 5) into an electronic signal that can then be recorded. A recording oscillograph with direct-print paper was used for this purpose. The accuracy of the measuring system was approximately ±0.0005 in.

14. The case assembly was clamped to the reference bar that was screwed to the support blocks, and the probe assembly was screwed into a brass extension that was epoxied to the bench-mark pipe cap (see plate 5 and photograph 6). The gages were calibrated mechanically by raising or lowering the case assembly clamp and measuring the magnitude of this

movement with a depth micrometer. The accuracy of the calibration method was ±0.0001 in.

15. The vibratory response of the foundation was monitored by velocity-type pickups (MB Electronics Type 120) that were epoxied directly to the concrete (photograph 6). The flat-frequency-response range of these pickups is 4 to 1000 Hz (cps), and they have a natural frequency of 2.5 Hz.

PART IV: RESULTS

Static Measurements

16. The zero-settlement readings were taken on 23 February 1967, at which time there was no superstructure load on the foundation. During the one-year superstructure construction period, 765,000 lb of dead load were applied to the foundation at a rate ranging from 2,000 to 200,000 lb per month. The foundation responded by settling at an almost constant rate of 0.0037 in. per month until January 1968 when the average settlement rate decreased to about 0.0030 in. per month. The last settlement readings prior to the preparation of this report were taken on 10 April 1968, at which time all the dead load had been applied to the foundation. They indicated that the foundation had settled an average of 0.049 in. and had undergone a differential settlement of approximately 0.022 in. This was the largest recorded differential settlement and is not representative of the average differential settlement, which was approximately 0.010 in. until January 1968. The foundation settlement is plotted as a function of time in plate 6.

17. Readings at all eight gages could not always be recorded due to either gage malfunction or inaccessibility. Gage 3 (see plate 3) was intermittently inaccessible during the construction period, and gage 4 was rendered permanently inaccessible in mid-May 1967 by a steel plate of the antenna stow mechanism. Gage 1 became inoperable twice, but was repaired and has been operational since July 1967. Gage 7 became inoperable in July and was not repaired until February 1968.

Dynamic Measurements

18. Transient ring-beam deflections were monitored during 360-deg azimuth rotations at rates of 0.2M, 0.4M, 0.6M, 0.8M, and 1.0M with a constant dish elevation of 90 deg (straight up), and 0.2M, 0.4M, and 1.2M with a dish elevation of 10 deg. The deflections at each Collins gage during the 0.2M tests are plotted as a function of antenna azimuth in

plates 7 and 8 for elevations of 90 deg and 10 deg, respectively. Gage 3 deflections plotted above the zero-deflection line because at the starting azimuth of 180 deg, gage 3 was located directly under a bogie, whereas the other gages were located halfway between bogies. The plots indicate that the transient deflections were almost identical during these two tests. The smallest peak deflection during the 90-deg-elevation 0.2M test was at gage 7 (cable tunnel) due to passing of the front nondrive bogie and was approximately 0.0044 in. The maximum deflection during this test occurred at gage 2 (between two ribs) due to passing of the back drive bogie and was approximately 0.0088 in. The difference in peak deflections caused by the lightest (front nondrive) and heaviest (back drive) bogie passing over any one gage was about the same at all gages (approximately 0.0009 in.) except for gages 7 and 8, which indicated about half this difference. Very little variation was noticed in the deflections of each gage due to different rates of azimuth rotation. To illustrate this, the deflections of gages 2, 3, and 7 were plotted as a function of antenna azimuth in plate 9 for azimuth rotation rates of 0.2M and 1.0M with a constant elevation of 90 deg, and in plate 10 for rates of 0.2M and 1.2M with an elevation of 10 deg.

19. The ring-beam foundation vibrated with a predominant frequency of 21 Hz during the azimuth rotation tests with a constant elevation; however, the entire range of recorded frequencies during these tests was approximately 10 to 170 Hz. Frequencies ranging from 10 to 17 Hz were recorded in the tangential mode at gage 6 at most azimuth rotation rates but they were only of relatively short duration with respect to the 21-Hz vibrations in this mode. The longest period of recorded low-frequency vibrations (11 Hz) was approximately 4 sec, which occurred while the back drive bogie was passing over gage 6 during the 0.2M test with an elevation of 10 deg (see plate 11). This frequency was probably due to the drive mechanism, because the drive gear was engaging about 11 drive-rail teeth per sec at this rate. The frequencies of tangential mode vibrations at gage 8 (cable tunnel) were slightly higher than the norm, ranging from 22 to 33 Hz (see plate 11). The frequency of radial mode vibrations at both gages 6 and 8 was predominantly 21 Hz with minor

variations. The vertical vibrations at gage 6 ranged in frequency from 20 to 25 Hz, but were predominantly 21 Hz. Vibrations ranging in frequency from 130 to 170 Hz were evident in all three modes at rates of azimuth rotation greater than 0.6M, but were relatively minor amplitude vibrations superimposed on the 10- to 33-Hz vibrations (see plates 12 and 13).

20. The amplitudes of foundation vibration were determined by integrating the velocity versus time records obtained from the vibratory pickups. The maximum peak-to-peak amplitude recorded in the three modes (vertical, radial, and tangential) during the constant-azimuth-rate tests varied somewhat with rate of rotation. A vertical pickup had not been installed during the tests conducted with an elevation of 90 deg; however, the tangential and radial modes indicated a maximum vibratory foundation response at an azimuth rotation rate of 0.8M. The maximum amplitude of response at this rate was approximately 0.00023 in. in the radial mode and was due to the front drive bogie passing gage 6 (see plate 12). The constant-azimuth-rate tests conducted with the dish elevation at 10 deg indicated a greater response at 1.2M than at either 0.2M or 0.4M; the largest amplitude was approximately 0.00037 in. in the vertical mode. The maximum recorded foundation vibration occurred at gage 6 under the back drive bogie during an azimuth deceleration test from a rate of 1.2M with a constant dish elevation of 10 deg (see plate 13). This vibration was in the vertical mode and was approximately 0.00070 in. peak to peak.

21. An elevation-mode test was conducted by rotating the dish from an elevation of 90 deg to 5 deg at a rate of approximately 0.3M with the azimuth constant at 315 deg. This test produced foundation vibrations ranging in frequency from 19 to 40 Hz, the main frequency being about 25 Hz. The test primarily produced vertical motion of maximum peak-to-peak amplitude approximately 0.000053 in. at gage 6; the radial motion was a maximum of approximately 0.000046 in., and there was practically no tangential motion (see plate 14).

22. One test was also conducted with both the elevation and azimuth modes in operation. The azimuth rotation was from 270 deg clockwise to 90 deg at a rate of 0.3M, and the elevation was simultaneously lowered

from 85 deg to 5 deg at a rate of 0.15M. The frequency in the vertical, tangential, and radial modes of vibration was primarily 17 Hz, which happens to be the number of azimuth drive teeth engaged per second at this azimuth rate. The largest peak-to-peak vibration during this test was 0.00042 in. in the vertical mode at gage 6 (see plate 14).

23. The maximum peak-to-peak amplitudes of vibration in the different modes, as determined by integrating the records of the different tests, are plotted as a function of azimuth rotation rate in plate 15. The lines connecting the points were drawn only to differentiate the data from different tests and are not meant as an interpolation of the gaps between data points.

PART V: ANALYSIS AND DISCUSSION OF RESULTS

Static Measurements

24. Settlement of the ring-beam foundation during the dead load application has been well documented. However, the accuracy of this documentation is not ±0.0001 in., which is the accuracy of the depth micrometer. The accuracy of the entire settlement gage is less than this due to thermal effects on the metal components of the gage and due to the improbability of placing the reference bar and micrometer in exactly the same position as during the previous reading. Thermal expansion properties of the components could result in the indicated settlement's being 0.001 in. greater on a sunny day than on a rainy day. Also, negligence of the person making the reading could greatly affect the accuracy of the reading; i.e., if the reading is not made on the pipe cap punch mark, the recorded settlement will be less than actual; if a grain of sand is under the micrometer stem, the reading will indicate more than actual settlement; if the micrometer is not held firmly when the reading is made, it could possibly indicate less than actual settlement; or if the micrometer bearing surface on the support bar is not clean, the reading will indicate less than actual settlement. However, these errors would not be consistent and can usually be recognized and disregarded in a general analysis of the settlement data.

25. The gage 1 readings taken subsequent to the initial reading incorporate a slight error because one of the support blocks broke loose twice and was reepoxied to the concrete. However, the gage has been operational since July 1967 and the readings, when compared with those of gage 2, indicate that presently the reference bar may be about 0.005 in. lower than its original position.

26. The rate of settlement from March 1967 to January 1968 was practically constant. This rate, approximately 0.0037 in. per month, was about the same during June-July 1967 when 200,000 lb of dead load were applied to the foundation as it was during November 1967-January 1968 when the loading rate was only about 10,000 lb per month. This constant

rate indicates a gradual adjustment of the well-graded coral sand and coral rock underlying the foundation. A 5-ft-thick coral rock lense, which is located at a depth of about 5 to 10 ft in all South Pacific coral atolls, could be an influencing factor in the magnitude of settlement rate and eventual total settlement. However, the constant settlement rate could indicate that the initial stress exerted on the subsurface materials by the concrete ring-beam foundation itself, approximately 900 psf, was more influential in determining its settlement characteristics than was the dead load stress applied by the superstructure, which is a total of approximately 200 psf if it can be assumed that the load is applied uniformly over the entire loading surface of the ring-beam foundation.

27. The differential settlement on 10 April 1968 was approximately 0.022 in., the maximum and minimum recorded settlements being at azimuth locations of 180 deg and 45 deg, respectively. The foundation apparently started tilting slightly toward the adjacent operations building during December 1967 (see plate 6). This could be due to a number of causes such as greater stress in the subsurface materials on this side of the foundation or more compressible materials under this side of the foundation, but the explanation would only be a guess without a complete picture of the loading history of the installation. In any case, the differential settlement of the foundation is still well within the tolerable limits that were specified as follows in the electronics system support criteria report:*

> A theoretical datum plane including the 118-foot-diameter azimuth wheel track and the center hub of the foundation shall be level prior to the application of the antenna superstructure loads. The uniform vertical settlement of this datum plane is not restricted; however, the differential settlement of this plane shall not exceed ±0.030 inch about the best fitted plane whose tilt shall not exceed 0.25 inch for the 118-foot-diameter from any load condition.

What has heretofore been referred to as differential settlement is actually very close to the tilt as referred to in the quote above. When the 10 April settlement readings are projected onto a vertical plane passing through the

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* Sylvania Electronics Systems-East, op. cit., p 3.

foundation at azimuths of 0 and 180 deg, a straight line in this plane incorporates practically all the points, indicating that only about 0.005 in. of differential settlement (as used in the quote above) has occurred and that the present tilt of the 118-ft azimuth wheel track is approximately 0.026 in. (see plate 16).

28. During the 14-month settlement-monitoring period, the foundation had settled a total average amount of approximately 0.049 in. However, as stated in the quote above, only the magnitudes of differential settlement and tilt are of importance. The total average settlement of the foundation is, therefore, primarily of academic interest and should not affect the accuracy of the radar installation.

29. It is not clear at present what effect, if any, the foundation vibrations and transient deflections resulting from azimuth rotation will have on the differential settlement and tilt of the foundation. On the basis of the settlement history, it is unlikely that any subsequent settlement of the foundation will be large enough to significantly affect the accuracy of the antenna.

Dynamic Measurements

30. Interpretation of the transient deflection measurements was subject to two types of errors: calibration errors, and the effect of thermal differentials on the Collins gages during data recording. The thermal effects during data recording can be considered insignificant because no single test lasted for more than a few minutes, and all the recording was done at night. The calibrating was done during the day, but the temperature difference between day and night should not affect these values. The gages were calibrated four times prior to and during the testing period at different times of the day with almost identical results each time.

31. The magnitude of peak transient deflections due to a 360-deg rotation of the support frame reflected exactly which of the four bogies was over the gage at each peak. For example, at an antenna azimuth of 45 deg, a bogie is located over each of the gage points except gage 3,

which at that azimuth is located halfway between two bogies. According to the data presented in plate 7, at an azimuth of 45 deg gages 1 and 2 are located under the lightest bogie, because they have their smallest peak deflection (with respect to their other peak deflections) at this azimuth, gage 3 is located halfway between the lightest and second lightest bogies, gages 5 and 6 are located under the second heaviest bogie, and gages 7 and 8 are located under the heaviest bogie. It should be reiterated that the heavy bogies are the two back bogies that transmit approximately 55 percent of the dead load to the foundation, and the two light bogies are the front bogies. The azimuth drive mechanisms add slightly more load to one of the front and one of the back bogies.

32. The maximum transient deflections at gages 1 and 2 were approximately 0.0002 in. greater than those diametrically across the foundation at gages 5 and 6. The magnitude of this difference is insignificant; however, it may indicate that the foundation is slightly weaker on one side than the other.

33. Analysis of the data showed that each gage on the outside of the azimuth wheel track (gages 2, 5, and 8) always had a greater peak deflection than the inside gage (gages 1, 5, and 7); i.e., the foundation was bending outward as a bogie passed over the point. This bending was maximum at gages 5 and 6 and minimum at gages 7 and 8. The magnitude of bending was apparently independent of which bogie passed over the point. The maximum difference in deflection was approximately 0.0016 in., which is a twist angle of about 8 sec. At this angle, the maximum difference in deflection between the inside and outside edges of the foundation was approximately 0.004 in. The difference in deflection for each pair of gages is illustrated in plate 17, which is a plot of the peak deflections due to each of the four bogies passing over each gage at a rate of 0.2M (dish elevation 90 deg). Data from different rates of azimuth rotation and different elevations were practically identical with the values presented in this plate. It can, therefore, be concluded that the angle of outward bending is independent of the load at each bogie and the rate of azimuth rotation although the vertical movement was, of course, proportional to the load.

34. Operating the antenna dish with the bogies located over the gage points (antenna at azimuth of 315 deg) did not create any noticeable response of the Collins gages. This means that, within the sensitivity of these gages, the dead loads transmitted to the foundation through the bogies are constant during operation in the elevation mode. This does not take into account any change in the loading due to wind forces. No deflections were recorded exclusively for wind load due to the length of time necessary for such a test.

35. The predominant frequency of the foundation is 21 Hz. Lower or higher frequencies were not persistent throughout the tests except for an indicated frequency of about 30 Hz in the tangential mode at the cable tunnel, but this would be expected due to the stiffening effect of the tunnel. The only frequencies that could be linked to the azimuth drive mechanism were 17 Hz recorded during the azimuth-plus-elevation test (see plate 14) and 11 Hz recorded during the 0.2M azimuth rate tests (see plate 11); these happened to be the number of azimuth drive-rail teeth per second engaged by the drive gear.

36. The amplitude of vibration was largest in the vertical mode, but was of such small magnitude that the Collins gages barely responded to this motion. This means that the peak-to-peak amplitude of vibration in the vertical mode at any of the seven Collins gage locations was usually less than 0.0001 in., the approximate sensitivity of the recording system. In fact, the largest recorded vibration of only 0.0007 in. was due to maximum deceleration from an azimuth rate slightly greater than the maximum design rate. The vibrations exceeded 0.0001 in. only during acceleration, deceleration, or when a bogie was passing over the gage point at an azimuth rotation rate greater than 0.4M. When a high rate of elevation is combined with a high rate of azimuth rotation, the amplitude of vibrations could possibly be greater than any recorded during these initial tests, but the indications are that operating in the elevation mode has a relatively minor influence on the magnitude of foundation vibration.

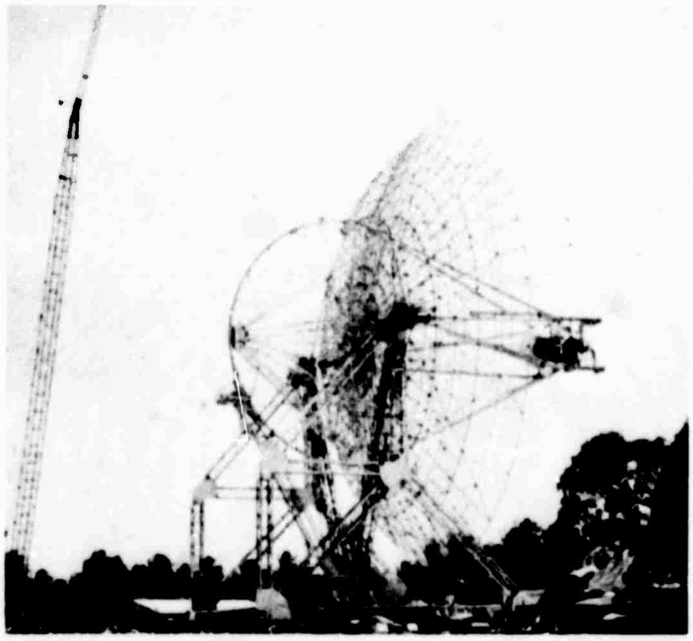
PART VI: CONCLUSIONS

37. During the 14-month, foundation-settlement-monitoring period ending in April 1968, the ALTAIR antenna ring-beam foundation had settled an average of 0.049 in. The rate of settlement, approximately 0.0037 in. per month, remained constant until January 1968, at which time the loading rate was decreased and the settlement rate decreased to about 0.0030 in. per month. The latest readings, 10 April 1968, indicated that the foundation had tilted almost as a plane toward the adjacent operations building by an amount of 0.026 in. for the 118-ft-diam azimuth wheel track. The maximum deviation from this plane was about 0.005 in.

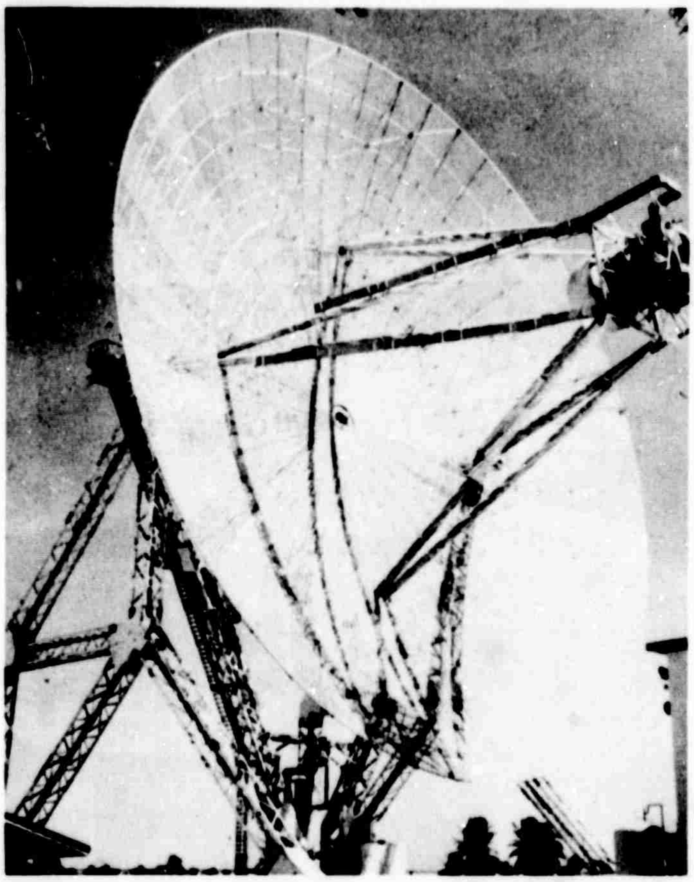
38. The transient (elastic) vertical deflections of the ring beam were almost constant for different rates of azimuth rotation and different elevations. A maximum deflection of approximately 0.0088 in. occurred at a point halfway between two rib connections, and a minimum deflection of approximately 0.0044 in. was measured at the cable tunnel connection. The maximum difference in peak deflections at any one gage caused by passing of the two bogies transmitting the minimum and maximum dead load to the foundation was approximately 0.0009 in. The data indicated that the foundation was twisting outward as a bogie passed over any of the gage locations. The angle of this twist was a maximum of approximately 8 sec, which means that the inside edge of the foundation was deflecting about 0.004 in. less than the outside edge.

39. The most dominant frequency of foundation response to antenna operation was 21 Hz. Frequencies as low as 10 Hz were recorded in the tangential mode, but these vibrations usually lasted for only a few cycles. The frequency of tangential vibration at the cable tunnel averaged about 30 Hz, which reflects the stiffening effect of this structure. High-frequency vibrations ranging from 130 to 170 Hz were superimposed on the lower frequencies at azimuth rotation rates greater than about half the maximum design rate. Vibrations resulting from the azimuth drive gear engaging with the teeth of the drive rail were transmitted through the foundation in the vicinity of the gear if their frequency was lower than 21 Hz.

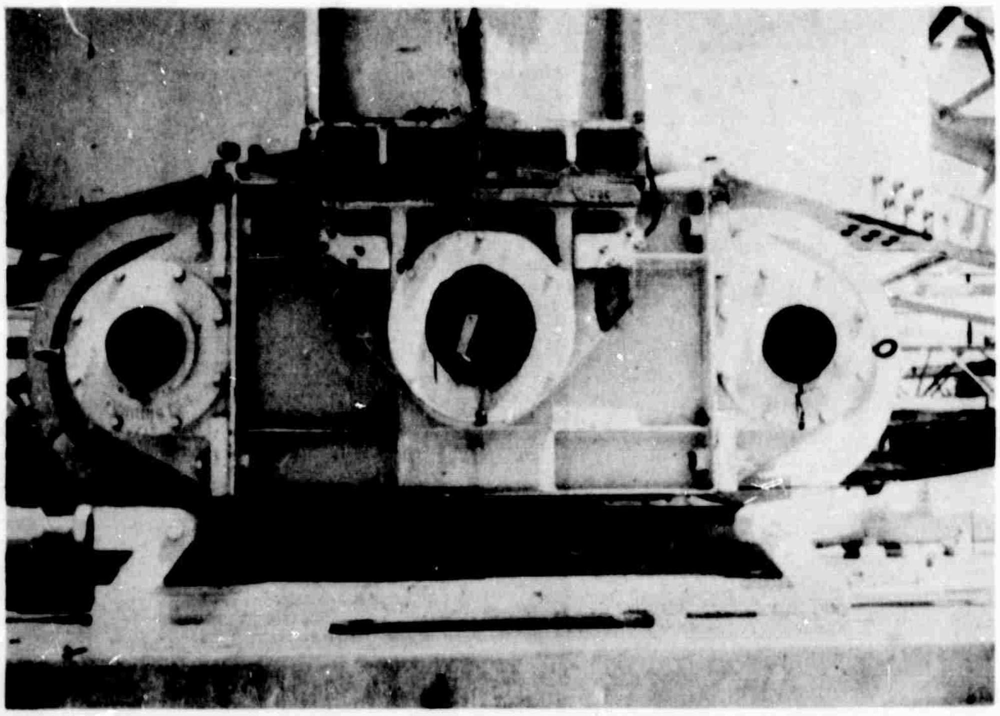
40. The maximum peak-to-peak amplitude of foundation vibration, determined by integrating the velocity versus time records, was about 0.0007 in. in the vertical mode and was caused by maximum azimuth deceleration from a rotation rate slightly greater than the design rate. The vibration amplitudes were less than about 0.0001 in. except during acceleration, deceleration, or in the vicinity of a bogie at rotation rates greater than about half the design rate. The maximum foundation vibrations during constant-rate azimuth rotation occurred at a rate slightly less than the design rate. Operating the antenna only in the elevation mode (constant azimuth) produced practically no tangential foundation vibration and only minor vibrations in the radial and vertical modes.



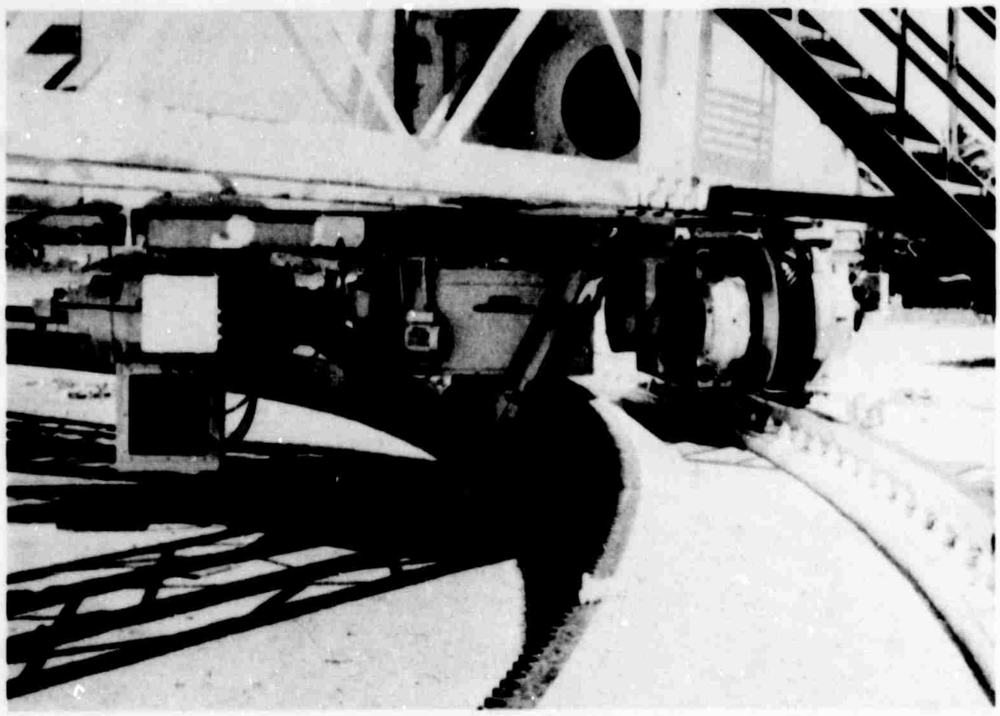
Photograph 1. General view of ALTAIR antenna superstructure



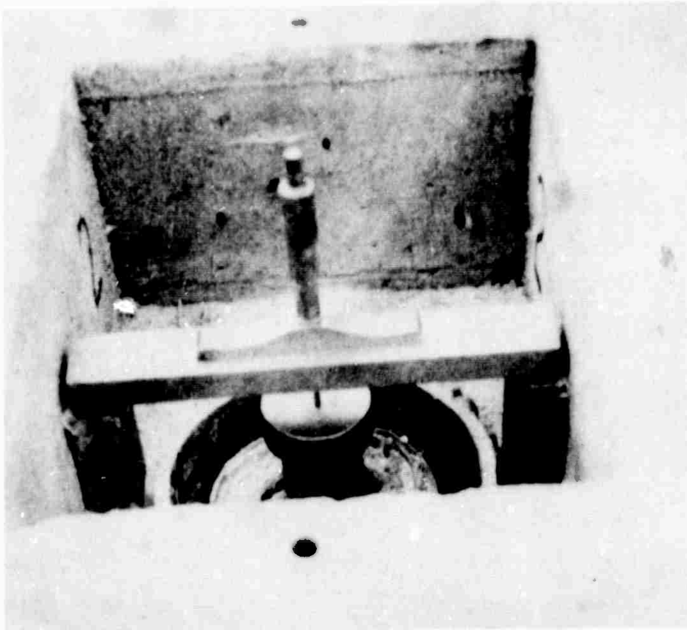
Photograph 2. Close-up of dish and support frame



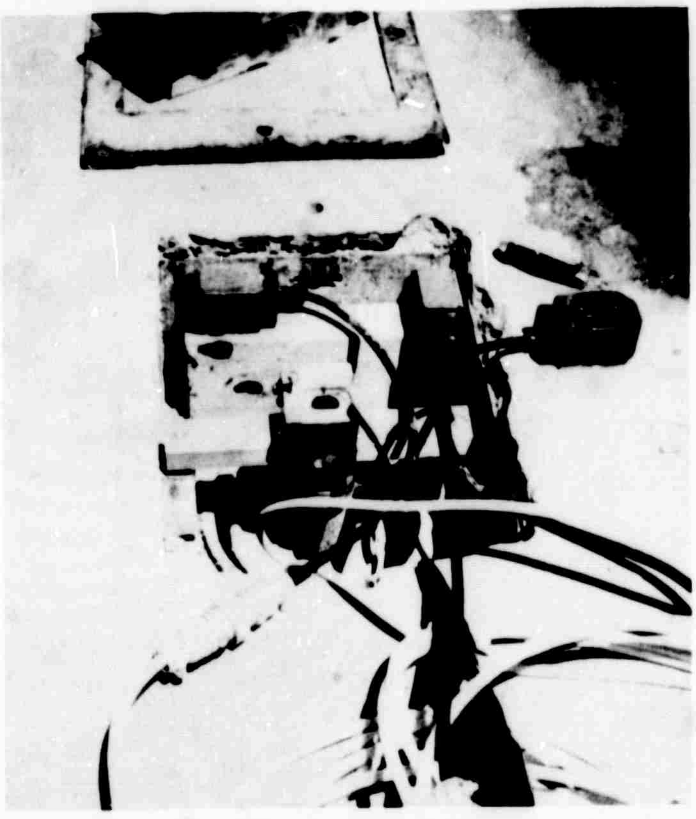
Photograph 3. Bogie at stow position



Photograph 4. One of azimuth drive mechanisms (at drive rail on inside of foundation)



Photograph 5. Settlement gage



Photograph 6. Deflection gage (center) and three vibration pickups

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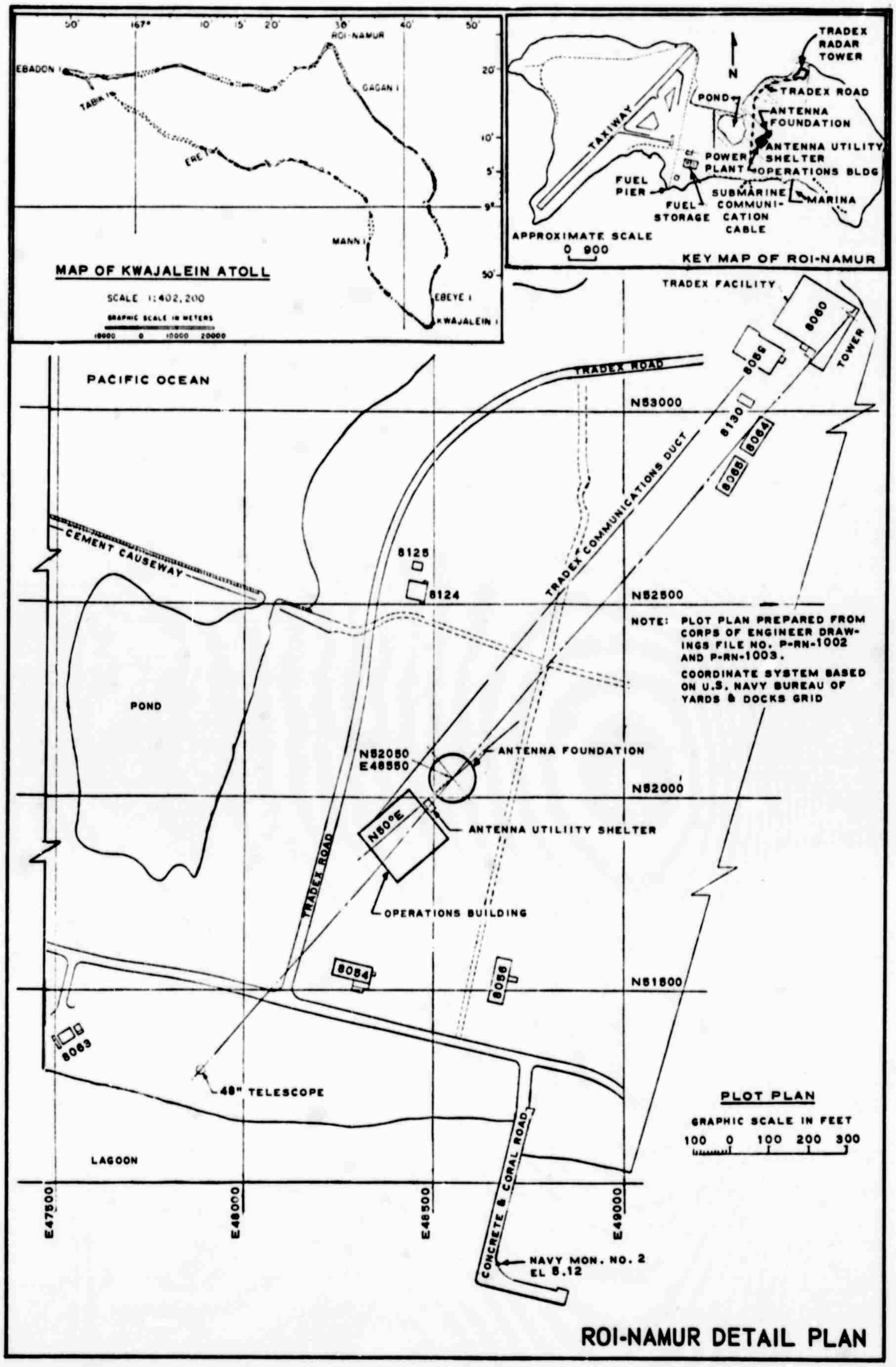
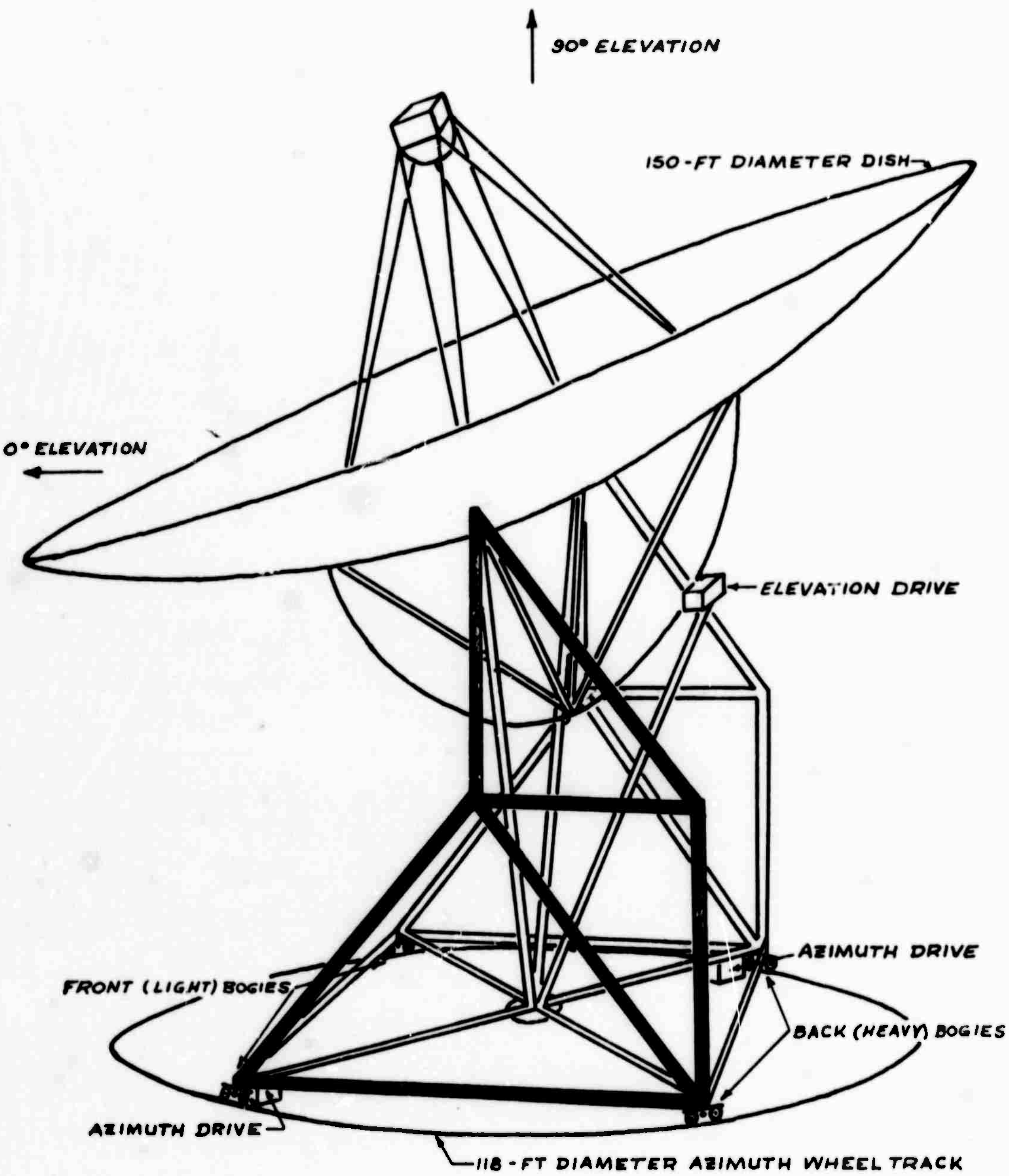

MAP OF KWAJALEIN ATOLL
SCALE 1:402,200
GRAPHIC SCALE IN METERS
ROI-NAMUR
EBADON I
GAGAN I
MANN I
EBEYE I
KWAJALEIN I
TRADEX RADAR TOWER
TRADEX ROAD
POND
ANTENNA FOUNDATION
ANTENNA UTILITY SHELTER
OPERATIONS BLDG
TAXIWAY
POWER PLANT
FUEL PIER
FUEL STORAGE
SUBMARINE COMMUNICATION CABLE
MARINA
APPROXIMATE SCALE
0 900
KEY MAP OF ROI-NAMUR
TRADEX FACILITY
PACIFIC OCEAN
TRADEX ROAD
TOWER
N53000
TRADEX COMMUNICATIONS DUCT
CEMENT CAUSEWAY
8125
8124
N52500
NOTE: PLOT PLAN PREPARED FROM CORPS OF ENGINEER DRAWINGS FILE NO. P-RN-1002 AND P-RN-1003.
COORDINATE SYSTEM BASED ON U.S. NAVY BUREAU OF YARDS & DOCKS GRID
POND
N52050
E48550
ANTENNA FOUNDATION
N52000
N50°E
ANTENNA UTILIITY SHELTER
TRADEX ROAD
OPERATIONS BUILDING
8054
8056
N51500
8063
48" TELESCOPE
PLOT PLAN
GRAPHIC SCALE IN FEET
100 0 100 200 300
LAGOON
CONCRETE & CORAL ROAD
E47500
E48000
E48500
E49000
NAVY MON. NO. 2
EL 8.12
ROI-NAMUR DETAIL PLAN

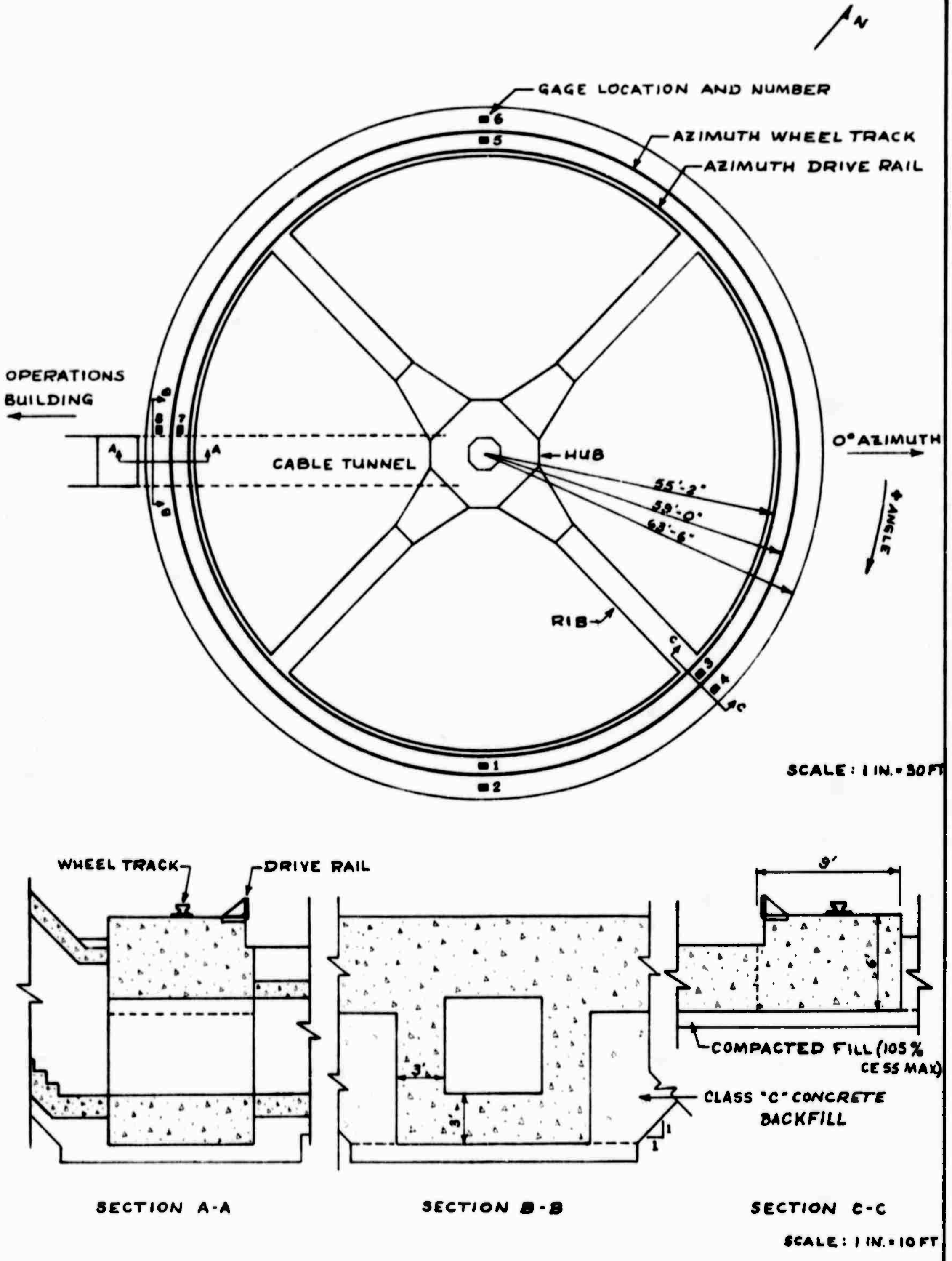
PLATE I



NOTE: BACK BOGIES TRANSMIT 55 PERCENT OF DEAD LOAD
FRONT BOGIES TRANSMIT 45 PERCENT OF DEAD LOAD
DISH IS COUNTERBALANCED

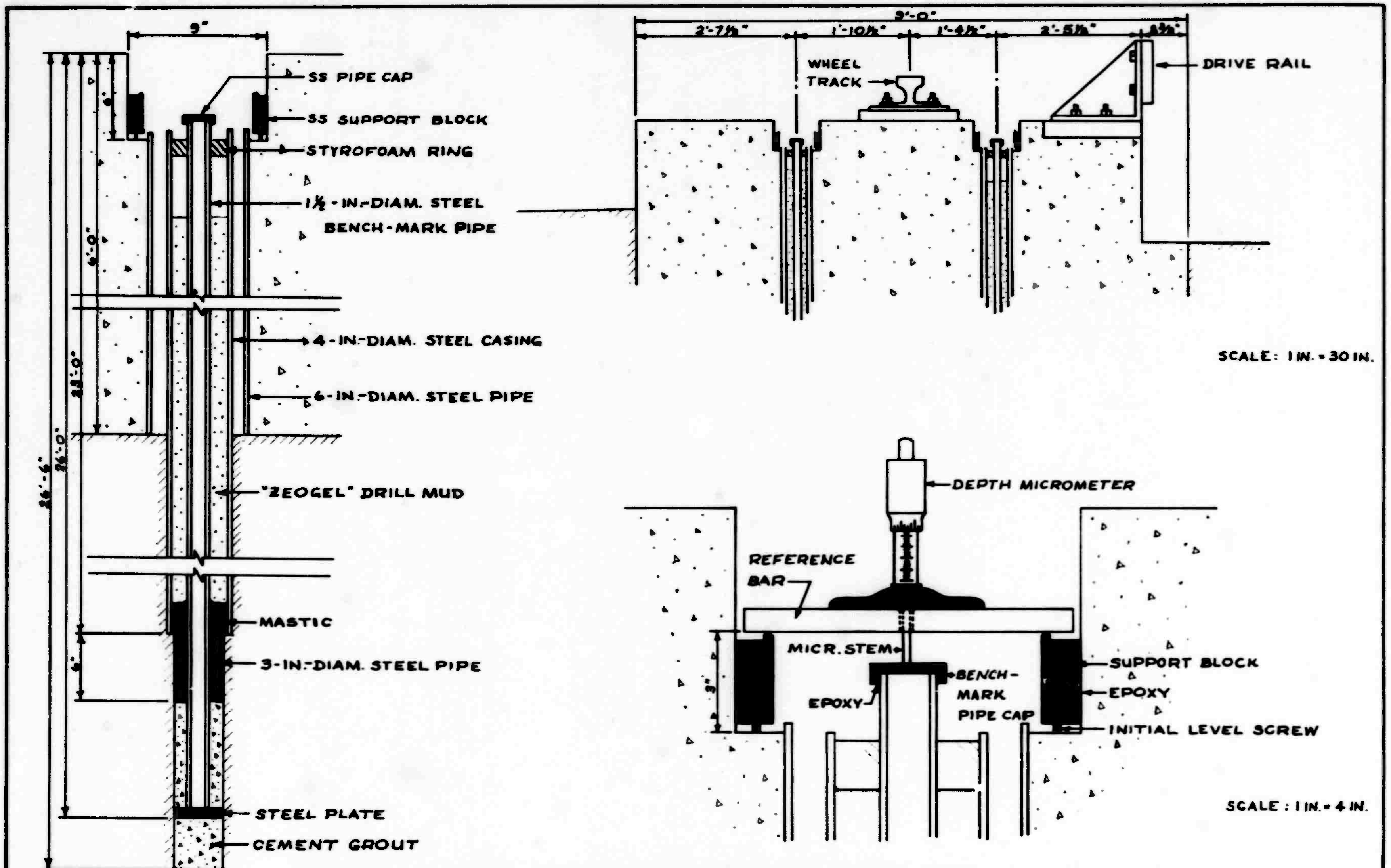
ALTAIR SUPERSTRUCTURE

PLATE 2

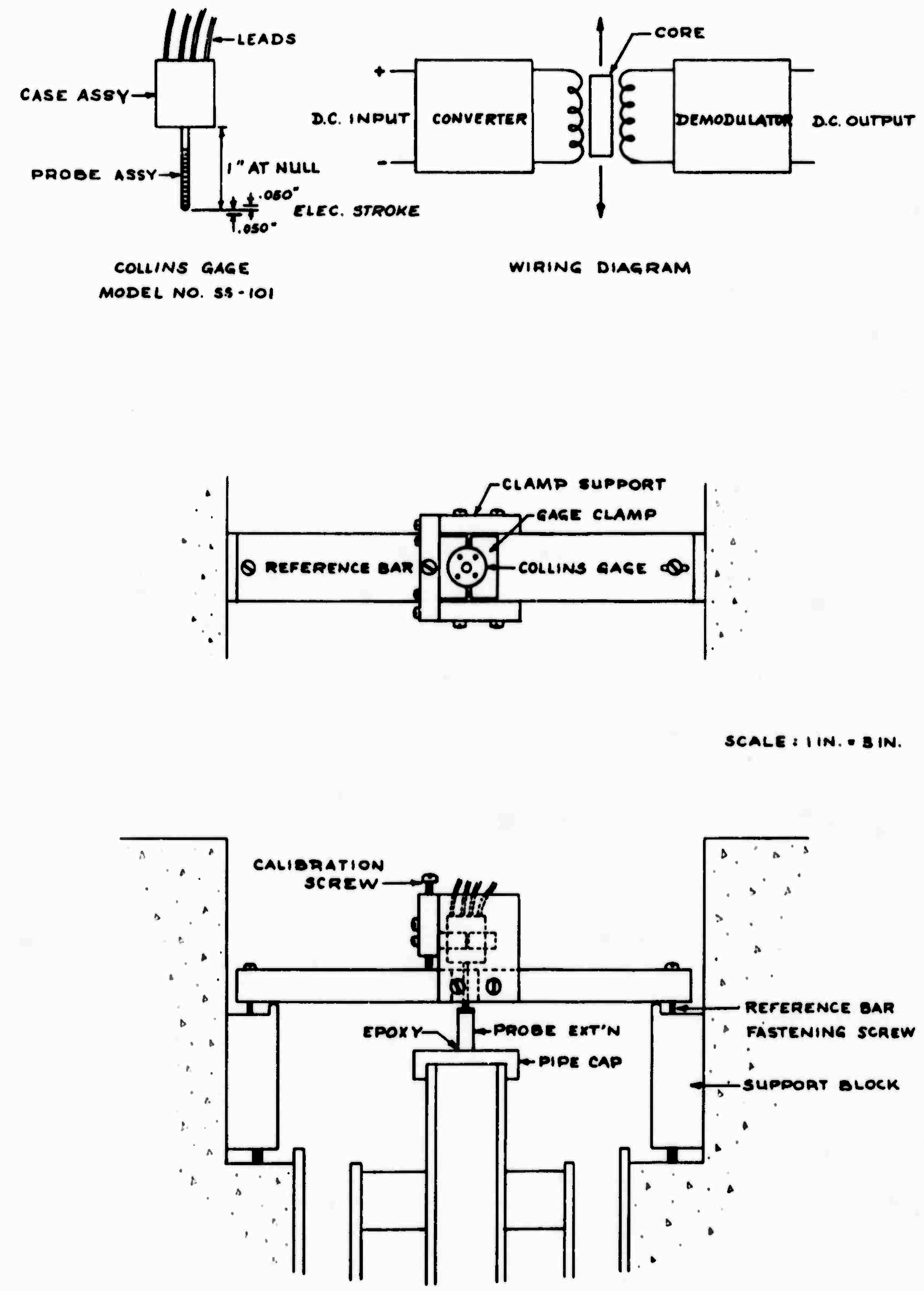


ANTENNA FOUNDATION AND GAGE LOCATIONS

PLATE 4

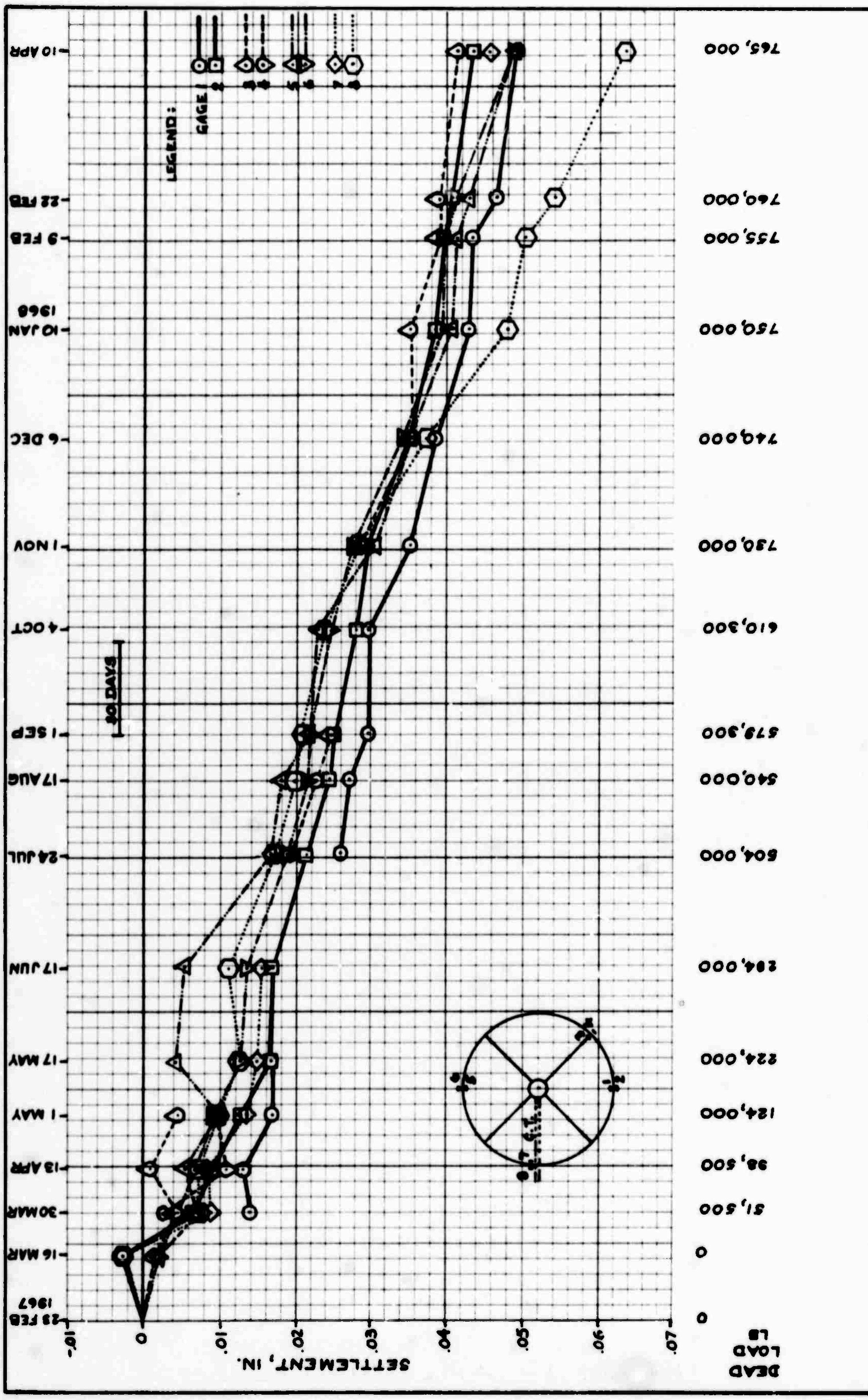


BENCH-MARK INSTALLATION AND SETTLEMENT GAGE ASSEMBLY



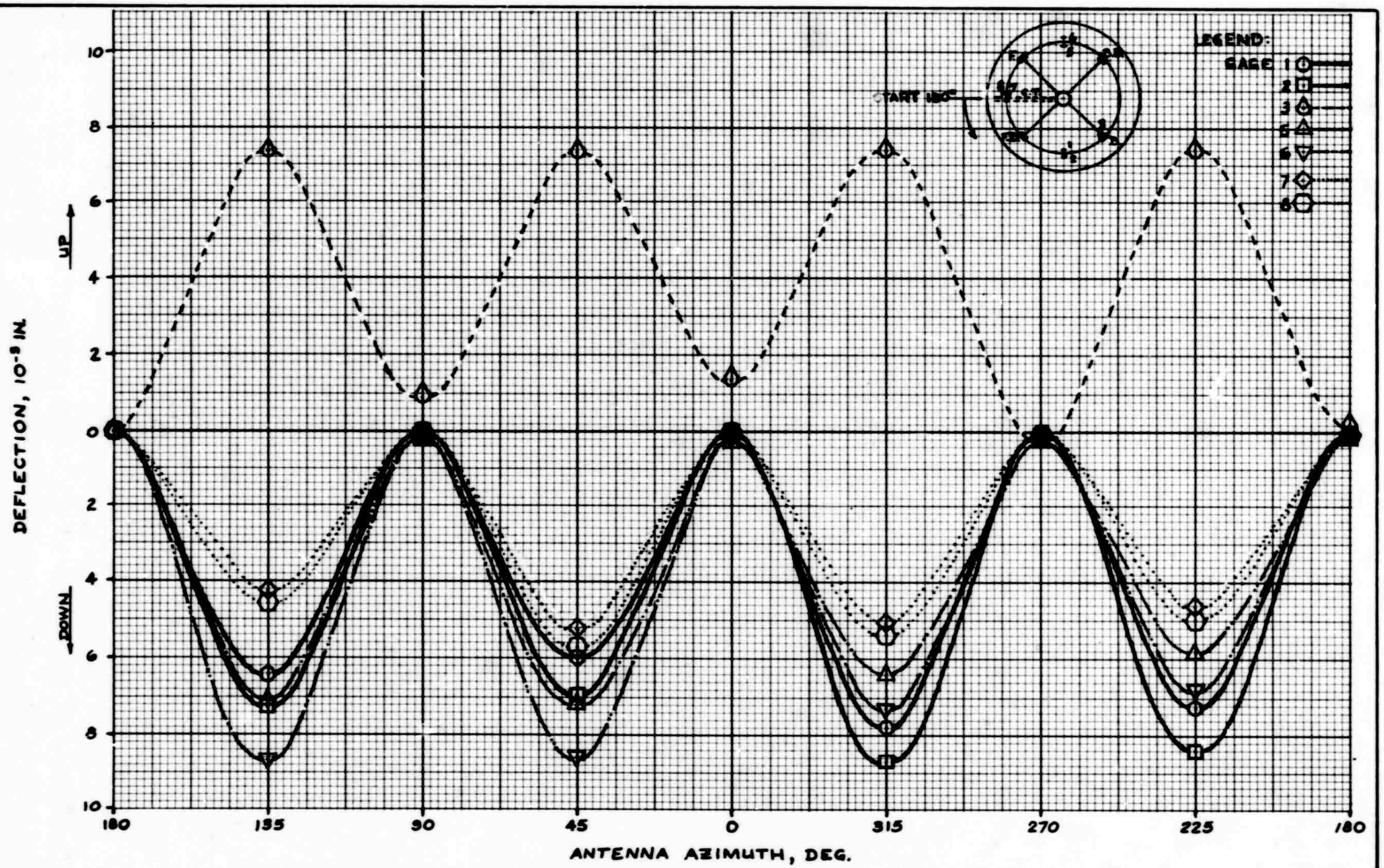
TRANSIENT DEFLECTION GAGE

PLATE 5



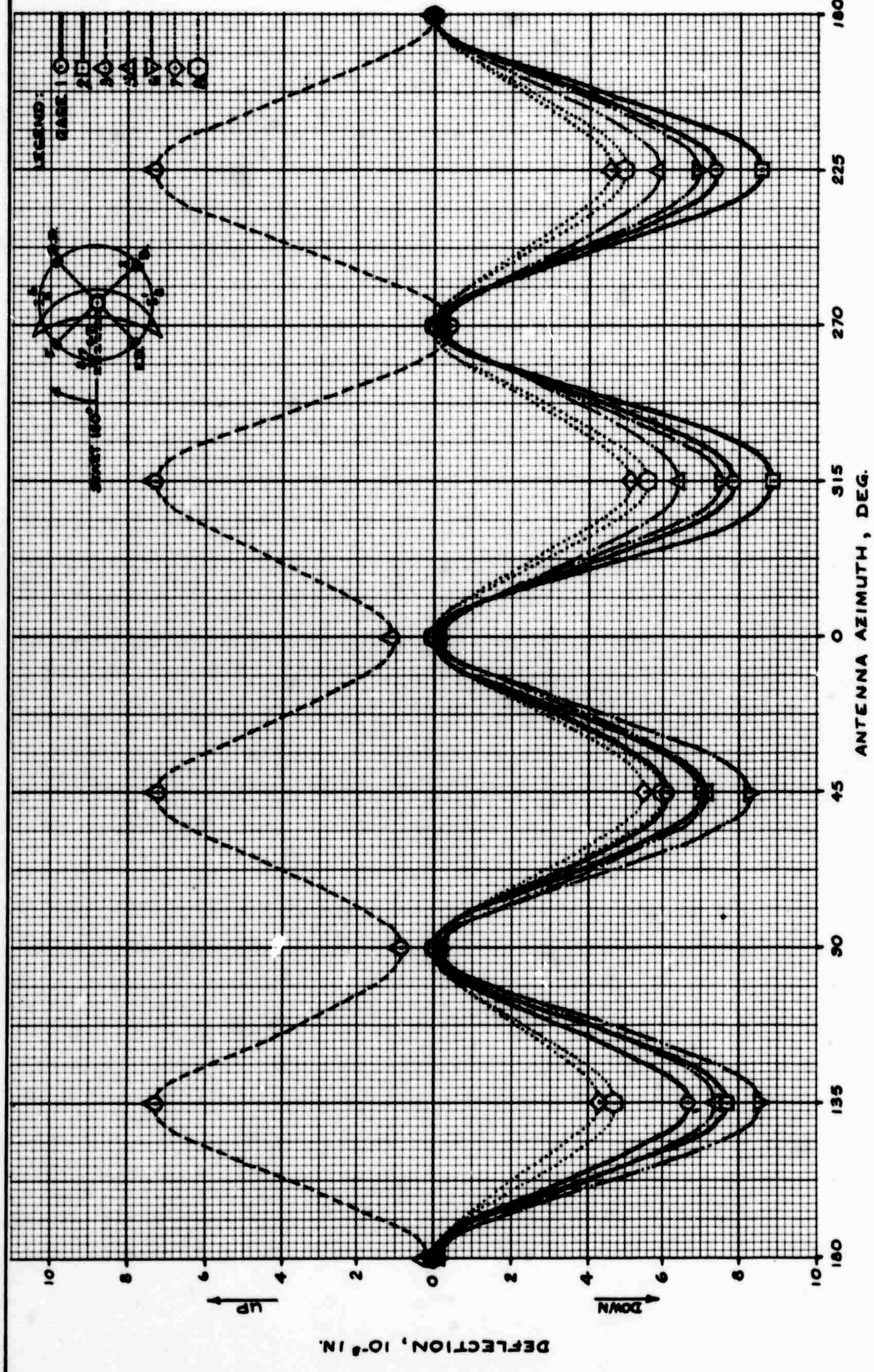
FOUNDATION SETTLEMENT

PLATE 6



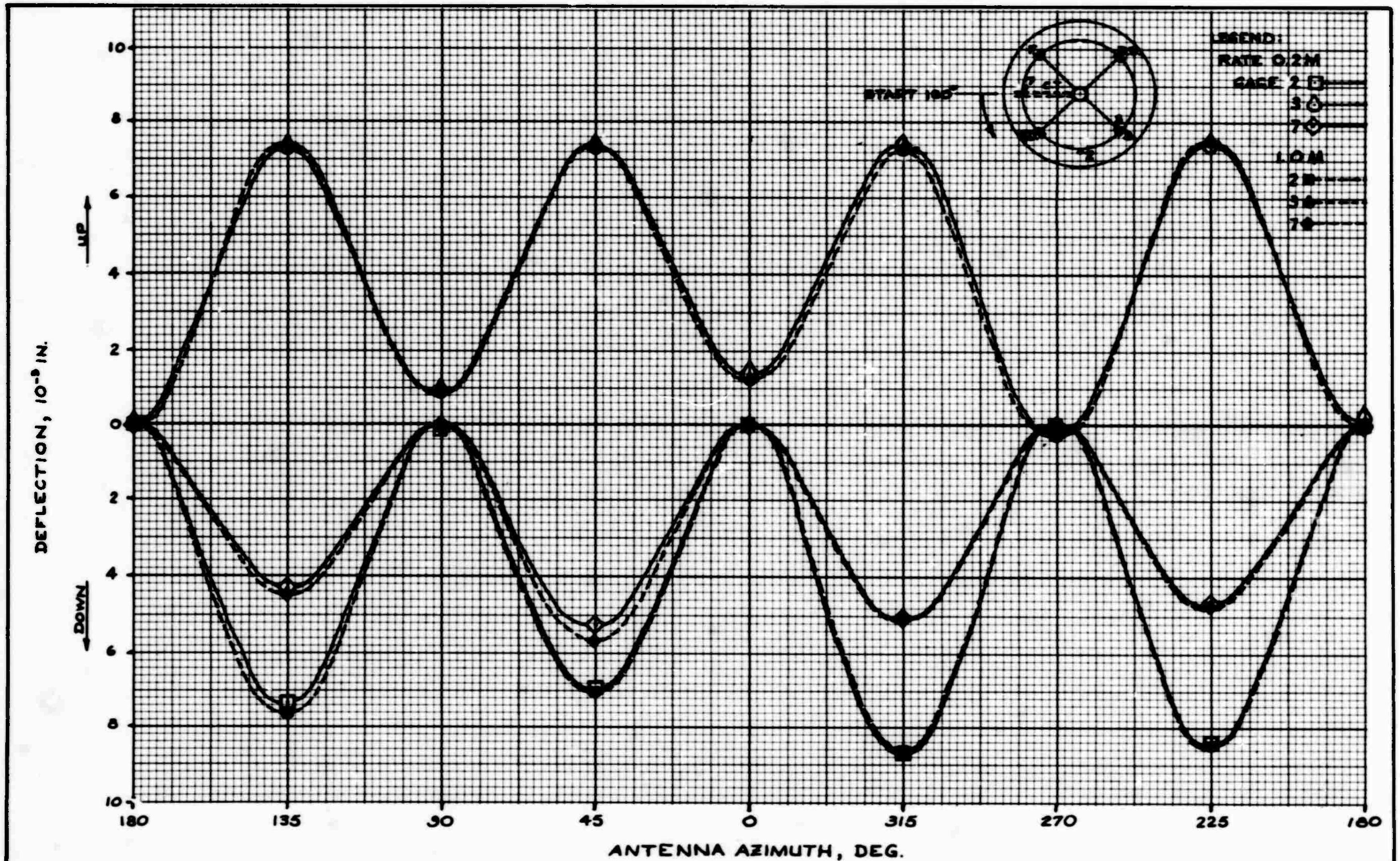
TRANSIENT DEFLECTION, ELEV. 90° - RATE 0.2M

PLATE 7



TRANSIENT DEFLECTION, ELEV. 10° - RATE 0.2M

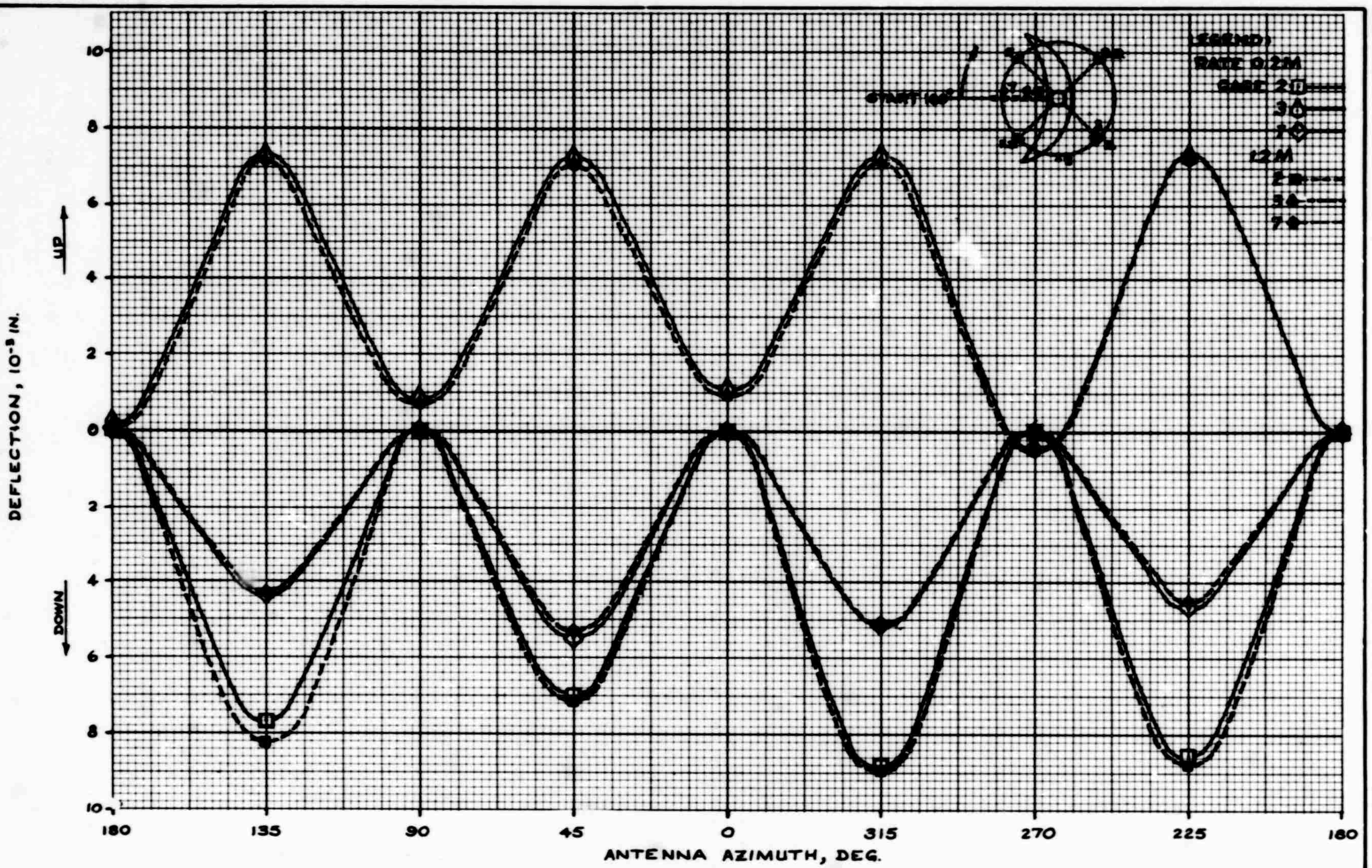
PLATE 8



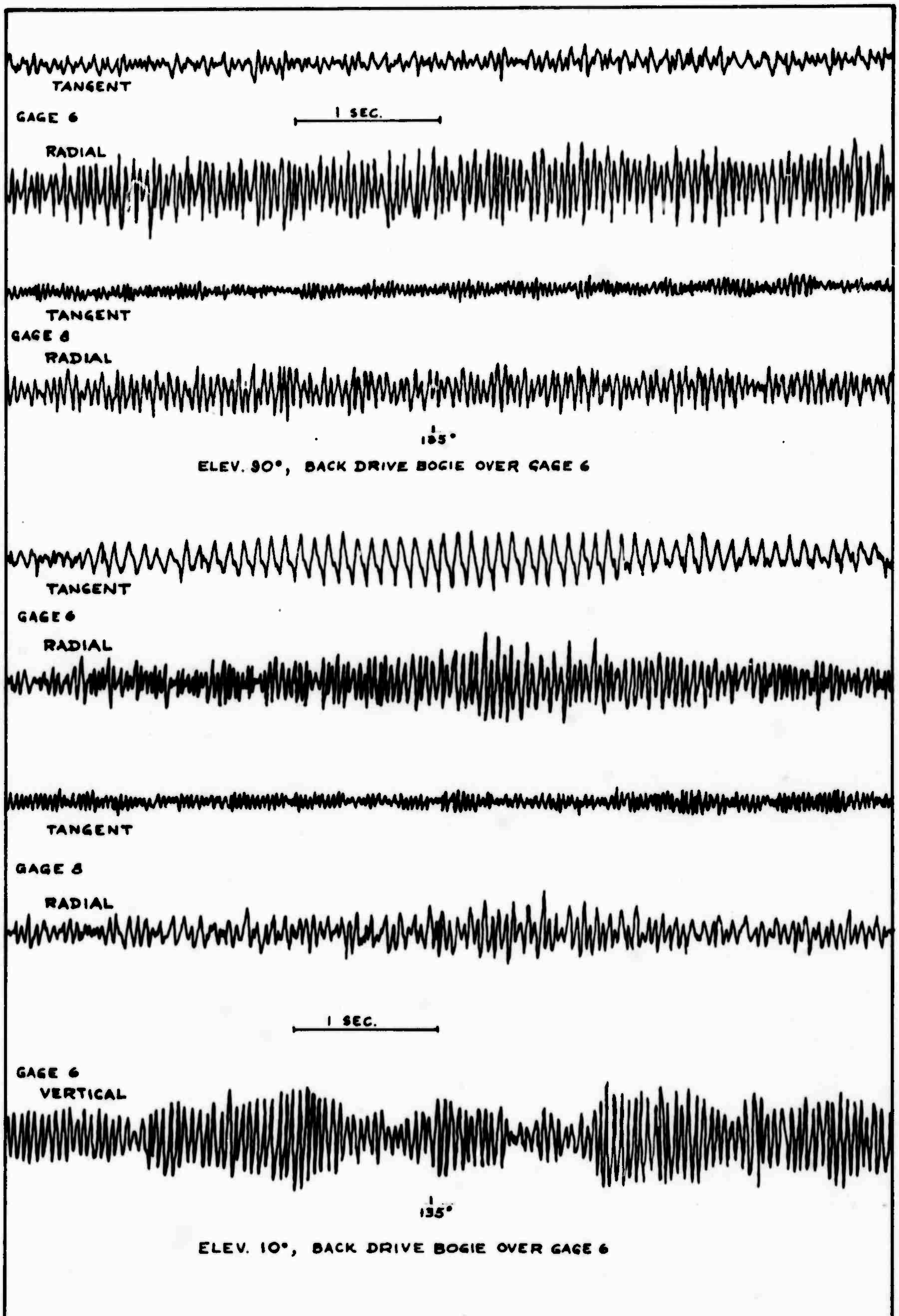
TRANSIENT DEFLECTION, ELEV. 90° - RATE 0.2M AND 1.0M

PLATE 9

PLATE 10

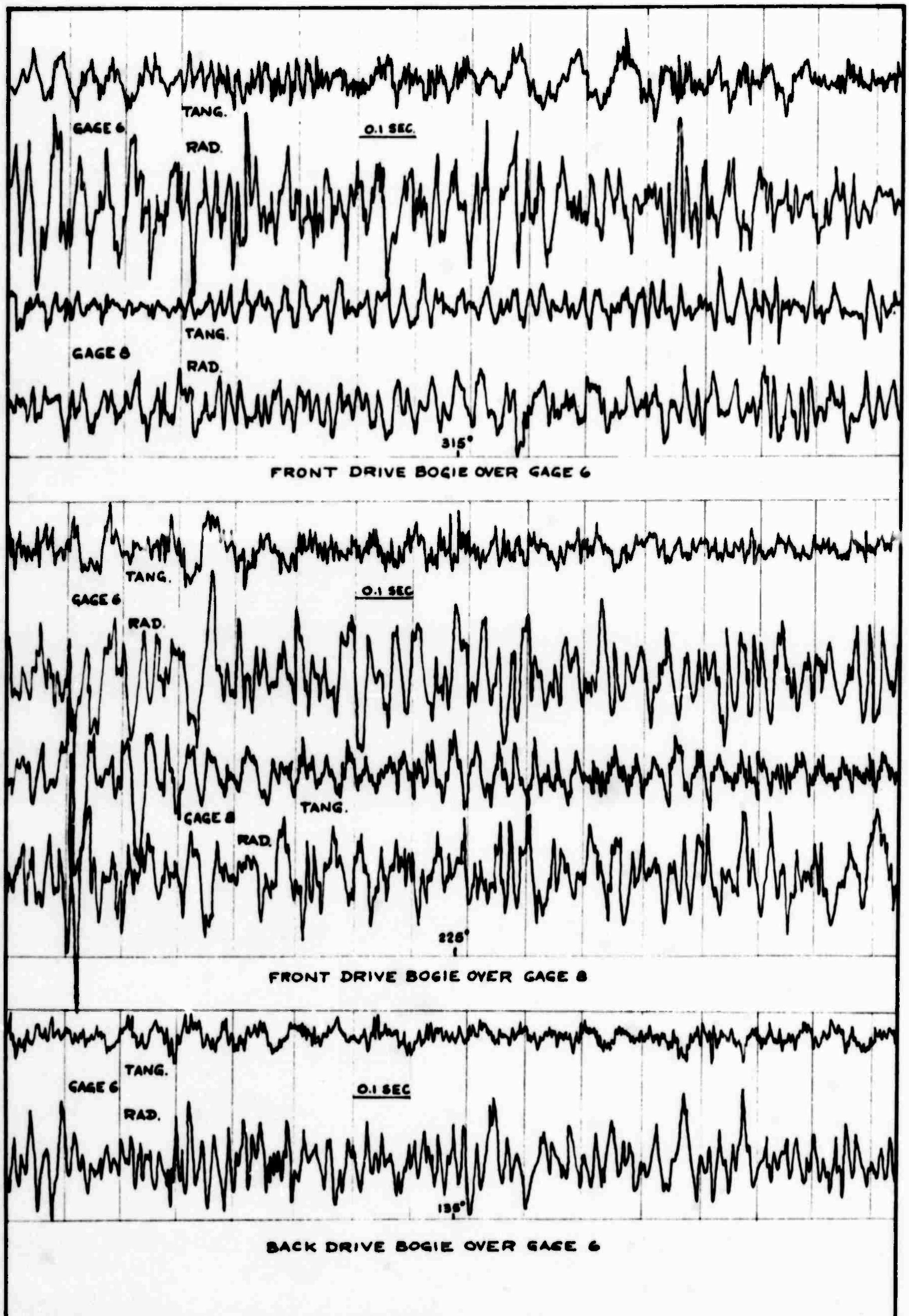


TRANSIENT DEFLECTION, ELEV. 10° - RATE 0.2M AND 1.2M



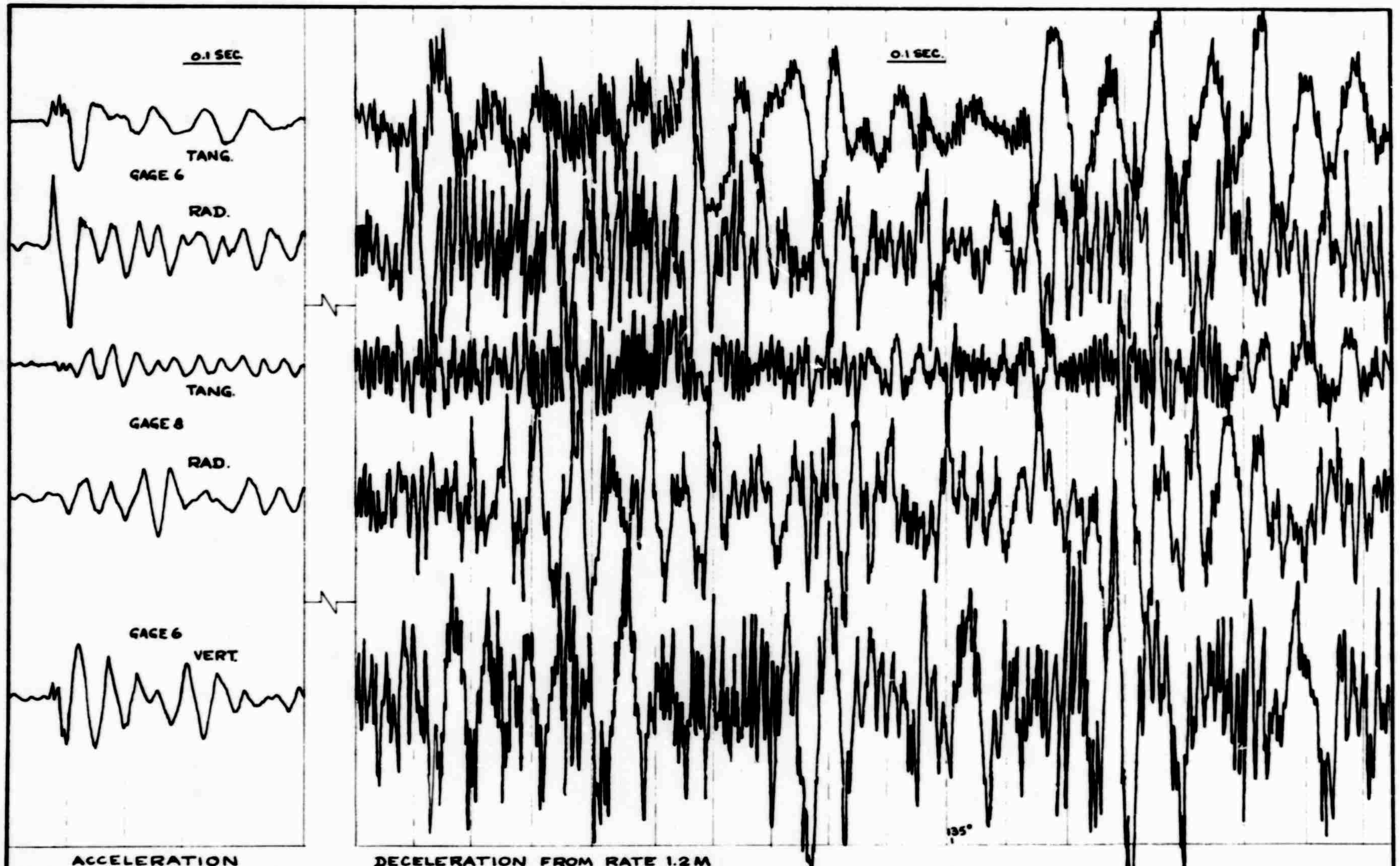
VIBRATION RECORD, VELOCITY VS. TIME - RATE 0.2M

PLATE 11



VIBRATION RECORD, VELOCITY VS. TIME - EL. 90°, RATE 0.8M

PLATE 12



VIBRATION RECORD, VELOCITY VS. TIME: MAXIMUM ACCELERATION - DECELERATION, ELEV. 10°

PLATE 13

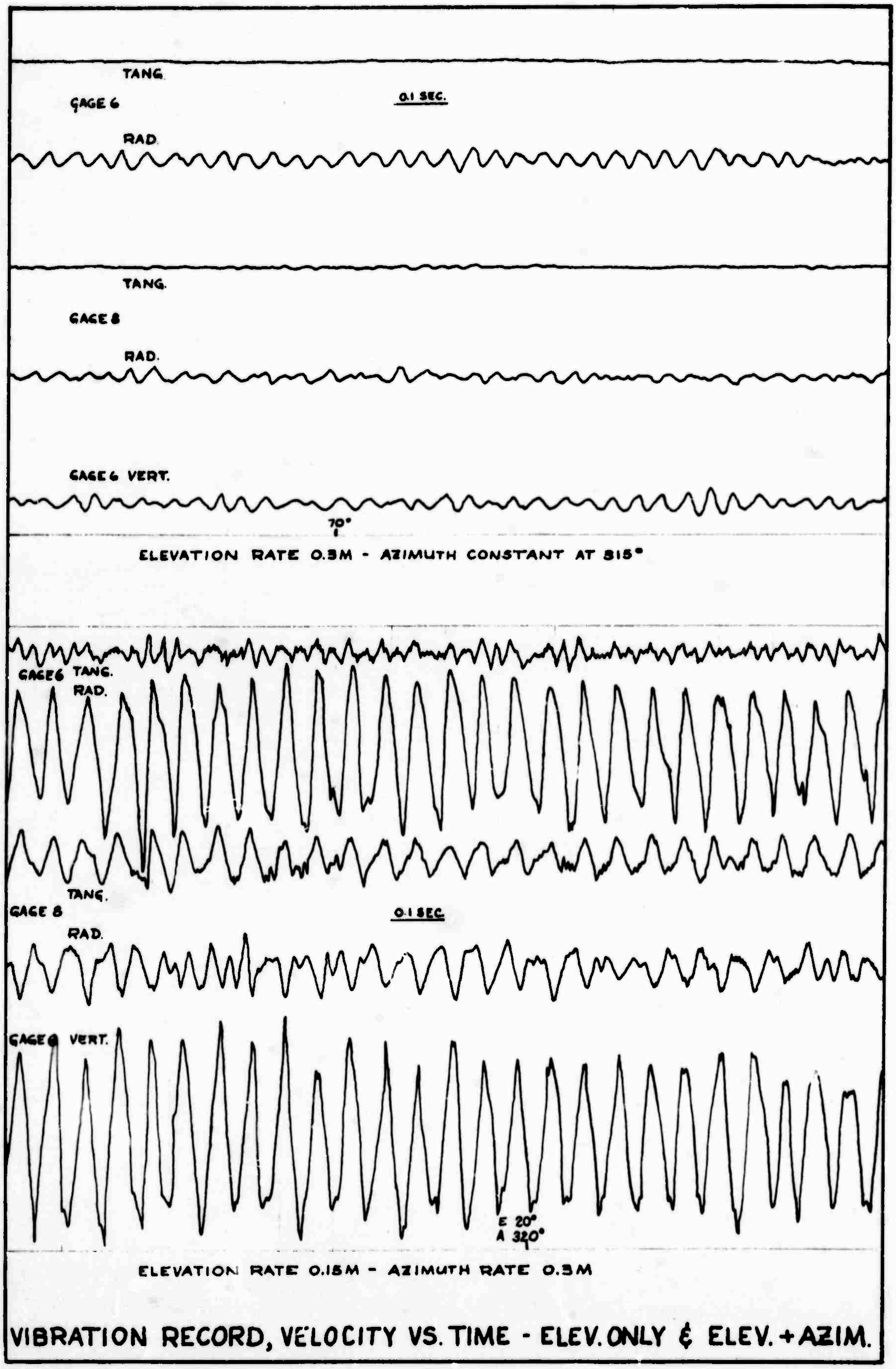
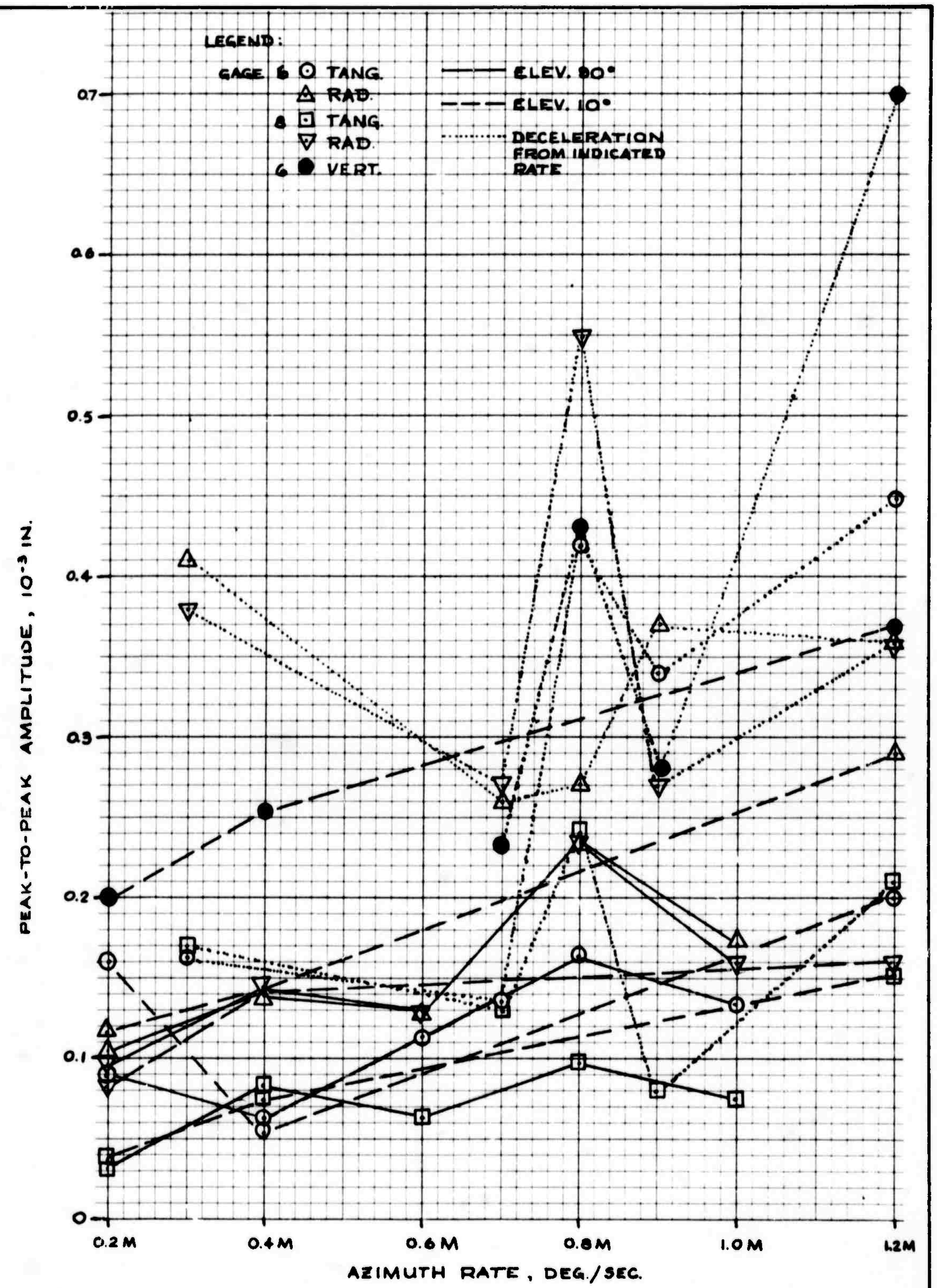
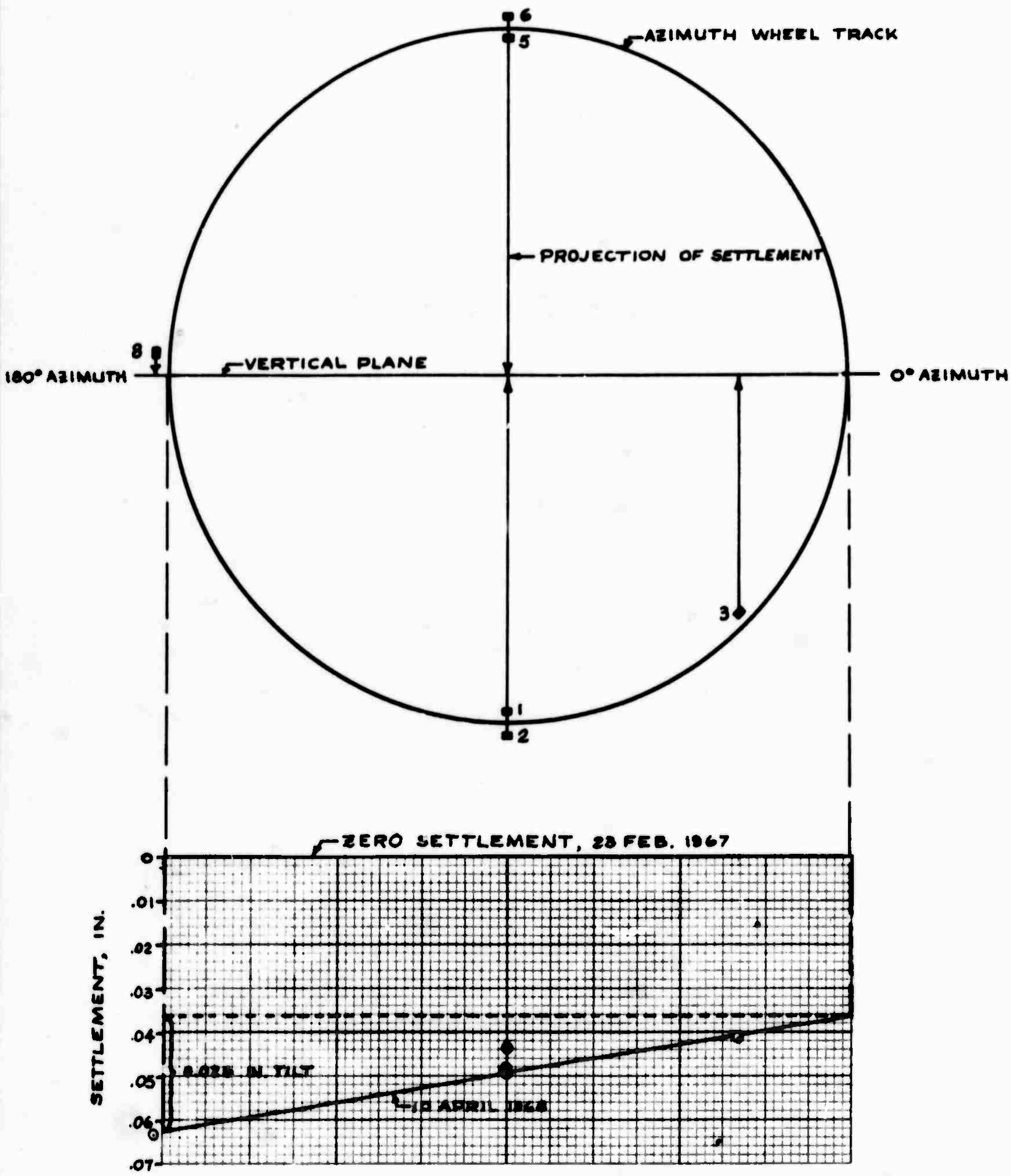

TANG.
GAGE 6
0.1 SEC.
RAD.
TANG.
GAGE 8
RAD.
GAGE 6 VERT.
70°
ELEVATION RATE 0.3M - AZIMUTH CONSTANT AT 315°
GAGE 6 TANG.
RAD.
TANG.
GAGE 8
0.1 SEC.
RAD.
GAGE 6 VERT.
E 20°
A 320°
ELEVATION RATE 0.15M - AZIMUTH RATE 0.3M
VIBRATION RECORD, VELOCITY VS. TIME - ELEV. ONLY & ELEV. + AZIM.

PLATE 14



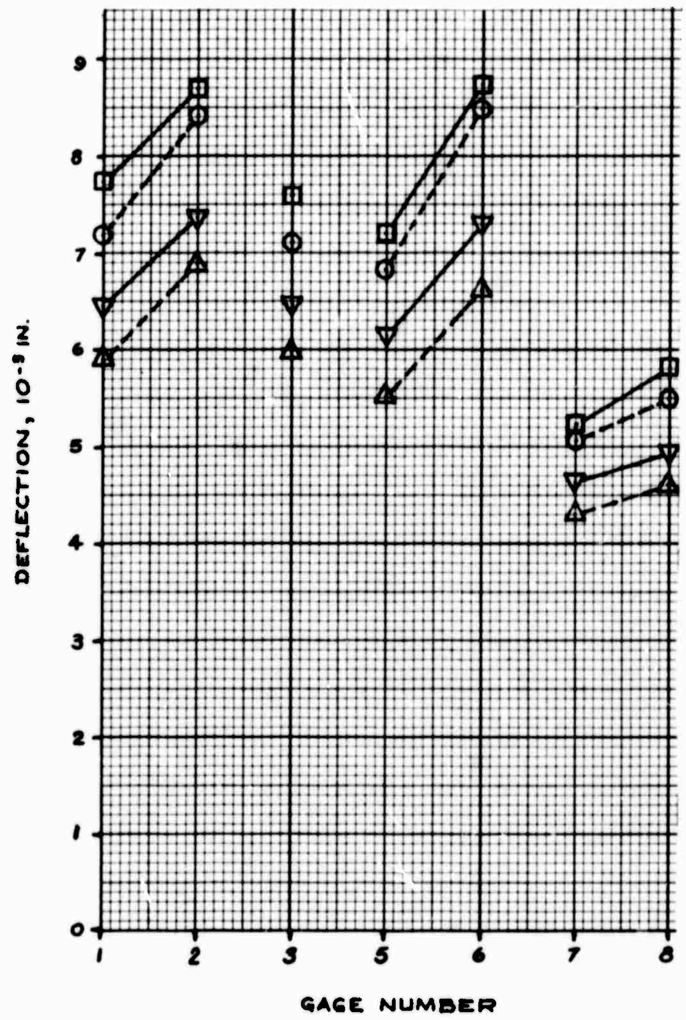
NOTE: AMPLITUDE DETERMINED BY INTEGRATION OF VELOCITY-VS.-TIME RECORDS

VIBRATION AMPLITUDE, ELEV. CONSTANT



TILT OF AZIMUTH WHEEL TRACK, 10 APRIL 1968

PLATE 16



LEGEND:

- ⊡— PEAK DEFLECTION DUE TO BACK DRIVE BOGIE
- ▽— PEAK DEFLECTION DUE TO FRONT DRIVE BOGIE
- ⊙-- PEAK DEFLECTION DUE TO BACK NON-DRIVE BOGIE
- △--- PEAK DEFLECTION DUE TO FRONT NON-DRIVE BOGIE

PEAK TRANSIENT DEFLECTION DIFFERENCE, 90° - 0.2M

Unclassified

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13. ABSTRACT

ALTAIR is an experimental radar installation. Its 150-ft-diam antenna dish is supported by a four-legged frame that rotates on a 118-ft circular track. The track is centrally located on a 9-ft-wide ring-beam foundation. Four radial ribs and a cable tunnel connect to the beam and act as stiffeners. The subsurface materials consist of coral sand and rock. The antenna dish operates in two modes: elevation (vertical) and azimuth (horizontal). The elevation is changed by rotating the dish about a horizontal axis passing through the base of the dish, and the azimuth is varied by rotating the entire support frame. The transient (elastic) deflection of the beam due to rotation of the superstructure ranged from 0.0044 to 0.0088 in., depending on the beam stiffness at the monitoring station. The beam twisted outward as any of the bogies passed any of the monitored points. The angle of this twist was a maximum of about 8 sec. The foundation vibration was monitored radially, tangentially, and vertically to the circular foundation. The main frequency of response in all three modes was 21 Hz. Short-duration frequencies as low as 10 Hz were recorded in the tangential mode. High-frequency vibrations (130 to 170 Hz) of relatively minor amplitude were superimposed on the lower frequencies at azimuth rotation rates greater than about half the design rate. The maximum recorded vibration was 0.0007 in. peak to peak vertically, and was caused by maximum azimuth deceleration from a rotation rate slightly greater than design rate.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Antenna towers						
Radar antennas						
Tower foundations						