Collapse of the Dallas Cowboys Indoor Practice Facility, May 2, 2009

Building and Fire Research Laboratory
National Institute of Standards and Technology

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Study Objectives

- Determine why and how the Dallas Cowboys indoor practice facility collapsed during a severe thunderstorm
- Identify areas for improvement to current building codes, standards, and practices for this type of structure

Team

- **NIST Team**
  - John Gross, Ph.D., P.E., Lead Investigator: failure investigations, behavior and design of steel structures
  - Joseph Main, Ph.D.: computational structural analysis, wind engineering
  - Long Phan, Ph.D., P.E.: failure investigations, wind engineering
  - Fahim Sadek, Ph.D.: computational structural analysis, wind engineering, failure investigations
  - Stephen Cauffman: failure investigations

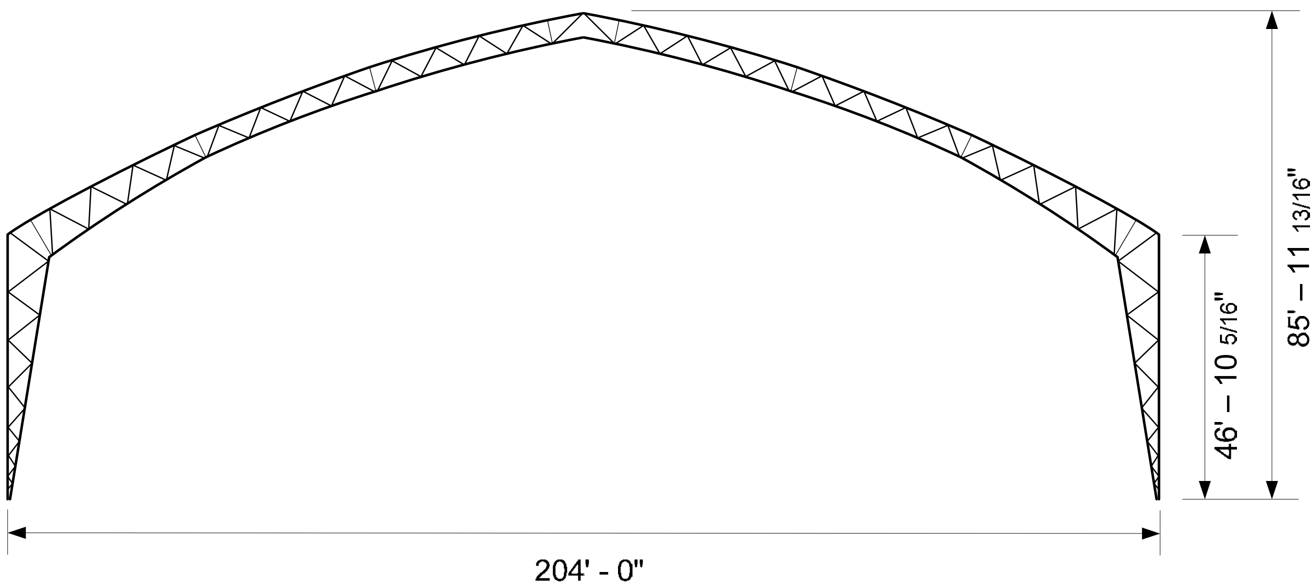
- **Independent Expert Reviewers**
  - David Jorgensen, Ph.D., NOAA National Severe Storms Laboratory: microburst expert, co-author of report
  - Richard Kaehler, P.E., Computerized Structural Design: failure investigations, steel design, industrial buildings
  - Douglas Smith, Ph.D., P.E., Texas Tech University: wind engineering, low-rise buildings
  - James Fisher, Ph.D., P.E., Computerized Structural Design: design of industrial buildings, light gage steel structures, Chairman AISC Committee on Specifications
  - Kishor Mehta, Ph.D., P.E., Texas Tech University: wind engineering and wind load standards

Motivation for Study

- Dallas Cowboys practice facility collapsed May 2, 2009 during a severe thunderstorm.
- Approximately 70 persons were in the facility at time of collapse.
- Twelve persons were injured, one seriously.
- Reason for collapse was not known.
- Unique opportunity to obtain valuable insight and data on: (1) performance of a full-scale structure during a wind event, and (2) adequacy of building codes, standards, and practices
- Many structures of this type are currently in use, including: sports facilities, industrial and agricultural facilities, casinos, storage facilities, military installations, aircraft hangers, etc.

Dallas Cowboys Practice Facility

- Gable-roof, steel frame structure with tensioned fabric covering
- 204 ft x 406 ft in plan
- 86 ft high at ridge
- Designed and constructed in 2003
- Upgraded in 2008 (new roof and reinforcement added to some members)



Scope of the Study

- **Field Data Collection**
  - **Three BFRL structural engineers deployed to the collapse site to:**
    - Document collapsed structure to identify collapse patterns and common failure modes
    - Survey wind damage in area surrounding the site
    - Collect relevant information (plans, specifications, and design calculations) on the structure from the Dallas Cowboys organization and the City of Irving, Texas
- **Data Review**
  - **Reviewed design drawings and calculations for the 2003 design and 2008 upgrade**
  - **Interviewed representatives of the owner and designer/builder**
  - **Collected and analyzed data on wind environment**
- **Analytical Study**
  - **Developed structural model of a typical frame, not the entire structure**
    - Since all interior frames in the structure were identical, results from analysis of a single frame are representative of the building response.
  - **Conducted analyses to calculate demand-capacity ratios for structural frame members under:**
    - Design wind loads (90 mph wind speed) – *design condition*
    - Actual wind loads based on wind conditions at time of collapse – *nominal condition*
- **Findings and Recommendations**
  - **Determined:**
    - Design factors that contributed to collapse, and
    - Likely collapse sequence
  - **Issued recommendation for improving safety of this type of structure**

Wind Environment on May 2, 2009

- Obtained and reviewed data from:
  - **May 2, 2009 Public Information Statement (NWS)**
  - **Survey of wind damage to trees on Dallas Cowboys Complex (NIST)**
  - **Observations of wind damage in neighboring areas (City of Irving)**
  - **Automated Surface Observing System data (NOAA)**
  - **Terminal Doppler Weather Radar data (NOAA)**
- NIST worked with NOAA's National Severe Storms Laboratory to estimate the wind conditions at time of collapse
- **Summary:**
  - **Wind was predominantly westerly**
  - **Maximum wind speed gusts at time of collapse were estimated to be 55 mph to 65 mph**
  - **The stagnation point (center of microburst) was located about 1 mile southwest of collapse site at time of collapse.**

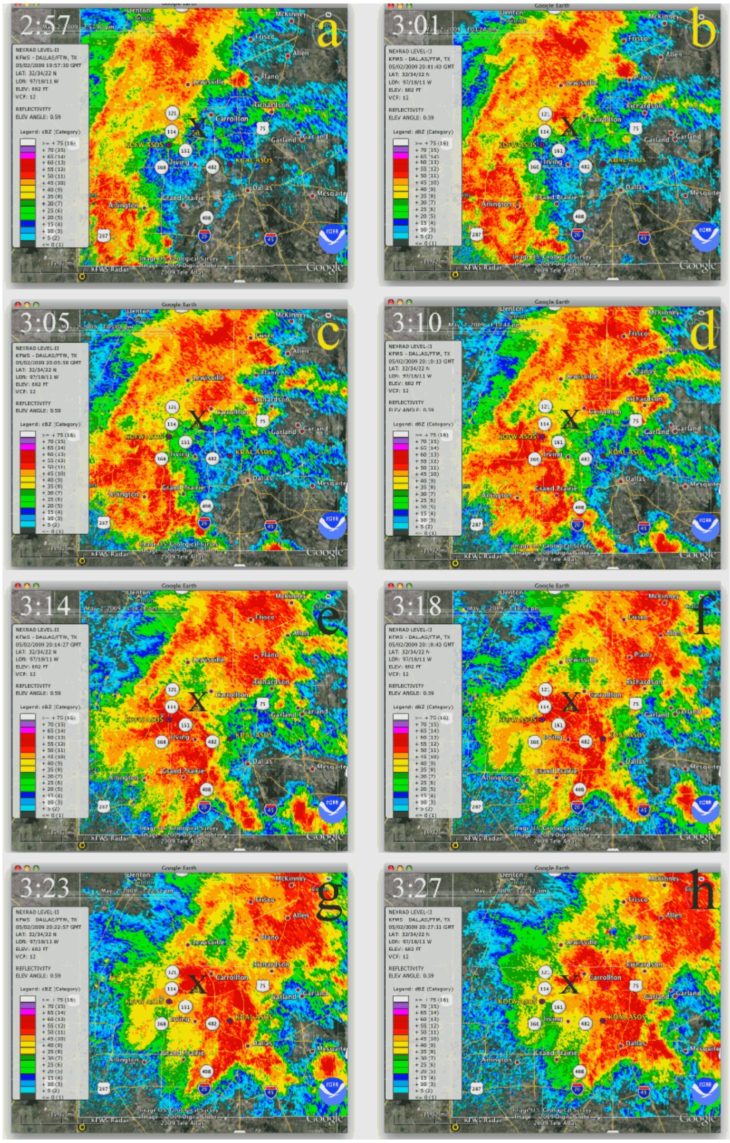
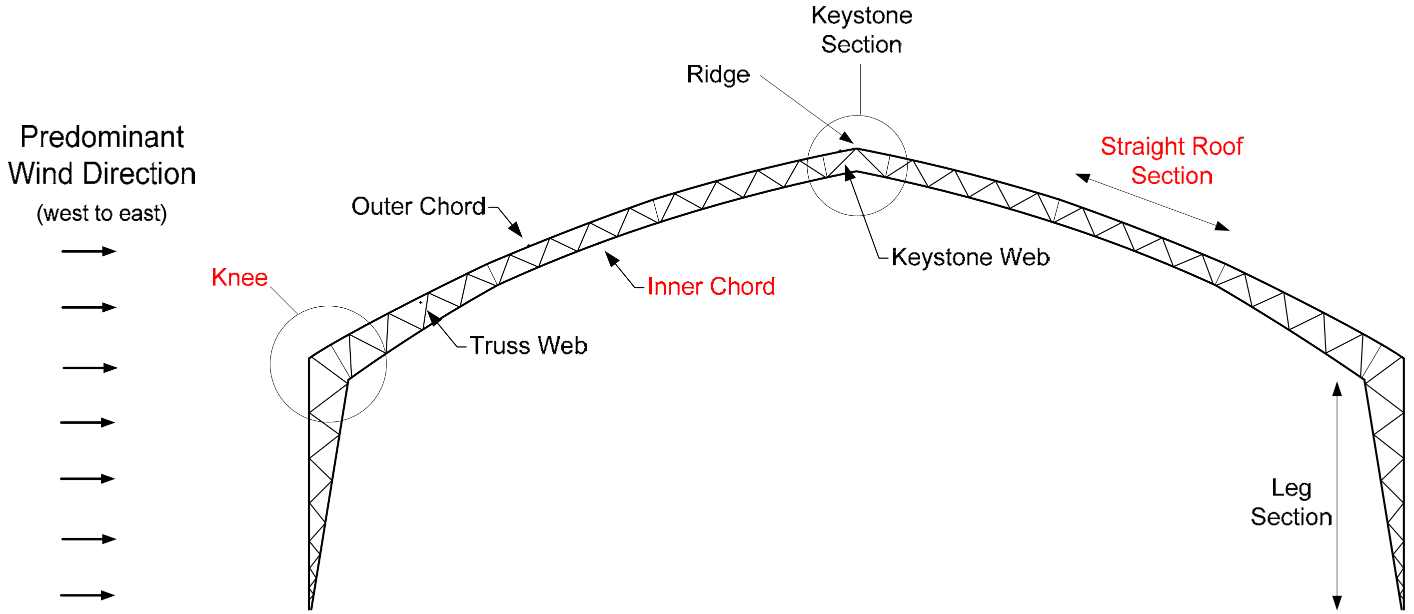


Image credits: Google Earth and NOAA

Principal Findings (1)

Summary of Analyses

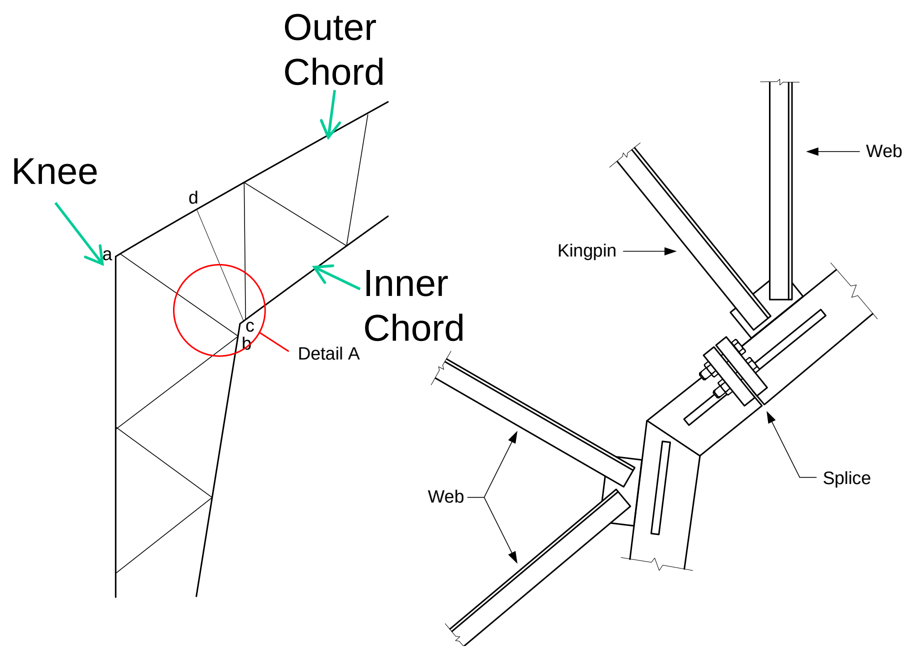
- **Wind speed at time and location of collapse** (55 mph to 65 mph) was **well below the 90 mph design wind speed** specified by the ASCE 7-98 and ASCE 7-05 Standards for that location.
- At wind loads corresponding to the 90 mph design wind speed, **demands significantly exceeded capacities** (design demand-capacity ratio as high as 6.0), especially for frame members around the knees and in the straight sections of the roof.
- At wind loads corresponding to 60 mph wind speed normal to the ridge (consistent with the wind environment on May 2, 2009), **demands exceeded capacities** (nominal unfactored demand-capacity ratio as high as 2.0), especially for inner chord members on the east (leeward) side of the frame, both in the straight section of the roof and around the knee.

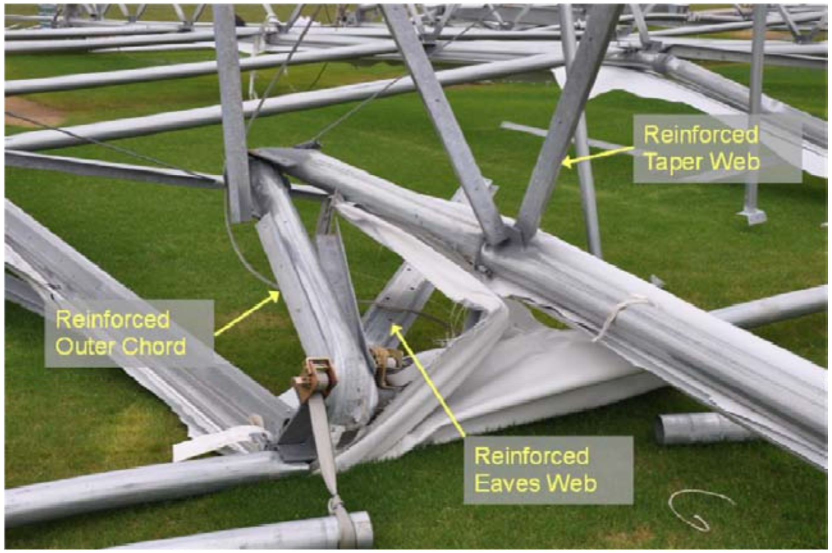


Principal Findings (2)

Design Factors Contributing to Collapse

- Wind loads used for both the original 2003 design and the 2008 upgrade differed from wind loads calculated based on the provisions of both the ASCE 7-98 and ASCE 7-05 Standards, producing significantly lower design demands **by a factor of up to 3.9**.
- Frame member capacities reported in the original 2003 design were considerably larger than the capacities calculated by NIST based on the AISC specifications **by a factor of up to 3.0**.
- Details of joints, particularly at the knees of the frames, produced large bending moments and shear forces in the chords of the frame that were not considered in the design (increasing demand-capacity ratios **by a factor of up to 2.3**).
- Reinforcements added in 2008 had a minimal effect as they affected only the compressive capacity of selected members; the most critical members were not reinforced.





Principal Findings (3)

Details of Contributing Factors

- **Wind load calculations – 2003 original design**
  - **Used approach for mean roof height < 60 ft – actual mean roof height was 67 ft**
  - **Used wind loads for frame near the middle of building – frames near end walls with higher loads were not considered**
  - **Did not include internal wind pressure – required by the ASCE 7 Standard**

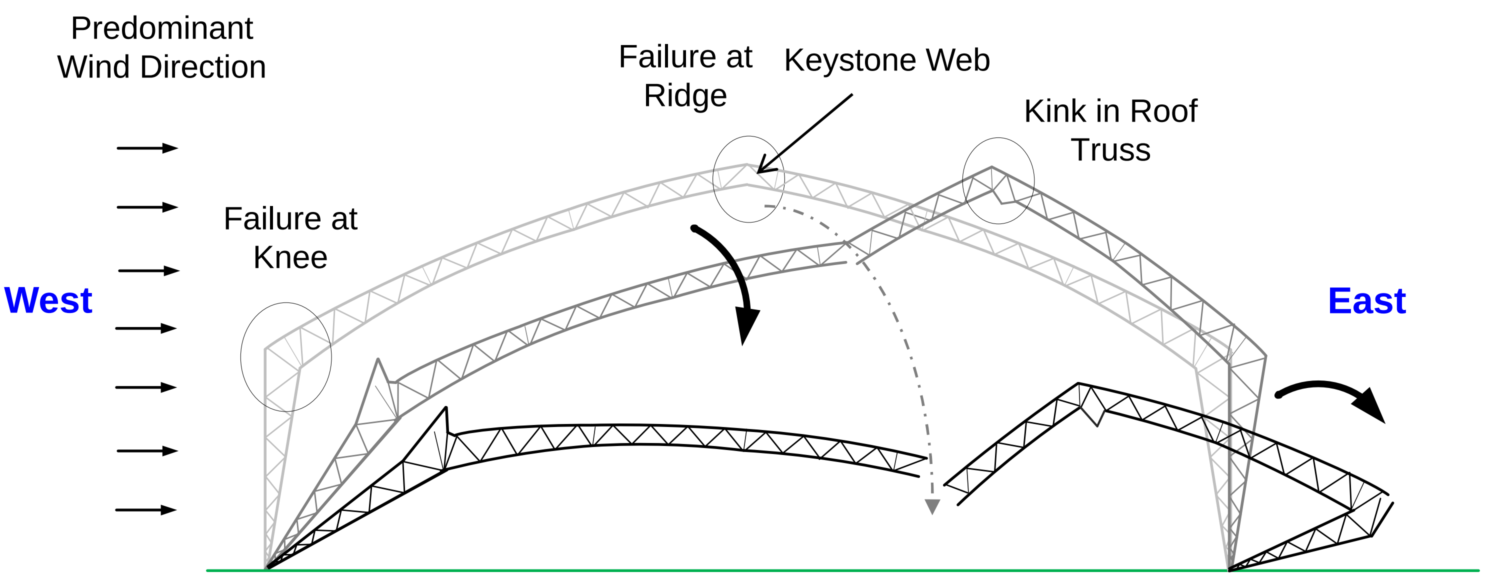
- **Wind load calculations – 2008 upgrade**
  - **Used roof slope of 11º – actual roof slope was 21º**
  - **Assumed building to be "fully enclosed" – building vents and doors render this building "partially enclosed" (internal pressure coefficient 3 times larger)**

- **Member capacity calculations**
  - **Assumed that the exterior fabric provided lateral bracing to the outer chord members**
  - **Used (1) an effective length factor of K=0.5 for chord members instead of the more appropriate value of K=1.0, and (2) unbraced lengths that were not consistent with the design drawings**
  - **Used splice and connection details that resulted in large moments and shear forces in chord members; these moments were not considered in design**

Principal Findings (4)

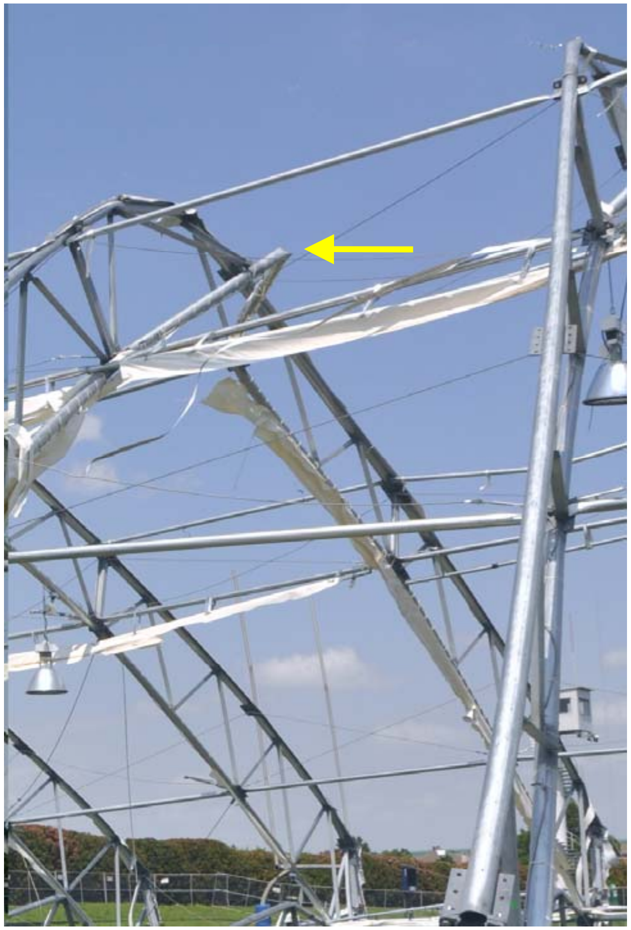
Likely Collapse Sequence

- Buckling of the inner chord in the straight section of the roof on the east side resulted in formation of a kink in the frame at this location (see photographs on next slide)
- Failures at the east and west knees allowed the frame to sway eastward (in the direction of the wind)
- Compressive failure of the east keystone web led to tensile fracture of the inner and outer keystone chords at the ridge
- Spread of individual frame failures in similar patterns, through load redistribution and loss of lateral bracing, resulted in total collapse of the practice facility



Principal Findings (5)

Likely Collapse Initiation Buckling of inner chords in straight sections of the roof on the east side



Recommendation

- **NIST recommends that fabric-covered frame structures be evaluated to ensure the adequate performance of the structural framing system under design wind loads. Of particular concern are (1) the use of the fabric covering to provide lateral bracing for structural frames, (2) determination of the appropriate enclosure classification in the calculation of internal pressures for design wind loads, and (3) the ability of the structural system, including the lateral bracing, to maintain overall structural integrity.**

- *Affected Standards:* There is no US standard directly applicable to fabric covered structures. An ASCE/SEI standards committee has developed a standard pertaining to tensioned fabric structures which is in the process of being released. NIST has briefed the ASCE/SEI committee on the findings of this study and will provide technical support to the committee if they choose to develop a standard pertaining to fabric covered structures or expand their existing standard to address such structures.

- *Model Building Codes:* The standard on tensioned fabric structures should be adopted in the IBC model building code by mandatory reference to, or incorporation of, the latest edition of the standard.