Structural Response of Columns Under Fire Loading

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Introduction & Purpose

On May 22, 2017, the Greenwich (CT) Fire Department responded to reports of a working structure fire at 6 Perkley Road, Old Greenwich. The first-arriving officer on scene found a 2-1/2 story wood-frame dwelling with heavy fire showing from two garage bays extending toward the second floor via the exterior of the building. [1]

After instructing crews to advance a large attack line, the officer conducted a 360° size-up of the fire building. During this investigation, a loud explosion was heard. It was later identified that the cause of this explosion was the rupture of two columns supporting a W12x26 I-beam within the garage. One such column ruptured with enough force to penetrate an exterior wall, coming to rest in the driveway of the residence. Without remaining supports, the I-beam fell to the ground and resulted in a severely weakened structure, unsafe for crews to enter.

The purpose of this research is to identify the mechanism by which these columns failed and to develop mitigating strategies to prevent such an occurrence in the future.

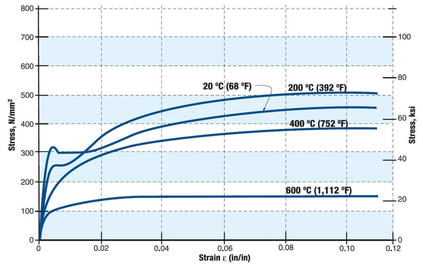
Methodology

To replicate the column rupture, an advanced engineering simulation software (ANSYS) was utilized to examine stresses resulting from loading, thermal conditions, and internal pressure. Through analysis of these resultant stresses, a determination can be made as to whether or not failure has occurred. In order to successfully model such a phenomenon in ANSYS, specific data was required:

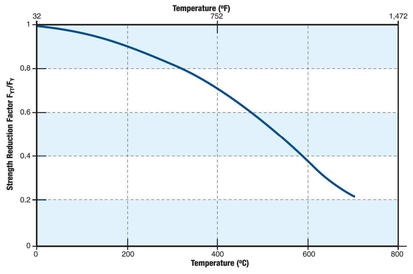
- **Fire Scenario Data**:
  - Fuel Load, Temperature, Duration
- **Column Data**:
  - Material(s), Dimensions
- **Material Properties at Elevated Temperatures**

After the successful identification of a failure mechanism for the column, mitigating strategies and procedures can be developed and put in place: fire departments' standard operating procedures, contractor procedures, and building code requirements.

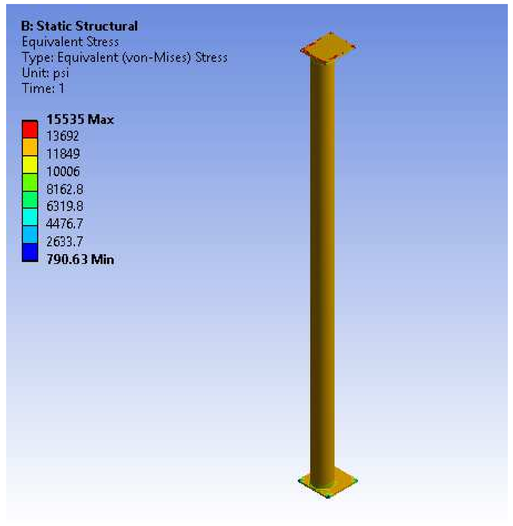
Results



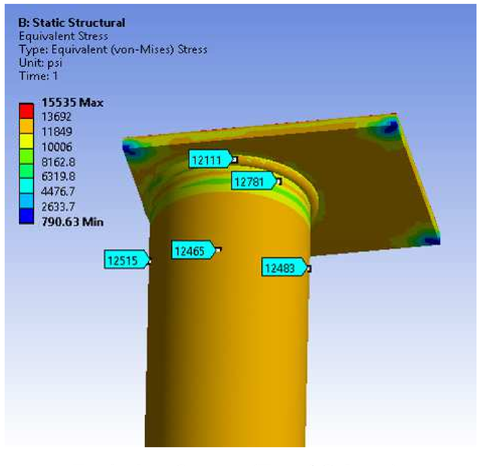
A-36 Stress v. Strain at Elevated Temperatures [2]



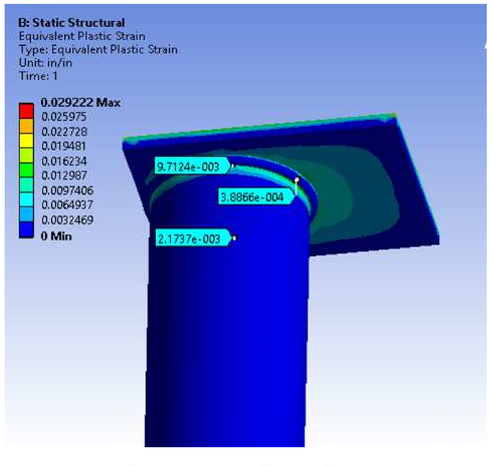
A-36 Strength Reduction [2]



Equivalent Stresses (Full Column)



Equivalent Stresses (Top of Column)



Plastic Strain (Top of Column)

Conclusions

- Based upon the applied thermal condition of 1200°F, it does not seem plausible that thermal stresses alone can cause column failure.
- The fixed boundary conditions utilized for this model may not be accurate in representing the boundary conditions for the true column.
- In addition to elevated temperatures, there are most likely additional factors that precipitated column failure: internal pressure caused by vapor expansion, the presence of a concrete core, buckling behavior, and eccentric loading.
- Firefighters responding to similar incidents must make an effort to cool structural components to relieve thermal stresses.

Future Research

As a solution has not yet been identified to mitigate a similar column failure in the future, additional research is necessary:

- Due to the limitations of available information on fire conditions, a uniform thermal condition was applied to the column. Similar analysis must be conducted utilizing a non-uniform thermal condition similar to what would be observed under actual fire loading.
- Recent investigation has identified that the columns may have been filled with concrete indicating the possible presence of moisture in the column. Future analysis will determine if rupture by vapor expansion is plausible.
- All simulations to this point have separated the columns from all surroundings. Future analysis will be on a more macroscopic scale and include column connections and loadings.
- For the previous simulations, a fixed boundary condition was applied to top and bottom plates. This does not necessarily indicate real-world boundary conditions and must be studied further.
- Future analysis will include simulations to determine whether or not columns indicate a buckling failure mode.
- If a simulation identifies plausible failure mechanisms, laboratory tests may help to replicate real-world scenarios and confirm simulation results.

Acknowledgments

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- Thank you to the Greenwich Fire Department for facilitating the acquisition of the damaged columns and granting me the opportunity to utilize them in any way I wish.
- Thank you to Lt. Ryan Brainerd for carefully, and repeatedly, walking me through the entire incident as he witnessed it.

References

[1] Lt. Ryan Brainerd, "Perkley Road Fire." Personal Interview. 15 June. 2017.
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[2] FEMA. *World Trade Center Building Performance Study: Data Collection, Preliminary Observations, and Recommendations.* New York: Greenhorne & O'Mara, 2002. Document.