Fatigue Analysis for Arecibo Radio Telescope
Arecibo, Puerto Rico

Subsequent to a fracture in a main truss member on the Arecibo Radio Telescope, Ammann & Whitney performed a detailed analysis of member stresses in the platform. This analysis indicated that the fractured member could have been subject to as much as 33% above its maximum allowable stress under current operational parameters for the telescope. Subsequent strain gauge measurements showed a close agreement with the analytical results and, based on those results, selected members in the supporting trusses were reinforced.

While the member that fractured was stressed beyond its allowable limits, it was not stressed to its ultimate breaking strength. Since the telescope is essentially a machine and undergoes frequent changes in geometry and stress levels a possible mechanism for the observed fracture would be metal fatigue. A study has been performed to assess the probable fatigue life for the reinforced structure.

Since the fatigue life of a structure is a finite number of cyclic loads, the first step in predicting the remaining life of the structure involved a determination of the number of cycles that have been imposed on critical members. Data was provided by NAIC staff indicating the probable number of full stress range cycles that the telescope has experienced since the 1995 upgrading (data is attached) using unbalanced moments calculated from recorded azimuth and zenith angles. This information was used in conjunction with LARSA (a non-linear structural analysis program) and STAAD-III (a linear structural analysis program) to compute individual platform member stresses.

Evaluations of stress ranges for both the pre and post 2010 upgrading were performed using procedures outlined in Appendix 3.3 of the 13th Edition of the AISC Steel Construction Manual. Noting that fatigue damage is a cumulative phenomenon we also reviewed stress levels prior to the 1995 Gregorian upgrading to determine if significant fatigue damage may have accumulated over the instrument's early lifetime.

Members U2-U2L3, U1-L2 and U3-L4 were identified as being subject to the largest stress ranges in the telescope's platform structure. The stress ranges for the pre 1995 conditions were calculated based on member forces listed on the drawings. Stress ranges for both the post 1995 structure and the post 2010 structure were calculated using forces derived from our recent analysis.

The U2-U2L3 members were determined to be the governing elements for fatigue life. Pre-1995 conditions would have subjected this member to a 16.6 ksi stress range which is below the 24 ksi fatigue damage threshold level for the original member configuration. The stress range for the 1995 upgrade using operational parameters listed on the drawings would have resulted in a stress range of 25.9 ksi. The member, as modified in the 1995 upgrade would have had a fatigue damage threshold of 16 ksi and a stress range of 25.9 ksi would result in a predicted fatigue life of 690,000 cycles using the latest steel design codes. The stress range calculated for the actual post 1995 conditions was 38.7 ksi which is more than twice the 16 ksi threshold for the initiation of fatigue damage. Finally, the as reinforced condition sees a stress range of 24.6 ksi which is slightly less than the as-designed 1995 stress range.

Based on the cyclical usage data provided by NAIC personnel, at least one third of the predicted fatigue life of the original U2-U2L3 channels has been used up. Assuming that a residual load of 50 kips remained in each of the original channels during the 2010 reinforcement work and applying Miner's Rule (a standard method for combining cumulative fatigue damage at varying stress levels), an approximate expected useful life of 540,000 cycles remains for the two original U2-U2L3 channels. Based on NAIC's cyclical usage data this would correspond to over 115 years of expected life for the reinforced structure.

We note that the estimated lifetime calculations are based on a number of assumptions:

1. The data provided accurately predicts the number of times a member has been cycled from minimum to maximum stress post 1995
2. The telescope will continue to be operated in a similar manner with approximately the same number of cycles per year at the different unbalanced moments
3. We have assumed that the fatigue damage at high stress levels is proportional to the stress level in a member[1]
4. We have assumed that the data provided includes cyclic loads that result from movements of the telescope required for maintenance operations and are not restricted to use of the telescope for observations

As a final caveat, these fatigue life estimates do not include allowances for material anomalies or for fabrication errors. Given the unusually high stress ranges that were imposed on the U2-U2L3 members following the 1995 Gregorian upgrading, miss-drilled holes, holes drilled with ragged edges or internal flaws in the original steel all could have had a significant effect on reducing the available fatigue life.

With the reduction in operational stress ranges for the U2-U2L3 members in the reinforced structure it is our opinion that the telescope should be capable of providing decades of useful observations. These conclusions can be further validated by confirming the actual cyclic loading of the members. It is recommended that strain gauges be installed on one U2-U2L3 member at each of the three corners and monitored for a significant period of time (a minimum of one year is recommended). Data obtained from these instruments would then be compared to the cyclical data used to complete this study and the predicted fatigue life could be either validated or adjusted based on that comparison.

[1] Fatigue criteria in the AISC manual are based on members that are loaded in accordance with AISC code provisions. Since the U2-U2L3 members were stressed beyond typical allowable loads it is possible that standard fatigue criteria may not be conservative.