Appendix C
Telescope Structure and Cable System History

1.0 Introduction

After the original structure of the Arecibo Telescope was completed in 1963, the structure was modified several times over its 57-year lifespan before collapsing in 2020. In addition to occasional changes, repairs, and reinforcements, two major upgrades were completed in 1974 and 1997.

This appendix traces the structure's history, with a focus on the events that affected the cable tension, including a significant modification of the cable system during the second upgrade and several changes in the weight of the suspended structure over time. The structure also experienced numerous wind storms and earthquakes, and the impact of these events on the cable tensions are covered in Appendix J and Appendix K. The evolution of the condition of the cable system is detailed in Appendix D.

2.0 Construction

The Arecibo Telescope was constructed over three years from 1960 to 1963. The site was selected for its topography, with a natural sinkhole large enough to fit the 1,000-foot-diameter reflector with minimal excavation work (Figure 1). The three towers needed to support the telescope's feeds 500 feet above the reflector were built on hills surrounding the sinkhole (Figure 2, Figure 3), reducing the tower height required. The platform was first assembled at the bottom of the sinkhole and lifted into place using temporary cables supported by the towers (Figure 4). The permanent cables between the towers and platform were then installed and tensioned. We found no record of the specific cable tensioning procedure used at the time, but the general method indicates that during construction the original cables did not experience tensions greater than the final tensions. Finally, the ring girder and the azimuth arm were hoisted up from the platform (Figure 5) and connected to complete the suspended structure (Figure 6). The telescope became operational in November 1963.

The design cable tensions in the newly-constructed telescope are provided in the original structural drawings by Praeger-Kavanagh (Figure 7) for several load cases. These include a baseline case where the structure only supports its own weight, unaffected by exterior conditions or events, and an ultimate case where the structure has cooled down by 20°F and resists 140 mph winds. The cable tensions in these two cases are compared to the minimum breaking strength of the cables in Table 1. The average safety factor (SF) is 2.07 in the baseline case and 1.67 in the ultimate case.

To determine the design weight of the suspended structure, we calculated the vertical reactions at the platform end of the mains and tiedowns. With the calculations based on standard catenary equations and the known cable weight, endpoint coordinates and baseline tensions, the suspended structure weight is estimated to be 1,220 kilopound (kip).

The backstays were surveyed in 1972 in preparation for the first upgrade of the telescope and, as shown in Table 1, the measured backstay tensions were within three percent of the design tensions. While we did not find any similar survey results for the main cables, the close agreement of the design and surveyed backstay tensions suggests that in 1972, the other cable tensions and the suspended structure's weight were likely close to the design values provided in the original structural drawings.

Figure 1: Telescope site during partial excavation of hills around the natural sinkhole in December 1960 *(photo: NAIC Arecibo Observatory, a facility of the NSF).*

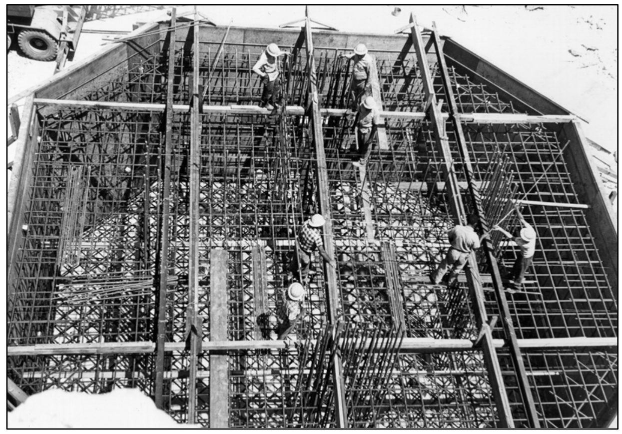


Figure 2: Reinforcement being laid out in the pedestal of Tower 12 in April 1961 *(photo: NAIC Arecibo Observatory, a facility of the NSF).*

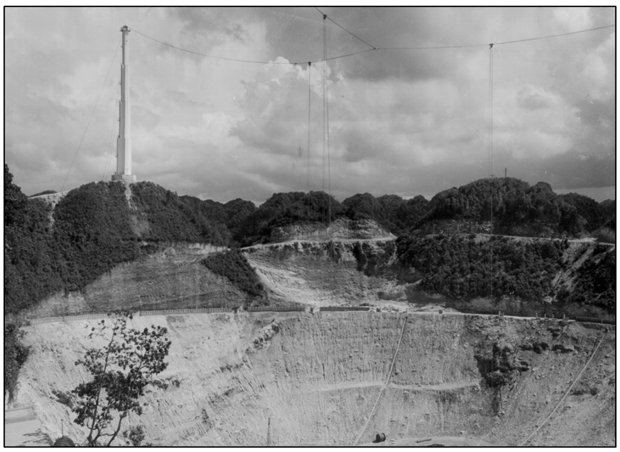


Figure 3: Temporary cable system, later used to lift the platform in September 1962 *(photo: NAIC Arecibo Observatory, a facility of the NSF).*

Figure 4: Platform being lifted into place in October 1962 *(photo: NAIC Arecibo Observatory, a facility of the NSF).*

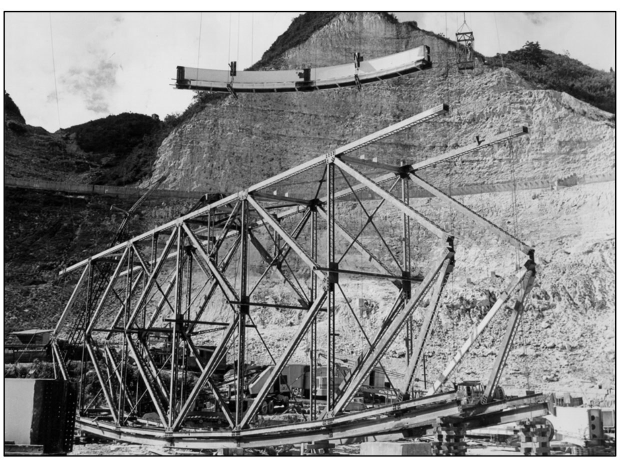


Figure 5: Ring girder segment being lifted to the platform while the azimuth arm is being assembled in December 1962 *(photo: NAIC Arecibo Observatory, a facility of the NSF).*

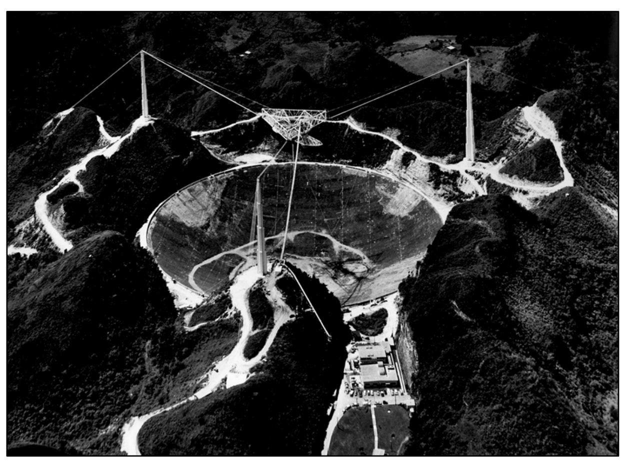
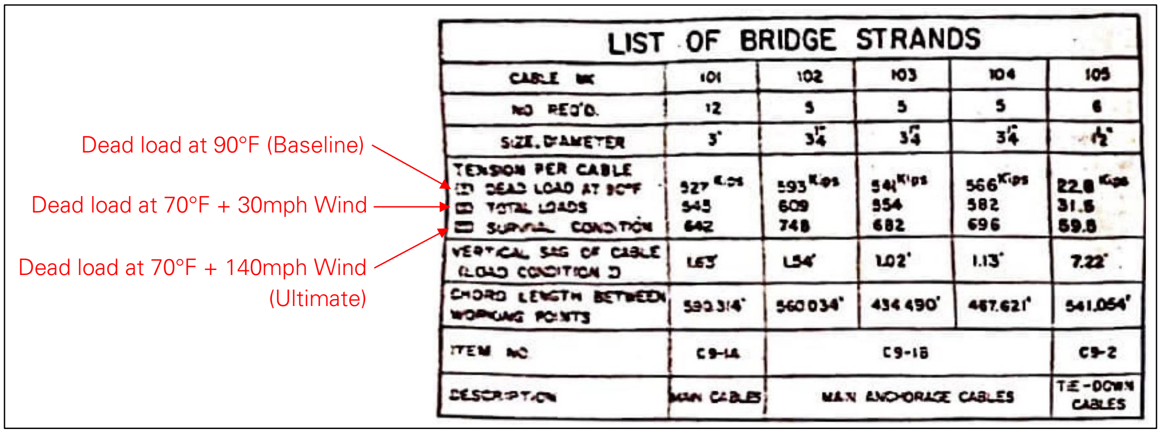


Figure 6: Original telescope structure essentially complete in August 1963 *(photo: NAIC Arecibo Observatory, a facility of the NSF).*



LIST OF BRIDGE STRANDS

CABLE MK	101	102	103	104	105
NO REQ'D	12	5	5	5	6
SIZE, DIAMETER	3"	3¼"	3¼"	3¼"	1½"
TENSION PER CABLE (1) DEAD LOAD AT 90°F (2) TOTAL LOADS (3) SURVIVAL CONDITION	527 Kips 545 642	593 Kips 609 748	541 Kips 554 682	566 Kips 582 696	22.8 Kips 31.5 59.5
VERTICAL SAG OF CABLE (LOAD CONDITION 2)	1.63'	1.54'	1.02'	1.13'	7.22'
CHORD LENGTH BETWEEN WORKING POINTS	593.314'	560.034'	434.490'	467.621'	541.054'
ITEM NO	C9-1A	C9-1B			C9-2
DESCRIPTION	MAIN CABLES	MAIN ANCHORAGE CABLES			TIE-DOWN CABLES

Figure 7: Design cable tensions in original structural drawings
(image: structural drawings, courtesy of NAIC Arecibo Observatory, a facility of the NSF).

Table 1: Design and measured cable tensions and safety factors (SF) before first upgrade.

		Mains	Tower 4 Backstays	Tower 8 Backstays	Tower 12 Backstays	Average[C]
1960 Design Drawings[A]	Minimum Breaking Strength [kip]	1,044	1,212	1,212	1,212	-
	Baseline Tension [kip] (SF)	527 (1.98)	593 (2.04)	541 (2.24)	566 (2.14)	(2.07)
	Ultimate Tension [kip] (SF)	642 (1.63)	748 (1.62)	682 (1.78)	696 (1.74)	(1.67)
	Ultimate / Baseline	1.22	1.26	1.26	1.23	1.24
1972 Survey[B]	Average Tension [kip] (SF)	-	590 (2.05)	523 (2.32)	556 (2.18)	(2.18)
	Maximum Tension [kip] (SF)	-	658 (1.84)	558 (2.17)	577 (2.10)	-
	Tension Coefficient of Variation	-	7.1%	4.1%	2.7%	-
	Survey Average / Design Baseline	-	1.00	0.97	0.98	0.98

[A] Praeger-Kavanagh. Structural drawings for original telescope. December 1, 1960. Drawings provided by Arecibo Observatory.

[B] Ammann & Whitney. *Results of Survey of Suspended Structure and Reflector Cable Anchorages*. August 1972. Report retrieved from Cornell University archives.

[C] Average weighted by number of cables.

3.0 First Upgrade

The first major upgrade of the telescope was completed in 1974. The most significant change consisted in covering the primary reflector with aluminum panels to improve the accuracy of the reflector surface (Figure 8), which had no impact on the telescope's superstructure.

The cable system of the superstructure was also modified (Figure 9). The original cable system included six inclined tiedowns connecting the platform to the ground and providing torsional stiffness to the suspended structure. The tiedowns had to be sufficiently pre-tensioned (23 kip at 90°F per the original structural drawings) to minimize sag and provide the required stiffness. As part of the first upgrade, a carrier cable with a set of hangers was installed directly over each tiedown to support it from above, eliminating tiedown sag. As a result, the tiedown stiffness was increased without increasing the pre-tension, which was in fact decreased, down to 8 kip at 90°F per the structural drawings of the first upgrade (Figure 10). This modified tiedown system was designed by Ammann & Whitney (AW).

The first upgrade also added 30 kip of new equipment[1] to the suspended structure, increasing its total weight to 1,250 kip. However, the reduction in tiedown pre-tension adequately compensated for the weight increase, so that the net effect of the first upgrade was a slight reduction in the main cable tensions (Table 2). We estimated the reduction to be 1.4 percent.

Figure 8: Aluminum panels being installed on the primary reflector during the first upgrade
(photo: NAIC Arecibo Observatory, a facility of the NSF).

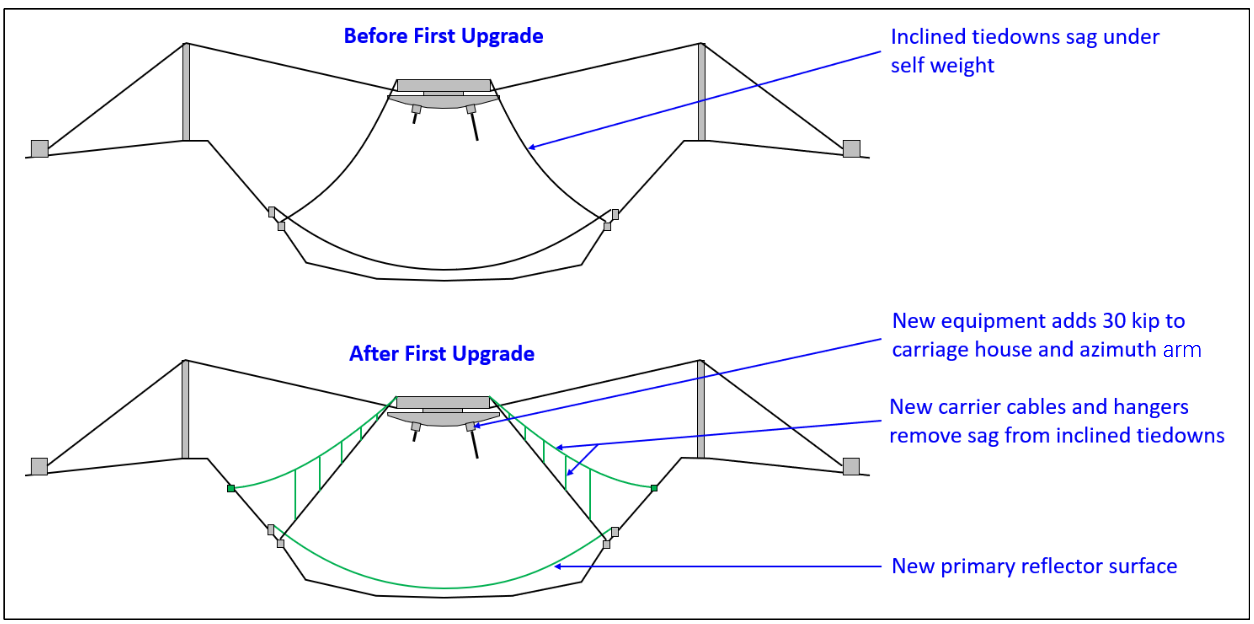
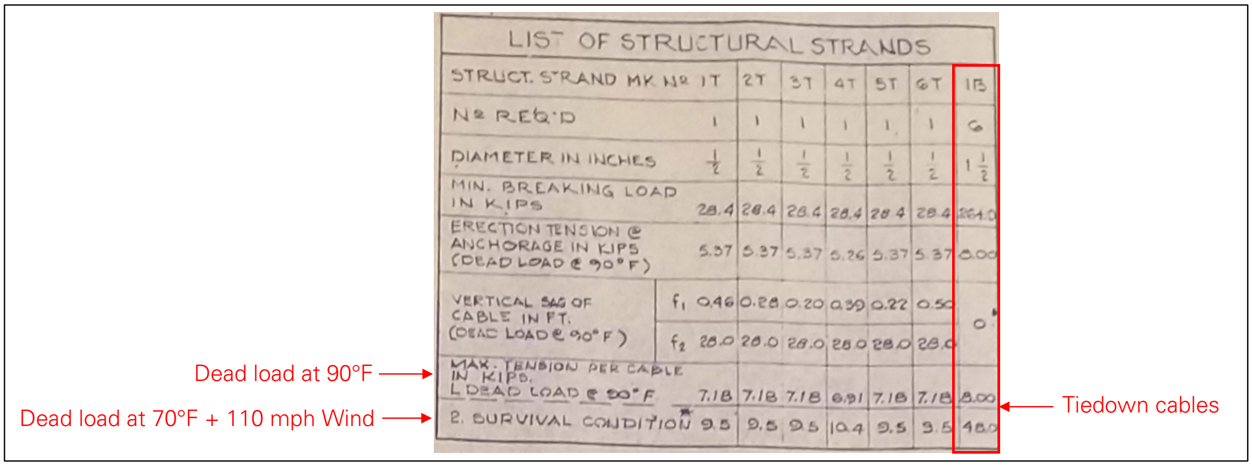


Figure 9: First upgrade of telescope structure.

[1] Lalonde, L.M. "The Upgraded Arecibo Observatory". *Science*. Vol 186. October 18, 1974.



LIST OF STRUCTURAL STRANDS

STRUCT. STRAND MK Nº		1T	2T	3T	4T	5T	6T	1B
Nº REQ'D		1	1	1	1	1	1	6
DIAMETER IN INCHES		1/2	1/2	1/2	1/2	1/2	1/2	1 1/2
MIN. BREAKING LOAD IN KIPS		28.4	28.4	28.4	28.4	28.4	28.4	264.0
ERECTION TENSION @ ANCHORAGE IN KIPS (DEAD LOAD @ 90°F)		5.37	5.37	5.37	5.26	5.37	5.37	8.00
VERTICAL SAG OF CABLE IN FT. (DEAD LOAD @ 90°F)	f_1	0.46	0.28	0.20	0.39	0.22	0.50	0
	f_2	28.0	28.0	28.0	28.0	28.0	28.0	
MAX. TENSION PER CABLE IN KIPS. 1. DEAD LOAD @ 90°F		7.18	7.18	7.18	6.91	7.18	7.18	8.00
2. SURVIVAL CONDITION		9.5	9.5	9.5	10.4	9.5	9.5	48.0

Figure 10: Tiedown tensions in structural drawings for first upgrade
(image: structural drawings, courtesy of NAIC Arecibo Observatory, a facility of the NSF).

Table 2: Impact of first upgrade on main cable tensions. Tiedown and carrier cable tensions are for dead load at 90°F.

	Before First Upgrade	After First Upgrade	Relative Change
Suspended Structure Weight [kip]	1,220	1,250	+2.5%
Tiedown Average Tension [kip]	22.8	8	-64.9%
6 Tiedowns Total Vertical Pull on Platform [kip]	111	37	-66.7%
Carrier Cable Average Tension [kip]	-	5.5	-
6 Carrier Cables Total Vertical Pull on Platform [kip]	-	26	-
Total Vertical Force Resisted by Main Cables [kip]	1,331	1,313	-1.4%

4.0 Between Upgrades

The telescope structure did not change significantly between the two major upgrades, although the weight of the suspended structure likely varied as equipment and instruments were added and removed over time. We estimated its weight to be 1,250 kip after the first upgrade (section 0 above), while the cable tensioning sequence for the second upgrade started with a weight of 1,300 kip (section 5.0 below). This 50-kip discrepancy may reflect an actual weight increase between the upgrades, but could also be due to differences in calculation assumptions between the two upgrades. In any case, 50 kip is less than five percent of the suspended structure's weight.

One noteworthy event between the two upgrades is the replacement of a backstay cable in September 1981. After discovering a sixth broken wire at the ground end of cable B12-3, Arecibo Observatory (AO) had the cable replaced to prevent further wire breaks and potential cable failure. The cable end and socket with the broken wires were analyzed at Cornell University (Figure 11), with the findings presented in a paper by Phoenix, Johnson, and McGuire.[2] In 1988, AO determined that the replacement cable had

[2] Phoenix, S.L., Johnson, H.H., and McGuire, W. "Condition of Steel Cable after Period of Service". *Journal of Structural Engineering.* 112(6). 1986.

lost approximately 10 percent of its tension,[3] which according to AW was due to regular cable relaxation after installation, and caused only a 2.5 percent tension increase in the other four backstays of Tower 12.

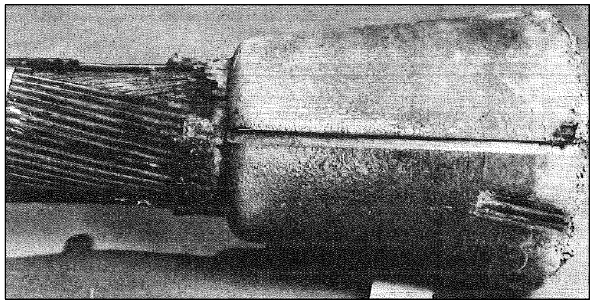


Figure 11: Zinc casting at ground end of cable B12-3 replaced in 1981 *(photo: Phoenix, Johnson, and McGuire[4]).*

5.0 Second Upgrade

The second major upgrade of the telescope, undertaken between 1995 and 1997, significantly modified the suspended structure and cable system (Figure 12). The primary purpose of the upgrade was to replace one of the carriage houses and line feeds with a Gregorian dome (Figure 13), henceforth referred to as the Gregorian. The Gregorian is an enclosure containing new instruments that added capabilities to the telescope (secondary and tertiary reflectors and new radio feeds). The Gregorian, however, is more than five times heavier than the removed carriage house (200 kip v. 35 kip), so to mitigate the imbalance on the suspended structure, a counterweight was added at the tip of the azimuth arm opposite the Gregorian. In addition, the steel trusses of the platform and azimuth arm had to be reinforced to accommodate the new loads, further increasing the suspended structure's weight. Finally, the inclined tiedowns and carrier cables were removed and replaced with vertical tiedowns, which required the addition of outriggers at the platform corners so that the new vertical tiedowns were kept clear of the azimuth arm rotation.

[3] Joe Vellozzi (Ammann & Whitney). Letter to Jose Maldonado (Arecibo Observatory). September 27, 1988. Correspondence retrieved from Cornell University archives.

[4] Phoenix, S.L., Johnson, H.H., and McGuire, W. "Condition of Steel Cable after Period of Service". *Journal of Structural Engineering.* 112(6). 1986.

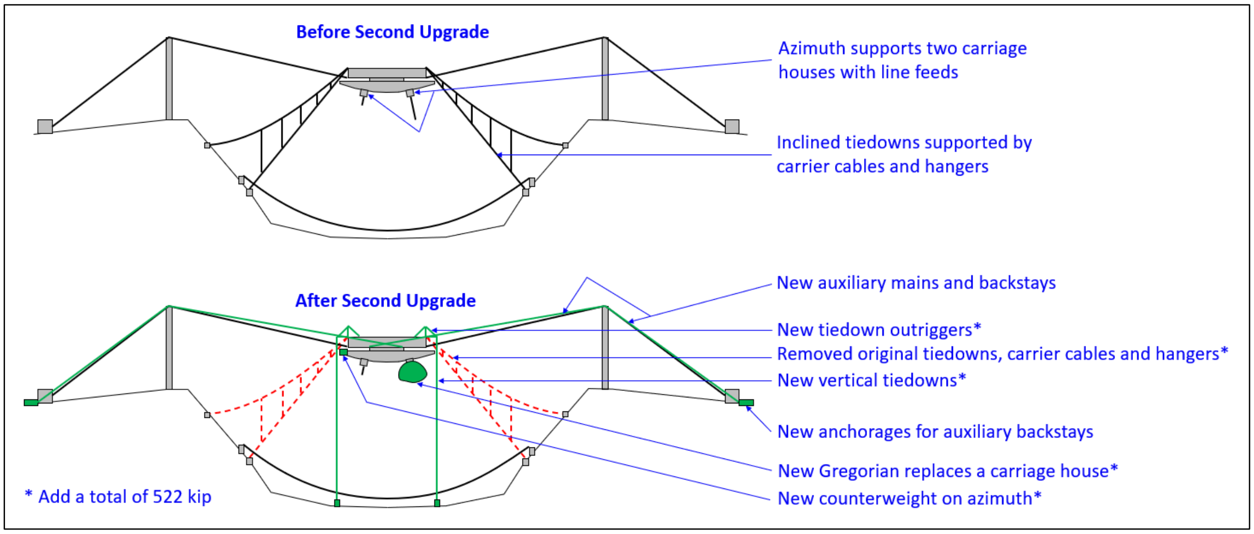


Figure 12: Second upgrade of telescope structure.

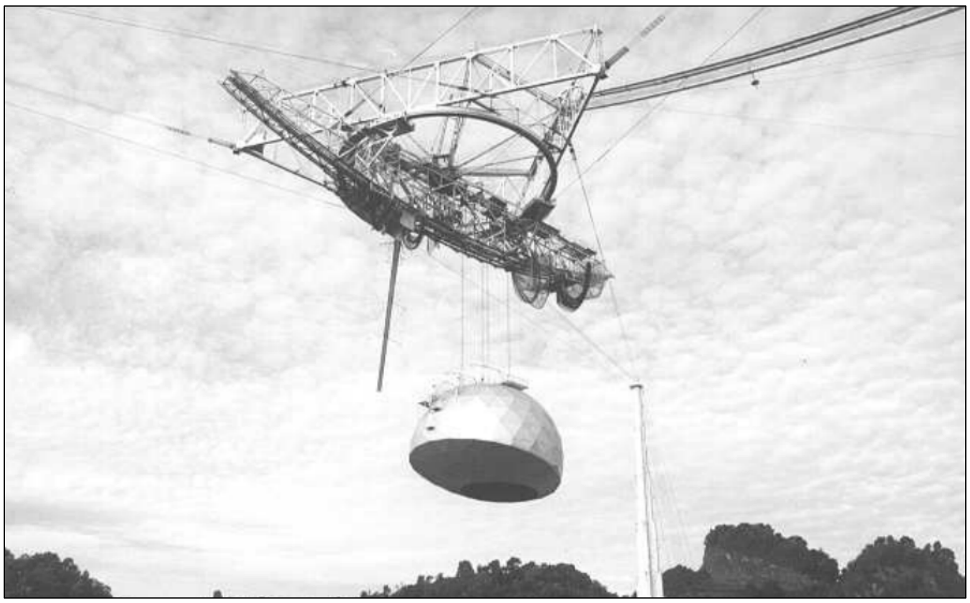


Figure 13: Gregorian being lifted into place during second upgrade
(photo: NAIC Arecibo Observatory, a facility of the NSF).

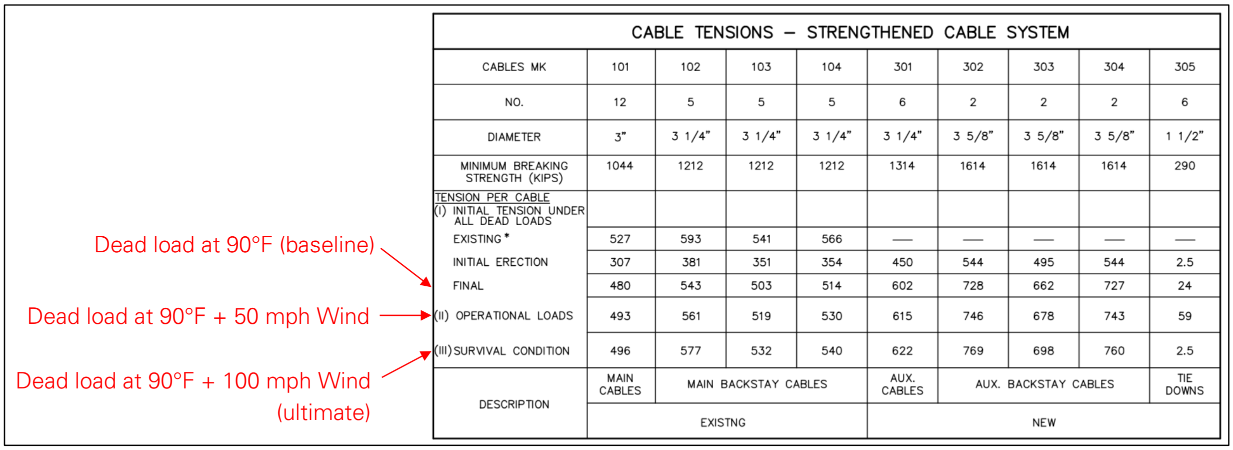
AW provided the structural design of the second upgrade, and Table 3 provides a breakdown of the changes to the suspended structure's weight and tiedown tensions specified in AW's structural drawings. The total weight of the suspended structure was increased by 522 kip, a 42 percent addition over the estimated weight of 1,250 kip before the upgrade. After adding the contribution of the tiedown tensions, the total vertical load resisted by the main cables increased by up to 616 kip. The new tiedowns were expected to be released in advance of major wind events (*storm condition* in Table 3) to reduce the vertical load on the main cables.

Table 3: Suspended structure weight and tiedown tension changes in second upgrade.
Adapted from structural drawings for second upgrade.

	Suspended Structure Weight Change [kip]	Tiedown Total Vertical Force Change [kip]	Change in Total Vertical Force Resisted by Main Cables [kip]
Platform Reinforcement	+70	-	+70
New Tiedown and Outrigger System	+48	-	+48
Changes to Ring Girder and Azimuth Arm Trolleys	+78	-	+78
Azimuth Arm Reinforcement and Add'l Equipment	+135	-	+135
Carriage House Removal	-33	-	-33
New Gregorian	+170	-	+170
New Counterweight and Framing	+54	-	+54
Inclined Tiedowns and Carrier Cables Removal	-	-50	-50
New Tiedowns (Storm Condition)	-	+144 (+15)	+144 (+15)
Total (Storm Condition)	+522	+94 (-35)	+616 (+487)

To accommodate the increased load, 12 cables were added to the structure. These new cables are referred to as auxiliary cables. At each of the three towers, two auxiliary cables were added between the tower and the platform (auxiliary mains), and two were added between the tower and the ground (auxiliary backstays). Each auxiliary cable is larger in diameter and designed to carry more tension than the corresponding original cable. The design cable tensions for several load cases are provided in the structural drawings (Figure 14), including a baseline case (dead load only) and an ultimate case (maximum wind). The baseline and ultimate cable tensions before and after the upgrade are summarized in Table 4, with the corresponding safety factors. The upgrade increased the safety factor in the original cables, on average from 2.07 to 2.26 in the baseline case, and from 1.67 to 2.16 in the ultimate case. For the auxiliary cables, the average safety factor was 2.24 in the baseline case and 2.15 in the ultimate case. The safety factors were therefore essentially identical for the original and auxiliary cables after the upgrade.

On average over all of the cables, the ultimate tension was only 5 percent higher than the baseline tension after the upgrade, while the difference was 24 percent before the upgrade. There are two reasons for this discrepancy. First, the design of the upgraded structure assumes that the new tiedowns will be released in advance of a significant wind event, so that the main and backstay tensions are reduced before the arrival of the ultimate wind load. Second, according to the structural drawings, the design wind speed for the upgraded structure was 100 mph, while the original structure was based on a design wind speed of 140 mph. The design wind speed is further discussed in Appendix J.



CABLE TENSIONS – STRENGTHENED CABLE SYSTEM

CABLES MK	101	102	103	104	301	302	303	304	305
NO.	12	5	5	5	6	2	2	2	6
DIAMETER	3"	3 1/4"	3 1/4"	3 1/4"	3 1/4"	3 5/8"	3 5/8"	3 5/8"	1 1/2"
MINIMUM BREAKING STRENGTH (KIPS)	1044	1212	1212	1212	1314	1614	1614	1614	290
TENSION PER CABLE (I) INITIAL TENSION UNDER ALL DEAD LOADS									
EXISTING *	527	593	541	566	—	—	—	—	—
INITIAL ERECTION	307	381	351	354	450	544	495	544	2.5
FINAL	480	543	503	514	602	728	662	727	24
(II) OPERATIONAL LOADS	493	561	519	530	615	746	678	743	59
(III) SURVIVAL CONDITION	496	577	532	540	622	769	698	760	2.5
DESCRIPTION	MAIN CABLES	MAIN BACKSTAY CABLES			AUX. CABLES	AUX. BACKSTAY CABLES			TIE DOWNS
	EXISTNG				NEW				

Figure 14: Cable tensions in structural drawings for second upgrade
(image: structural drawings, courtesy of NAIC Arecibo Observatory, a facility of the NSF).

Table 4: Impact of second upgrade on cable tensions.

		Minimum Breaking Strength [kip]	Baseline		Ultimate		Ultimate / Baseline	
			Before 2nd Upgrade [kip (SF)]	After 2nd Upgrade [kip (SF)]	Before 2nd Upgrade [kip (SF)]	After 2nd Upgrade [kip (SF)]	Before 2nd Upgrade	After 2nd Upgrade
Original Cables	Mains	1,044	527 (1.98)	480 (2.18)	642 (1.63)	496 (2.10)	1.22	1.03
	T4 Backstays	1,212	593 (2.04)	543 (2.23)	748 (1.62)	577 (2.10)	1.26	1.06
	T8 Backstays	1,212	541 (2.24)	503 (2.41)	682 (1.78)	532 (2.28)	1.26	1.06
	T12 Backstays	1,212	566 (2.14)	514 (2.36)	696 (1.74)	540 (2.24)	1.23	1.05
	Average[A]	-	(2.07)	(2.26)	(1.67)	(2.16)	1.24	1.05
Auxiliary Cables	Mains	1,314	-	602 (2.18)	-	622 (2.11)	-	1.03
	T4 Backstays	1,614	-	728 (2.22)	-	769 (2.10)	-	1.06
	T8 Backstays	1,614	-	662 (2.44)	-	698 (2.31)	-	1.05
	T12 Backstays	1,614	-	727 (2.22)	-	760 (2.12)	-	1.05
	Average[A]	-	-	(2.24)	-	(2.15)	-	1.04

[A] Average weighted by number of cables.

The second upgrade was implemented by gradually tensioning the new auxiliary cables as weight was added to the suspended structure. In a final step, the original mains were tensioned with the auxiliary cables to raise the suspended structure by 2 feet. Our review of the correspondence between the different parties involved (in particular, AO, AW, and the primary contractor Comsat RSI) indicates that the specific sequence of cable tensioning and weight increase was changed during the project. The final sequence is described in a March 14, 1996 letter by AW,[5] and shown in Figure 15. We observe that the original cables did not exceed their pre-upgrade tension throughout the sequence, as the auxiliary cables were tensioned before each weight increase. Similarly, the auxiliary cables did not exceed their final post-upgrade tension at any point during the sequence. The total weight added to the suspended structure per the final sequence is 489 kip, which is 6 percent less than the 522 kip budgeted in the structural drawings.

[5] Jow Vellozzi (Ammann & Whitney). Letter to Kurt Samuelson (Arecibo Observatory). March 14, 1996. Correspondence retrieved from Cornell University archives.

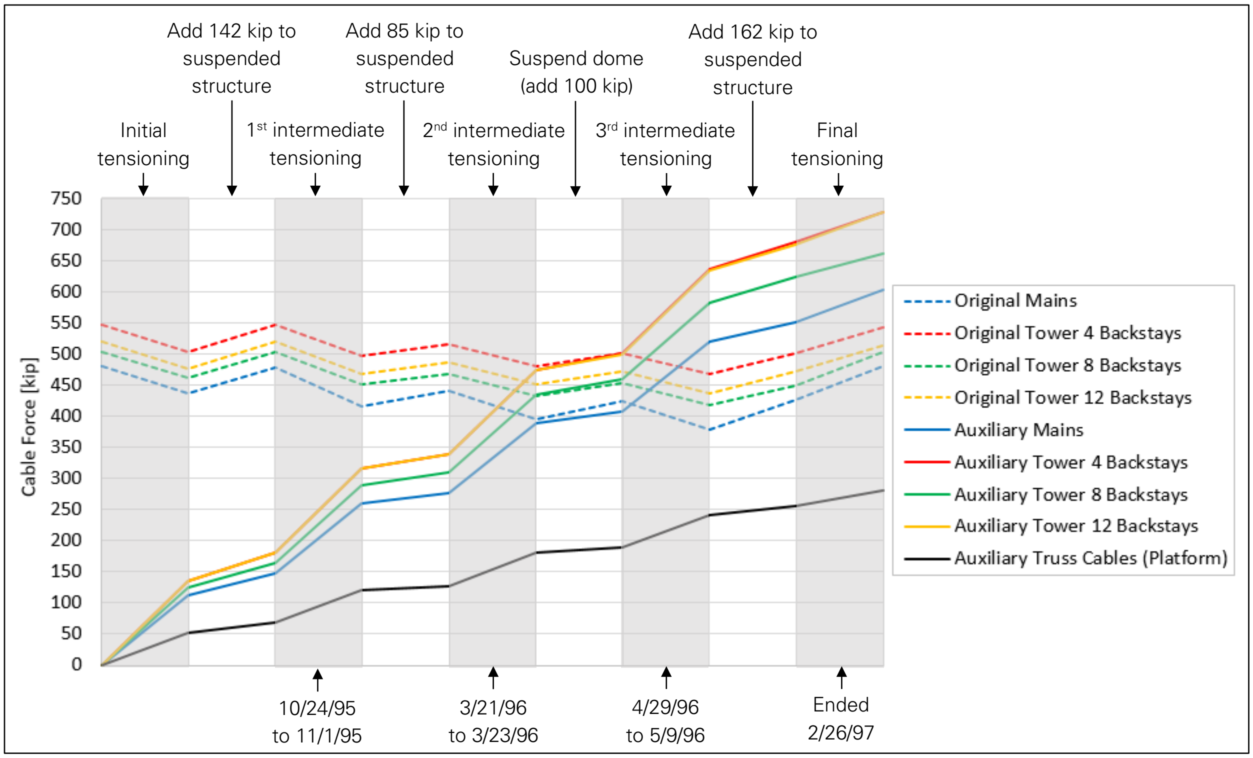


Figure 15: Cable tensioning sequence per AW's 3/14/1996 memorandum.

According to RSI's reports on the first,[6] second,[7] and third[8] intermediate tensioning steps, difficulties in confirming the cable tensions were encountered several times during the project. Those issues are summarized in a report by NAIC,[9] who also retained a consultant (William McGuire) to review the circumstances. Our review of the different reports and associated correspondence found no evidence that any cable tension significantly exceeded the final design tension during the tensioning procedure. The cable tensioning operations were completed on 2/26/1997.[10]

On 1/31/1997, a threaded rod connecting the socket of cable M8-4 to the platform was damaged as contractors were cutting a nut that prevented the installation of a jack required for a cable tensioning operation[11] (Figure 16). The damage consisted of several cuts on the surface of the rod (Figure 17), raising concerns about potential crack propagation through the rod. Fracture Analysis Consultants

[6] Comsat RSI. *Intermediate Tensioning and Tower Deflection Report*. December 14, 1995. Report retrieved from Cornell University archives.

[7] Comsat RSI. *2nd Intermediate Tensioning*. April 9, 1996. Report retrieved from Cornell University archives.

[8] Comsat RSI. *3rd Intermediate Tensioning*. May 23, 1996. Report retrieved from Cornell University Archives.

[9] Arecibo Observatory. *Cable Tension Inconsistencies*. September 19, 1996. Report retrieved from Cornell University archives.

[10] Kurt Samuelson (Arecibo Observatory). Letter to Steve Young (Comsat RSI). February 26, 1997. Correspondence retrieved from Cornell University archives.

[11] Jose Maldonado (Arecibo Observatory). Letter to Kurt Samuelson (Arecibo Observatory). January 31, 1997. Correspondence retrieved from Cornell University archives.

analyzed the damage and a rod sample, and concluded that the rod remained fit for service[12]. However, a structural bypass was installed to catch the socket in the event that the damaged threaded rod fails.

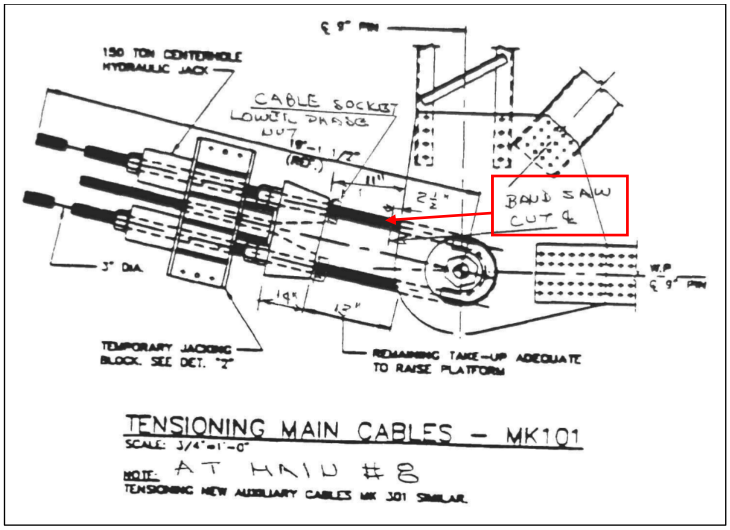


Figure 16: Location of threaded rod damage on M8-4 connection to platform *(image: NAIC Arecibo Observatory, a facility of the NSF[11]).*

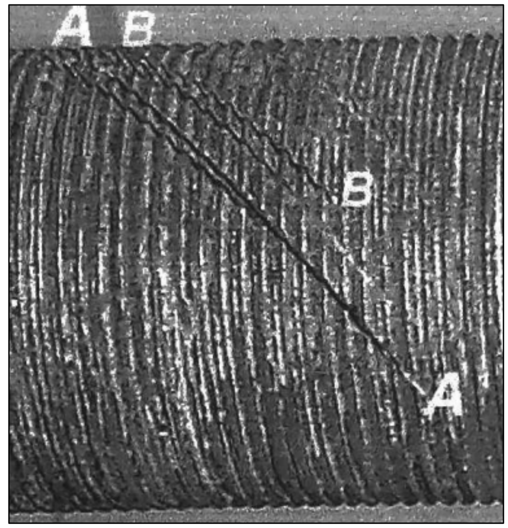


Figure 17: Cuts in M8-4 hairpin *(photo: Fracture Analysis Consultants[12]).*

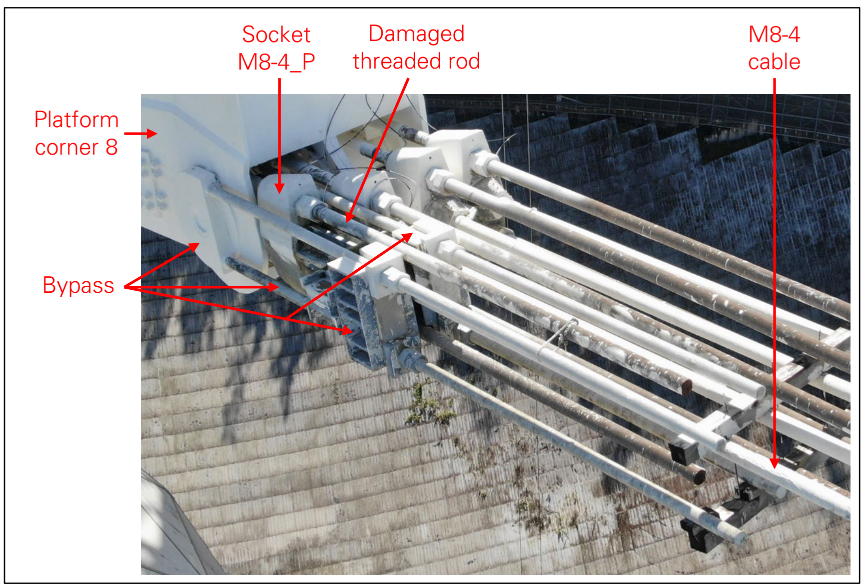


Figure 18: Bypass on socket M8-4_P *(photo: NAIC Arecibo Observatory, a facility of the NSF).*

[12] Fracture Analysis Consultants, Inc. *Fracture and Fatigue Analyses of Damaged Hairpin Rod at Arecibo*. March 3, 1997. Report retrieved from Cornell University archives.

6.0 After Second Upgrade

On 2/3/2010, local damage was discovered on a diagonal truss member of the platform (Figure 19), near the east backstay of the corner 12 tiedown outrigger. After re-analysis of the structure, AW prescribed the reinforcement of the damaged member and 23 other platform truss members, adding 14 kip of steel to the platform.

Puerto Rico was hit by an earthquake of magnitude 6.4 on 1/13/2014, and the next day the AO staff discovered several broken wires near the splice in cable M8-4. Cable M8-4 had been spliced near the top of Tower 8 during construction of the telescope in the 1960s, possibly because it was fabricated too short. After inspecting the splice, AW determined that the short segment of cable between the splice and the tower had at least 12 broken wires and was at risk of failing. AW designed a bypass system that connects the splice to the tower with a beam and a pair of threaded rods, which was installed in March 2014[13] (Figure 20). AW described the bypass as a temporary solution and recommended that the M8-4 cable be replaced. Preparations to replace M8-4 were being made when the M4N cable failed in August 2020.

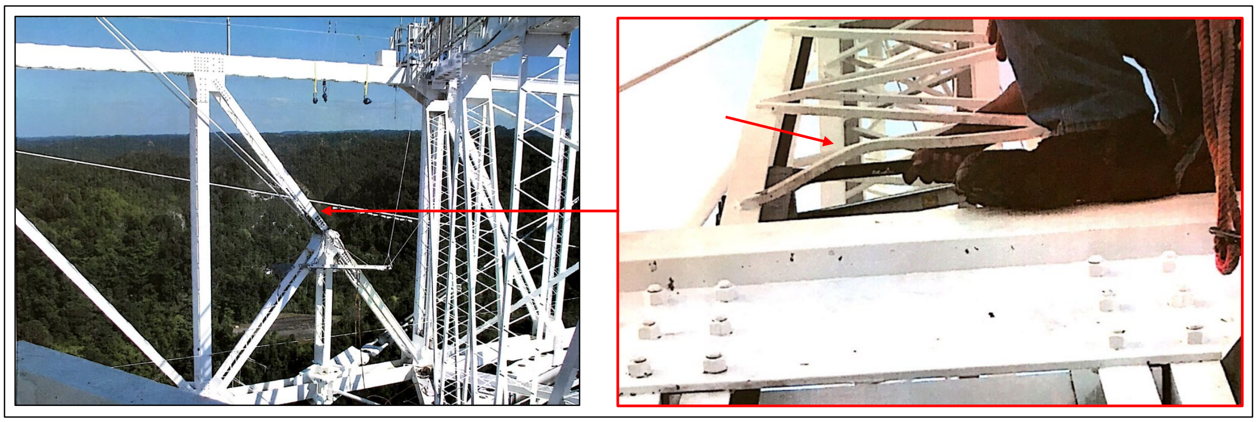


Figure 19: Damaged truss member lacing near outrigger 12 east backstay connection to platform on February 5, 2010. *(photos: NAIC Arecibo Observatory, a facility of the NSF).*

[13] Joel Stahmer (Ammann & Whitney). Letter to R. Kerr (Arecibo Observatory). March 11, 2017.

Figure 20: M8-4 splice bypass *(photos: NAIC Arecibo Observatory, a facility of the NSF).*

The cable system was surveyed several times after the second upgrade. In our review of the documents provided by AO and retrieved from the Cornell University Archives, we identified three of those surveys with complete data for the main cables. The surveys were performed in 2003,[14] 2006,[15] and 2016,[16] and the results are summarized in Table 5. The cable tensions are affected by temperature, telescope position, and tiedown tensions, but from the survey reports we could not always verify these parameters when each cable was surveyed. The results of the different surveys are nonetheless generally consistent with the cable tensions and suspended structure weight expected after the second upgrade.

Table 5: Main cable tensions and suspended structure weight surveyed after second upgrade.

	Design (End of 2nd Upgrade in 1997)	2003 Survey[14]	2006 Survey[15]	2016 Survey[16]	Survey Average	Survey Coefficient of Variation	Survey Average / Design
M4 Tension [kip]	480	510	481	498	496	2.4%	1.03
M4N Tension [kip]	602	654	631	566	617	6.0%	1.02
M4S Tension [kip]	602	582	577	634	598	4.3%	0.99
M8 Tension [kip]	480	509	516	490	505	2.2%	1.05
M8N Tension [kip]	602	654	666	625	648	2.7%	1.08
M8S Tension [kip]	602	642	647	594	628	3.8%	1.04
M12 Tension [kip]	480	496	491	449	479	4.4%	1.00
M12E Tension [kip]	602	599	600	576	592	1.9%	0.98
M12W Tension [kip]	602	634	593	572	600	4.3%	1.00
Suspended Structure Weight [kip]	1,789	1,798	1,798	1,748	1,781	1.3%	1.00

[14] Ammann & Whitney. *Suspended Platform Weight and Cable Tensions from Measured Cable Sags*. May 28, 2003. Report retrieved from Cornell University archives.

[15] Ammann & Whitney. *Suspended Platform Weight and Cable Tensions from Measured Sags*. August 29, 2006. Report retrieved from Cornell University archives.

[16] Louis Berger. *Main Cable Tensions and Suspended Platform Weight from LIDAR Measured Cable Sags*. April 24, 2017. Report provided by Arecibo Observatory.