EVALUATION REPORT
OF THE DEFLATED ROOF OF THE METRODOME

for the

METROPOLITAN SPORTS FACILITIES COMMISSION
Minneapolis, MN

By

GEIGER ENGINEERS
02.04.2011

INTRODUCTION

On December 12, 2010 the Metrodome roof deflated in a blizzard's snowstorm. Geiger Engineers was subsequently commissioned to evaluate the state of the deflated roof to access the damage, and provide recommendations for the reuse of the roof structure and envelope.

THE EVENT

Snow had accumulated onto the roof to such an extent that it was not possible to remove it without endangering the laborers. As the snow accumulated, the roof became unstable and fabric panel started to invert. The snow mass became unstable and slid down a triangle panel (104) impacting the ring beam. The fabric was caught in between the snow and the edge of ring beam, rupturing it. The result was a tear in the panel that caused the loss of the interior building's pressure, which led to the deflation. During the deflation snow slid towards the center of the roof, impacting the air exhaust fans. The impact to the fans created stress risers in the fabric, which caused it to failed. These were the diamond panels 23 and 24.
The roof fabric was then exposed for several weeks to heavy loads from the ice and snow before it could be fully melted. During that time snow and ice shifted on the roof's fabric panels.

THE INVESTIGATION

Subsequent investigations i.e. tests of the fabric and observations of the condition of the fabric were performed to determine the suitability of it for future use and what panels could be saved.

Samples were taken from heavily loaded as well as lightly loaded panels, and tested for tensile strength as well as flex fold and trapezoidal tear. Tests performed were strip tensile, wet and dry, in the warp and fill, as well as flex fold and trapezoidal tear. The purpose of testing the low loaded materials was to find a comparison between the two and to determine what damage was done from the heavy loads on the material. Results were also compared with samples that had been taken in 2003 to establish a stress comparison of the fabric before and after the deflation.

The surface of the roof was inspected for abrasion, cuts, and other surface damage. In addition to the above investigations electron microscope pictures were taken of the surface. Again surfaces of heavily loaded panels and very lightly loaded panels where examined.

THE RESULTS

The results of the test show that the fabric has aged and suffered from the deflation event.

Following are the average strengths of the fabric tested:

TEST		% TO VIRGIN MATERIAL	COMMENTS
Strip tensile (Dry)	Warp Fill	95% 100%	Good Good
Strip tensile (Wet)	 Warp Fill	 > 100% >100%	 Good Good
Strip tensile Flexfold	Warp Fill	74% 79%	Not so good Not so good
Trapezoidal Tear	Warp Fill	75% 75%	Not so good Not so good

The lowest test results were 22% and 55% in a trapezoidal tear test in the fill and warp respectively. No similar low stress results were obtained in the tests of 2003.
The low tests were confirmed during a biaxial test in which the fabric failed at 20 pli (27% of virgin strength value)

OBSERVATIONS

The surface of the fabric was examined through an electron microscope. The results showed craters at the intersections of the yarn and the loss of coating over the filler glass beads. The examination was not conclusive in weather they extend to the glass fibers which would expose them to moisture and weaken them.
Birdair personnel inspected the fabric for abrasions, cuts and tears. Based on the survey there are numerous areas of abrasions and cuts that were caused by the sliding ice on the roof. Tears were observed along the fabric clamp lines where the membrane had been "pinched" by the clamp bars during deflation. Areas of creases in the fabric from the ice resting and sliding on it were observed in numerous locations. Discoloration of the fabric indicates wicking or moisture infiltration into the fabric.

The structural hardware of the roof (cables, sockets and cable anchor plates) was inspected for damage. No damage was found. Four cables at the triangular panels on the Southwest and northeast were slightly bent at their anchorage.

The fabric clamp system along the panels that failed was distorted and several clamp bolts were bent or broken. The clamp bars them selves appeared to be in salvageable condition.

EVALUATION:

The Fabric:

Based on the observations as well as the tests, the fabric appears to have lost a significant level of strength. Compared to fabric tests conducted in 2003, the strip tensile flex fold strength as

well as the trapezoidal tear strength is significantly reduced. These reductions in material strength are usually associated with damage to the fabric. Of particular concern are the samples that yielded very low tear strength.
While the low results were only a very few out of numerous test, it indicated a random deterioration of the fabric of which the location is not predictable.
The design tear strength was correlated with the load effect of a 90 mph wind. Using the low tear strength obtained from the test and using the same design parameters of the original design the allowable wind velocity would be 53mph and 65 mph respectively. The probability of these wind speeds to occur is great, since statistically a wind of 75 mph occurs yearly.
In addition, the fabric surface was severely abraded as documented in the electron microscope examination. The lack of full protection from the coating is cause to question the longevity of the fabric. Water absorption tests showed the rate to be10 times the specified value, indication water infiltration into the yarn. Water deteriorates the yarn strength characteristics.
Numerous cuts and tears were observed. They can be repaired if found, but with a 10 acre roof, the probability to repair them all is highly doubtful. Again, since tears initiate fabric failures, they are of great concern.

The Hardware:
The cables were found to be in good condition and thus are suitable for future use in the roof structure. The bent cables at their socket at the triangular panels did not over-stress them due to the low load and thus are deemed structurally sound.
The clamping system other than the threaded clamping rods, did not sustain any significant damage. Bent and broken rods need to be replaced.

Based on the observations of the ring beam and columns, these appear to be in good service condition.

RECOMMENDATION:

The fabric experienced the greatest damage from the deflation. Without further extensive testing the extent of the damage is not known. Time for further testing will expose the fabric to wind damage, if the roof stays deflated. This will result in replacement of panels that were not damaged in the deflation. Further testing would be required to evaluate that damage.

If the roof would have been inflated as soon as new temporary panels could have been available after melting of the ice and snow, the probability of a deflation would have been high, based on the low tear strength, as is it is now known, and the numerous small tears along the clamp lines and all the other tears that were observed. Some of these tears are only discoverable through the removal of the fabric clamp bars.

Based on all information, observation and testing to date, I could not sign off on a repair scheme that only replaced a portion of the panels. The probability of undetected defects in the 10-acre roof, that can initiate another deflation, is very high. As the engineer of record for this roof structure, it is my professional opinion that the only acceptable solution at this point is a complete replacement of the roof fabric to eliminate any uncertainty as to its integrity. One must keep in mind that only a failure of one panel will deflate the roof. The deflation may not cause human injury directly, however in a public stadium, the panic it will create, will undoubtedly result in injuries.

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