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Industry Recommendations from Arecibo Observatory Zinc Spelter Socket Joint Failure Analysis

A structural analysis and forensic investigation concluded that the Arecibo Observatory M4N socket joint failure in August 2020 was primarily due to cumulative damage caused by initially low structural design margins and a high percentage of sustained load, resulting in zinc creep deformation, progressive internal socket wire damage, and eventual loss of joint capacity. Open spelter sockets of this type are used throughout industry in stay cables. Recommendations are proposed to prevent failures of similar socket joints, including verification of positive stress margins in socket joint wires for all failure modes, periodic visual inspections with pass/fail criteria for zinc extrusion that are tied to structural qualification, and revisiting codes/industry standards to capture lessons learned.

Background

The Arecibo Observatory's telescope consisted of an instrument platform suspended above the dish by stay cables connected to three towers. In August 2020, an auxiliary cable slipped from its socket joint on one of the towers, eventually leading to the total collapse of the observatory in December 2020.

NASA structural analysis and forensic investigation concluded that the M4N Arecibo socket joint failure was primarily due to cumulative damage caused by initially low structural design margins and a high percentage of sustained load, leading to zinc creep deformation, progressive internal socket wire damage, and eventual loss of joint capacity. Visual inspections identified progressive zinc extrusion, which in hindsight was evidence of cumulative damage due to creep [1].

Socket Termination Overview and Mechanics

Zinc spelter socket joints are terminations in stay cables used throughout industry that transfer loads between adjacent structures. The socket termination comprises stay cable wires that are unraveled, broomed, and then embedded/bonded into a zinc casting inside a conical volume. Cable tension wedges the zinc material against the slanted conical surface, so that a large compression zone develops within the zinc such that failure occurs outside the socket joint in the cable span. Stay cables in the United States are regulated by ASCE 19-10 and 19-96 [2].

Findings

Finite element analysis and forensic investigation of an open conical zinc spelter socket with 1x127 cable strand showed non-uniform stress distribution across wires at half the cable breaking load, with outer wires stressed near ultimate strength but with residual elongation capability.

Traditional design/build verification methodologies for similar socket terminations may not adequately consider constituent stresses and localized stress concentrations in demonstrating positive structural margins; consequently, these socket terminations may be vulnerable to time-dependent cumulative damage from fatigue and creep.

Analysis also showed that in applications with a high percentage of sustained (dead) load and a design factor of safety of approximately 2, there is a greater potential for zinc creep. Creep will visually manifest as zinc extrusion from the socket and was shown to further reduce wire capacity at the socket termination.

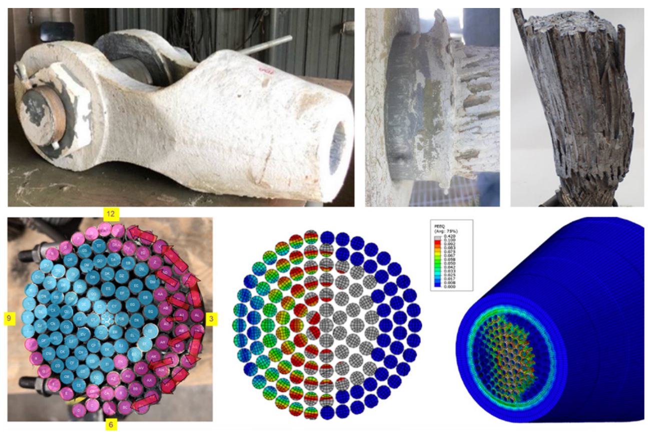

Figure 1: NASA Investigation of failed Arecibo Aux M4N cable. Top: socket (left); zinc extrusion (center); pulled out cable (right). Bottom: forensic and finite element model recreation of M4N failure progression.

Forensic investigation also found internal damage due to environmental conditions, which in combination with wire defects may have further degraded capacity of the socket joint without clear external indication.

Recommendations

1. Socket joint constituents should be verified to have positive structural margins for strength, fatigue, and creep failure modes for the service life of the socket for all design load combinations.
2. Periodic visual inspection of socket joints should include pass/fail criteria for zinc extrusion tied to a structural qualification test program that verifies the creep failure mode. Qualified processes such as cable replacement and socket joint refurbishment should then be defined to restore joint capacity in the event of failed inspection.
3. ASCE 19-10 and 19-96 codes should be revisited to ensure that the design factors consider time-dependent creep effects in dead load dominated structures, environmental conditions, and workmanship sensitivity to wire defects or brooming.

References

1. "Arecibo Observatory Auxiliary M4N Socket Termination Failure Investigation," 30 June 2021, NASA/TM-20210017934.
2. American Society of Civil Engineers (ASCE) 19-10/ASCE 19-96 "Structural Applications of Steel Cables for Buildings."