Repair of the DSS-14 Pedestal Concrete

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64-Meter Rehabilitation and Performance Upgrade Project

The 64-meter antenna at the Goldstone Deep Space Communications Complex was dedicated in 1966, the first of three 64-meter antennas in the Deep Space Network. About three years after the antenna was dedicated, grout under the hydrostatic bearing runner was found to be interacting with the runner, causing rust to form between the runner and the sole plates upon which it rests. The rust formed unevenly and the runner could not be kept flat so in 1969 the grout was removed and replaced with a Portland cement and sand dry-pack grout that was less likely to produce rust. In the years that followed, oil leaking from the runner assembly caused progressive deterioration of the dry-pack grout. In 1982 over one thousand hours of spacecraft tracking time were lost due to this deterioration. In 1982 a plan was developed to rehabilitate the bearing. The plan called for raising the rotating structure free from the concrete pedestal and placing it on three pairs of external support columns. With the weight of the structure transferred to the columns, the pads and runner could be removed and the repair started. The very successful repair described here included the replacement of a significant portion of the antenna pedestal.

I. Background

The pedestal is the structure which supports the rotating part of the antenna. It is a cylindrical reinforced-concrete structure, 80 feet in diameter and about 30 feet high. Figure 1 shows a cross section of the pedestal. Lateral loads from the antenna are supported by the azimuth radial bearing assembly. Vertical loads from the antenna alidade are supported at three locations on hydrostatic bearing pads spaced equidistantly around the perimeter of the pedestal. Each pad rides on a thin film of oil on a steel runner 5 inches thick. The runner rests directly on steel sole plates grouted to the top surface of the pedestal. Figure 2 is a simplified cross-section diagram of this system.

The pedestal was designed such that the deflection of the runner and concrete under the bearing pad load matched that of the pad to allow the proper operation of the hydrostatic bearing. The concrete mix was designed to achieve a Young's Modulus of Elasticity (MOD E) of at least 5 million psi. Careful quality control was observed during the placement of the concrete to insure that the high MOD E requirement was met, and the test cylinders cast at that time (1964) confirmed the design.

By 1980, 16 years after the pedestal was built, surface cracking in an unusual pattern was noticed. Table 1 is a chronological listing of the events that followed. In May 1980 a core was removed in an effort to determine the depth of one of the vertical cracks in the haunch. The core was sent to a laboratory for a petrographic examination. The examination report suggested alkali aggregate reactivity. At the time the pedestal was built, in 1964, it was known that reactive aggregate was being used. The American Society of Testing Materials (ASTM) specified the use of a low alkali cement (Type II) when this type of aggregate was used based on the results of tests it had conducted. These tests showed no expansion due to reactivity if low alkali cement was used. Unfortunately, these tests were conducted only over a one-year period. It now appears that the use of low alkali cement only postpones the inevitable.

Perhaps the most sobering event came with the measurement of the MOD E for the first cores removed in July 1982. Figure 3 shows the expected behavior of the MOD E with time. Very little data is available since the MOD E is not ordinarily a concrete design characteristic; concrete design engineers usually design for strength, not stiffness. Nevertheless, the measured values of less than 2 million to about 4 million psi were considerably less than the approximately 7 million psi expected. This was the first evidence that a serious problem was at hand. (It should be noted that there was no danger of the pedestal collapsing; the strength was more than adequate.) It was the declining stiffness that was alarming, for that could be contributing to the hydrostatic bearing problem.

A literature search showed that silica alkali reaction in concrete was first recognized in the late 1930s by the California Department of Highways. Although the process was recognized, most work was devoted to understanding the causes and effects. Little was being done to find remedies or corrective action for existing structures.

The primary concerns were establishing what the minimum acceptable MOD E could be, and at what rate the MOD E was deteriorating. In addition to removing and testing core samples, a program of frequent measurements using ultrasonic test equipment was started. The velocity of ultrasonic waves through concrete is proportional to the MOD E, but no information regarding the absolute value can be obtained. However, it is useful for establishing a trend, and, used in concert with the other tests, might give some idea of the useful life of the pedestal. Figure 4 shows the results of these tests. In terms of pulse velocity, the haunch area under the runner was the poorest.

When the pedestal was built, Carlson strain meters were embedded in the concrete. Their purpose was to monitor the curing process of the concrete. Typically concrete shrinks as it cures, fairly rapidly for the first year, then very slowly thereafter. These meters were read regularly for about 24 months, then the readings were discontinued because the meters were indicating little if any shrinkage was continuing to take place. When the readings were resumed in 1981, several of them showed significant expansion since the last readings 16 years earlier, exactly what would be expected if an alkali-aggregate reaction were taking place.

By late 1982 three monitoring programs were under way: 1) removal and test of core samples, 2) ultrasonic testing, and 3) reading of the Carlson strain meters.

In February 1983, measurements of pedestal deflection under load were made. These measurements were compared to similar measurements made in 1968 which confirmed a decrease in the MOD E of the pedestal concrete (Reference 1).

Recognizing that expert help was needed, a contract was let on March 1, 1983, to Construction Technology Laboratories (CTL) in Skokie, Illinois, a division of the Portland Cement Association. CTL is recognized in the construction industry as the leading concrete research organization in the United States, if not the world. It was asked to review the existing data, take its own measurements as required, and address the following:

(1) Confirm that the MOD E was deteriorating.

(2) Determine the rate of deterioration.

(3) Recommend when corrective action should be taken.

(4) Recommend solutions.

The thrust of its activity was to seek a solution that did not require complete replacement of the pedestal, and to do so before the start of the antenna downtime for the hydrostatic bearing repair scheduled for June of that year.

In its first report (Reference 2) CTL stated that the concrete quality had deteriorated within several of the sampled areas of the pedestal, and that it was continuing to deteriorate in the haunch. The average rate of deterioration was estimated to be 5% per year, with the largest estimated rate at particular locations to be approximately 15% per year. CTL went on to state:

> From a review of the data currently available, it cannot be assured with any degree of certainty that concrete in the pedestal will continue to provide the required stiffness for the operation of the hydrostatic bearing. It is possible that the bearing pads may become inoperable in certain regions of the pedestal within the next two years.

Voyager Uranus encounter was 30 months away.

With the hydrostatic bearing downtime scheduled to start June 6, it seemed appropriate to develop a solution before the downtime started. If the solution proved to require significant planning, it could be necessary to delay the start of the downtime. With this in mind, an Engineering Review Panel was established, and the review set for late in the month of May. At that review CTL presented the results of its study effort.

At the review several schemes were presented for repairing the pedestal. Figure 5 illustrates those considered. Plans A and C were basically containment schemes. Plan B was modified to include as much of the haunch as practical (Plan B-1) and was the plan adopted. The review panel unanimously agreed that removal of most of the haunch was the prudent course of action.

II. Description of Repair Action

On June 13, 1983, the antenna was taken out of service and preparations made to start the repair. Prior to this time the steel support columns had been designed, fabricated and shipped to the site. The design criterion of these columns (illustrated in Fig. 6) was that they must support the antenna such that it could withstand all forces included in the basic design. This included wind and seismic forces. Reinforced concrete spread footings for these columns had been constructed several weeks prior to the start of the downtime period.

All components that were to be removed and saved for reinstallation were tagged with plastic identification labels. After the reservoir walls and hydrostatic bearing piping were removed, hydraulic jacks were placed under each of the three corners of the alidade structure. The estimated weight of the alidade was 2.1 million pounds at Pad #3, and 2.0 million at each of the other two pads. Four jacks were placed under each corner weldment: two rated at 400 tons and two rated at 300 tons for a lifting capability of 2.8 million pounds. All jacks and associated equipment had been previously tested and certified by an independent laboratory.

The antenna structure had to be raised enough to allow the removal of the pad assembly. In previous situations the structure was lifted 0.25 inch. In this case, since the structure weight was to be transferred to external supporting columns, the compression of the columns, and the soil under the columns, had to be considered. The column compression was straightforward to calculate and found to be 0.100 inch. The soil characteristics were less well known and the most conservative estimate of compression was 0.60 inch. All factors considered, it was decided to raise the antenna 0.9 inch. Instrumentation was installed to monitor not only the vertical motion as the structure was being raised, but the horizontal as well. This was necessary to insure that undue forces were not transmitted to the radial bearing during this operation.

The structure was raised 0.1 inch at a time at each of the three corners. A 6-inch-diameter steel stool was placed alongside each jack as a safety precaution, and shims were added to fill the gap as the structure was raised. When the antenna had been raised the full amount, the bearing pads were removed, and the steel support columns installed. When Pad #2 was removed, a crack was discovered in the bottom plate of the corner weldment. This crack is similar to one found at DSS-43 several years earlier. The crack appeared to be an old one and was repaired before the pad was reinstalled.

To prevent sudden loading of the soil under the column foundations, the load was transferred from the jacks to the columns over a three-day period. Instrumentation was installed to monitor the settling of the columns. After several days the settlement stopped at about 0.45 inches. The actual weight of the rotating part of the antenna was measured as 6,123,856 pounds based on the hydraulic pressure required to raise it.

With the pedestal free of the antenna structure, the hydrostatic bearing runner segments were removed. Particular care was taken during this removal so that the condition of the old grout could be observed. Of special interest was the epoxy grout which had been installed 9 months earlier as a test case. Epoxy grout was being evaluated as an alternative to the Portland cement grout because of its better oil resistance property. While it appears to be a viable product for grout repair, the complex and demanding handling requirements were too severe for use in this repair task.

The runner segments were removed to a work area to the east of the antenna where they could be reworked. Before the runner was removed, careful measurements were taken of the distance from the top of the runner to the top of the azimuth bull gear. In this way the runner could be replaced at the same elevation.

With the runner segments off the pedestal, work could start on the removal of the concrete. Although the MOD E was below the design requirements, the compressive strength was still quite high and it was recognized that this would make removal difficult. In addition, the concrete contained a large amount of reinforcing steel which further complicated removal. Prior to the antenna downtime a proprietary expansive agent had been tested which could be used to crack the concrete in preparation for removal by jackhammers. One-inch holes were drilled six feet deep on 12-inch centers in a horizontal plane. These holes were then filled with the expansive material and allowed to set for 24 hours. Although some cracking did take place, the contractor had considerable difficulty in breaking up the concrete with jackhammers. At this point he employed a hydraulically powered machine which imparted forces on the concrete of several thousand pounds at 250 cycles per minute. This caused the whole pedestal to vibrate such that there was concern for its safety. Work on concrete removal was stopped until another approach could be developed.

After a week of tests, a stronger expansive agent was employed, and a new pattern of breakage was established. First, the outer four inches of the pedestal wall were removed, exposing the one-inch reinforcing steel. These steel bars were then cut, and horizontal holes were drilled on 12-inch centers, so that a horizontal cracking plane was established. The stronger expansive agent generated horizontal cracks of 0.5 to 1 inch. Removal by jackhammer was thus made easier. It took about 5 days for a crew of four men to remove a segment forty feet long.

The concrete was not removed all at one time. The pedestal is basically a cylindrical structure with a roof deck. The portion to be removed consisted of the corner between the vertical wall and the roof deck. It was impractical to support the roof deck from below. Furthermore, the radial bearing, which resists lateral loads, is an integral part of the roof deck. Two steps were taken to insure the structural integrity of the pedestal during the removal process. First, six 2.25-inch-diameter steel cables were wrapped around the pedestal just below the area to be removed. These cables were tensioned to 180,000 pounds and provided circular restraint. Second, the concrete was removed three segments at a time as shown in Fig. 7. After each set of three segments had been replaced with new concrete, it was allowed to cure for seven days before removal was started on the adjacent segments. In this way, two-thirds of the connection between the pedestal wall and roof deck was in place at all times. The first three segments removed were those at the pad locations. Thus, when the antenna structure was replaced on the pedestal, it would rest on the oldest concrete. This strategy was adopted to minimize creep since it would be several months before the antenna would be rotated.

Replacing the concrete meant that a new mix design had to be developed. Several sources of non-reactive aggregate were identified in California and three of these were selected for test. Construction Technology Laboratories tested fourteen mix designs which are summarized in Table 2. Aggregate from Lytle Creek in San Bernardino County has the reputation for being of excellent quality and had the added advantage of being close to the job site. It was therefore disappointing when the MOD E values for those samples were lower than the design goal of 5.0 million psi. Investigation revealed that the aggregate, from a river bed, had a relatively soft surface due to long term exposure to the elements. This made it necessary to consider only quarried and crushed aggregate so that the surface would be "fresh." The aggregate ultimately selected came from a quarry near Mountain View, California, some 400 miles from the job site.

Other factors which influence concrete quality are the cement content (sacks/cubic yard), the water/cement ratio (which determines the slump), and the use of a super-plasticizer (which improves workability of a mix with a low water/cement ratio). In general the MOD E is improved with increasing cement factor and decreasing water/cement ratio. There is no test data to indicate the effect on the MOD E with the use of a super-plasticizer although CTL felt there would be no deleterious effect.

Mix 12-7 with super-plasticizer was selected for the replacement concrete. Pumping the concrete into the first section was extremely difficult. It was concluded that the large (1.5 inch) aggregate was getting lodged in the hose, so the mix was changed to use 1-inch aggregate, and the water/cement ratio lowered to 0.42 from 0.45. As it later developed, the difficulty was that the water content was lower than thought due to the way the aggregate absorbed the moisture. Fortunately, low water content raises the MOD E, a desirable feature. Table 3 summarizes the two mixes.

Test cylinders were cast during the placement of the concrete and these cylinders were tested after cure times of 7, 28 and 60 days. The results of these tests show MOD E values well in excess of the 5 million psi specified. The test results are plotted in Fig. 8.

III. Conclusion

Raising the 6-million-pound antenna and placing it in a temporary support structure, removing the hydrostatic bearing, and removing and replacing 450 cubic yards of concrete was a monumental task. The task was completed on schedule, within budget, and without a lost-time accident. The concrete replacement required working with state-of-the-art technology, and the development of new design considerations for high MOD E concrete. As a result, the replacement concrete now provides a stiff ring around the pedestal which will provide excellent support for the hydrostatic bearing at DSS-14 for many years.

Acknowledgment

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References

1. H. McGinness and G. Anderson, "Evaluation of Antenna Foundation Elastic Modulus," TDA Progress Report 42-73, January-March 1983, Jet Propulsion Laboratory, Pasadena, California, pp. 89-91.
2. "Evaluation of DSS-14 Pedestal—Review of Concrete Quality, Report No. 1 to JPL Contract No. 956494," May 1983, Construction Technology Laboratories, Skokie, Illinois.

Table 1. History of DSS-14 pedestal concrete analysis

Date	Comment
May 1980	Cracks in the pedestal had been observed prior to this time, but in May 1980, a core was removed from the haunch area (135 degrees trough azimuth). This core was taken on a vertical crack in an effort to determine how deep the crack went. The sample was sent to an independent laboratory for a petrographic examination.
August 1980	A report was made to the DSS-14 Life Maintenance Task Force which included results of the petrographic study on the pedestal cores. The petrographic study included the words "strongly suggest" alkali aggregate reactivity. A recommendation was made at that time to reestablish the Carlson meter readings, maintain integrity of the paint (to prevent moisture intrusion), caulk the cracks, and discontinue steam cleaning the pedestal.
Late 1980 to Mid 1982	An extensive literature search was conducted. Also, the contract industry was surveyed to determine what others had experienced in the way of reactive aggregate and, furthermore, what steps might be taken to arrest the reaction. Some of the organizations contacted were: Owl Rock, owner of the Barstow Pit (source of the original aggregate); Bureau of Reclamation; Caltrans; Corps of Engineers; Holmes and Narver (did original pedestal design); Portland Cement Association; and University of California, Berkeley.
October 1981	Dave Stark of Construction Technology Laboratories (CTL) visited both DSS-13 and DSS-14 to inspect cracking and concluded that reactivity was occurring in both antennas.
December 1981	Started recording Carlson strain meter readings once a month. (The start was delayed due to some difficulty in locating the documentation of the first two years' readings, the measurement device, and instructions for using it.)
July 1982	Started a program to periodically remove core samples from various portions of the pedestal. These samples were to be tested for Young's Modulus of Elasticity (MOD E) in an effort to determine if the MOD E was changing.
August 1982	Contracted for the consulting services of Mr. J. Dobrowolski (a private consultant) to perform pulse-velocity tests through the concrete pedestal at several locations. Mr. Dobrowolski was formerly with the Portland Cement Association and is a distinguished engineer in the concrete industry. Pulse-velocity measurements were taken once a month in an effort to develop the rate of the MOD E deterioration. These tests were to complement the direct measurement of the MOD E on core samples removed from the pedestal.
December 1982	JPL cognizant engineer met with CTL engineers to outline a program to determine rate of deterioration and possible solutions to the problem of the pedestal. The feeling at that time was that the issue would have to be addressed either shortly before Neptune encounter (1989) or perhaps after that encounter.
January 25, 1983	Proposal from CTL was received.
March 1, 1983	A contract was let to CTL to: a. Confirm that the MOD E was deteriorating. b. Determine the rate of deterioration. c. Determine when corrective action should be taken. d. Recommend solutions. The thrust of the CTL activity was to find out when corrective action was necessary and if something short of replacing the entire pedestal was feasible. The time schedule was to provide a preliminary report in April, with the final report due in October 1983.
April 8, 1983	In a letter reporting its preliminary findings, CTL stated that the rate of deterioration in the haunch area was such that serious hydrostatic bearing support problems could be expected within the next two years if corrective action was not taken. It further recommended that some form of corrective action be taken during the hydrostatic bearing downtime scheduled to start June 6, 1983.
May 2, 1983	CTL made a presentation to JPL which showed the results of its analysis of test data taken both before and after CTL was placed on contract. Based on this presentation, a meeting was set for the next day to seek solutions.
May 3, 1983	Meeting was held at JPL with JPL engineers, Project staff, CTL, and Mr. Robert Hoggan (a professional structural engineer consultant from H. Robert Hoggan & Associates). The purpose of the meeting was to explore means of replacing the major portion of the haunch concrete as recommended by CTL. Two options were developed but additional test data was needed to support the design of either of them.
May 27, 1983	An engineering review panel met at JPL to review the options for replacing haunch concrete and the advantages, disadvantages, cost, and schedule impact for each. The review panel and audience included structural engineering personnel, engineering managers, and Project staff, with CTL participating in the review. At the conclusion of the review, the unanimous choice of the review board, as well as the engineering personnel in the audience, was a plan to remove essentially all of the haunch material and replace it with new concrete.
June 13, 1983	The antenna was taken out of service, and the repair work started. Over the next twelve months, the rotating structure was raised and supported on temporary columns, the hydrostatic bearing removed, the haunch concrete removed and replaced, the bearing replaced, and the antenna returned to service. The performance of the hydrostatic bearing was equal to, and in some areas exceeded, the original performance.
June 15, 1984	The antenna was placed on-line to support the Mark IVA implementation.

Table 2. Mix designs and test results

Mix number	Coarse aggregate	Fine aggregate	Cement, sacks/yard^3	Water/ cement	SWR^a	Slump, inches	Density, PCF	Compressive strength and MOD E^b		
								1 day	7 days	28 days
10-1	Owl Rock Lytle Creek	Owl Rock Lytle Creek	7.0	0.35	Melment	2.4	152.5	4825 3.21	4170 2.97	
10-3	Kaiser	Owl Rock Lytle Creek	7.0	0.35	Melment	1.5	154.5	3935 3.09	5830 4.82	7330 5.32/5.26
10-4	Watsonville Rock Co.	Kaiser Olympia	7.0	0.35	Melment	0.5	155.6	6400 4.10	6600 4.38	8280/8280 4.93/4.76
10-5	Kaiser	Kaiser Olympia	7.0	0.35	Melment	2.6	153.0	5280 4.56	5740 5.04	7440 5.59/5.68
10-7	Kaiser	Kaiser Olympia	7.0	0.35	Melment	0.4	152.9	6160 5.34	6400 5.67	7910 5.90
12-1	Owl Rock Lytle Creek	Owl Rock Lytle Creek	6.7	0.42	None	3.3	150.5	3445 3.51	4710 3.10	N/A N/A
12-2	Watsonville Rock Co.	Owl Rock Lytle Creek	6.7	0.45	None	1.5	155.3	4340 3.04	N/A N/A	7230 4.2
12-3	Kaiser	Owl Rock Lytle Creek	6.7	0.42+ (0.33?)	None	3.7	151.0	5755 4.80	3900 3.90	5700 4.43
12-3A	Kaiser	Owl Rock Lytle Creek	6.7	0.41	None	1.0	151.9	4810 3.96	N/A N/A	7700 5.38
12-4	Watsonville Rock Co.	Kaiser Olympia		0.45	None	0.6	154.3	4670 3.52	5140 3.85	7100/7100 4.50/4.30
12-5	Kaiser	Kaiser Olympia	6.7	0.42	None	1.3	151.0	4735 4.29	5020 4.44	7320 5.38
12-7	Kaiser	Kaiser Olympia	6.7	0.45	None	0.9	150.9	4370 4.51	4850 4.84	7030 5.31

[a] Super Water Reducer

[b] Top value is compressive strength, psi. Bottom value is MOD E, psi x 10^6.

Table 3. Comparison of design and final mix

Ingredient	Design mix quantity, lb/cubic yard^a	Final mix quantity, lb/cubic yard^a
Cement	627	627
Water (net)	284	260
Coarse aggregates:		
1.5 inches to .75 inch	660	2011
1 inch to No. 4	1340	
Fine aggregate	1196	1214
Admixture	None	8.2
Slump	0.9 inch	1.13 inch
(after admixture)	Not applicable	3.87 inch

[a] Weights based on 1% air in concrete.

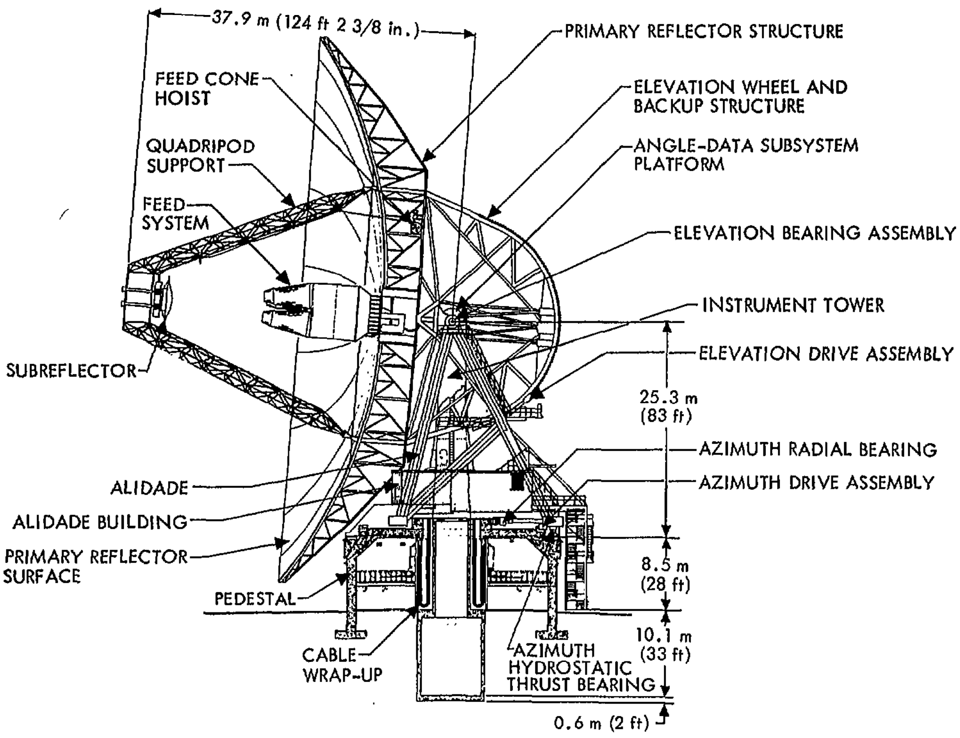


Fig. 1. DSS-14 antenna cross section

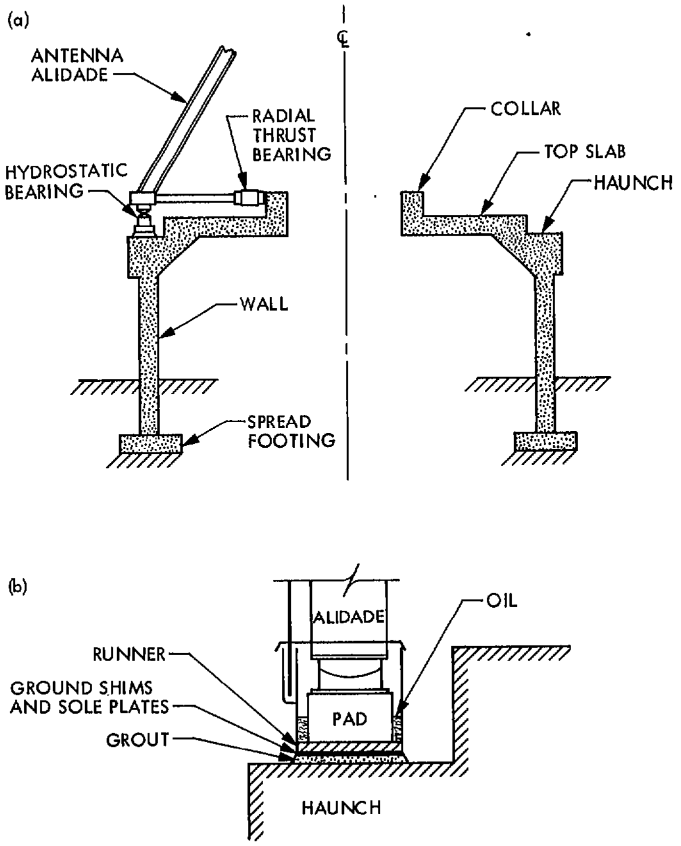


Fig. 2. Simplified cross section of (a) pedestal, and (b) hydrostatic bearing

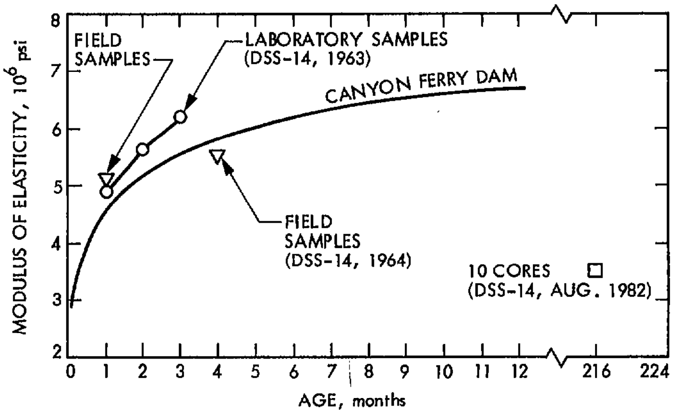


Fig. 3. Modulus of elasticity vs. time

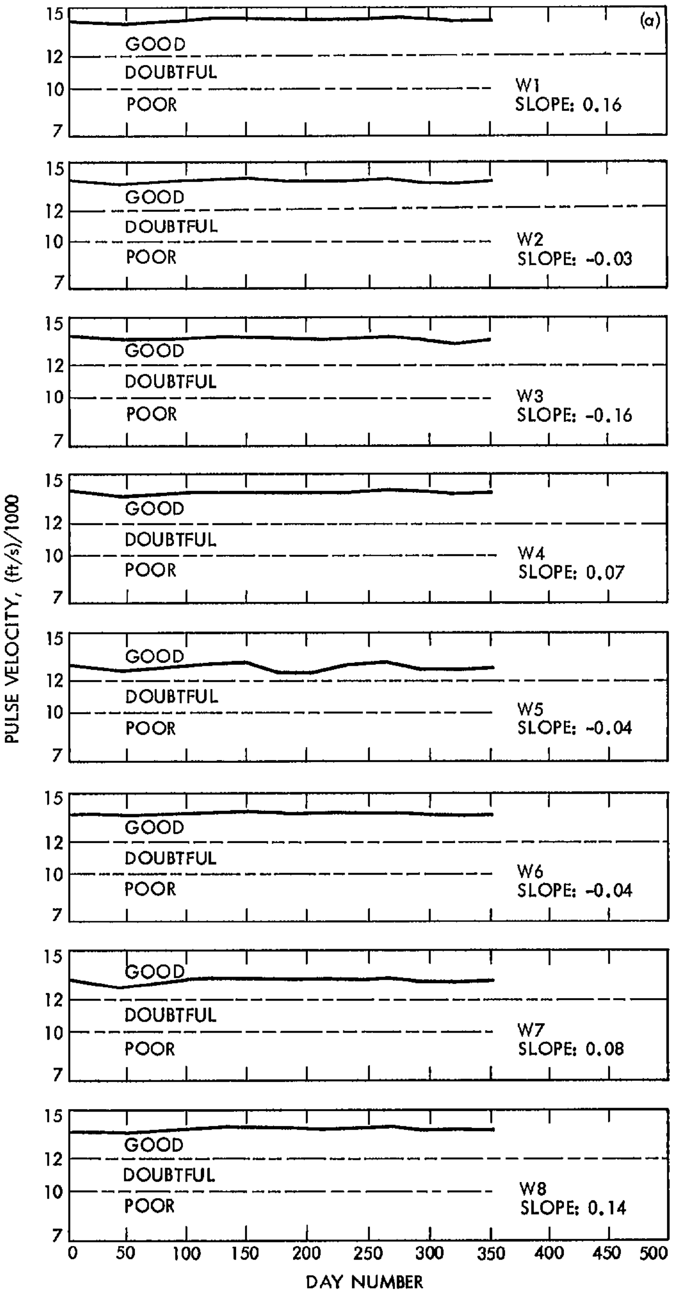


Fig. 4. DSS-14 pulse velocity readings of the (a) pedestal wall, (b) pedestal haunch, and (c) pedestal collar. Day 0 is July 21, 1982, and the slope is in units of (ft/s/year)/1,000.

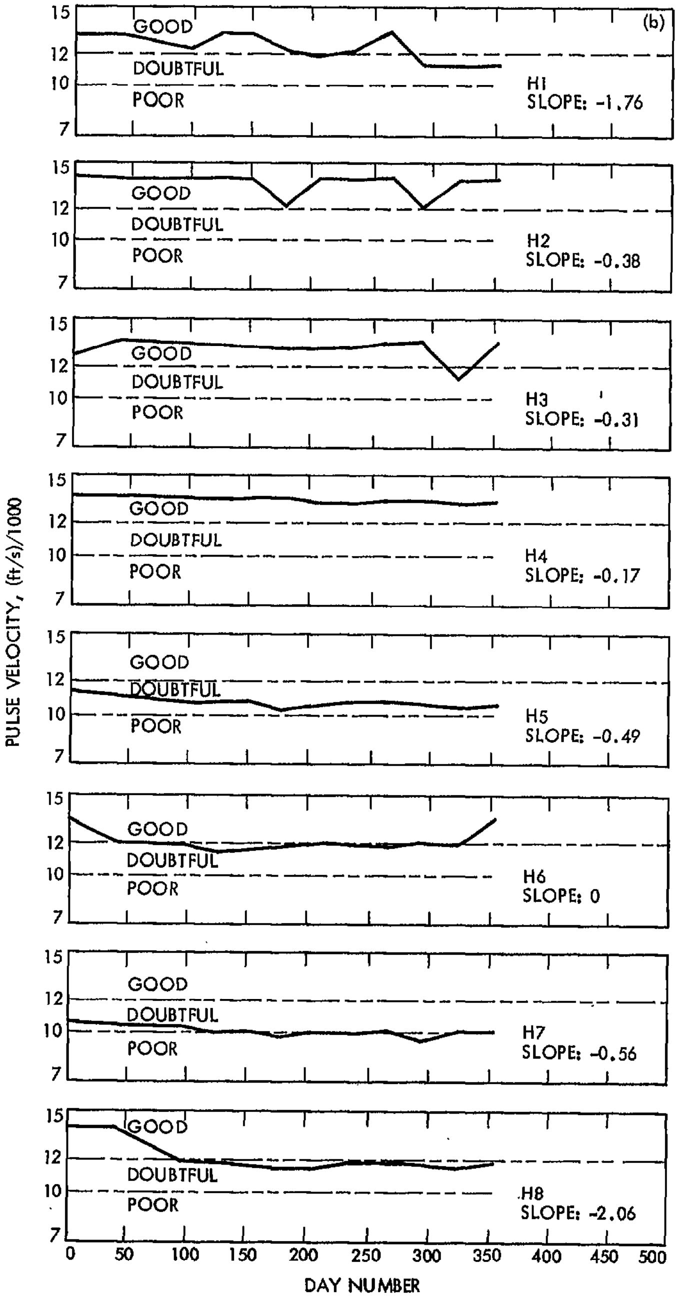


Fig. 4 (contd)

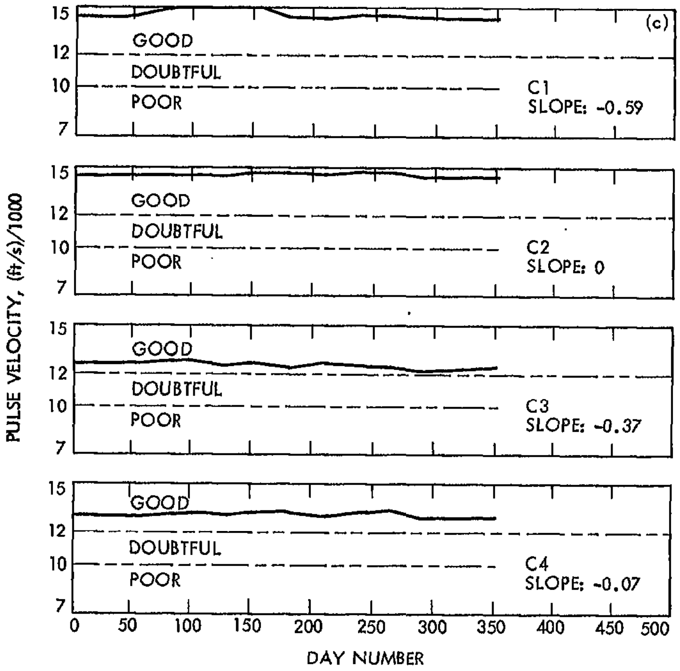
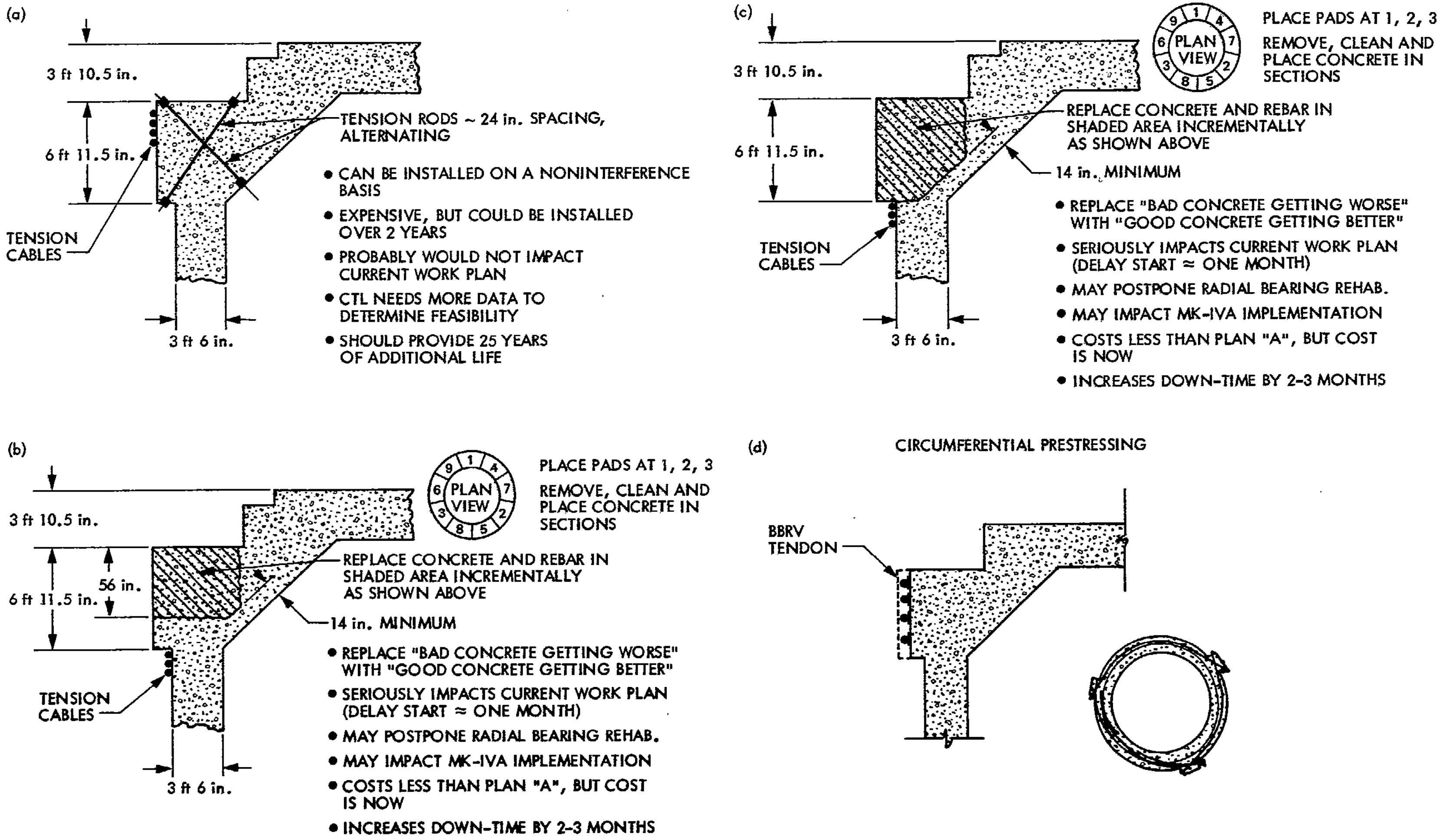


Fig. 4 (contd)



(a)

- CAN BE INSTALLED ON A NONINTERFERENCE BASIS
- EXPENSIVE, BUT COULD BE INSTALLED OVER 2 YEARS
- PROBABLY WOULD NOT IMPACT CURRENT WORK PLAN
- CTL NEEDS MORE DATA TO DETERMINE FEASIBILITY
- SHOULD PROVIDE 25 YEARS OF ADDITIONAL LIFE

(b)

- REPLACE "BAD CONCRETE GETTING WORSE" WITH "GOOD CONCRETE GETTING BETTER"
- SERIOUSLY IMPACTS CURRENT WORK PLAN (DELAY START ≈ ONE MONTH)
- MAY POSTPONE RADIAL BEARING REHAB.
- MAY IMPACT MK-IVA IMPLEMENTATION
- COSTS LESS THAN PLAN "A", BUT COST IS NOW
- INCREASES DOWN-TIME BY 2-3 MONTHS

(c)

- REPLACE "BAD CONCRETE GETTING WORSE" WITH "GOOD CONCRETE GETTING BETTER"
- SERIOUSLY IMPACTS CURRENT WORK PLAN (DELAY START ≈ ONE MONTH)
- MAY POSTPONE RADIAL BEARING REHAB.
- MAY IMPACT MK-IVA IMPLEMENTATION
- COSTS LESS THAN PLAN "A", BUT COST IS NOW
- INCREASES DOWN-TIME BY 2-3 MONTHS

Fig. 5. Repair plan options: (a) Plan "A," (b) Plan "B," (c) Plan "B-1," and (d) Plan "C"

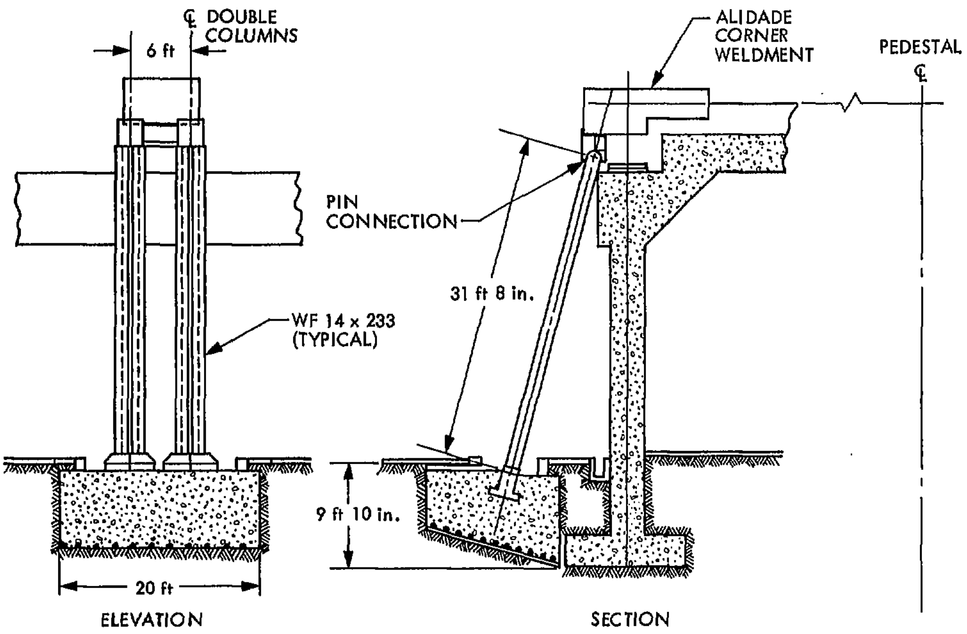


Fig. 6. Support structure and foundation

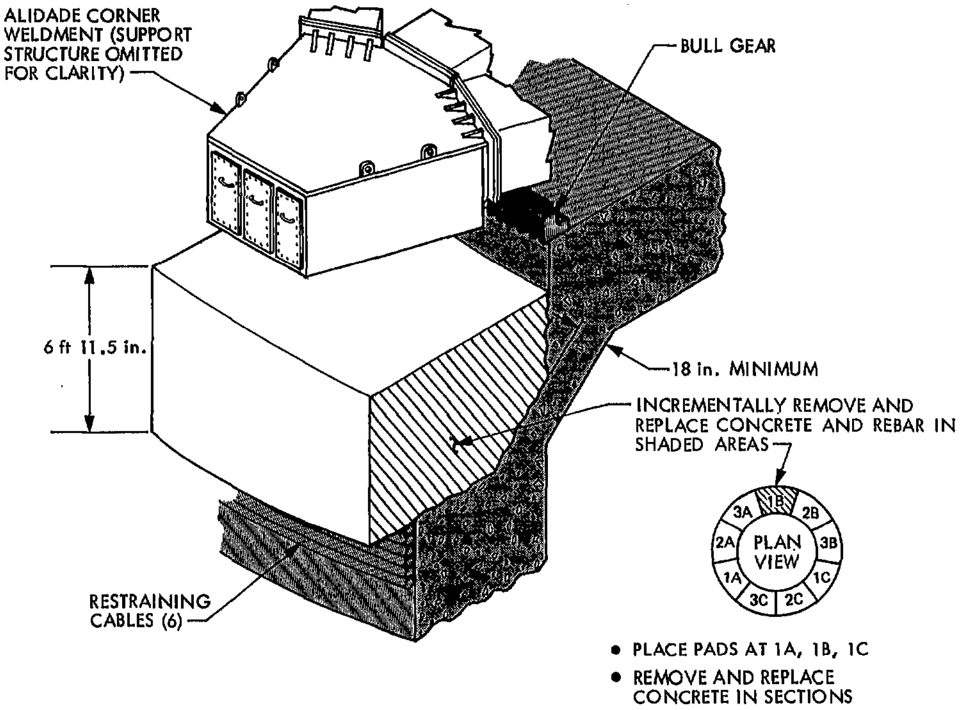


Fig. 7. Pictoral of replacement strategy

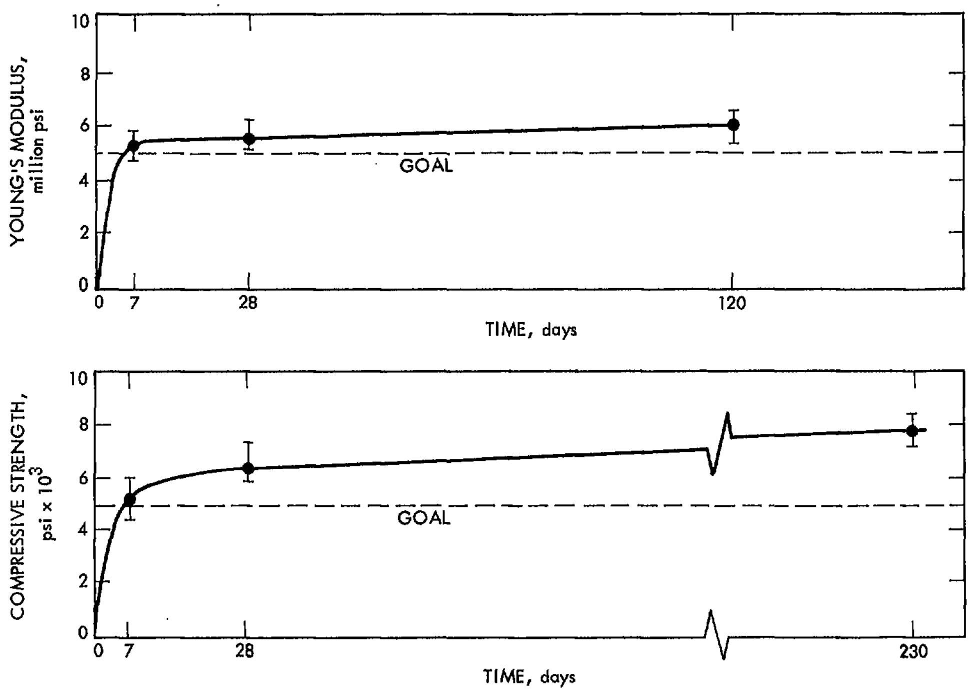


Fig. 8. Replacement concrete test results