EMBARGOED UNTIL 11:30 A.M. U.S. Eastern Time, 11/19/2020

National Science Foundation Arecibo Observatory Damage Press Call

Advance materials contents:

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NSF begins planning for decommissioning of Arecibo Observatory's 305-meter telescope due to safety concerns

Following a review of engineering assessments that found damage to the Arecibo Observatory cannot be stabilized without risk to construction workers and staff at the facility, the U.S. National Science Foundation will begin plans to decommission the 305-meter telescope, which for 57 years has served as a world-class resource for radio astronomy, planetary, solar system and geospace research.

The decision comes after NSF evaluated multiple assessments by independent engineering companies that found the telescope structure is in danger of a catastrophic failure and its cables may no longer be capable of carrying the loads they were designed to support. Furthermore, several assessments stated that any attempts at repairs could put workers in potentially life-threatening danger. Even in the event of repairs going forward, engineers found that the structure would likely present long-term stability issues.

"NSF prioritizes the safety of workers, Arecibo Observatory's staff and visitors, which makes this decision necessary, although unfortunate," said NSF Director Sethuraman Panchanathan. "For nearly six decades, the Arecibo Observatory has served as a beacon for breakthrough science and what a partnership with a community can look like. While this is a profound change, we will be looking for ways to assist the scientific community and maintain that strong relationship with the people of Puerto Rico."

Engineers have been examining the Arecibo Observatory 305-meter telescope since August, when one of its support cables detached. NSF authorized the University of Central Florida, which manages Arecibo, to take all reasonable steps and use available funds to address the situation while ensuring safety remained the highest priority. UCF acted quickly, and the evaluation process was following its expected timeline, considering the age of the facility, the complexity of the design and the potential risk to workers.

The engineering teams had designed and were ready to implement emergency structural stabilization of the auxiliary cable system. While the observatory was arranging for delivery of two replacement auxiliary cables, as well as two temporary cables, a main cable broke on the same tower Nov. 6. Based on the stresses on the second broken cable -- which should have been well within its ability to function without breaking -- engineers concluded that the remaining cables are likely weaker than originally projected.

"Leadership at Arecibo Observatory and UCF did a commendable job addressing this situation, acting quickly and pursuing every possible option to save this incredible instrument," said Ralph Gaume, director of NSF's Division of Astronomical Sciences. "Until these assessments came in, our question was not if the observatory should be repaired but how. But in the end, a preponderance of data showed that we simply could not do this safely. And that is a line we cannot cross."

The scope of NSF's decommissioning plan would focus only on the 305-meter telescope and is intended to safely preserve other parts of the observatory that could be damaged or destroyed in the event of an unplanned, catastrophic collapse. The plan aims to retain as much as possible of the remaining infrastructure of Arecibo Observatory, so that it remains available for future research and educational missions.

The decommissioning process involves developing a technical execution plan and ensuring compliance with a series of legal, environmental, safety and cultural requirements over the coming weeks. NSF has authorized a high-resolution photographic survey using drones, and is considering options for forensic evaluation of the broken cable -- if such action could be done safely -- to see if any new evidence could inform the ongoing plans. This work has already begun and will continue throughout the decommissioning planning. Equipment and other materials will be temporarily moved to buildings outside the danger zone. When all necessary preparations have been made, the telescope would be subject to a controlled disassembly.

After the telescope decommissioning, NSF would intend to restore operations at assets such as the Arecibo Observatory LIDAR facility -- a valuable geospace research tool -- as well as at the visitor center and offsite Culebra facility, which analyzes cloud cover and precipitation data. NSF would also seek to explore possibilities for expanding the educational capacities of the learning center. Safety precautions due to the COVID-19 pandemic will remain in place as appropriate.

Some Arecibo operations involving the analysis and cataloging of archived data collected by the telescope would continue. UCF secured enhanced cloud storage and analytics capabilities in 2019 through an agreement with Microsoft, and the observatory is working to migrate on-site data to servers outside of the affected area.

Areas of the observatory that could be affected by an uncontrolled collapse have been evacuated since the November cable break and will remain closed to unauthorized personnel during the decommissioning. NSF and UCF will work to minimize risk in the area in the event of an unexpected collapse. NSF has prioritized a swift, thorough process with the intent of avoiding such an event.

NSF recognizes the cultural and economic significance of Arecibo Observatory to Puerto Rico, and how the telescope serves as an inspiration for Puerto Ricans considering education and employment in STEM. NSF's goal is to work with the Puerto Rican government and other stakeholders and partners to explore the possibility of applying resources from Arecibo Observatory for educational purposes.

"Over its lifetime, Arecibo Observatory has helped transform our understanding of the ionosphere, showing us how density, composition and other factors interact to shape this critical region where Earth's atmosphere meets space," said Michael Wiltberger, head of NSF's Geospace Section. "While I am disappointed by the loss of investigative capabilities, I believe this process is a necessary step to preserve the research community's ability to use Arecibo Observatory's other assets and hopefully ensure that important work can continue at the facility."

Engineering summary

Arecibo Observatory's telescope consists of a radio dish 1,000 feet (305 meters) wide in diameter with a 900-ton instrument platform hanging 450 feet above. The platform is suspended by cables connected to three towers.

On Aug. 10, 2020, an auxiliary cable failed, slipping from its socket in one of the towers and leaving a 100-foot gash in the dish below. NSF authorized Arecibo Observatory to take all reasonable steps and use available funds, which amounted to millions of dollars, to secure the analysis and equipment needed to address the situation. Engineers were working to determine how to repair the damage and determine the integrity of the structure when a main cable connected to the same tower broke Nov. 6.

The second broken cable was unexpected -- engineering assessments following the auxiliary cable failure indicated the structure was stable and the planning process to restore the telescope to operation was underway. Engineers subsequently found this 3-inch main cable snapped at about 60% of what should have been its minimum breaking strength during a period of calm weather, raising the possibility of other cables being weaker than expected.

Inspections of the other cables revealed new wire breaks on some of the main cables, which were original to the structure, and evidence of significant slippage at several sockets holding the remaining auxiliary cables, which were added during a refit in the 1990s that added weight to the instrument platform.

Thornton Tomasetti, the engineering firm of record hired by UCF to assess the structure, found that given the likelihood of another cable failing, repair work on the telescope -- including mitigation measures to stabilize it for additional work -- would be unsafe. Stress tests to capture a more accurate measure of the remaining cables' strength could collapse the structure, Thornton Tomasetti found. The firm recommended a controlled demolition to eliminate the danger of an unexpected collapse.

"Although it saddens us to make this recommendation, we believe the structure should be demolished in a controlled way as soon as pragmatically possible, " said the recommendation for action letter submitted by Thornton Tomasetti. "It is therefore our recommendation to expeditiously plan for decommissioning of the observatory and execute a controlled demolition of the telescope."

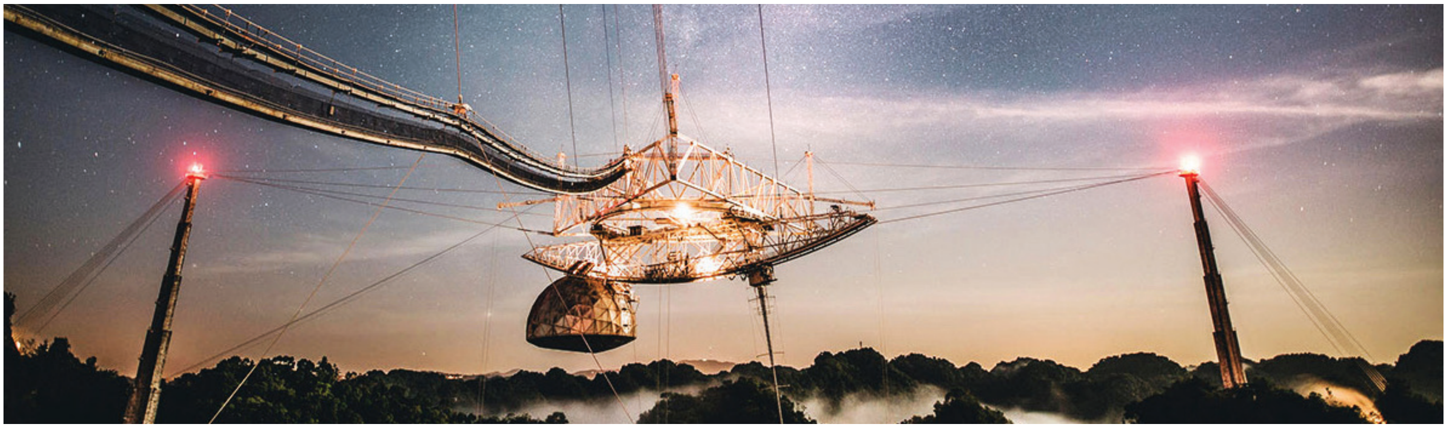
UCF also hired two other engineering firms to provide assessments of the situation. One recommended immediate stabilization action. The other, after reviewing Thornton Tomasetti's model, concurred that there is no course of action that could safely verify the structure's stability and advised against allowing personnel on the telescope's platforms or towers.

“Critical work remains to be done in the area of atmospheric sciences, planetary sciences, radio astronomy and radar astronomy,” UCF President Alexander N. Cartwright said. “UCF stands ready to utilize its experience with the observatory to join other stakeholders in pursuing the kind of commitment and funding needed to continue and build on Arecibo’s contributions to science.”

After receiving the contracted assessments, NSF brought in an independent engineering firm and the Army Corps of Engineers to review the findings. The firm NSF hired concurred with the recommendations of Thornton Tomasetti and expressed concern about significant danger from uncontrolled collapse. The Army Corps of Engineers recommended gathering additional photographic evidence of the facility and a complete forensic evaluation of the broken cable.

Given the fact that any stabilization or repair scenario would require workers to be on or near the telescope structure, the degree of uncertainty about the cables' strength and the extreme forces at work, NSF accepted the recommendation to prepare for controlled decommissioning of the 305-meter telescope.

ARECIBO: FACTS AND FIGURES



Completed in 1963 and stewarded by the U.S. National Science Foundation since the 1970s, Arecibo Observatory has contributed to many important scientific discoveries, including the first discovery of a binary pulsar, the first discovery of an extrasolar planet, the composition of the ionosphere, and the characterization of the properties and orbits of a number of potentially hazardous asteroids.

Location: Arecibo Observatory's principal observing facilities are located 19 kilometers south of the city of Arecibo, Puerto Rico.

Operation and management: Arecibo Observatory is operated and managed for NSF by the Arecibo Observatory Management Team, which is led by the University of Central Florida in partnership with the Universidad Ana G. Méndez and Yang Enterprises Inc.

NSF has invested over $200 million in Arecibo operations, management and maintenance over the past two decades. The observatory has undergone two major upgrades in its lifetime (during the 1970s and 1990s), which NSF funded (along with partial NASA support), totaling $25 million. Since Fiscal Year 2018, NSF has contributed around $7.5 million-per-year to Arecibo operations and management.

Technical specifications and observational capabilities: Arecibo Observatory's principal astronomical research instrument is a 1,000 foot (305 meter) fixed spherical radio/radar telescope. Its frequency capabilities range from 50 megahertz to 11 gigahertz. Transmitters include an S-band (2,380 megahertz) radar system for planetary studies and a 430 megahertz radar system for atmospheric science studies and a heating facility for ionospheric research.

THE HISTORY

Funding for initial radar design studies came from military sources, including the Office of Naval Research and the U.S. Air Force. The Advanced Research Projects Agency, or ARPA, agreed to finance the engineering and construction of the dish, signing a contract with Cornell University, which the Air Force monitored.

Arecibo Observatory was originally intended for ionospheric research and radio astronomy, but the former was of more interest to ARPA, which wanted to study and monitor the Earth's ionosphere as part of its Defender Program to develop ballistic missile defenses.

The Arecibo Ionospheric Observatory, as it was originally named, was the world's largest radio telescope at the time of its dedication in 1963.

By the late 1960s, however, Arecibo's fate was uncertain due to ARPA's shrinking research budget.

In 1967, NSF agreed to replace the Air Force as the government agency monitoring the Arecibo contract, beginning the transformation of Arecibo into a civilian facility.

In 1971, Arecibo received a new name: the National Astronomy and Ionospheric Center. That same year, NSF and NASA signed a memo of understanding to share the costs of major upgrades to Arecibo. NSF funded the resurfacing of the dish reflector and NASA funded the addition of S-band radar equipment.

In 1997, a second major upgrade, which included the Gregorian dome and a second line feed for the ionospheric radar, was completed.

As a result of the upgrades, Arecibo became a powerful tool for scientific research focused on ionospheric physics, radar and radio astronomy, and aeronomy.

EXAMPLES OF DISCOVERIES MADE BY ARECIBO

1967
Arecibo discovered that the rotation rate of Mercury is 59 days, not the previously estimated 88 days.

1972
Arecibo was used to simultaneously heat and observe the D- and E- regions of the ionosphere.

1974
Arecibo discovered the first ever binary pulsar. The 1993 Nobel Prize in physics was awarded to Russell A. Hulse and Joseph H. Taylor for this discovery.

1975
Arecibo made S-band radar observations of Mars to support NASA's Viking mission.

1981
Arecibo produced the first radar maps of the surface of Venus.

1992
Arecibo discovered the first ever exoplanet: In subsequent observations, an entire planetary system was found around the pulsar PSR 1257+12.

1994
Arecibo mapped the distribution of polar ice on Mercury.

1996
Detection of ionized helium layer in the ionosphere made by Arecibo.

2006
Arecibo used to make observations of ionospheric perturbations driven by a tropical storm.

2008
Astronomers use Arecibo to detect for the first time, methanimine and hydrogen cyanide molecules -- two organic molecules that are key ingredients in forming amino acids -- in a galaxy 250 million light-years away.

2016
Arecibo discovered the first-ever repeating fast radio burst. Repeating fast radio bursts are millisecond-duration radio pulses that appear to be extragalactic. The repeater demonstrates that its source survives the bursts and rules out a class of models requiring catastrophic explosions.

2017
Arecibo discovered two pulsars that seem to vanish and reappear intermittently, upending the widely held view that all pulsars are the orderly ticking clocks of the universe.

Image credit: University of Central Florida

Thornton Tomasetti

Via email:Ramon.lugo@ucf.edu

November 12, 2020

Ramon Lugo III
Director, Florida Space Institute
University of Central Florida
12354 Research Parkway
Partnership 1 Building, Suite 214
Orlando, Florida 32826

RE: RECOMMENDATION FOR COURSE OF ACTION AT ARECIBO OBSERVATORY
TT Project No. U20209

Dear Ray:

This letter is to inform you of our opinion as engineer of record for the stabilization and remediation of the damaged telescope, which is to decommission the telescope and perform a controlled demolition of the structure as soon as pragmatically possible. As you know, on the morning of August 10 a 3¼-inch-diameter cable, spanning from Tower 4 to the platform, failed as the tower end of the cable pulled from its socket and fell to the ground. This cable was one of the auxiliary system of twelve cables installed twenty-seven years ago. The auxiliary cables supplemented the cables from the telescope's original construction in the 1960s to accommodate the weight added to the receiver platform by the installation of the Gregorian dome.

Thornton Tomasetti, Inc. [TT] was retained to produce the design of any components necessary to stabilize the structure and then to design the remediation to engage permanent repairs. The assignment required TT to develop a digital model of the structure to determine the state of load effects in the platform components, towers and cables in their current and possible future configurations. We calibrated the model using survey data, data from instrumentation installed on the telescope after the failure and data obtained by the observatory upon the cable's failure. The model was checked internally and peer reviewed by an external party, Wiss, Janney, Elstner Associates, Inc. [WJE]. The model is a tool that predicts load effects, or forces and deformations of the structure, hence the demands on its elements. The model does not predict capacity of the elements. The true capacity of these original cables and auxiliary sockets as they exist today is unknown, because the specific cause and extent of the deterioration in each of these elements is not currently known. Each has failed at forces significantly less than the specified minimum breaking strength.

The structural design is highly redundant (meaning it has the ability to survive collapse after the loss of a critical element). Each of the three towers has four 3-inch-diameter original cables spanning to the near apex of the triangular platform and two 3¼-inch auxiliary cables connecting farther back on the platform. When the auxiliary cable that spans to Tower 4 failed in August, load was shed to the four original cables and the remaining auxiliary cable still connecting the platform to the tower. After the failure, observatory staff, TT, WJE and WSP inspected/reviewed the remaining structure for signs of distress and deterioration. Given the generally good appearance of the remaining elements; suitable factor-of-safety remaining in the platform elements, as shown through analysis; and adequate redundancy of the cable system, we believed the platform to be stable then and for some time forward. Our analysis had shown that the loss of another cable would not cause catastrophic collapse of the platform. Therefore, we believed work to stabilize the structure could begin, with continuous monitoring and safe operational procedures. The observatory procured materials and supplies and planned for installation.

As you know, TT proposed the stabilization scheme and until recently was developing remedial works to return the telescope to operating condition, with enhanced capability and performance such that the 60-year-old original cables would have less tension force in the them than in the past during normal operating conditions. Reduction of the load in these cables seemed prudent due to their age and a few documented wire breaks on the original cables over the years. We recommended that all remaining cables be inspected to determine their condition, to be certain that the wire breaks that were documented in the past were the full extent of the breaks and that the internal core of each cable was in good condition. Furthermore, TT recommended the replacement of all of the auxiliary cables, since the one 3¼-inch auxiliary cable completely pulled from its socket and numerous other auxiliary cables exhibited unusual slip at their sockets.

Another cable failed on November 6. This cable was one of the four 3-inch-diameter original cables also supporting the platform from Tower 4. These original cables had been operating at a factor of safety of 1.67, based upon specified minimum breaking strength for the cable just prior to failure. This corresponded to a load or tension force of 647 kips (1 kip = one thousand pounds) in the original cables. The tension in the remaining three original cables has increased from the 647 kips to 790 kips. This places them at a factor of safety of 1.32 (force in cable/specified minimum breaking strength = 790/1044). This is nearly 75% of the specified minimum breaking strength. The original cable failed near the anchor socket at the tower but did not pull from the socket. The design of the original structure and the upgrade in the 1990s intended a factor of safety of 2.1 or more for the cables.

With the loss of two cables, there are now three original cables (of four) and one auxiliary cable (of two) connecting the platform to Tower 4. Should another of these three original cables fail, the two remaining original cables will undergo static force demands at or above the specified minimum breaking strength. A catastrophic failure would be very likely. These cables are not capable of handling the required dynamic demands of a sudden failure of an adjacent cable. The structural redundancy is no longer available and cannot be factored into determining safety.

We have noted wire breaks on the three remaining 3-inch-diameter original cables from Tower 4, which occurred during the November event. We continue to monitor the structure and continue to note wire breaks since the failure last week. Furthermore, there is no evidence that the existing original cables can achieve the specified minimum breaking strength and certainly evidence to the contrary, since one failed at 62% of this strength. The failure event may have occurred over a period of eight minutes as evidenced by the increase in stress, measured from instrumentation installed on the south auxiliary cable to Tower 4, just prior to failure. Weather at the time of failure was calm, with no unusual winds or ambient temperatures and no ground shaking. Failure was unexpected.

Given the likelihood of additional cable failure, unless redundancy can be added to the structure at Tower 4 (by connecting more cables to the platform from Tower 4), it is unsafe to work on the platform or around the towers unless hazards are mitigated. However, mitigation cannot be practically achieved without working for long periods in these locations. There are no means within engineering certainty to provide an estimate of the factor of safety other than significantly reducing tension in these 3-inch-diameter original cables. We have modeled and studied several options, and it is unlikely any of these methods will yield sufficient reductions without placing crews in jeopardy.

It has been suggested that proof-loading the structure for a period of time – to demonstrate that the critical structural elements can sustain forces approximately 10% more than the predicted forces in these elements during the implementation of any remedial work – will provide a calculable margin of safety over some duration, and that repeated proof-loading could provide the means to ensure safety throughout the duration of work. However, we believe that even if proof loading does not cause collapse or further failure of an element, it will cause damage and reduce reserve capacity, making the structure less safe. If we accept collapse to be an acceptable outcome, we need to understand the collapse mechanism to reduce risk. Collapse from a proof-testing event will not be predictable and hence creates undue risk.

Now that we have witnessed two cables fail, one from the original set of cables and one from the auxiliary cables, both at tension forces significantly below their design strengths, it would appear that remediation will require replacement of all of the cables. This factor needs to be considered, as does the timing of the replacement program.

We believe the structure will collapse in the near future if left untouched. Controlled demolition, designed with a specific collapse sequence determined and implemented with the use of explosives, will reduce the uncertainty and danger associated with collapse. Although it saddens us to make this recommendation, we believe the structure should be demolished in a controlled way as soon as pragmatically possible. It is therefore our recommendation to expeditiously plan for decommissioning of the observatory and execute a controlled demolition of the telescope.

Very truly yours,

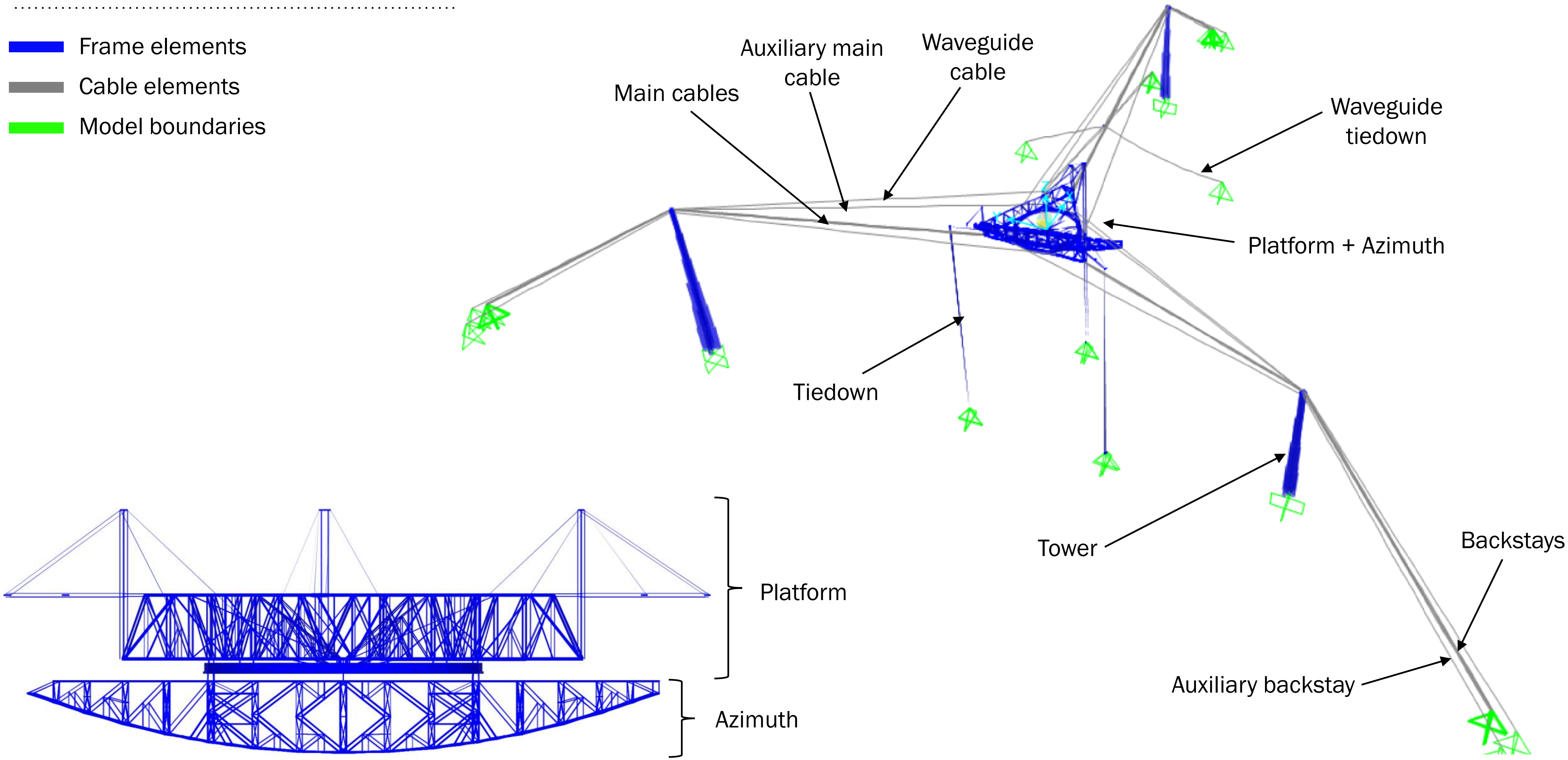
THORNTON TOMASETTI, INC.

John Abruzzo, PE, SE
Managing Principal

Attachments:
Model Calibrations
Results of model for various scenarios

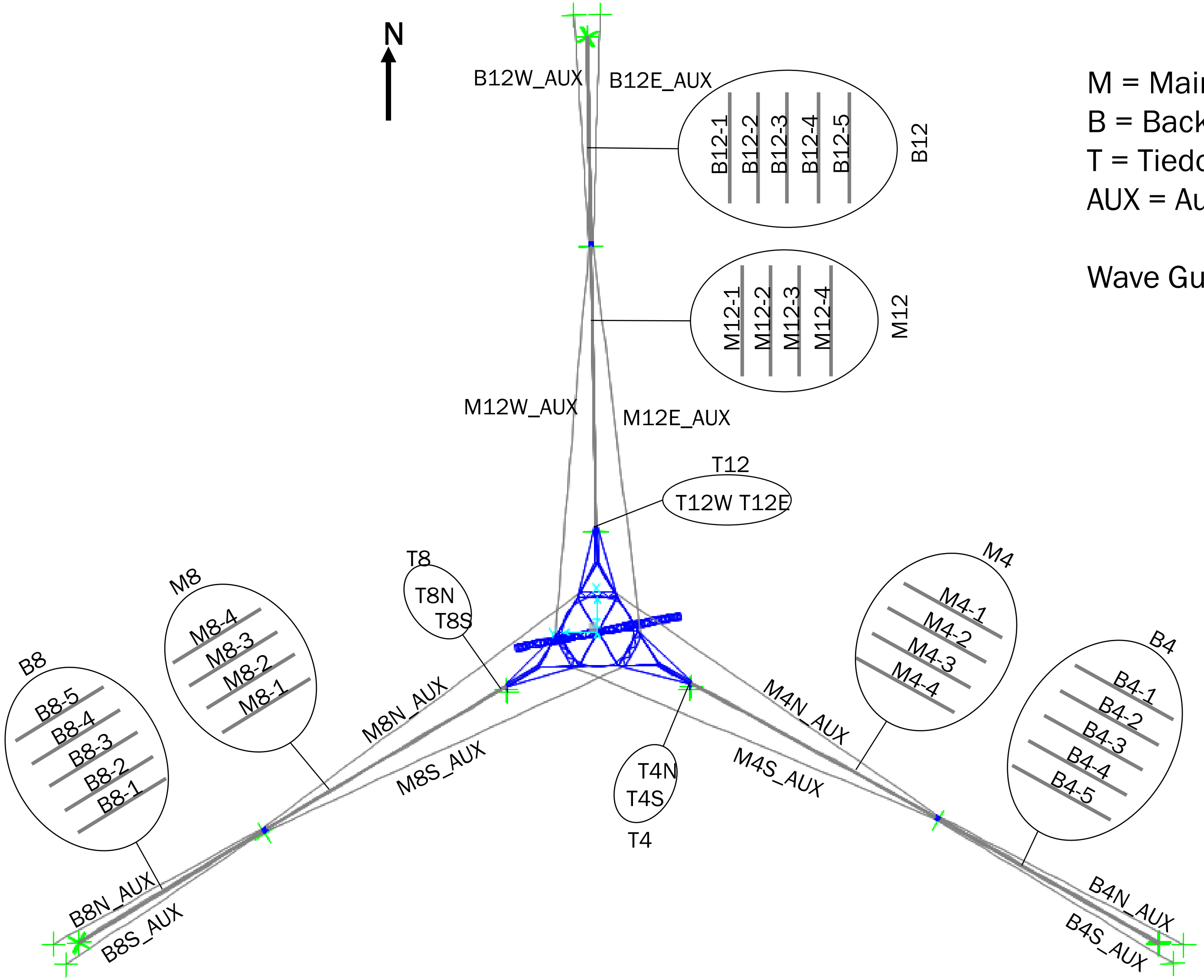
Copy:
Francisco Cordova
Director, Arecibo Observatory

Digital Model Scope and Nomenclature



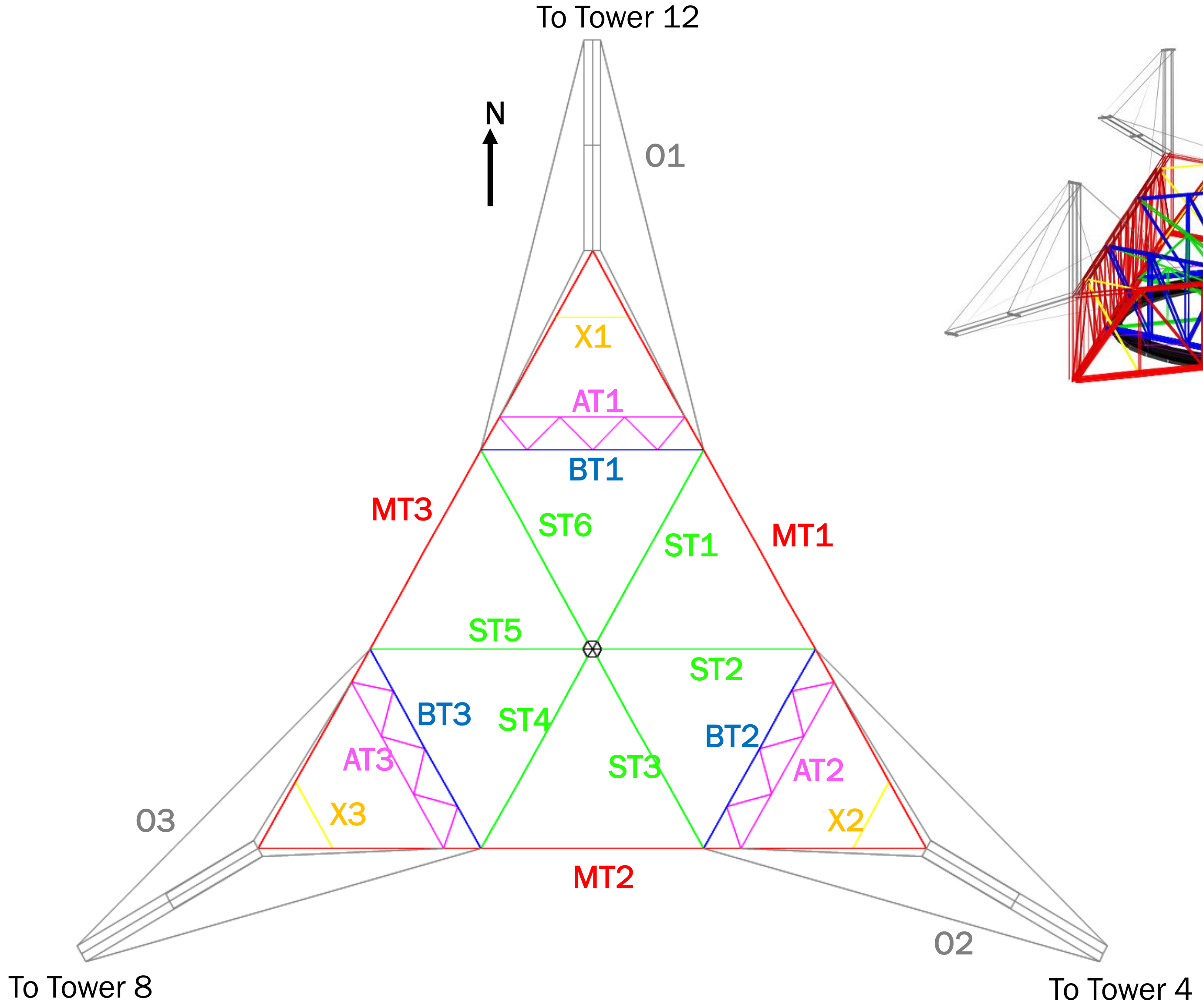
Digital Model Cable Nomenclature

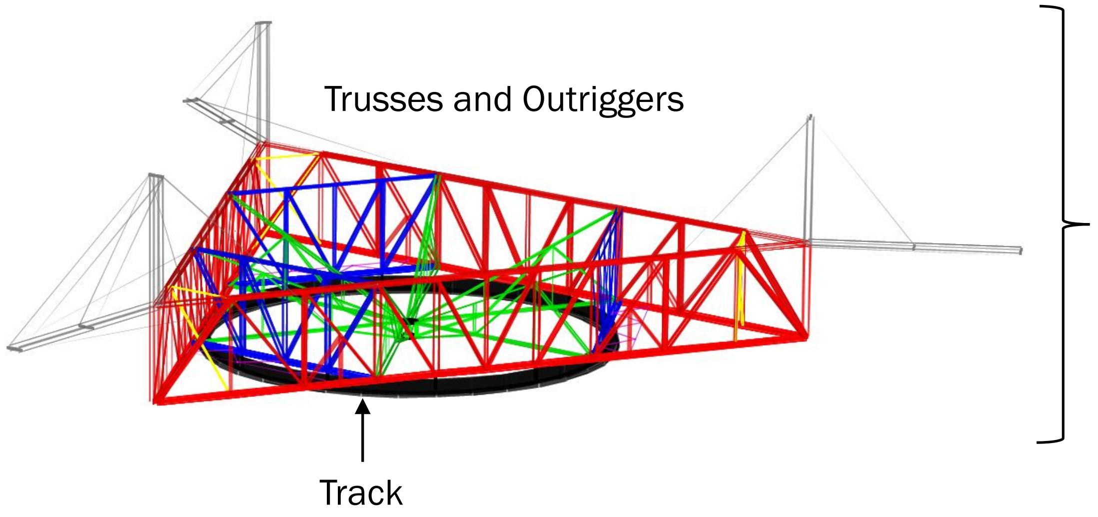
Thornton Tomasetti



M = Main cable
B = Backstay cable
T = Tiedown cable
AUX = Auxiliary cable (added 1992)

Wave Guide cables not shown

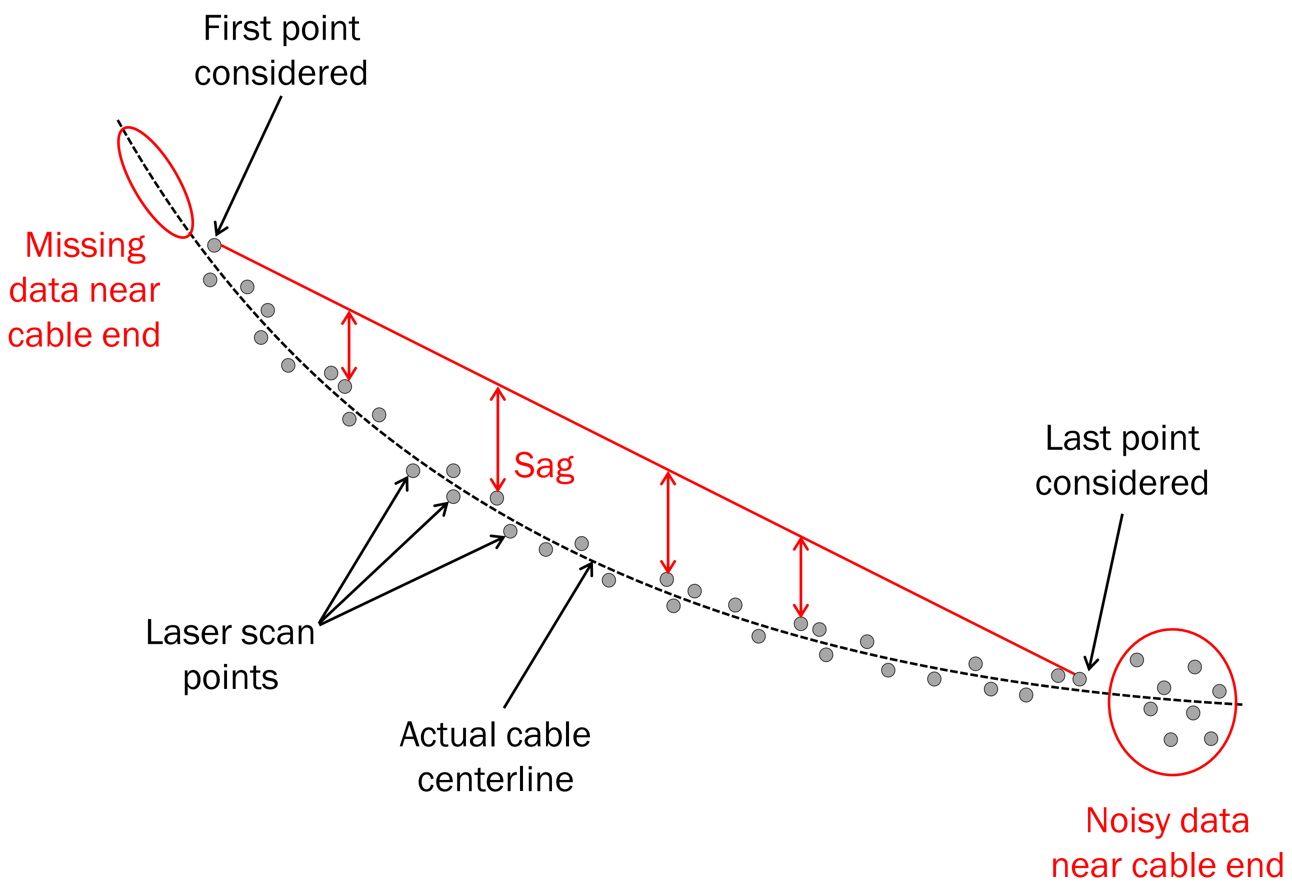




Original structure:
- MT = Main Trusses
- BT = Bracing Trusses
- ST = Secondary Bracing Trusses
- Track

1992 upgrade structure:
- AT = Auxiliary trusses
- X = X-Bracing
- O = Outriggers

2020 Sag Survey Processing



For each cable:

1) Select first and last points along top of cable, staying away from cable ends where data is missing or noisy.
2) Determine equation of straight line between first and last points.
3) For 10 points on top cable and approximately evenly-spaced between first and last points, calculate elevation difference between point and straight line. The maximum difference is the measured sag.
4) Using catenary equations, calculate cable force such that maximum sag matches measured sag. For this step, the cable is assumed to span between the first and last points considered above, and not the start and end points of the actual cable.
5) Using catenary equations, calculate vertical component of cable force at connection with suspended platform. The sum of these results is the suspended platform weight (+ tiedown forces).

Sag Survey (Before Second Cable Failure)

Thornton Tomasetti

Cables(s)	Number of Cables	Horizontal Force [kip]	Average Axial Force [kip]	Vertical Force at Platform End [kip]
M4	4	629	645	137
M4S	1	599	609	98
M8	4	483	495	104
M8N	1	522	531	84
M8S	1	724	736	120
M12	4	501	514	108
M12E	1	390	396	61
M12W	1	683	694	113

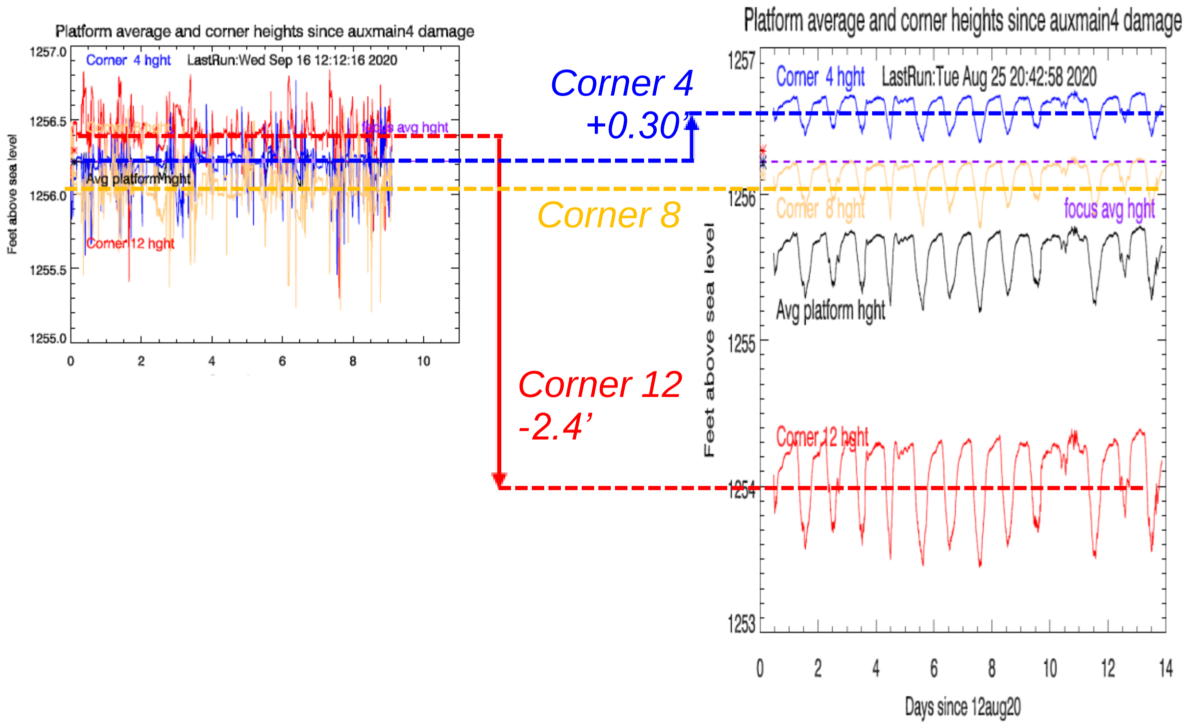
Cables(s)	Number of Cables	Horizontal Force [kip]	Average Axial Force [kip]
B4	5	465	572
B4N	1	535	657
B4S	1	535	657
B8	5	485	540
B8N	1	535	598
B8S	1	540	603
B12	5	455	560
B12E	1	575	706
B12W	1	490	601

Total vertical force on platform = 1,871 kip
Total tiedown force = 45 kip
⟶ Weight of suspended structure = 1,871 – 45 = 1,826 kip

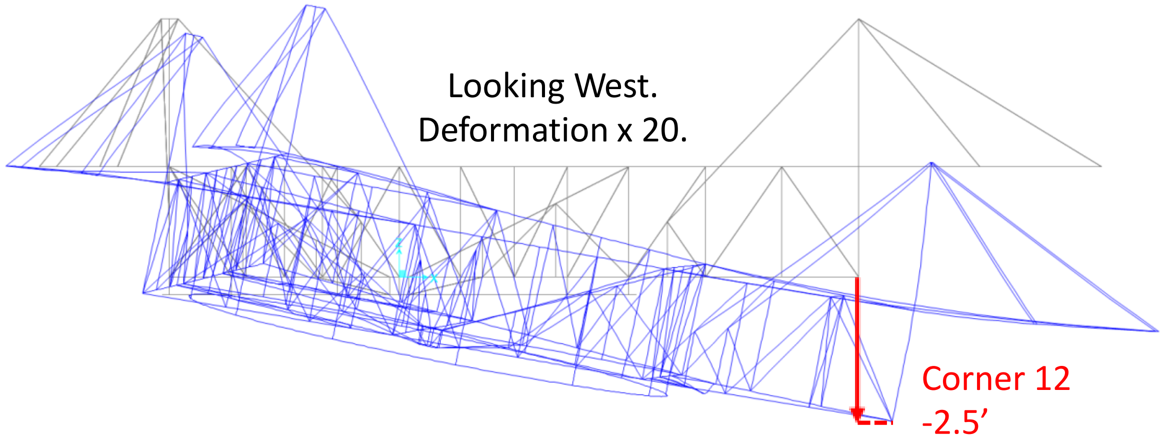
Validation: Platform Corner Elevation Change During Failure

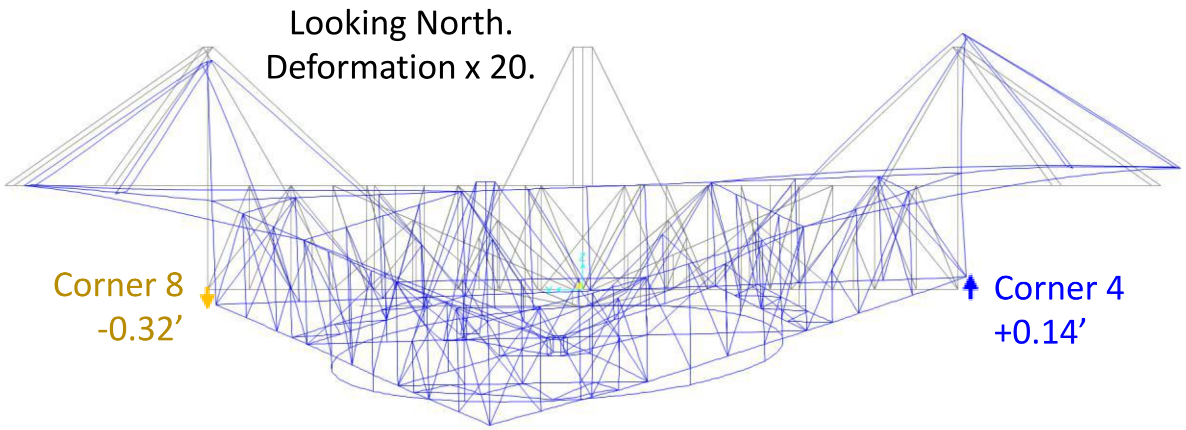
Thornton Tomasetti

Monitoring



FE Model

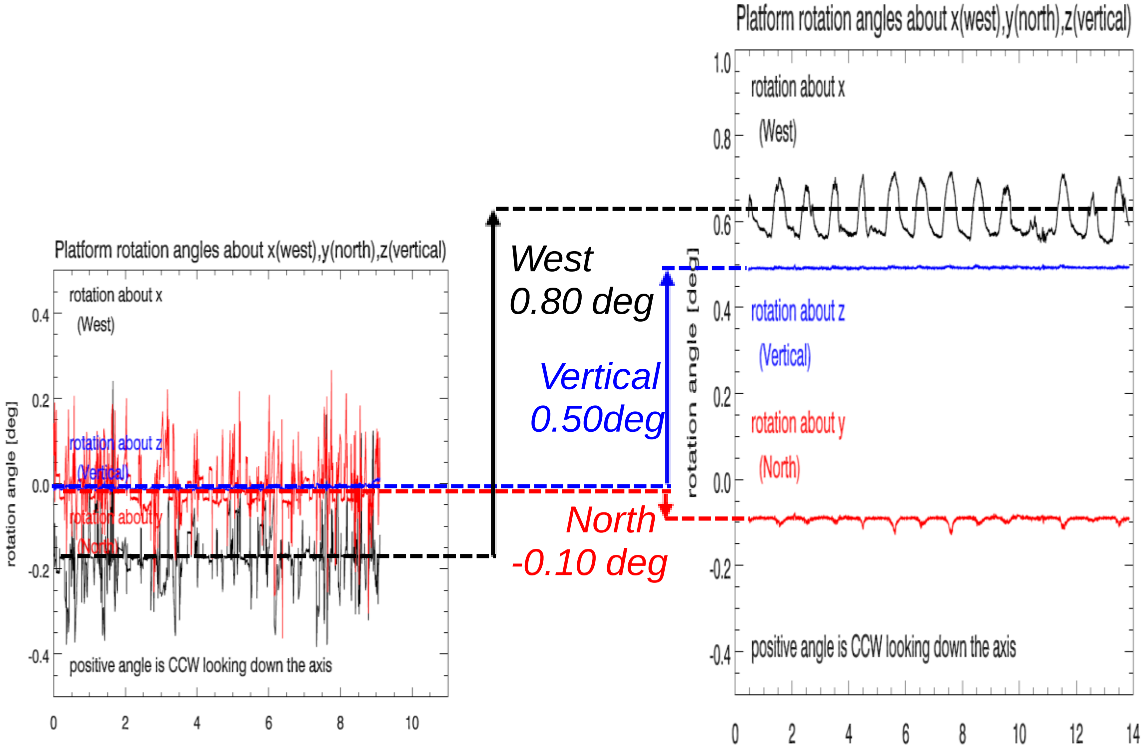




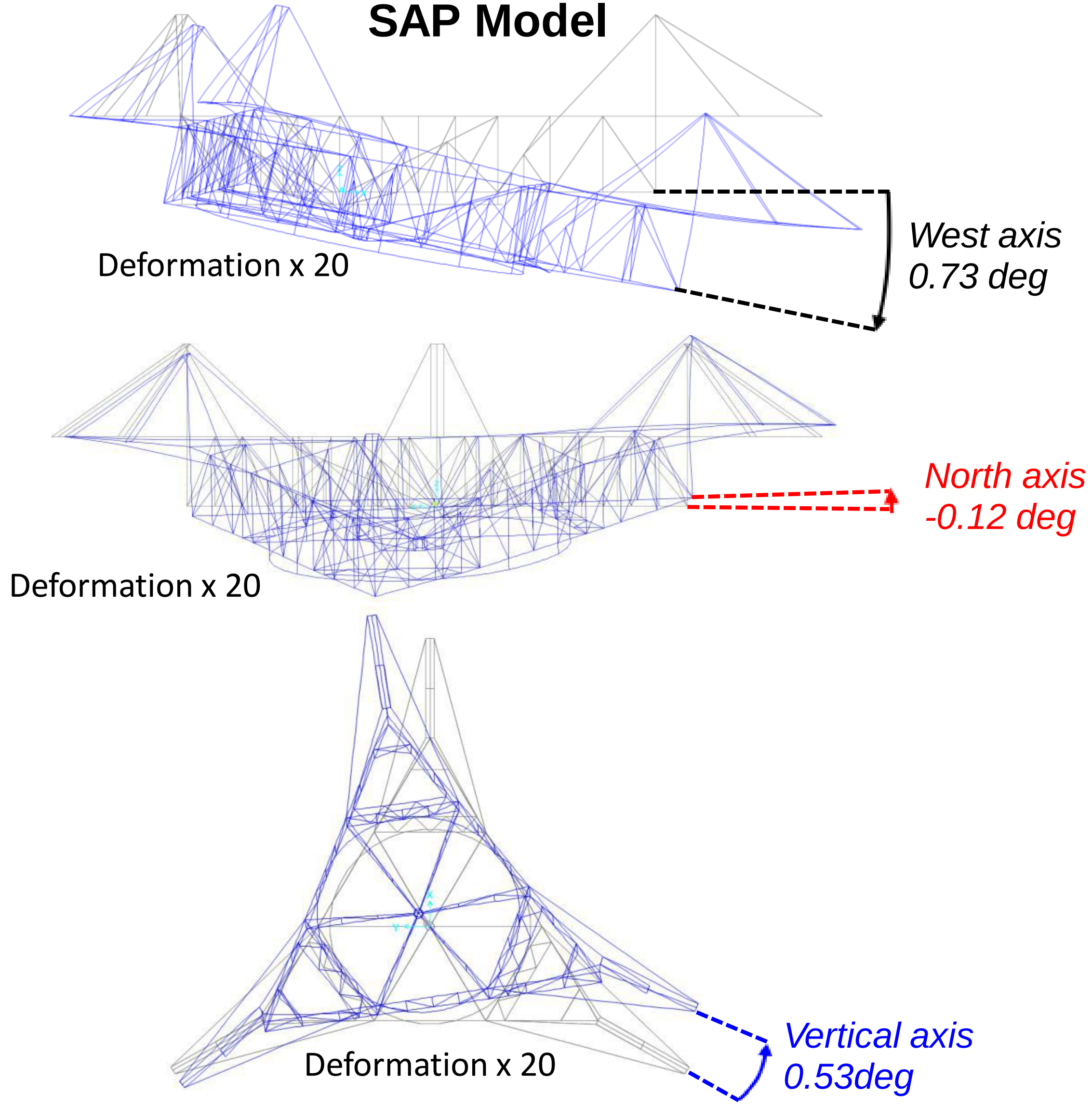
	Corner 4	Corner 8	Corner 12
Monitoring	0.30' (3.6")	0' (0")	-2.4' (-28.8")
FE Model	0.14' (1.6")	-0.32' (-3.9")	-2.5' (30.1")

Validation: Platform Rotation During

Monitoring



SAP Model

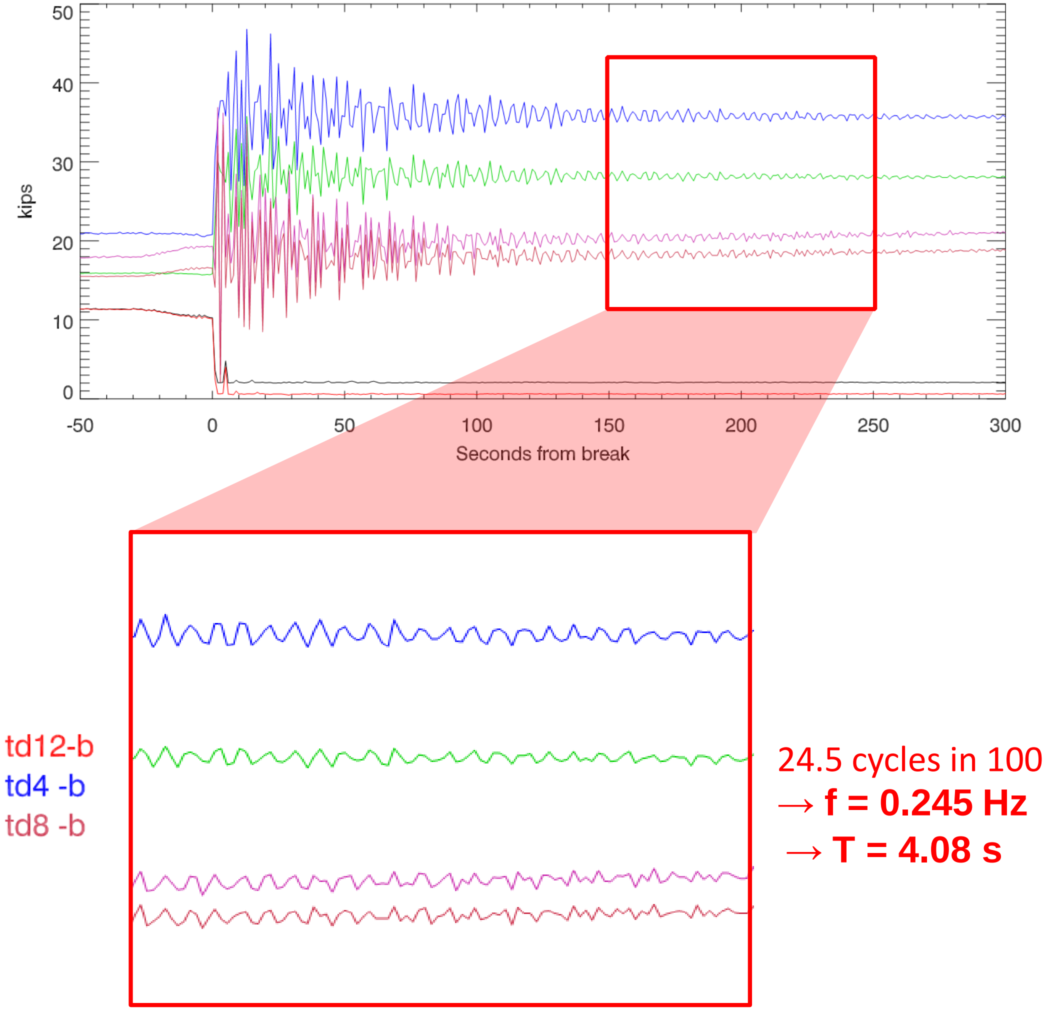


	West axis	North axis	Vertical axis
Monitoring	0.80º	-0.10º	0.50º
FE Model	0.73º	-0.12º	0.53º

Validation: Natural Frequency After Failure

Monitoring

Tiedown forces during failure

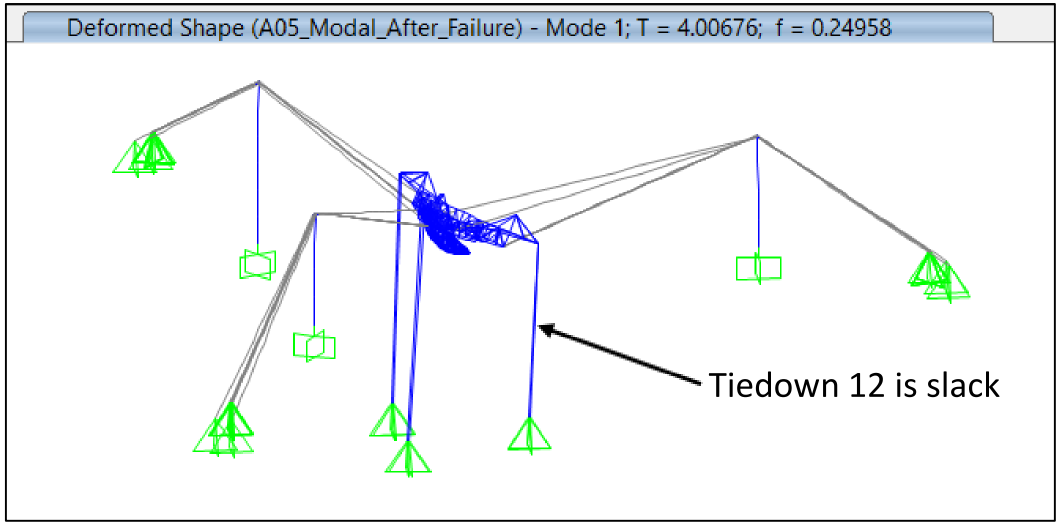


td12-a td12-b
td4 -a td4 -b
td8 -a td8 -b

24.5 cycles in 100 sec
→ **f = 0.245 Hz**
→ **T = 4.08 s**

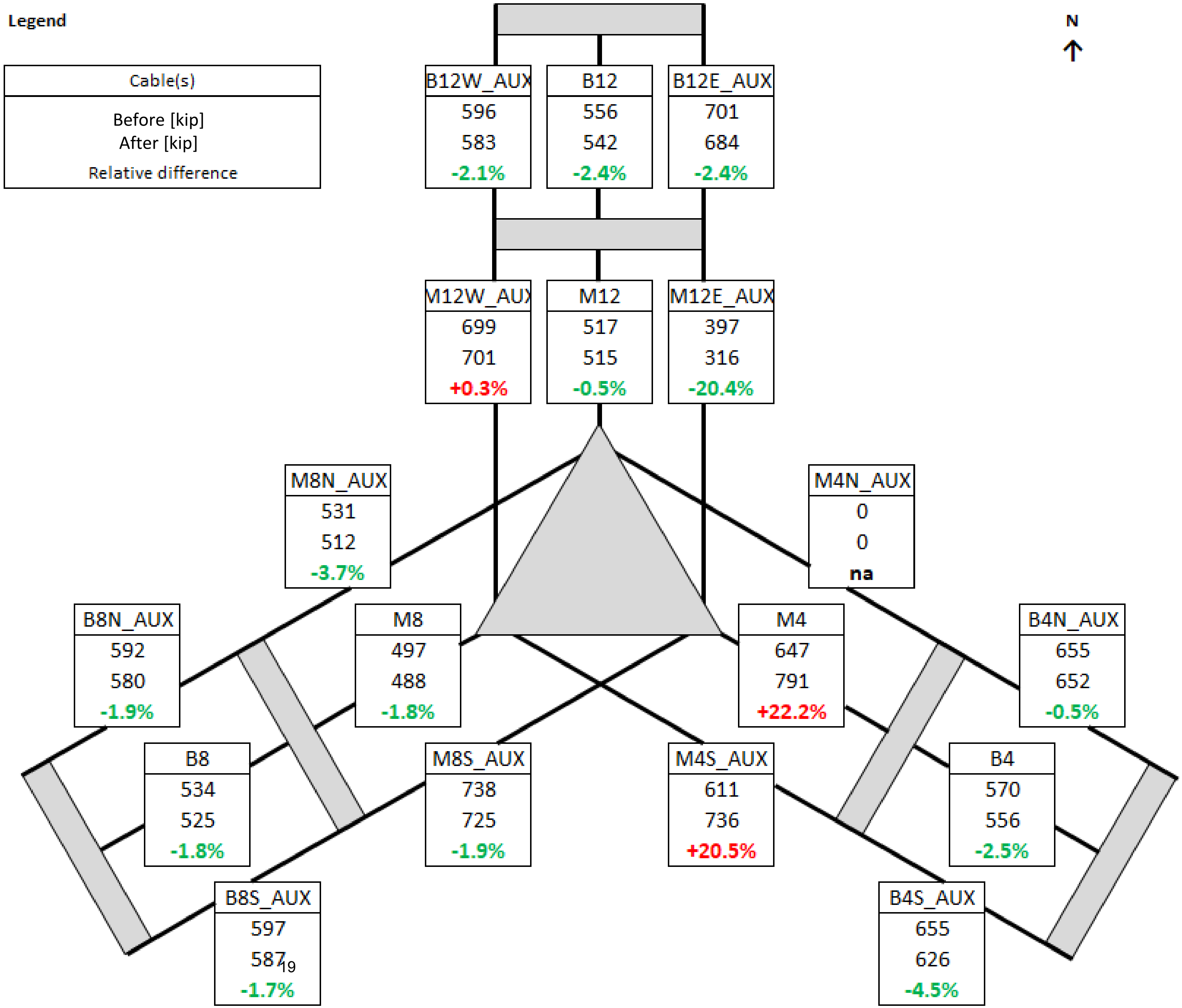
FE Model

Modal analysis with total structure mass of 1,826 kip and tiedown 12 removed



→ **f = 0.233 Hz**
→ **T = 4.30 s**

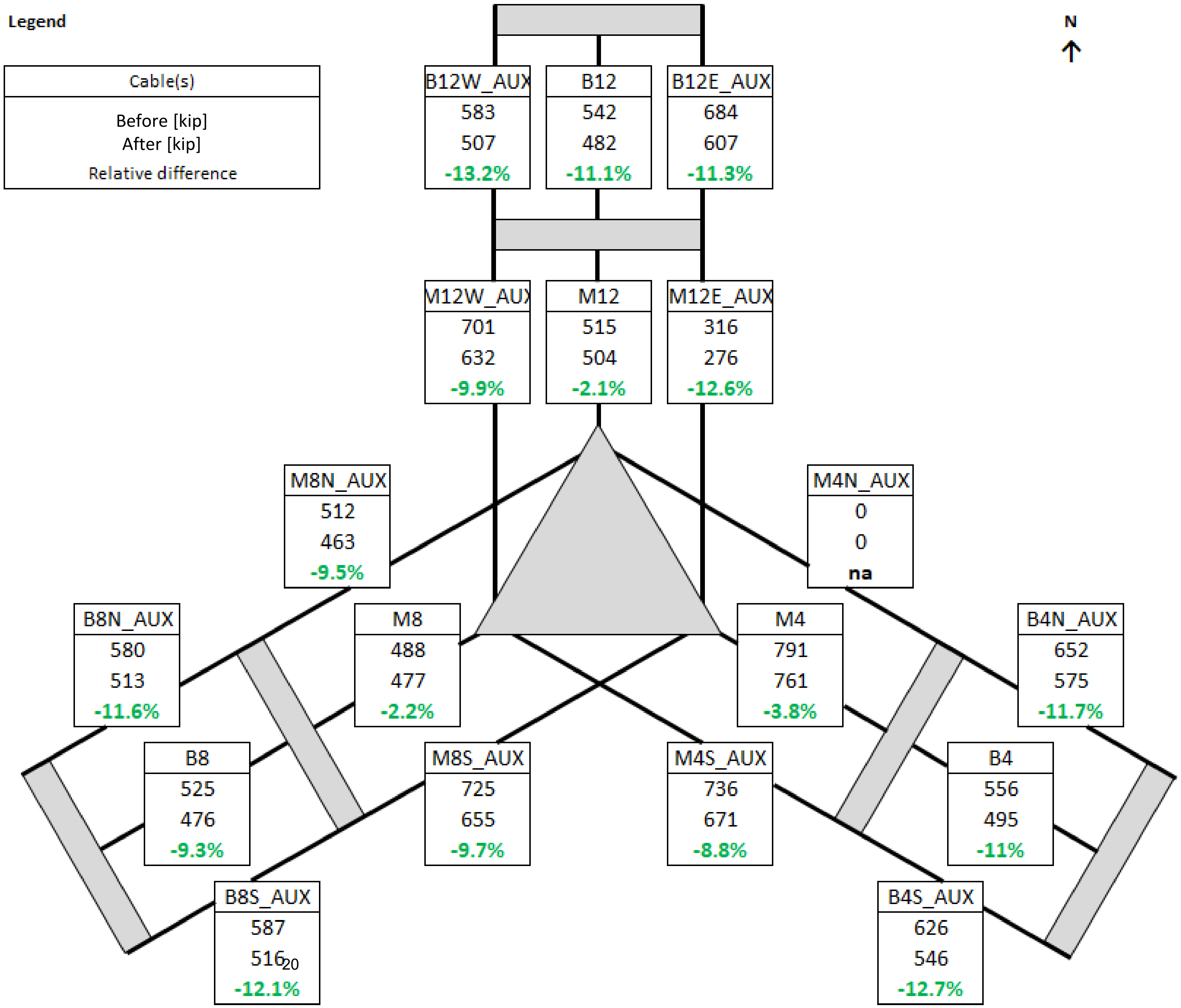
Cable Force Change
Due to Second Cable Failure



Cable Force Change

If De-Jacking all Backstays by 18"

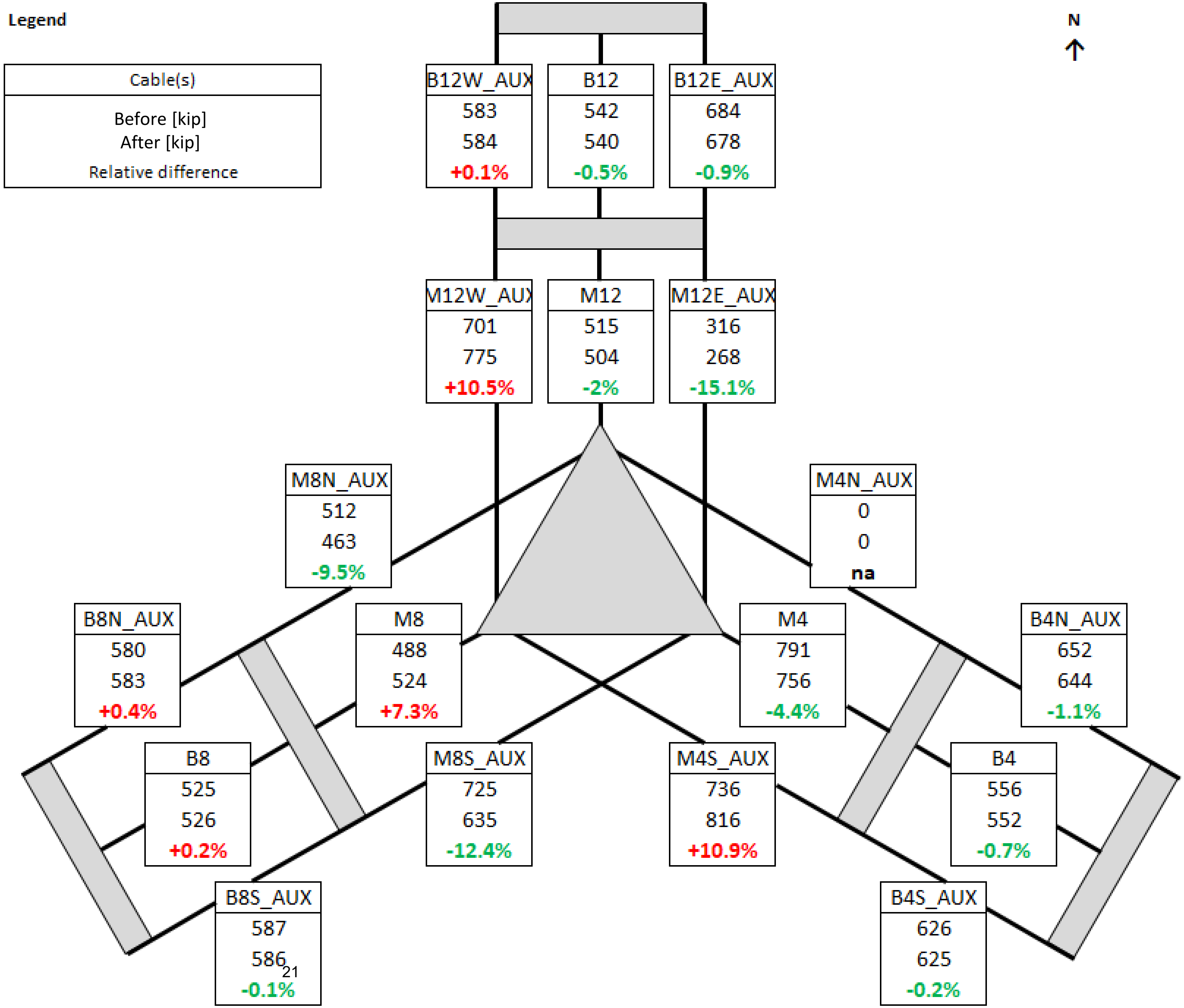
(starting from current condition)



Cable Force Change

If Moving Gregorian Out

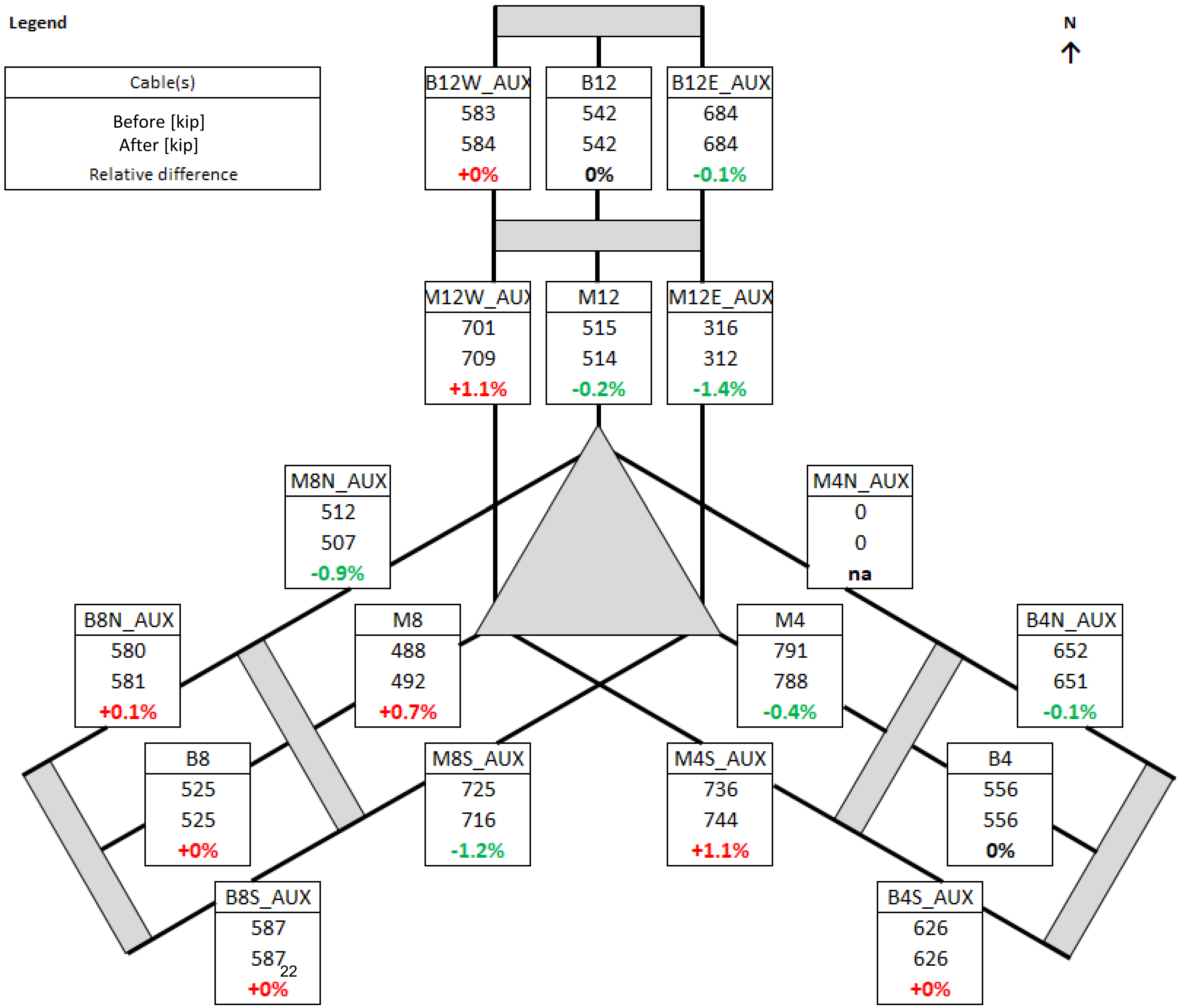
(starting from current condition)



Cable Force Change

If Moving Line Feed In

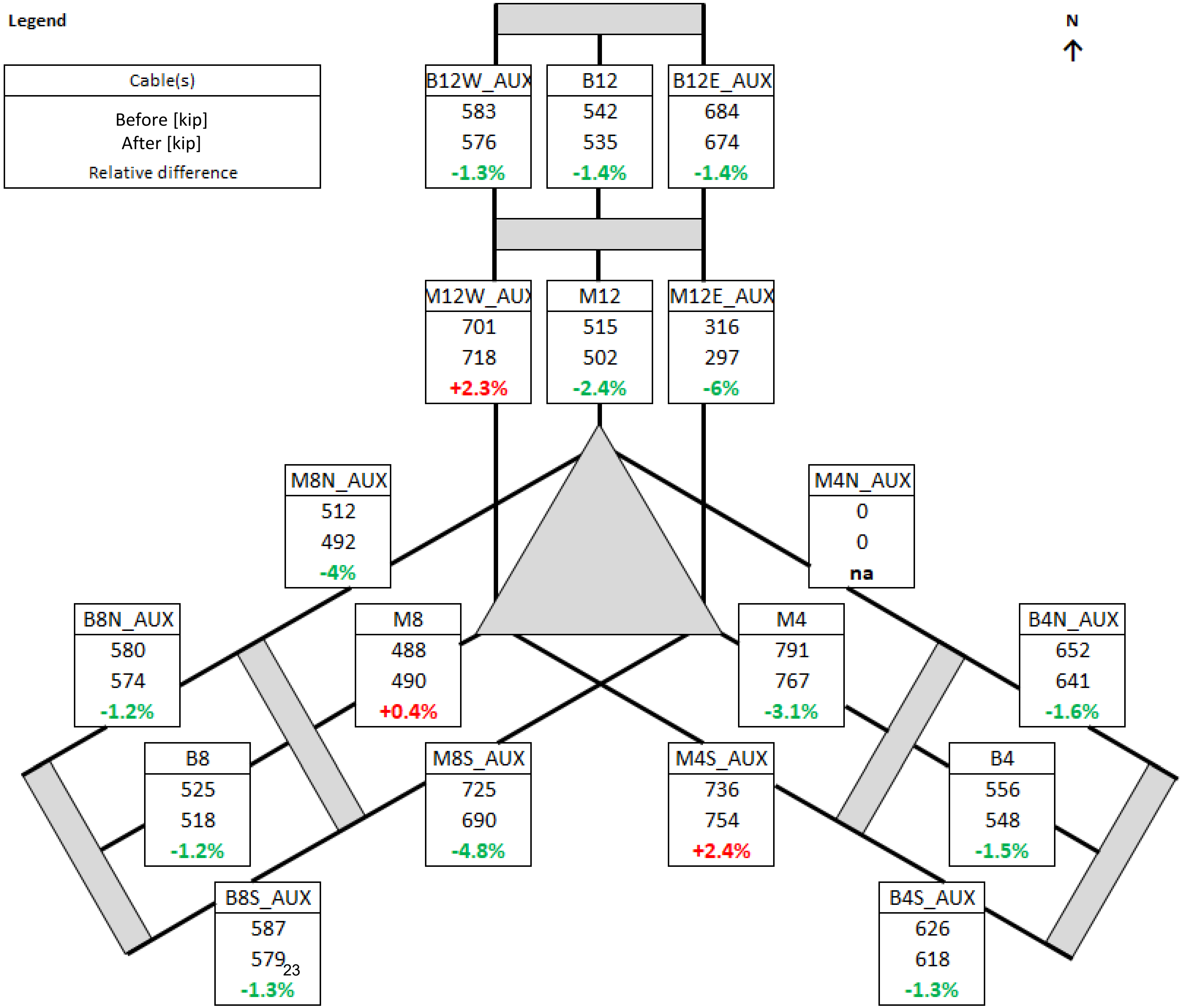
(starting from current condition)



Cable Force Change

If Dropping 38kip Counterweight

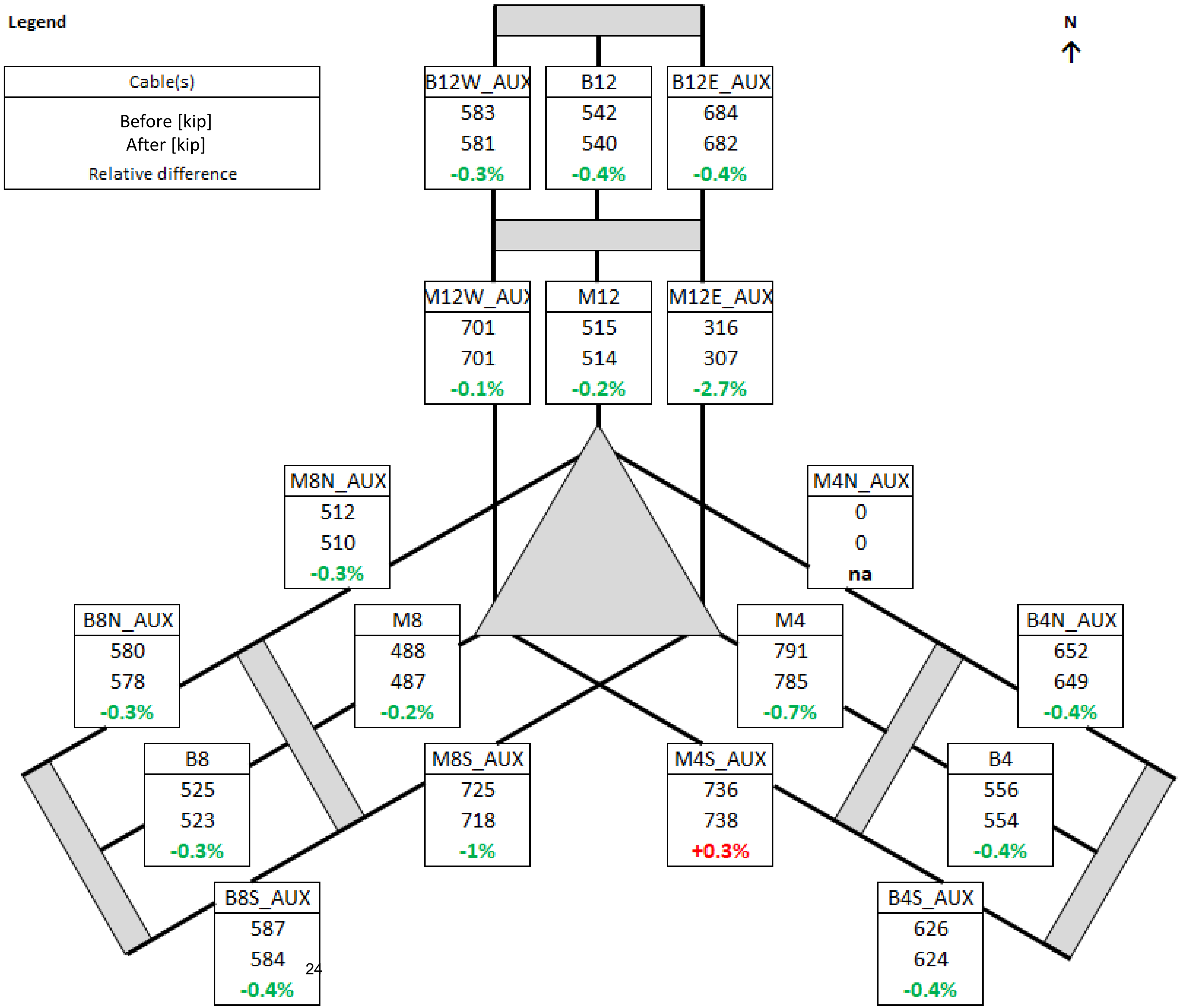
(starting from current condition)



Cable Force Change

If Cutting M4-4

(starting from current condition)



Cable Force Change

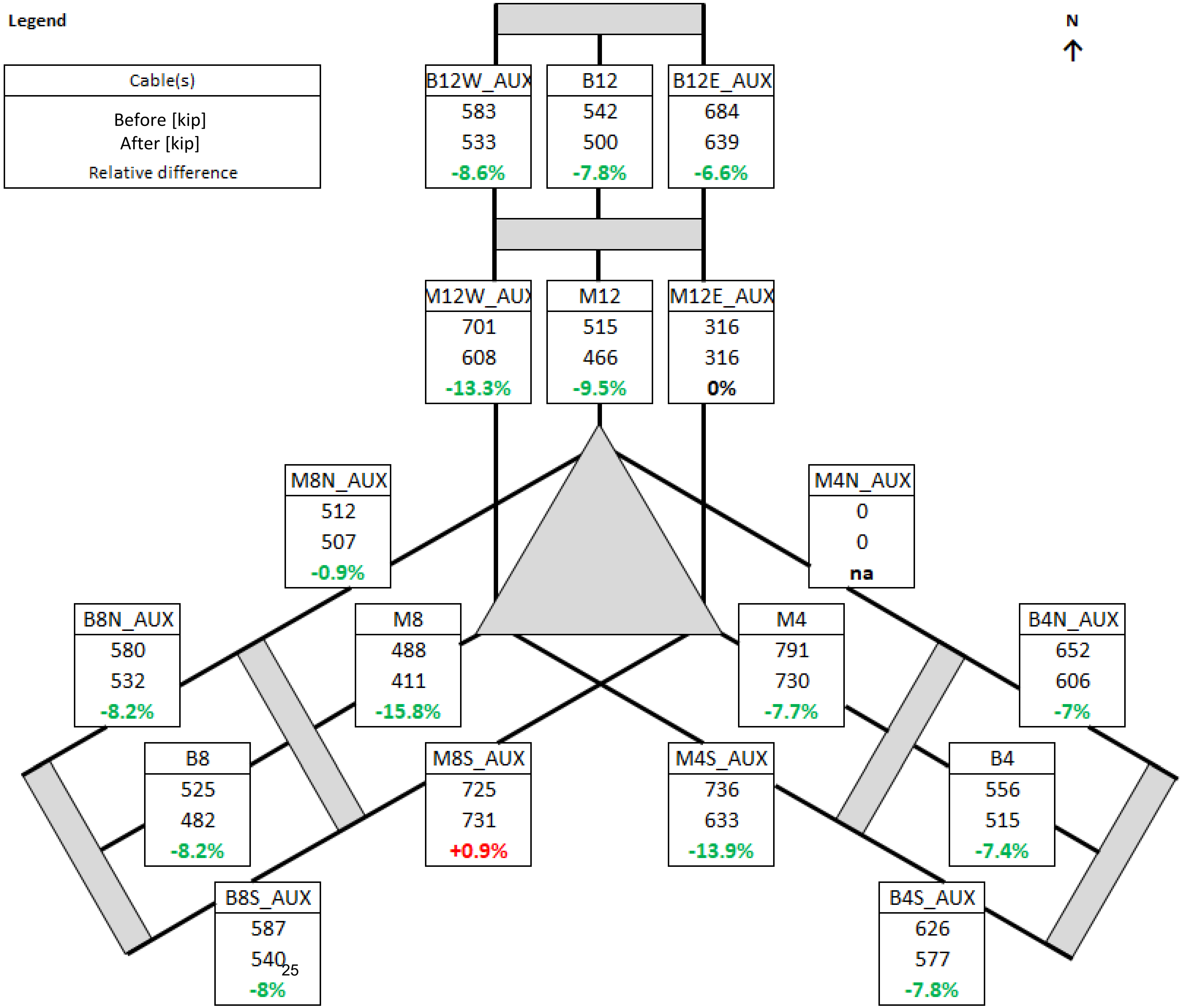
If Dropping Gregorian

(starting from current condition)

Legend

Cable(s)
Before [kip] After [kip] Relative difference

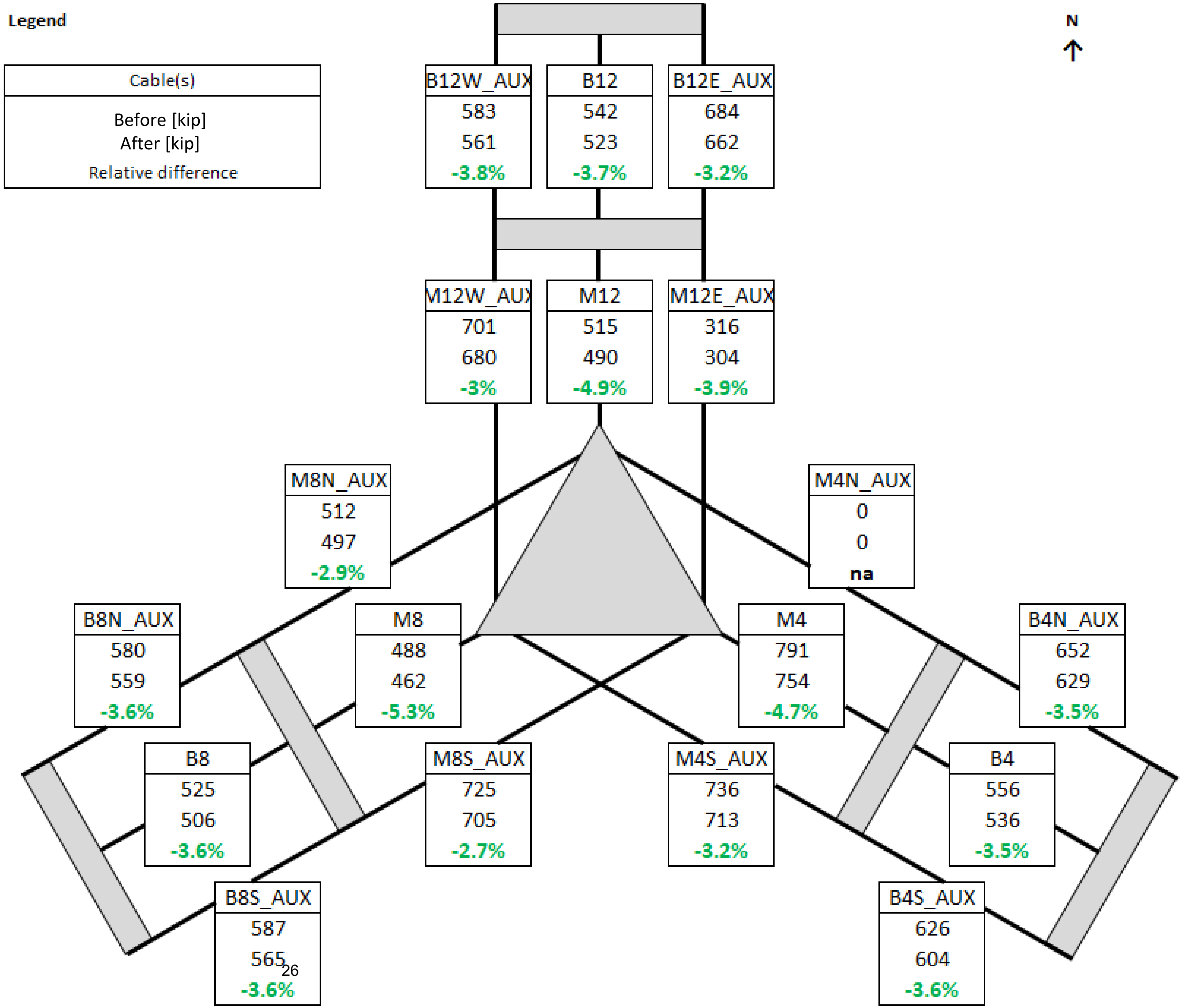
N ↑



Cable Force Change

If Dropping 100kip Uniformly from Platform

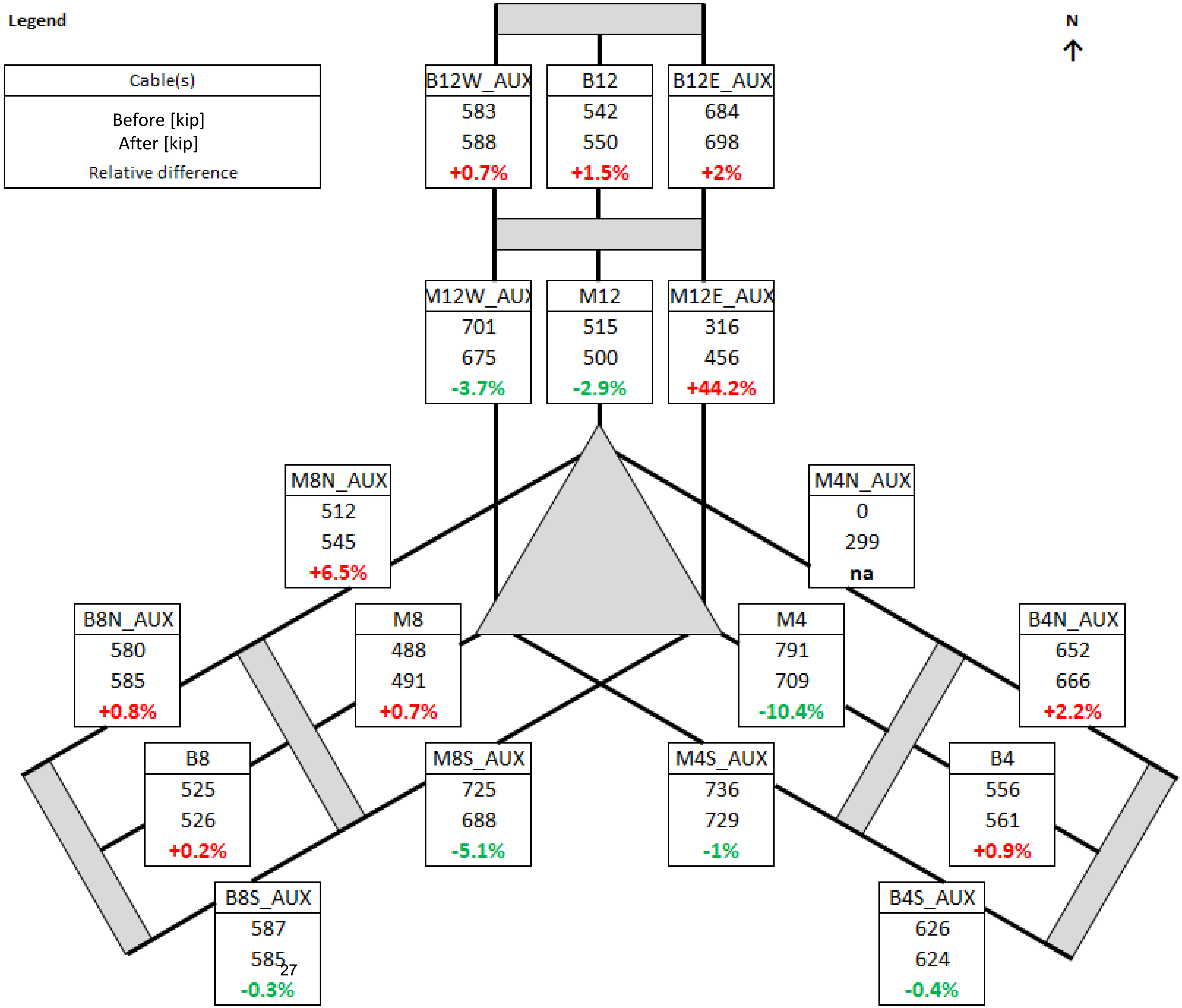
(starting from current condition)



Cable Force Change

If Reconnecting M4N_AUX and Re-tensioning by 300kip

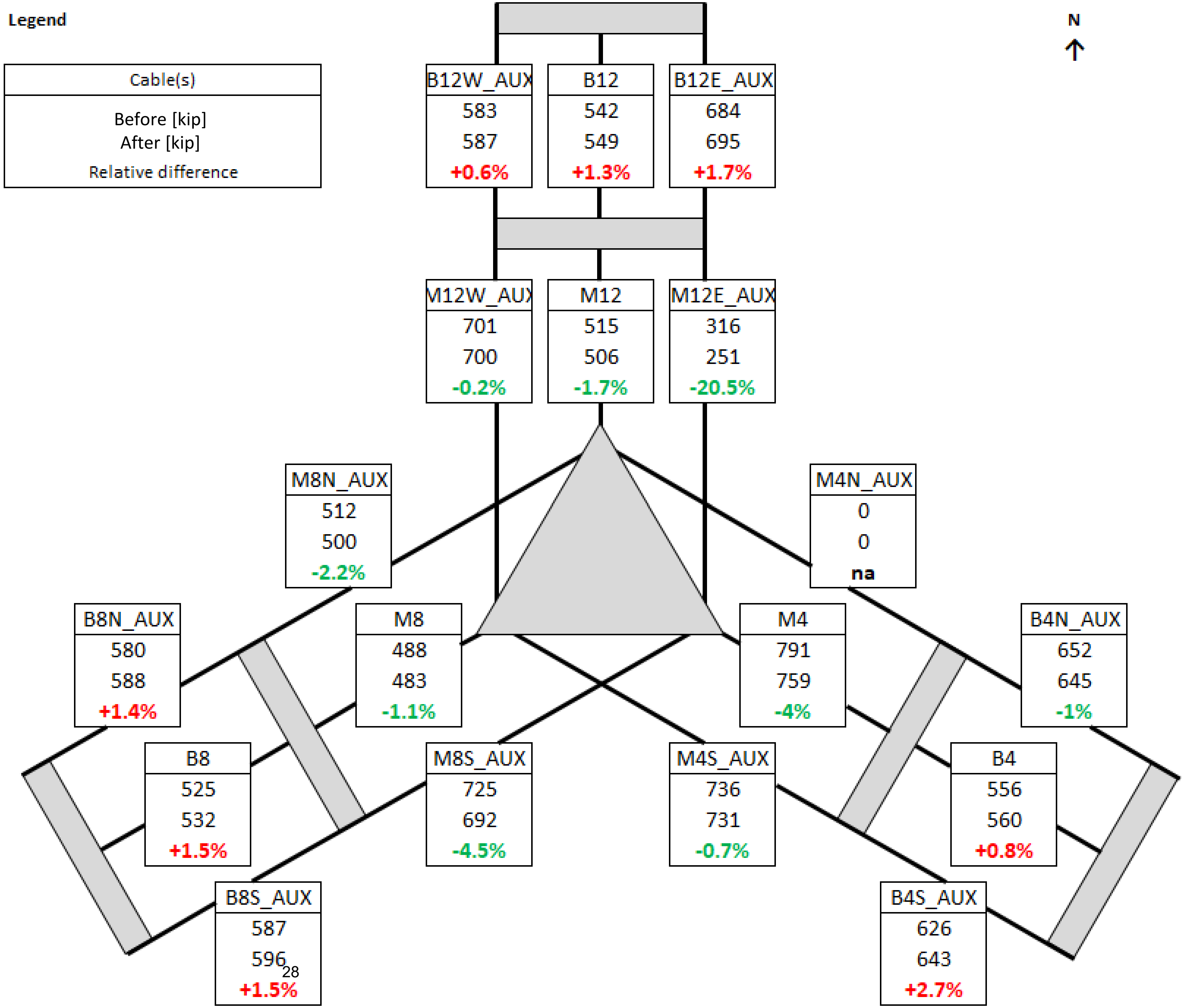
(starting from current condition)



Cable Force Change

If Lifting Platform from Waveguide System

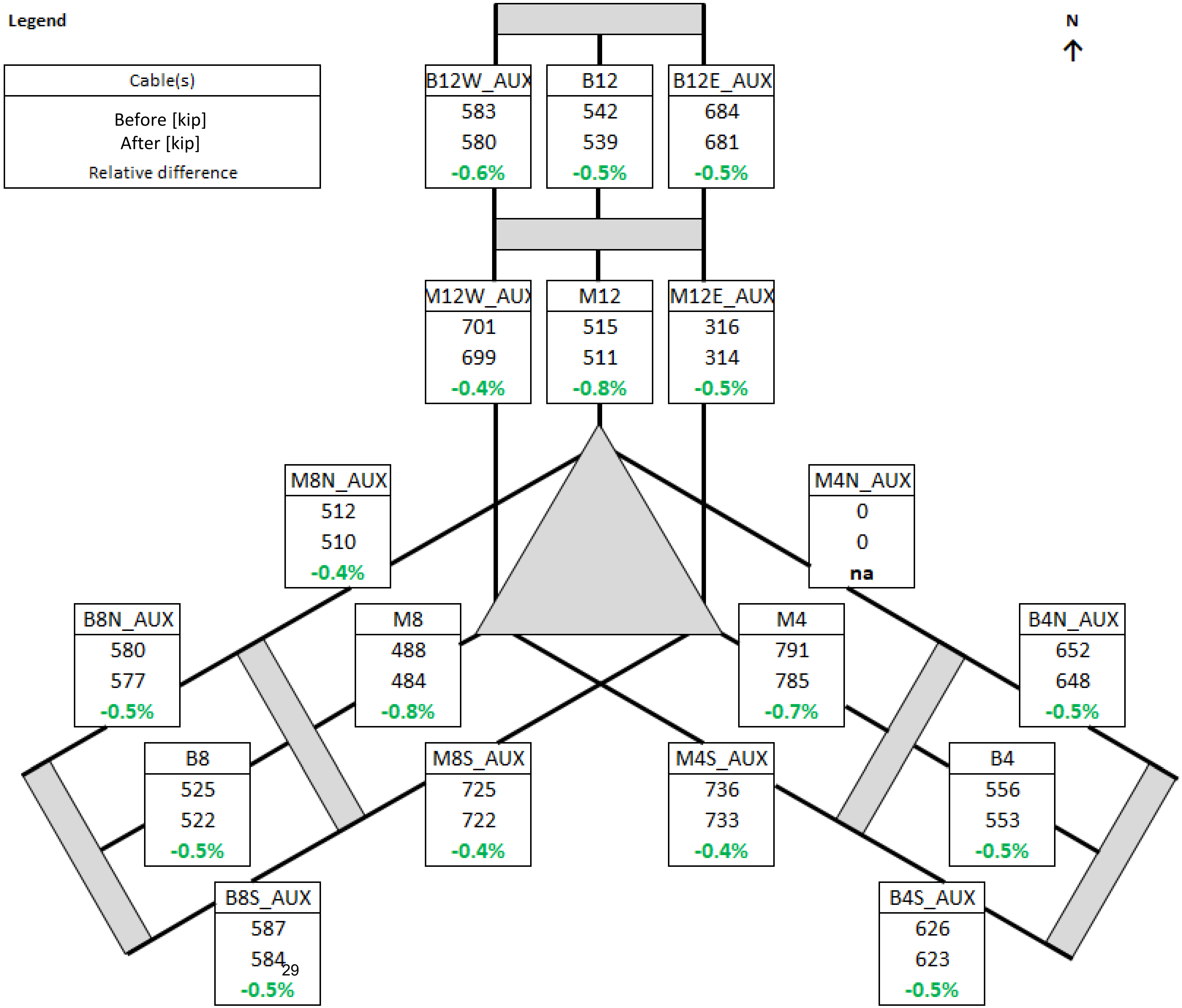
(starting from current condition)



Cable Force Change

If Dropping Tiedowns

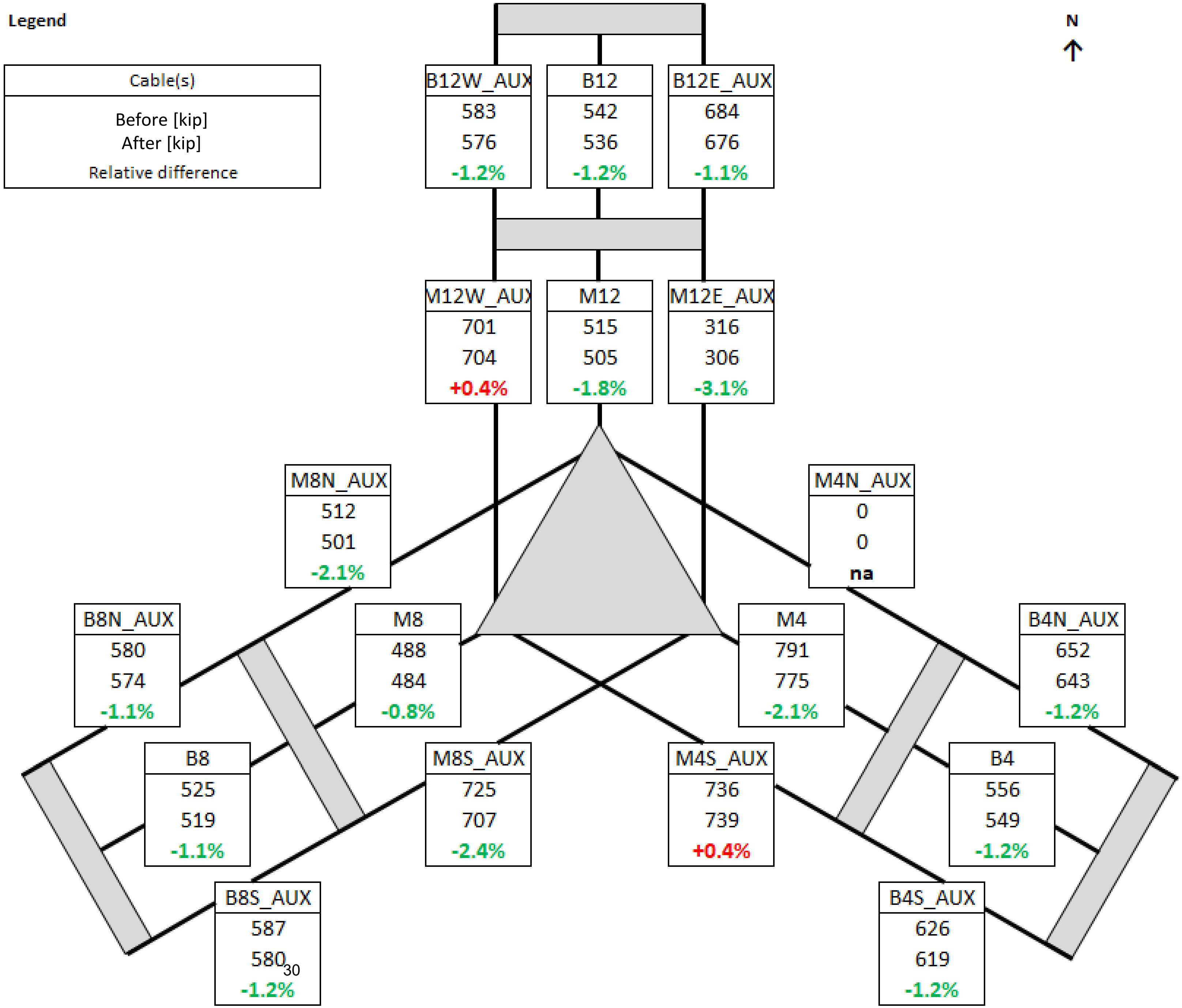
(starting from current condition)



Cable Force Change

If Dropping Line Feed

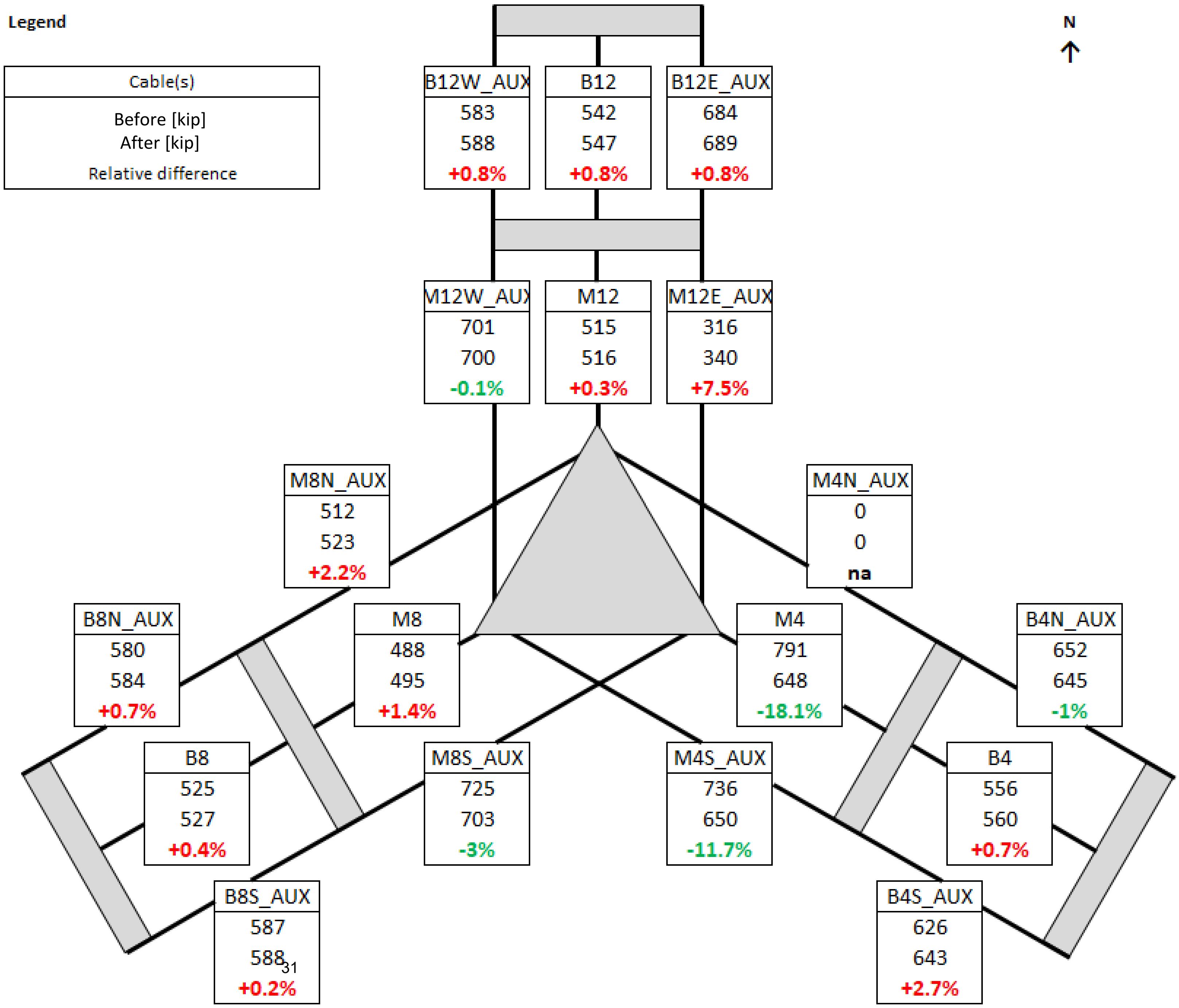
(starting from current condition)



Cable Force Change

If Adding Two 55mm Cables where M4-4 was, Tensioned to 50% Breaking Strength

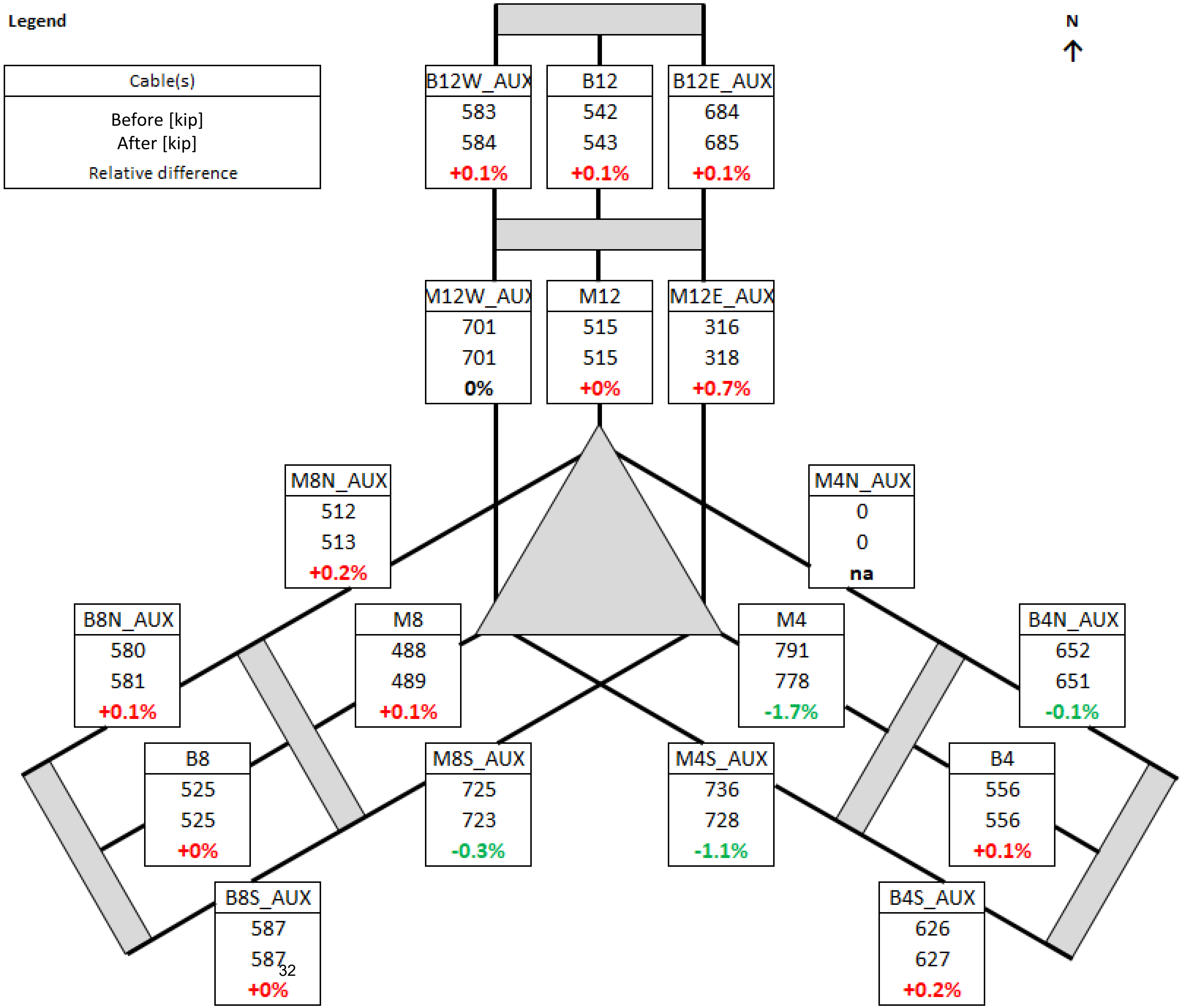
(starting from current condition)



Cable Force Change

If Adding a 1in Wire Rope where M4-4 was, Tensioned to Breaking Strength

(starting from current condition)

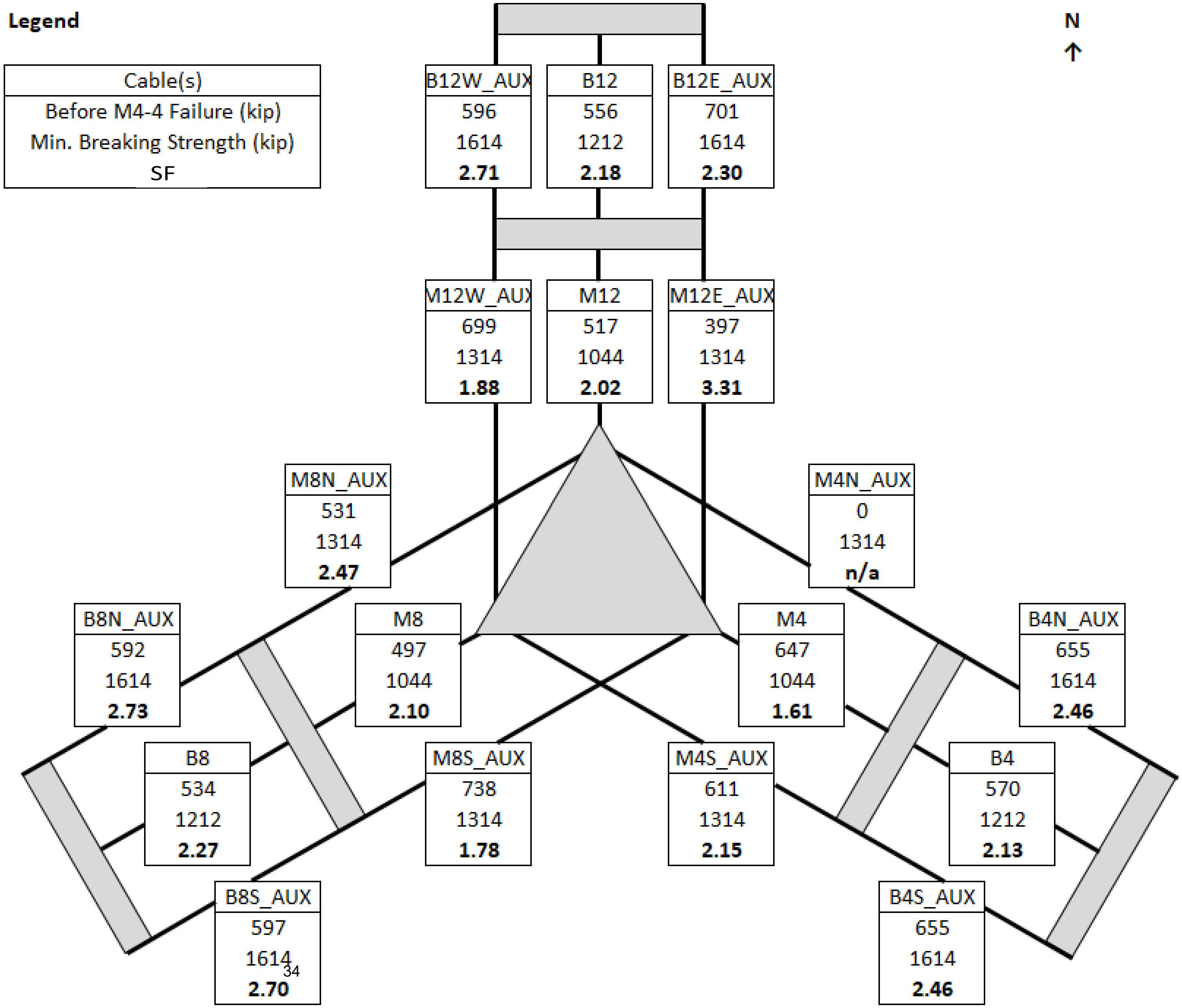


Cable Force Change

		Starting From Current Condition												
Cable(s)	Effect of Second Cable Failure	If Dejacking all Backstays by 18"	If Moving Gregorian Out	If Moving Line Feed In	If Dropping Counterweight	If Cutting M4-4	If Dropping Gregorian	If Dropping 100kip Uniformly from Platform	If Reconnecting M4N_AUX and Re-Tensionning to 300kip	If Lifting Platform From Waveguide Cables	If dropping Tiedowns	If dropping Line Feed	If adding 2 x 55mm cables where M4-4 was, tensionned to 50% breaking strength	If adding a 1in wire rope where M4-4 was, tensionned to breaking strength
M4	22.2%	-3.8%	-4.4%	-0.4%	-3.1%	-0.7%	-7.7%	-4.7%	-10.4%	-4.0%	-0.7%	-2.1%	-18.1%	-1.7%
M4N_AUX	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
M4S_AUX	20.5%	-8.8%	10.9%	1.1%	2.4%	0.3%	-13.9%	-3.2%	-1.0%	-0.7%	-0.4%	0.4%	-11.7%	-1.1%
M8	-1.8%	-2.2%	7.3%	0.7%	0.4%	-0.2%	-15.8%	-5.3%	0.7%	-1.1%	-0.8%	-0.8%	1.4%	0.1%
M8N_AUX	-3.7%	-9.5%	-9.5%	-0.9%	-4.0%	-0.3%	-0.9%	-2.9%	6.5%	-2.2%	-0.4%	-2.1%	2.2%	0.2%
M8S_AUX	-1.9%	-9.7%	-12.4%	-1.2%	-4.8%	-1.0%	0.9%	-2.7%	-5.1%	-4.5%	-0.4%	-2.4%	-3.0%	-0.3%
M12	-0.5%	-2.1%	-2.0%	-0.2%	-2.4%	-0.2%	-9.5%	-4.9%	-2.9%	-1.7%	-0.8%	-1.8%	0.3%	0.0%
M12E_AUX	-20.4%	-12.6%	-15.1%	-1.4%	-6.0%	-2.7%	0.0%	-3.9%	44.2%	-20.5%	-0.5%	-3.1%	7.5%	0.7%
M12W_AUX	0.3%	-9.9%	10.5%	1.1%	2.3%	-0.1%	-13.3%	-3.0%	-3.7%	-0.2%	-0.4%	0.4%	-0.1%	0.0%
B4	-2.5%	-11.0%	-0.7%	0.0%	-1.5%	-0.4%	-7.4%	-3.5%	0.9%	0.8%	-0.5%	-1.2%	0.7%	0.1%
B4N_AUX	-0.5%	-11.7%	-1.1%	-0.1%	-1.6%	-0.4%	-7.0%	-3.5%	2.2%	-1.0%	-0.5%	-1.2%	-1.0%	-0.1%
B4S_AUX	-4.5%	-12.7%	-0.2%	0.0%	-1.3%	-0.4%	-7.8%	-3.6%	-0.4%	2.7%	-0.5%	-1.2%	2.7%	0.2%
B8	-1.8%	-9.3%	0.2%	0.0%	-1.2%	-0.3%	-8.2%	-3.6%	0.2%	1.5%	-0.5%	-1.1%	0.4%	0.0%
B8N_AUX	-1.9%	-11.6%	0.4%	0.1%	-1.2%	-0.3%	-8.2%	-3.6%	0.8%	1.4%	-0.5%	-1.1%	0.7%	0.1%
B8S_AUX	-1.7%	-12.1%	-0.1%	0.0%	-1.3%	-0.4%	-8.0%	-3.6%	-0.3%	1.5%	-0.5%	-1.2%	0.2%	0.0%
B12	-2.4%	-11.1%	-0.5%	0.0%	-1.4%	-0.4%	-7.8%	-3.7%	1.5%	1.3%	-0.5%	-1.2%	0.8%	0.1%
B12E_AUX	-2.4%	-11.3%	-0.9%	-0.1%	-1.4%	-0.4%	-6.6%	-3.2%	2.0%	1.7%	-0.5%	-1.1%	0.8%	0.1%
B12W_AUX	-2.1%	-13.2%	0.1%	0.0%	-1.3%	-0.3%	-8.6%	-3.8%	0.7%	0.6%	-0.6%	-1.2%	0.8%	0.1%

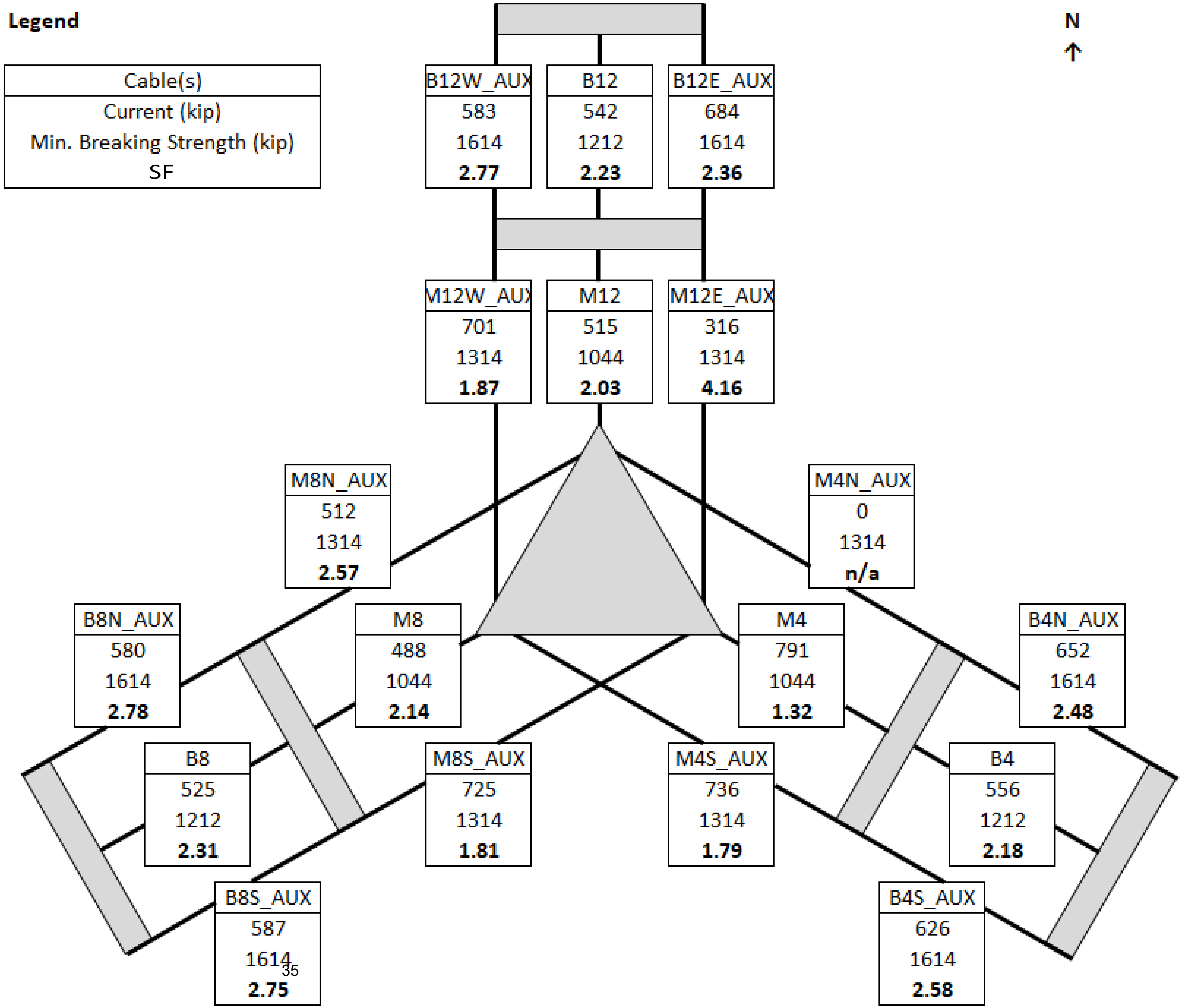
Cable Safety Factors

Before Second Cable Failure



Cable Safety Factors

Current Condition



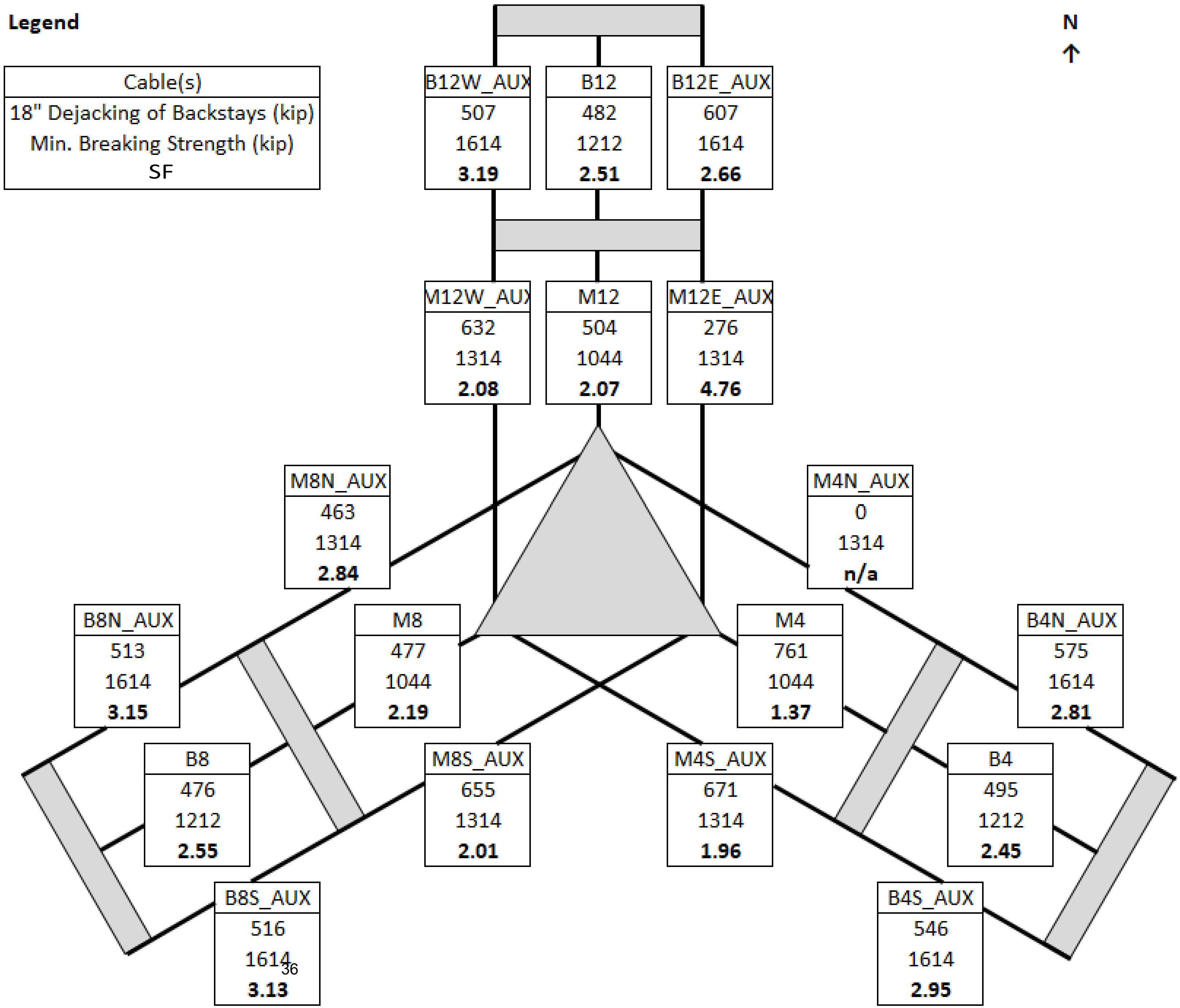
Cable Safety Factors

If De-Jacking all Backstays by 18"

(starting from current condition)

Legend

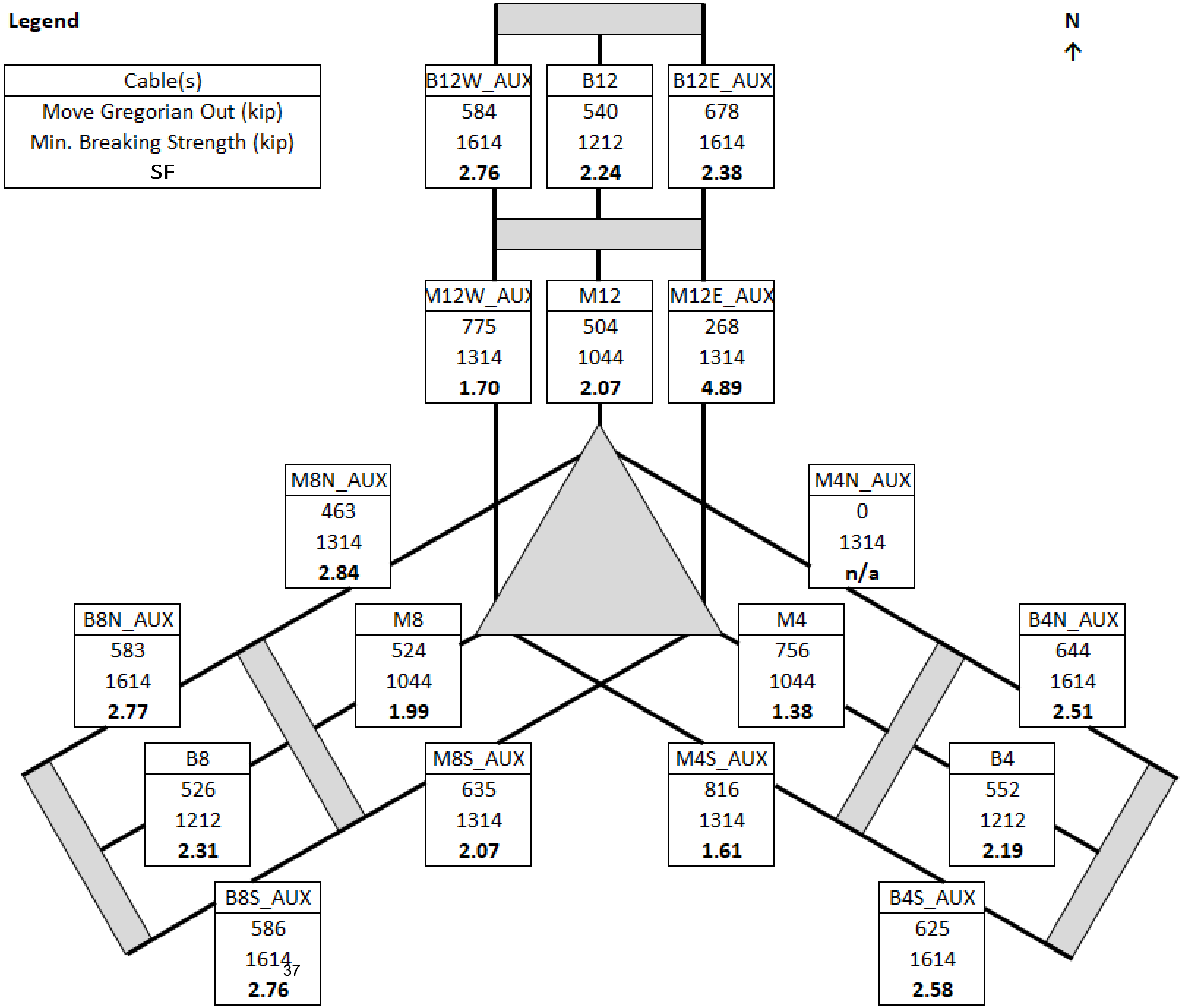
Cable(s)
18" Dejacking of Backstays (kip)
Min. Breaking Strength (kip)
SF



Cable Safety Factors

If Moving Gregorian Out

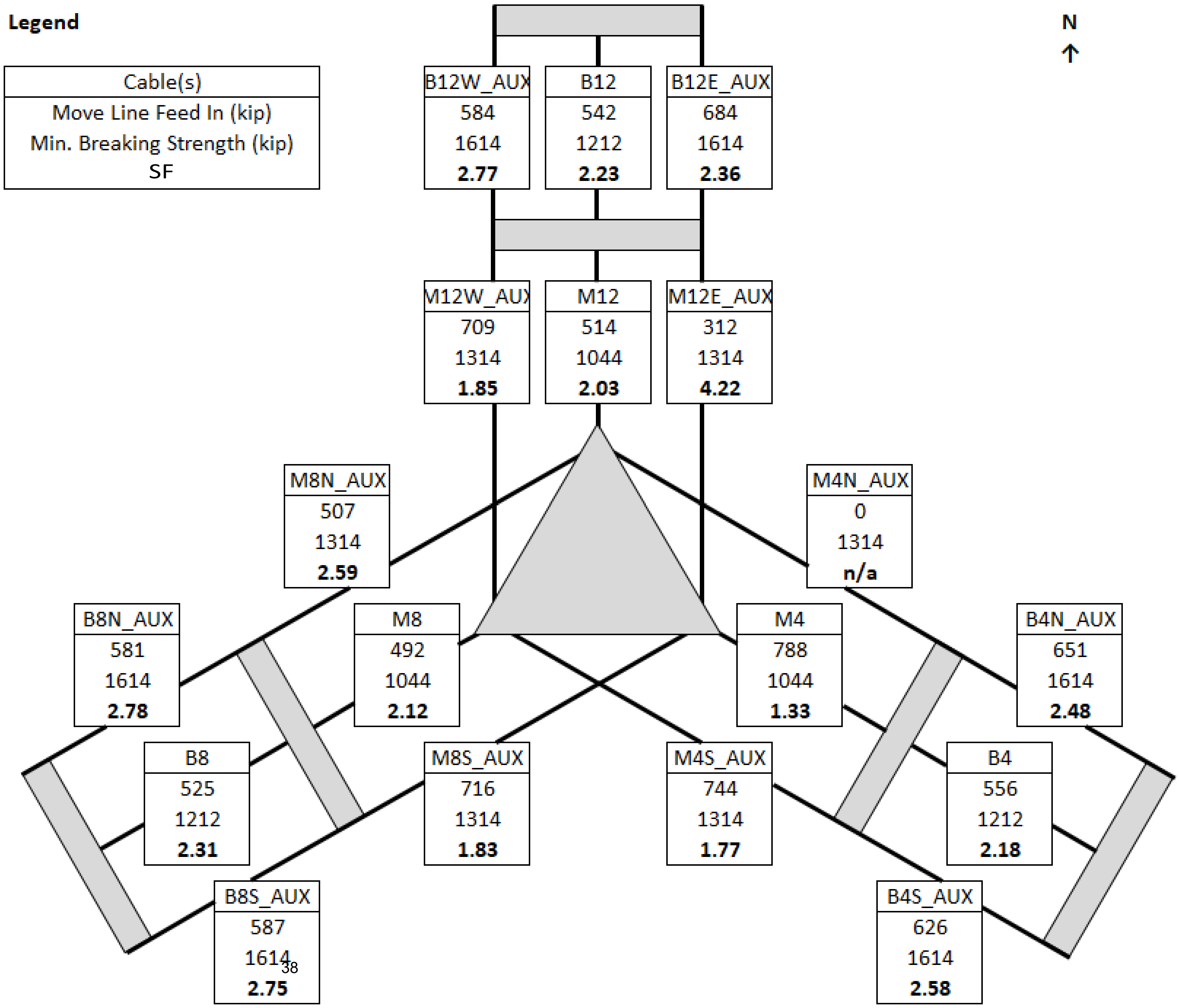
(starting from current condition)



Cable Safety Factors

If Moving Line Feed In

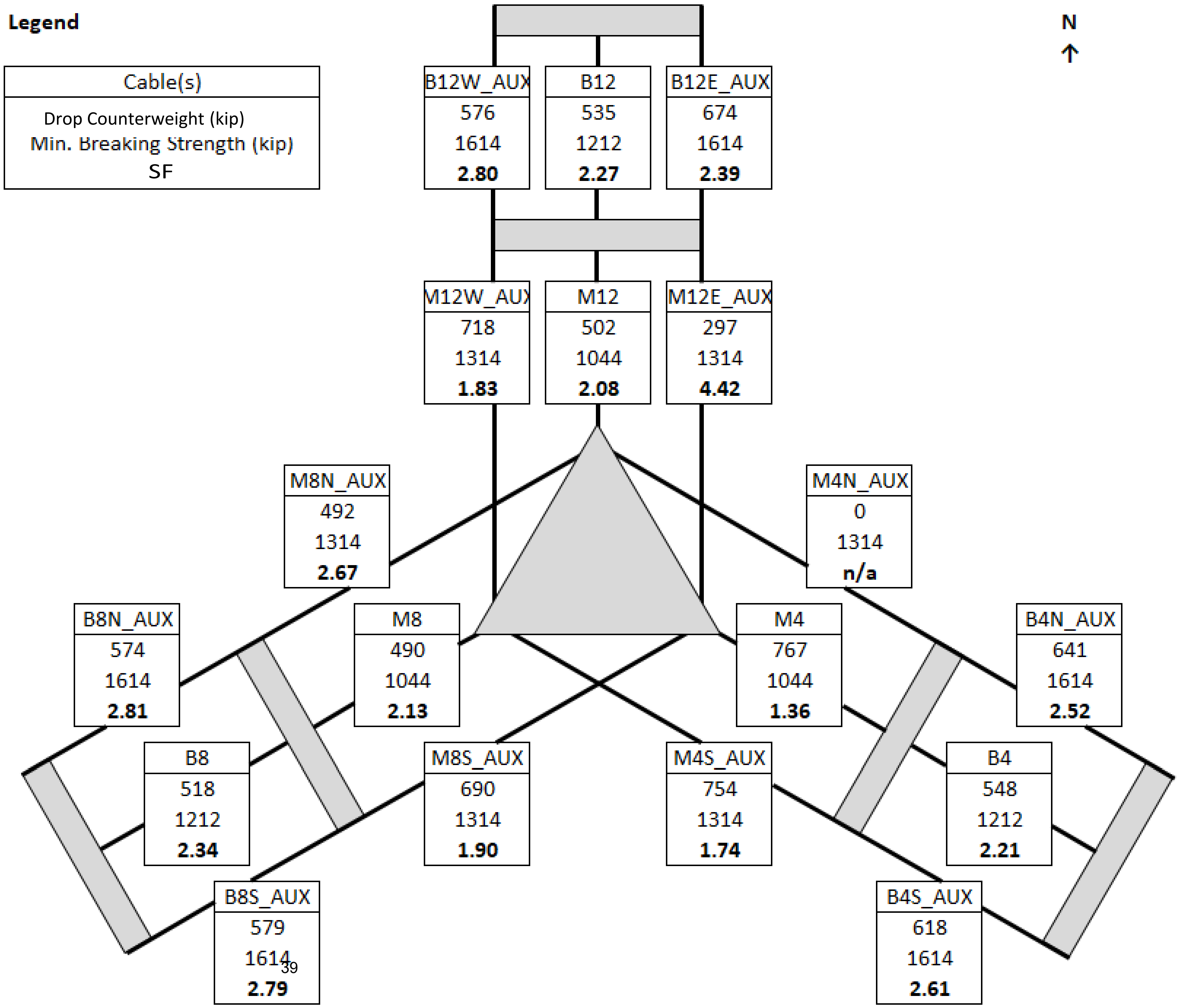
(starting from current condition)



Cable Safety Factors

If Dropping 38kip Counterweight

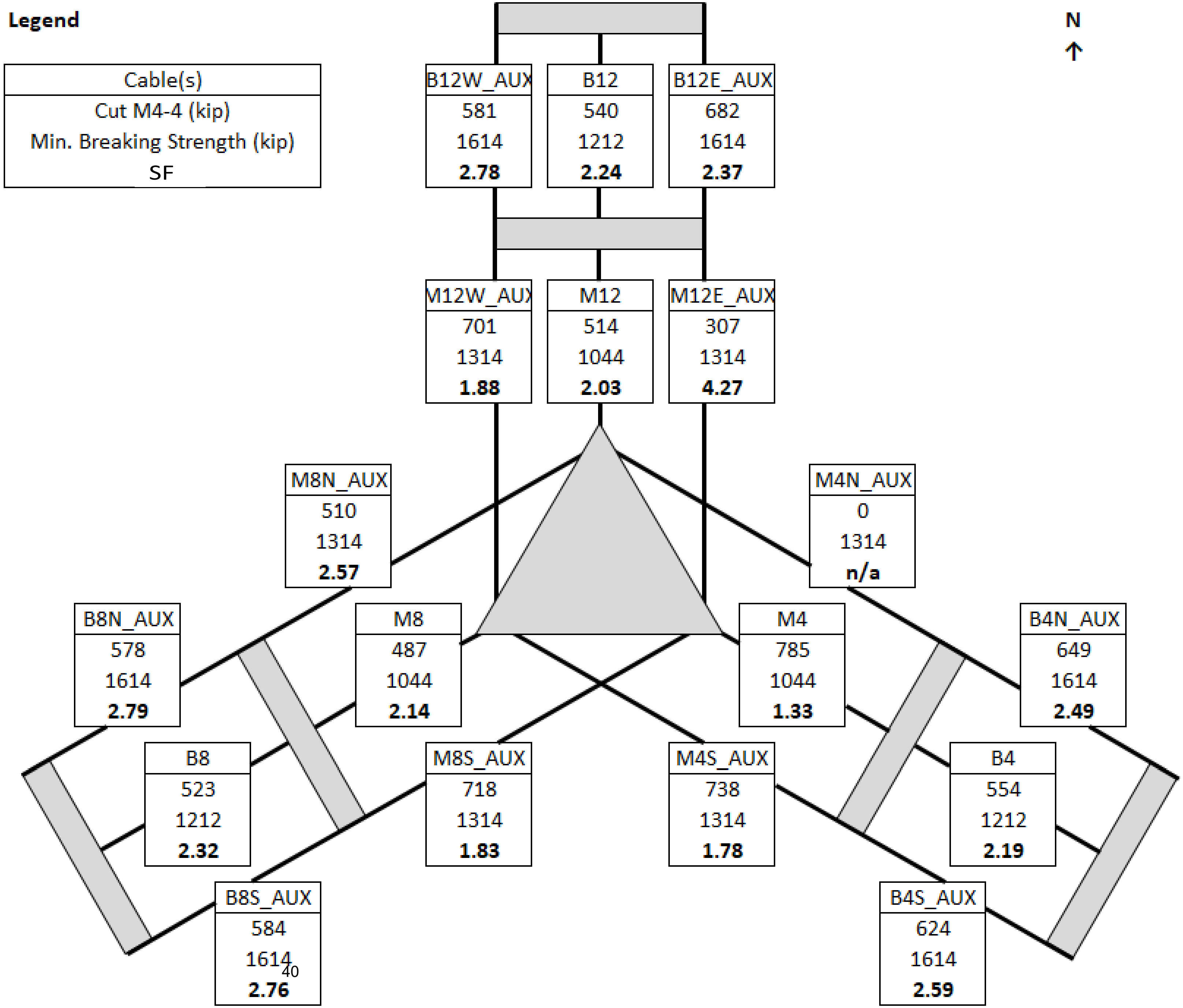
(starting from current condition)



Cable Safety Factors

If Cutting M4-4

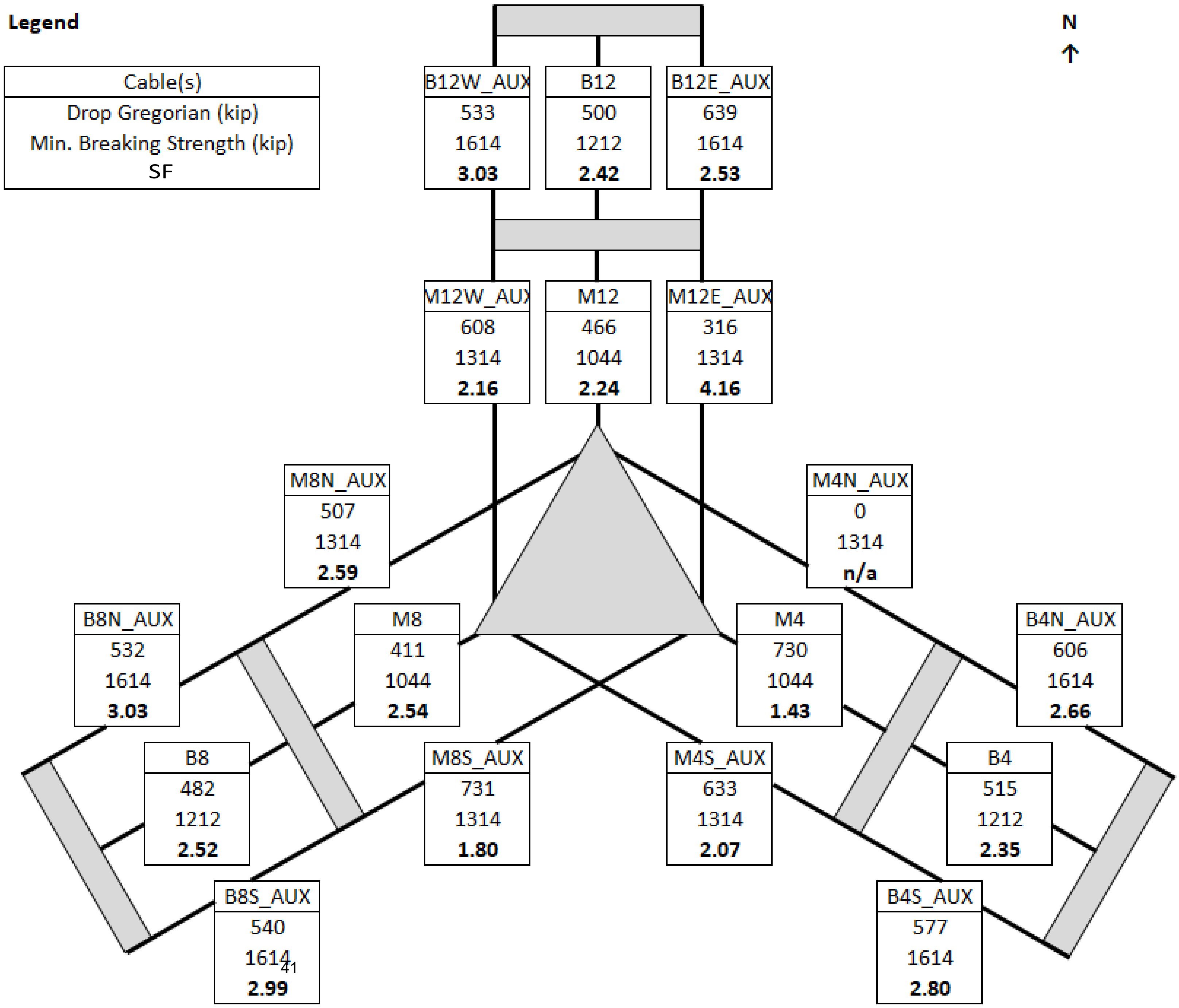
(starting from current condition)



Cable Safety Factors

If Dropping Gregorian

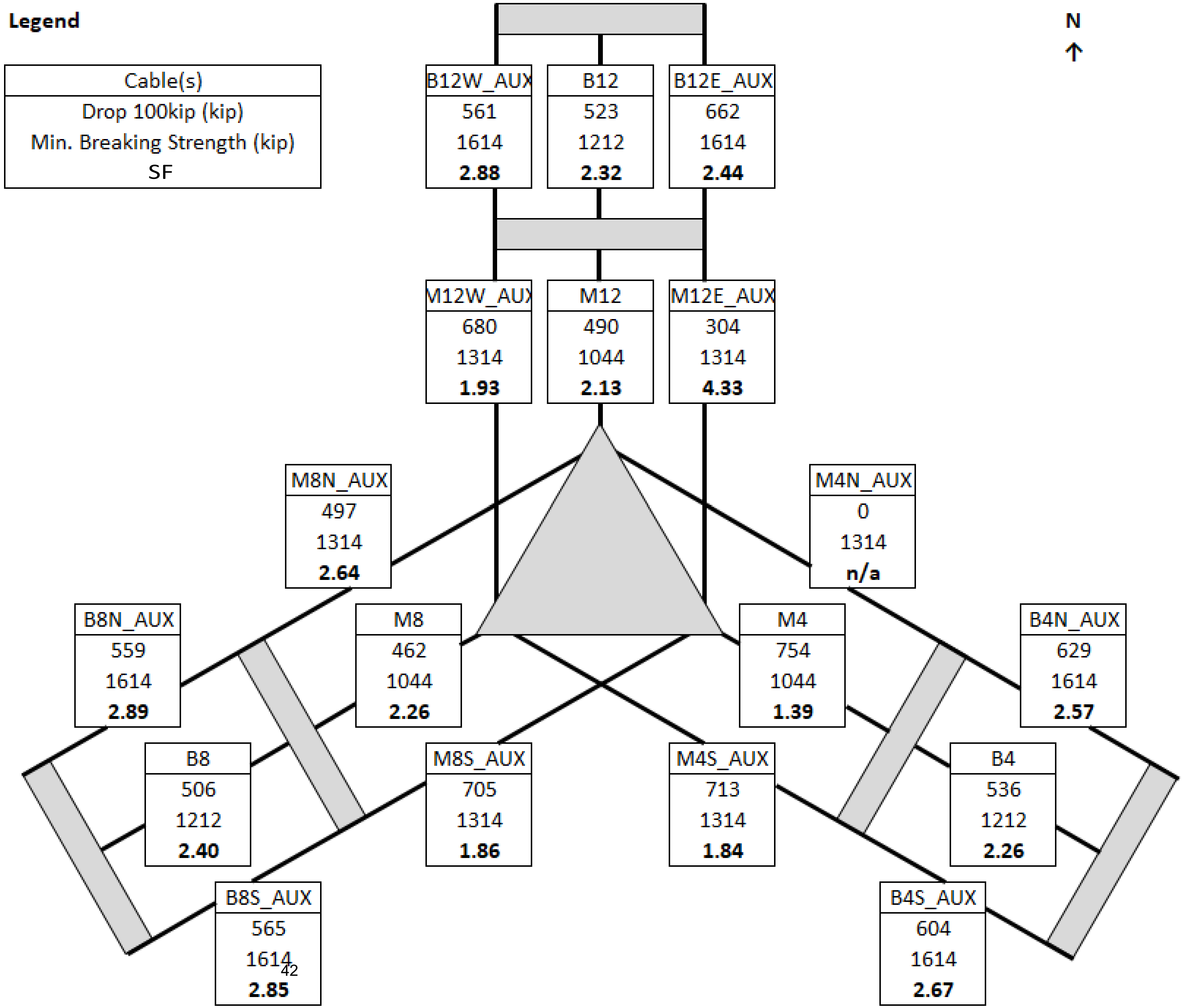
(starting from current condition)



Cable Safety Factors

If Dropping 100kip Uniformly from Platform

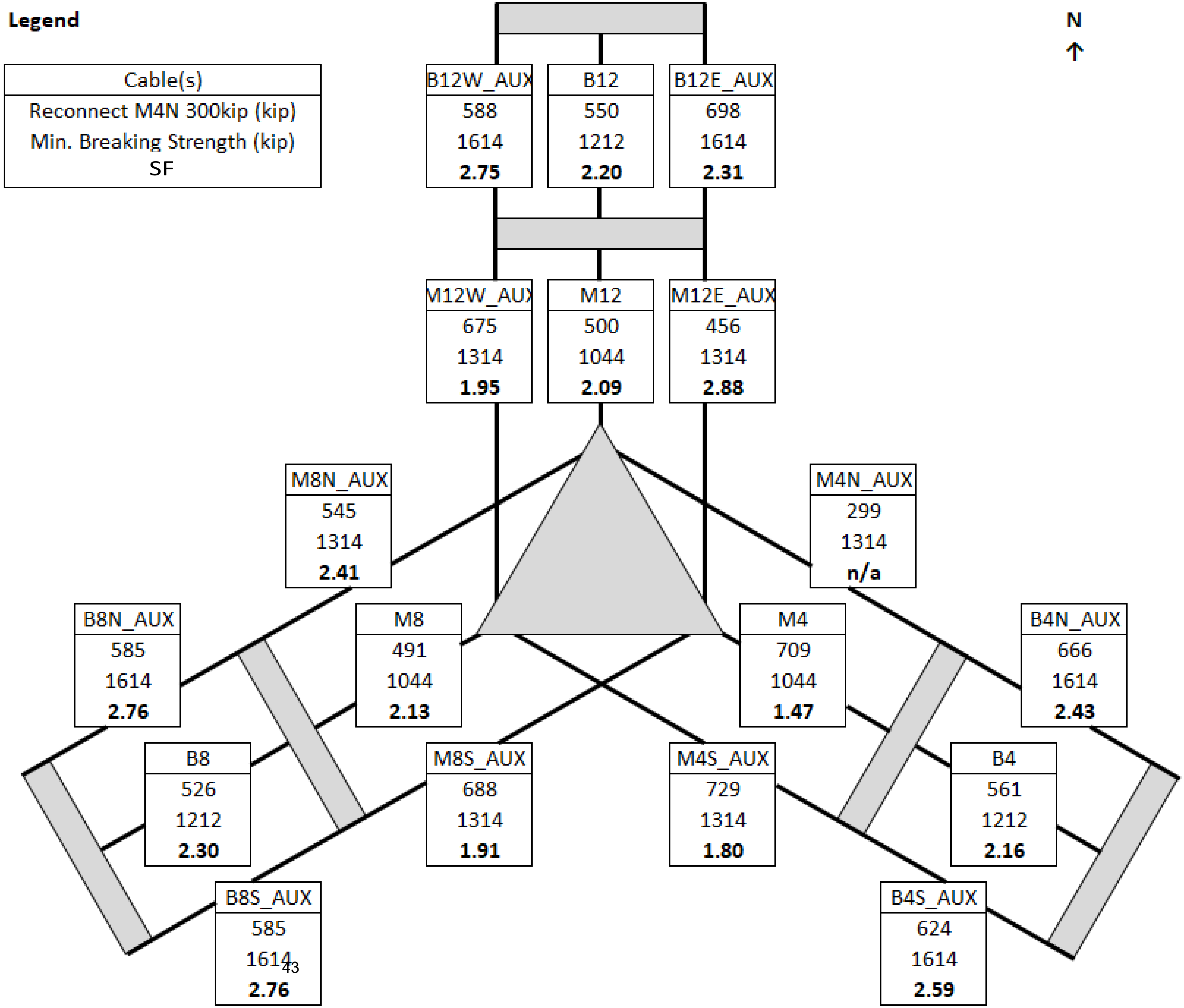
(starting from current condition)



Cable Safety Factors

If Reconnecting M4N_AUX and Re-tensioning by 300kip

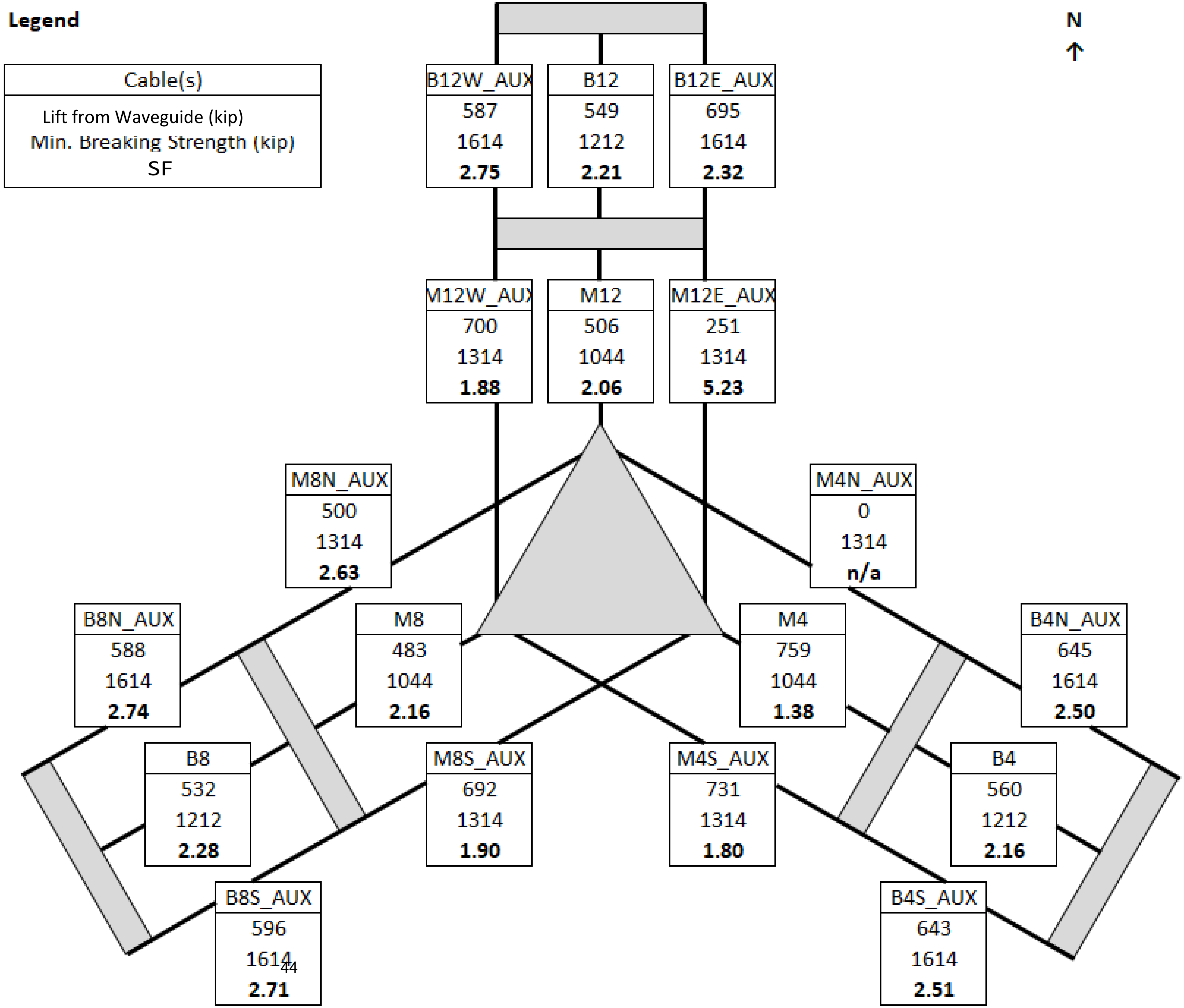
(starting from current condition)



Cable Safety Factors

If Lifting Platform from Waveguide System

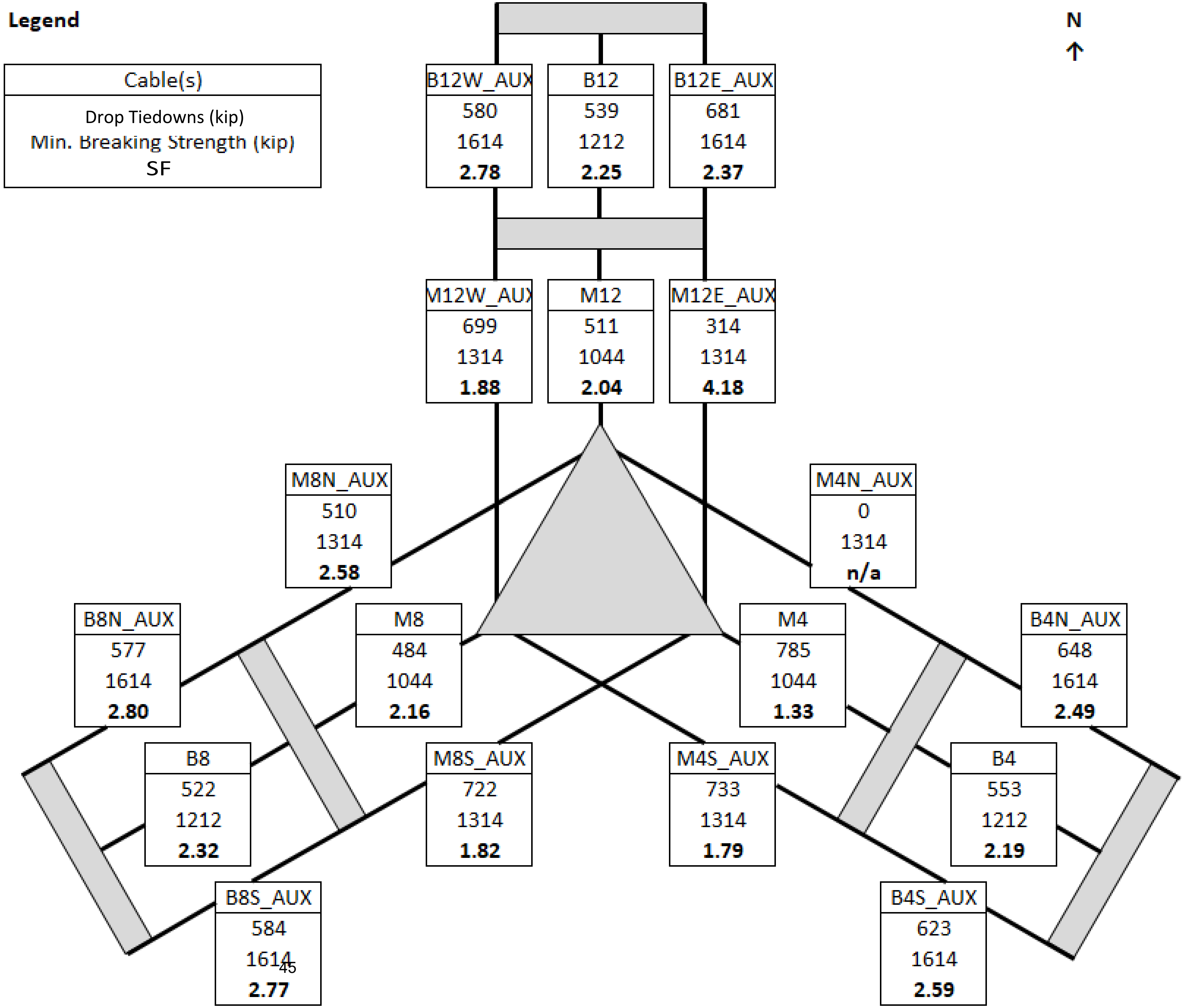
(starting from current condition)



Cable Safety Factors

If Dropping Tiedowns

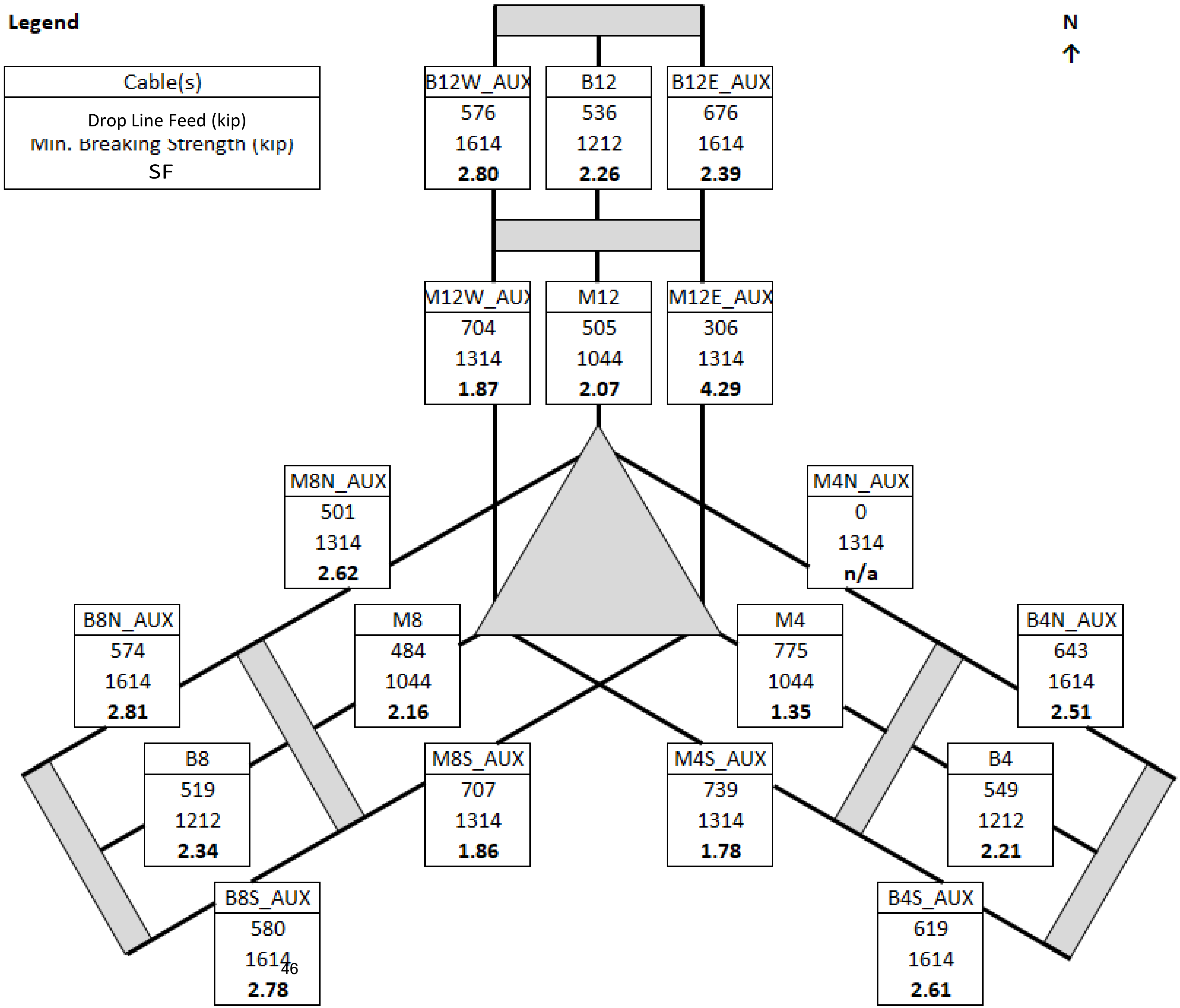
(starting from current condition)



Cable Safety Factors

If Dropping Line Feed

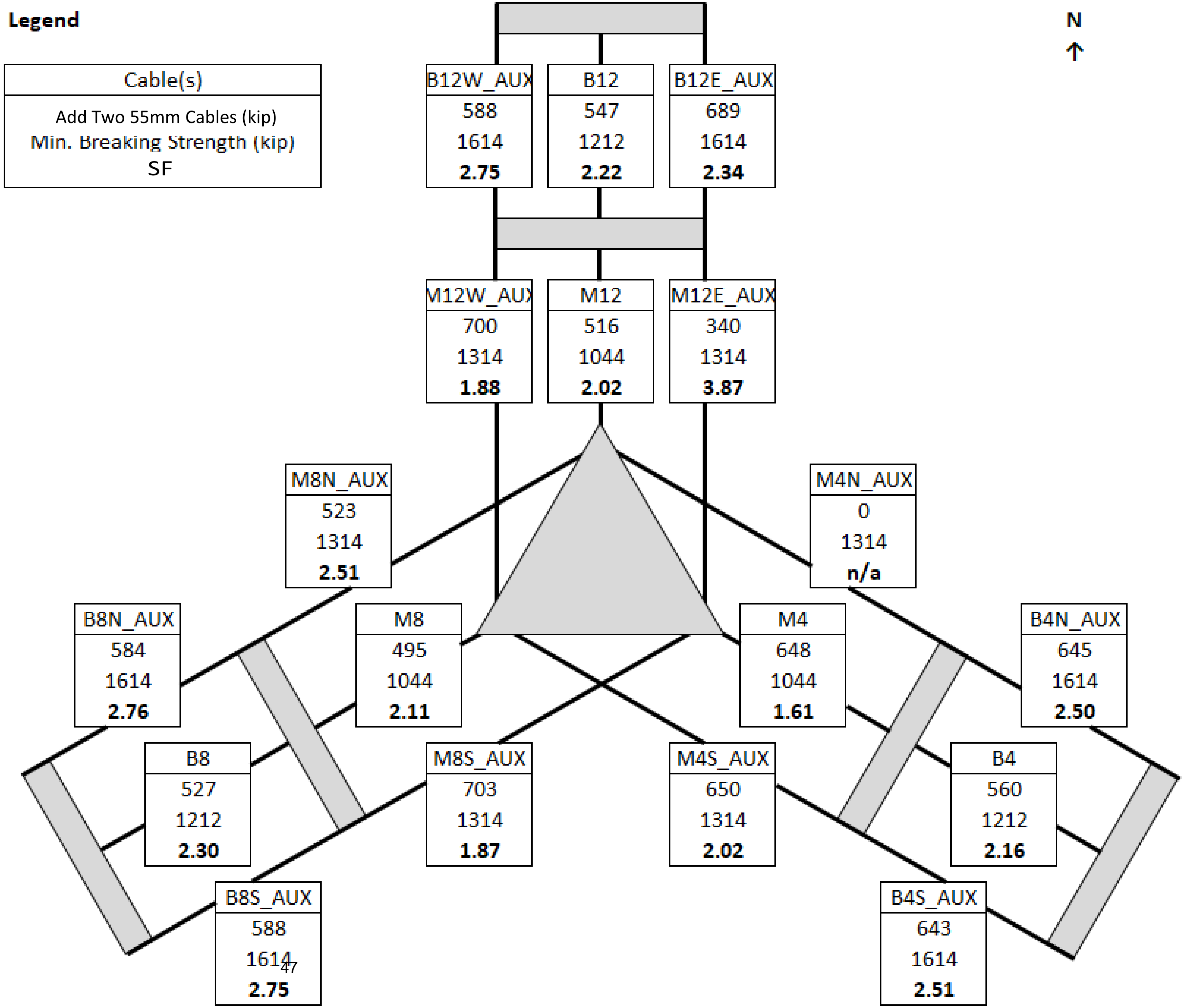
(starting from current condition)



Cable Safety Factors

If Adding Two 55mm Cables where M4-4 was, Tensioned to 50% Breaking Strength

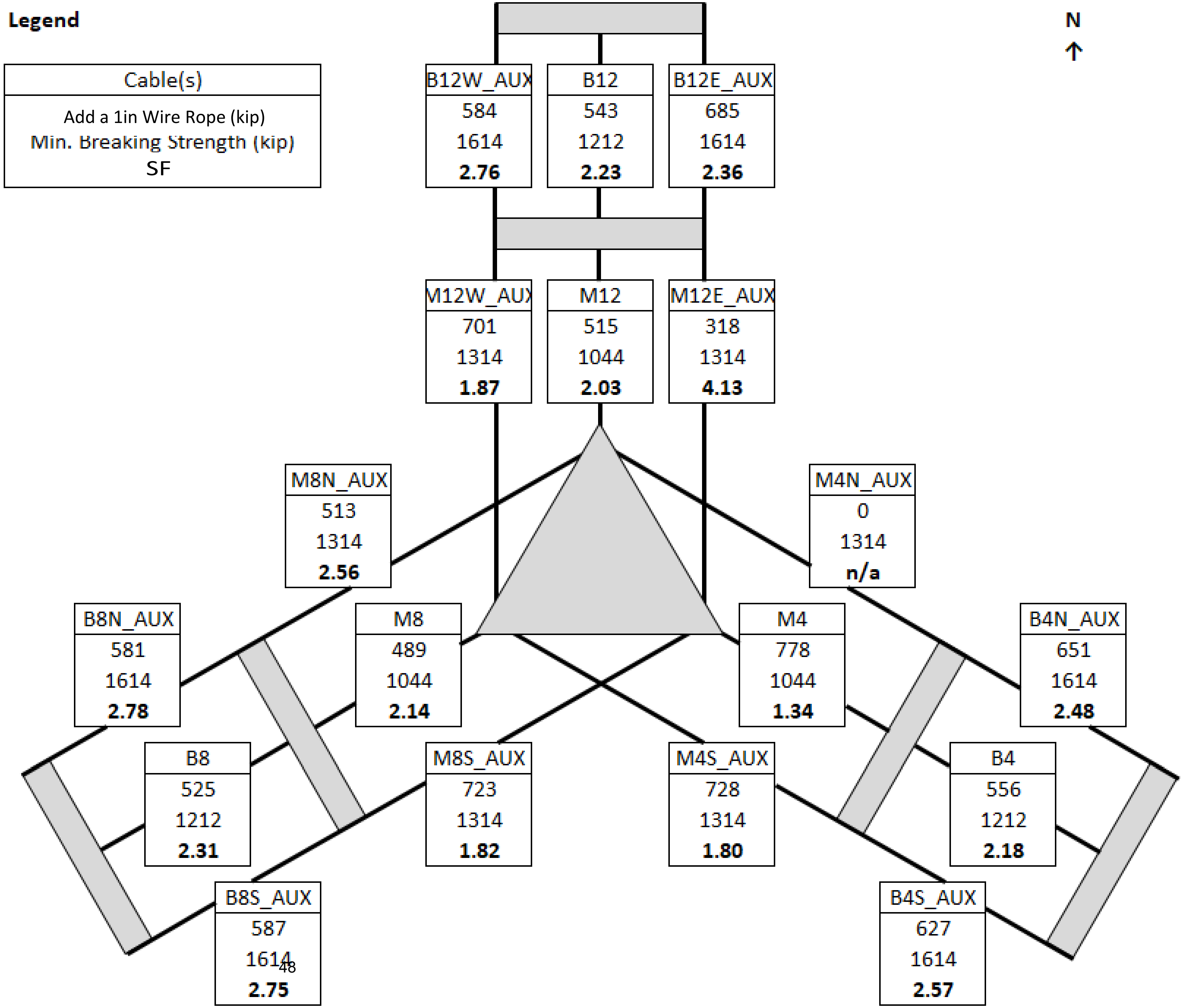
(starting from current condition)



Cable Safety Factors

If Adding a 1in Wire Rope where M4-4 was, Tensioned to Breaking Strength

(starting from current condition)



Cable Safety Factors

			Starting From Current Condition												
Cable(s)	Before Second Cable Failure	Current Condition	If Dejacking all Backstays by 18"	If Moving Gregorian Out	If Moving Line Feed In	If Dropping Counterweight	If Cutting M4-4	If Dropping Gregorian	If Dropping 100kip Uniformly from Platform	If Reconnection on M4N_AUX and Re-Tensionning to 300kip	If Lifting Platform From Waveguide Cables	If dropping Tiedowns	If dropping Line Feed	If adding 2 x 55mm cables where M4-4 was, tensionned to 50% breaking strength	If adding a 1in wire rope where M4-4 was, tensionned to breaking strength
M4	1.61	1.32	1.37	1.38	1.33	1.36	1.33	1.43	1.39	1.47	1.38	1.33	1.35	1.61	1.34
M4N_AUX	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	4.40	n/a	n/a	n/a	n/a	n/a
M4S_AUX	2.15	1.79	1.96	1.61	1.77	1.74	1.78	2.07	1.84	1.80	1.80	1.79	1.78	2.02	1.80
M8	2.10	2.14	2.19	1.99	2.12	2.13	2.14	2.54	2.26	2.13	2.16	2.16	2.16	2.11	2.14
M8N_AUX	2.47	2.57	2.84	2.84	2.59	2.67	2.57	2.59	2.64	2.41	2.63	2.58	2.62	2.51	2.56
M8S_AUX	1.78	1.81	2.01	2.07	1.83	1.90	1.83	1.80	1.86	1.91	1.90	1.82	1.86	1.87	1.82
M12	2.02	2.03	2.07	2.07	2.03	2.08	2.03	2.24	2.13	2.09	2.06	2.04	2.07	2.02	2.03
M12E_AUX	3.31	4.16	4.76	4.89	4.22	4.42	4.27	4.16	4.33	2.88	5.23	4.18	4.29	3.87	4.13
M12W_AUX	1.88	1.87	2.08	1.70	1.85	1.83	1.88	2.16	1.93	1.95	1.88	1.88	1.87	1.88	1.87
B4	2.13	2.18	2.45	2.19	2.18	2.21	2.19	2.35	2.26	2.16	2.16	2.19	2.21	2.16	2.18
B4N_AUX	2.46	2.48	2.81	2.51	2.48	2.52	2.49	2.66	2.57	2.43	2.50	2.49	2.51	2.50	2.48
B4S_AUX	2.46	2.58	2.95	2.58	2.58	2.61	2.59	2.80	2.67	2.59	2.51	2.59	2.61	2.51	2.57
B8	2.27	2.31	2.55	2.31	2.31	2.34	2.32	2.52	2.40	2.30	2.28	2.32	2.34	2.30	2.31
B8N_AUX	2.73	2.78	3.15	2.77	2.78	2.81	2.79	3.03	2.89	2.76	2.74	2.80	2.81	2.76	2.78
B8S_AUX	2.70	2.75	3.13	2.76	2.75	2.79	2.76	2.99	2.85	2.76	2.71	2.77	2.78	2.75	2.75
B12	2.18	2.23	2.51	2.24	2.23	2.27	2.24	2.42	2.32	2.20	2.21	2.25	2.26	2.22	2.23
B12E_AUX	2.30	2.36	2.66	2.38	2.36	2.39	2.37	2.53	2.44	2.31	2.32	2.37	2.39	2.34	2.36
B12W_AUX	2.71	2.77	3.19	2.76	2.77	2.80	2.78	3.03	2.88	2.75	2.75	2.78	2.80	2.75	2.76

November 11, 2020

Ramon Lugo
Director, Florida Space Institute

SUBJECT: Recommendation for Future Efforts at Arecibo Observatory

Dear Mr. Lugo:

There are currently two main cables that have failed at the Arecibo Observatory, both located from Tower 4 to the platform. It is known that the M4N Aux main cable failed from the socket on August 10, which is undergoing forensic analysis to confirm the hypothesis that fabrication or installation was at fault. When the M4-4 cable failed on November 6, the cable was at approximately 60% of its minimum breaking strength per available documentation. M4-4 failed in tension, the cause of which is believed to be degradation of the cable itself, potentially due to corrosion.

From Thornton Tomasetti's (TT) model, we can conclude with a high level of confidence, that if an additional main cable fails, a catastrophic collapse of the entire structure will soon follow.

All options initially considered to reduce the weight on the platform or to install cables to stabilize the structure would require having personnel on the platform and the towers. After the recent failure, WSP does not recommend allowing personnel on the platform or the towers, or anywhere in their immediate physical vicinity in case of potential sudden structural failure.

The current stability of the structure is unknown, and we cannot quantify the structure's factor of safety. Wiss, Janney, Elstner (WJE) has proposed using a proof load test to quantify the current factor of safety. WSP does not recommend performing a proof load test on the system for the following reasons:

1. Due to the compromised state and additional damage being observed in the remining cables from Tower 4, the maximum capacity of the remaining cables is unknown, and the additional load could cause additional cable failures.
2. It is not recommended to put the structure through additional load cycles due to the additional degradation that can occur by adding load to the system through proof loading.
3. The proof load proves capacity at that moment in time and it is unknown if the cables can support that load again in the future.

Conclusions and Recommendations

Since we are observing additional wire breaks, this leads us to believe that there is additional degradation of the cables and therefore less capacity than expected. At this time, WSP believes that there is no course of action that can be taken to confidently verify the structural integrity of the existing cables/structure. WSP strongly advises against allowing personnel on the platform or towers, or anywhere in their immediate physical vicinity in case of potential sudden structural failure.

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Therefore, based on an engineering alternatives assessment, WSP recommends the following course of action as the recommended alternative: controlled de-commissioning of the structure, with appropriate site access restriction and other safety precautions as determined by safety lead WJE in-place until decommissioning is complete.

Regards,

Vincent M. Antes, SE, PE
Program Manager

Wiss, Janney, Elstner Associates, Inc.
330 Pfingsten Road
Northbrook, Illinois 60062
847.272.7400 tel
www.wje.com

MEMORANDUM | November 12, 2020

Arecibo Observatory
Stabilization Efforts

WJE PROJECT NO. 2020.5191

TO	Ramon Lugo Principal Investigator University of Central Florida Florida Space Institute 12354 Research Parkway Partnership 1 Building, Suite 214 Orlando, FL 32826-0650
FROM	Jonathan C. McGormley, Brian J. Santosuosso

Engineering efforts have been underway to reevaluate the structure and reexamine options going forward after the November 6, 2020 failure of the M4-4 cable. Despite the many uncertainties regarding critical structural elements, WJE believes there is a possibility to save the structure without undue risk to workers. The key element in pursuing this path is reducing structural uncertainty to acceptable levels by demonstrating that key elements have the capacities needed to support the work that must be done.

It is apparent from the failure of M4N in August 2020 and M4-4 more recently that cable or socket capacity degradation has taken place over time. Thus, the ultimate capacities of the cables supporting the structure are currently unknown. We recognize that because of the unknown capacity of critical elements of the structure and the difficulty associated with executing their repair, demolition of the facility is an option if attempts to repair it cannot be pursued. However, we believe repairs are possible if stabilization efforts commence immediately. Therefore, we have developed a plan that starts with immediate reduction of load in all cables with the goal of obtaining a 10 percent demonstrated margin of capacity for each cable. We anticipate, however, that the load reduction process may not achieve this margin. Select cables will therefore require load testing to prove an appropriate margin. However, this does not necessarily mean that the load must be increased in the cables by 10 percent. For example, a cable carrying 100 kips whose load is reduced to 94 kips as part of the load reduction efforts would have shown a 6 percent reduction in load. In order to prove a 10 percent margin on 94 kips, the proof load would be 103 kips, which represents an increase of 3 percent over the current load.

Demonstrating adequate capacity for a given task may increase the risk of structural collapse (e.g., by temporarily increasing the load on critical elements). Of course, any such demonstration would be done without personnel in threatened positions. In short, risks during occupied times can be kept reasonably low by performing higher risk demonstrations while the structure is not occupied. Since the alternative to repair is demolition of the facility, the risk of possibly collapsing the unoccupied structure during an attempt to save it may be acceptable. Of course, if the requisite capacity cannot be successfully demonstrated at any time, risks to occupants would be excessive and repair efforts would cease, leaving demolition as the only option. In our opinion, areas threatened by a collapse of the structure should only be occupied if the Tower 4 cable group has a demonstrated capacity that is at least 10 percent greater than the demands that exist during occupancy.

As time passes, the capacities of the cables will decrease as evidenced by the two recent failures. In order to maintain a demonstrable 10 percent reserve capacity, the initial load reduction efforts may have to be supplemented by load testing. For example, if load reduction cannot keep up with a conservative estimate of strength loss, it may be necessary to demonstrate that adequate capacity remains by temporarily applying loads. When done properly, such proof testing can be used to demonstrate capacities, which is why load testing is a staple of the engineering profession. Such testing is done because there is uncertainty regarding the system's strength; hence there is a possibility that the structure will collapse during a test. As noted previously, this risk is taken on (while the structure is not occupied) so as to reduce the risk of collapse while it is occupied. And, since the alternative is destroying the structure, the risk of failure during a load test may be acceptable.

The following outlines activities designed to establish a 10 percent reserve capacity in the Tower 4 main cables so that work within the backstay anchorage perimeter including on the feed platform can be done.

Immediate Priority Tasks

Task 1 – Tower 4 Backstay relaxation. At the tower anchorages, all seven backstays will be relaxed in a sequenced approach to relieve load in the main cables. The tower top will move inward about 18 inches during this process, which will lower the main cable forces by about 2 percent. This work can be completed without subjecting personnel to hazards associated with an additional cable failure.

Task 2 – Towers 12 and 8 Backstay relaxation. Similar to the work carried out at Tower 4, the backstays at Towers 12 and 8 can be relaxed. This will further reduce the loads in the Tower 4 main cables by an additional approximate 2 percent.

Task 3 – Installation of 7/8-inch Wire Rope. Based on the possible availability of equipment currently at the facility, a 7/8-inch diameter wire rope will be connected to the pin at the platform connection of the M4 cables using a properly rated fabric sling. The cable will run to the top of Tower 4 and be redirected to a winch anchored near the tower base. The work to install the cable and hardware will utilize a helicopter. No personnel will be on the platform or top of tower. Installation of the wire rope will reduce the tension in the Tower 4 cables by about 2 percent

Task 4 – Cutting of Hanging M4-4 Cable. Using a helicopter, the failed M4-4 cable will be cut from its connection to the platform. This will reduce the load in the M4 cables by about 0.8 percent.

Task 5 – Removal of Azimuth Counterweight. There is currently about 45,000 pounds of lead counterweight positioned on the top of the azimuth structure. Most of the lead is in slabs weighing approximately 200-lbs each. An attempt will be made to throw the lead from the azimuth using workers positioned from a helicopter. If this is not successful, then some other method to remove the counterweight is needed that does not place personnel on the platform. Removal of the lead counterweight is estimated to reduce the M4 forces by 4 percent.

Additional Tasks. If Tasks 1 through 5 are successful and the load in the M4 cables is reduced by approximately 10 percent, limited and controlled access onto the platform and space below the reflector dish will be permitted. Additional tasks to be completed during this period would include the following:

1. Removal of the Gregorian dome hurricane stow pin
2. Movement of the Gregorian dome to a position on the current azimuth that further reduces the M4 main cable tensions
3. Repair of the tie-down anchors to improve load testing capabilities
4. Install two 55-mm temporary cables between Tower 4 and the platform that will replace the capacity lost by the failed main cable
5. Periodic load testing of the system to confirm the margin of safety has not been diminished by continued degradation of various cables/sockets

If the immediate priority tasks listed above cannot all be completed, hold-down cables will be used to load the system to the extent necessary to provide at least a 10 percent reserve capacity upon removal of the hold down load.

With the additional tasks completed, we are confident the stability of the structure will no longer be compromised by the failure of an additional M4 main cable. Restoration and investigative work can then safely proceed with the original plan.