Fire test underway beneath the cone calorimeter in the new Fire Technology Laboratory

FM Global Test Center

Today's buildings are designed to survive a major fire long enough to permit occupants to escape unharmed. But how does one design a building to withstand the effects of large-scale indoor fires on a daily basis? This was only one of the design challenges at commercial and industrial property insurer FM Global's new Research Campus in West Glocester, RI.

The $78 million project, which opened in the fall of 2003, includes four laboratories focused on property loss prevention research and product testing. These facilities include the world's largest Fire Technology Laboratory, as well as a natural hazards laboratory, an electrical hazards laboratory and a hydraulics laboratory.

At these facilities, FM Global scientists and engineers conduct small to full-scale tests to understand how to prevent and control major property risks, such as fires, explosions and windstorms. In turn, the information learned from this research benefits the policyholders of FM Global by providing them with solutions to best protect their facilities from such property threats.

By David Odeh

To complete the new Research Campus on an aggressive 24-month schedule, the design-build team — led by Dimeo Construction Company of Providence, RI, with structural engineer Odeh Engineers, Inc. – worked closely with FM Global's own research and engineering staff. The team executed a cost-effective design for the new facility through the development of a detailed Basis of Design in conjunction with FM Global, close coordination of the structure with testing and equipment requirements, and creative design of the structural systems.

The Fire Technology Laboratory, which is about the size of two football fields, presented the biggest challenges. Among the numerous structural hurdles were building a facility that could handle extreme thermal loads, and integrating massive ductwork and mechanical systems for smoke evacuation and data collection.

Needs for the New Laboratory

At the time of the project's conception, FM Global had already operated a fire test center on its 1,600 acre campus for 35 years. Interestingly, the new building design drew from both the historical operations of the original building and the results of testing performed within its laboratories.

The design team completed a detailed survey of the original Test Center, as well as interviews with FM Global scientists and engineers in order to incorporate lessons learned from operating the existing facility into the new design.

The original test center was a steel framed structure that withstood the effects of frequent fire tests, as well as the New England climate, remarkably well. However, the configuration and size of the facility limited the size and frequency of tests that could be performed.

In particular, the ability of FM Global to rapidly set-up, execute, and clean-up fire tests was critical. Large-scale tests of fire suppression systems must replicate the real conditions in buildings, including the types of combustible products (such as plastics, flammable liquids, or aerosols), the manner in which the products are stored (for example, on racks or shelving), and the location and configuration of sprinklers. Thus, fire simulations often involve variable heights of storage racks and ceilings in warehouses and other types of structures. In addition, the tests had to be performed with carefully controlled airflow into and out of the test facility.

In the original test center, large-scale fire tests were conducted in a single test bay under a fixed ceiling equipped with adjustable arrays of sprinklers. Tests were adapted to simulate variable ceiling height conditions by stacking the combustible goods on modular platforms. The long set-up time limited the number of tests that could be performed in the facility.

The new Fire Technology Laboratory was designed to greatly enhance the flexibility, capacity, and efficiency of FM Global's research and testing operations. The Laboratory is the largest facility on the campus at over 108,000 sq. ft. — more than double that of the original test center. Its control and data tracking systems allow researchers to study fire growth rates, flammability characteristics, fire suppression system effectiveness, and other factors. The largest room in the new Fire Technology Laboratory is its 33,000 square-foot burn lab, which includes three test bays and a sealed room with a full attic level above.

One of the test bays utilizes a unique moveable ceiling. The ceiling system, approximately 6,400 sq. ft. in area, can be configured with different fire suppression and detection arrays and then automatically lowered or lifted to the desired height, up to 60 feet above the test floor. To further facilitate test set-up and breakdown, the ceiling is equipped with a 10-ton capacity crane directly attached to its superstructure.

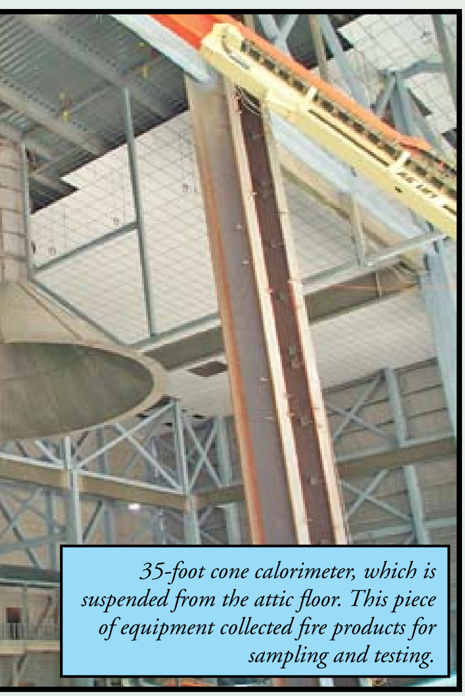
Smoke collection and data analysis is accomplished by a network of massive ducts, up to ten feet in diameter within the attic space. The attic, which has a barrel vault shaped roof, was designed to house all of the ductwork in a protected space over the fire testing area. The ductwork vents out to a new air emission control system adjacent to the facility.

Erection of the steel frame for the large burn room. Tubular steel concentric braced frames were utilized for the lateral force resisting system. Horizontal girts for metal panel wall system are also shown.

The Fire Technology Laboratory also includes laboratories for small to intermediate fire research and product testing, a visitor center, which can host meetings of up to 150 people, as well as office space.

The design-build team worked early in the project to develop a detailed Basis of Design in conjunction with a team of engineers and scientists from FM Global. As the project progressed, this served as a reference for all team members and was adjusted as required to achieve the goals of the client. Its use was critical to ensure that the project met the near-term needs of the tests being conducted by FM Global, but could also provide flexibility to service future research programs.

In many ways, the Research Campus is a showcase of FM Global property loss prevention engineering guidelines for highly protected construction. As part of its risk management services, FM Global writes and maintains a comprehensive set of rigorous engineering recommendations called Data Sheets, highly regarded by professionals and property owners worldwide. All of the facilities at the Research Campus fully incorporated these design standards, including snow, wind, rain, and seismic loading, and roof construction.



35-foot cone calorimeter, which is suspended from the attic floor. This piece of equipment collected fire products for sampling and testing.

Large Burn Lab Structural Design

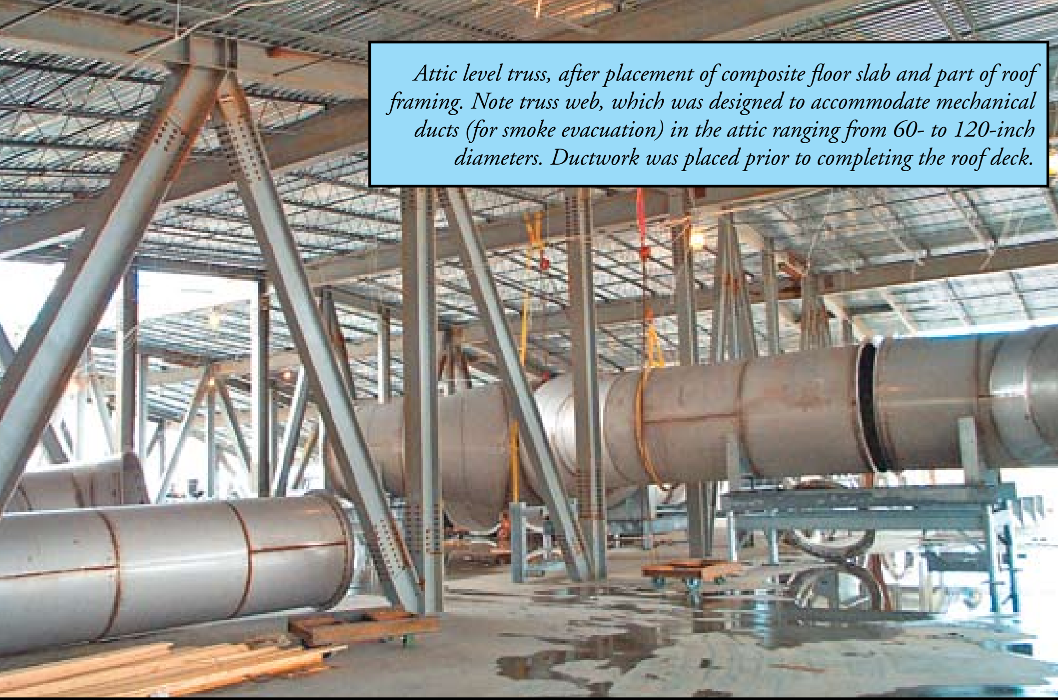
Odeh Engineers, Inc. designed the large burn lab structure in careful coordination with the moveable ceiling system fabricator, Handling Specialty, Inc. of Grimsby, Ontario.

To make the most efficient use of the large burn lab layout, the team utilized full-story depth trusses at the attic level to span across the 85- x 85-foot test bays. The truss top chords form the barrel-vault shape of the roof, which consists of wide flange girders framing into the truss panel points and open web steel joists spanning parallel to the roof slope. The truss bottom chords support a 6¼-inch deep composite slab. The composite slab at the attic level provides the necessary air seal of the test room below, supports the ductwork and equipment for smoke evacuation in the attic, and provides a rigid diaphragm to resist lateral forces from cranes and equipment in the test area as well as seismic and wind loads.

"...exposure of structural steel would be limited to 350° Fahrenheit..."

The 80-foot square moveable ceiling itself is framed with steel trusses, and is suspended from four bull nose screws hanging from the corners of the test bay at the attic level. The bull nose screws are attached to special cap plates on top of deep double column assemblies. The ceiling rides along special guides installed between two additional double column assemblies located between the bull nose screw supports.

The double column assemblies, which consist of two 67-foot high W36x245 columns with fixed bases spaced 5 feet apart center to center, provide multiple design advantages. First, the deep columns protect the bull nose screws, which are sensitive to thermal expansion and damage from fire debris. Second, the double columns could be braced to adjacent bays on the weak axis on the outside face of the assembly while leaving the inside space between columns clear for the bull nose screws



Attic level truss, after placement of composite floor slab and part of roof framing. Note truss web, which was designed to accommodate mechanical ducts (for smoke evacuation) in the attic ranging from 60- to 120-inch diameters. Ductwork was placed prior to completing the roof deck.

and guides, cutting the effective length to reasonable levels. Finally, the strong axis of the columns could be oriented to resist lateral thrust loading from the cranes attached to tracks on the moveable ceiling.

The lateral force resisting system of the structure consists of concentric braced frames. Tubular steel braces were used for all of the exposed bracing in the test areas. The tube shapes, which are located directly in front of louvers in many locations, have a more aerodynamic profile than other rolled shapes and allow for better air flow around the brace and through the louver. In addition, the flat faces of the tubes help to avoid the build-up of dust and soot that could occur on rolled sections. Bracing was designed for wind and seismic loads, as well as large loads from rail cranes and thermal expansion of the structure.

"…steel was coated with an immersion-grade, alkali-resistant epoxy paint compatible with fireproofing…"

Design for Thermal Loads

Thermal stresses from daily fire operations presented a unique challenge. The design team decided to protect members and locate the test bays such that direct temperature exposure of structural steel members would be limited to 350 degrees Fahrenheit. Team members felt that this service level temperature limit would limit strength and stiffness degradation of steel and concrete structural elements to sufficiently conservative levels.

The structural design included both protection of the steel framing from direct fire contact to avoid excessive temperatures, as well as design for the thermal stresses and expansion induced by typical fire tests.

The ceiling structures themselves, which are located directly above the fire and bear the brunt of the heat loading, were lined with a monolithic, castable refractory material. Tests performed on the refractory liner by FM Global's scientists and engineers showed that a temperature of 2,000 degrees Fahrenheit could be maintained directly below the ceiling for up to 30 minutes without exceeding the design criteria of 350 degrees Fahrenheit on the structure above the ceiling.

Handling Specialty designed the moveable ceiling assembly to expand up to 6 inches in length during fire tests. This design was facilitated by the double-column support system, which allows the suspended bull nose screws to move freely within the cavity space between the two columns. Another fixed ceiling in the high bay test area was equipped with Teflon-coated bearing pads to allow the ceiling to expand.

All major elements of the structure exposed to fire tests, including all columns and bracing, were provided with a heavy-grade, trowel-applied cementitious fireproofing material. The purpose of the fireproofing was not to protect the steel from the heat loads generated by daily fire tests, but to provide protection against catastrophic collapse in the event of a major building fire (for example, a fire test that gets out of control). The building is also equipped with its own sprinkler system to protect against such an occurrence.

Bullnose screw suspension assembly. The project team was on hand to witness a full scale mock-up of the moveable ceiling and its components prior to construction.

Due to the repeated fire suppression activities in the facility, moisture resistance was also important to the design. Moisture-resistant fireproofing cannot protect the steel itself from moisture infiltration and corrosion. Therefore, steel was coated with an immersion-grade, alkali-resistant epoxy paint compatible with the fireproofing prior to application.

In addition, low surface-to-volume ratio member sizes were selected for braces, columns, and beams in order to reduce the potential for high localized thermal stresses from hot gases, flaming debris, and other fire by-products that are difficult to control during testing operations. Such members have relatively high W/D ratios (where W is the weight of the member per unit length and D is the heated perimeter of the section), and have been shown to exhibit slower temperature rises under fire conditions than members with lower W/D ratios.

Erection of steel framing for the large burn room attic floor. W21x50 steel beams are shown framing into the truss bottom chords. Truss bearing condition on special double-column assembly is also shown.

> "…a truss design that allowed for stacked ducts to pass through an open 'vierendeel' panel at the truss center."

Concrete slabs on test floors were also analyzed for thermal stresses and long-term durability under repeated fire test loads. Based on years of successful performance at the original Test Center, the 85-foot square concrete test pads were designed as 18-inch thick mat slabs with top and bottom reinforcement, poured atop a sand cushion and separated from the surrounding floor by 18-inch wide trench drains on all four sides to allow for expansion of the mat. Careful control of the concrete water content was also required to improve performance and durability and minimize potential dehydration of the slab during fires (especially in the first year of operation).

Mechanical Systems Coordination Challenges

As one might expect, the volume of smoke generated by the fire test operations and air cleaning requirements necessitated the use of sophisticated mechanical systems. In turn, these systems added to the structural challenges of the project.

To meet FM Global's aggressive 24-month schedule, many of the mechanical systems had to be ordered before the final building design was completed. Careful coordination of these sophisticated systems with the structural steel during design and erection was crucial to the success of the project.

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Project Credits

Owner:
FM Global, Johnston, RI

Construction Manager:
Dimeo Construction Company, Providence, RI

Architect:
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Structural Engineer:
Odeh Engineers, Inc., Providence, RI

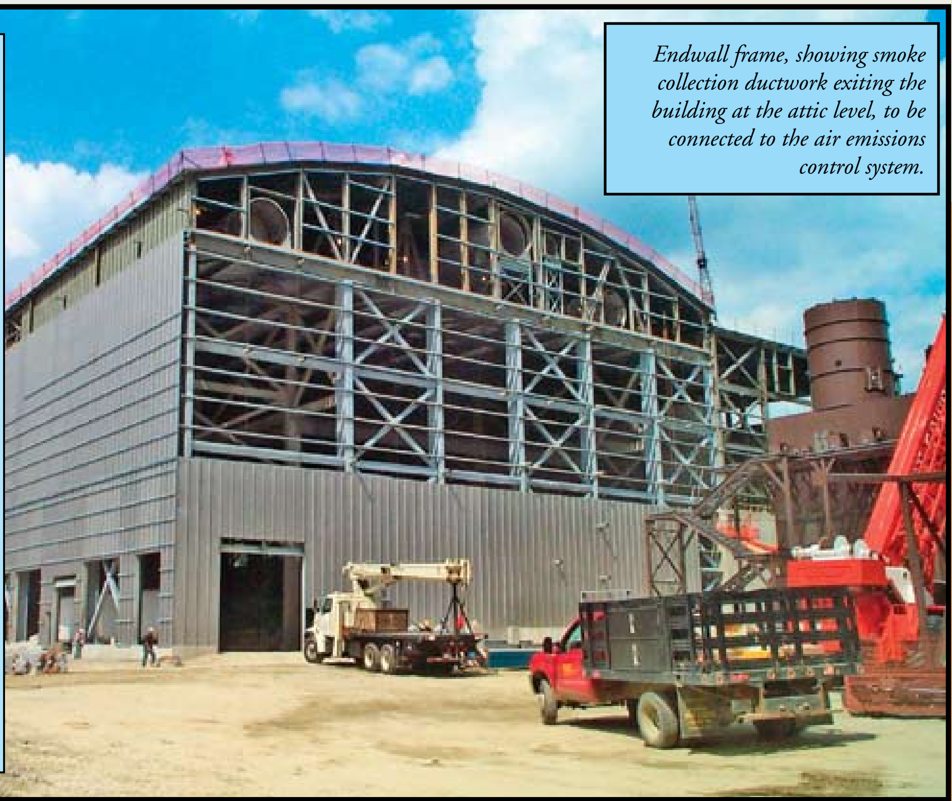
MEP Engineer (building systems):
R.G. Vanderweil Associates, Boston, MA

MEP Engineer (process systems):
R.W. Beck

Moveable Ceiling Fabricator:
Handling Specialty, Grimsby, ON

Steel Fabricator/Erector:
Capco Steel, Providence, RI

Structural Software:
STAAD 2000 Pro, RAM Structural System



Endwall frame, showing smoke collection ductwork exiting the building at the attic level, to be connected to the air emissions control system.

Close-up of truss bearing condition at double column assembly. Double columns support steel roof trusses and protect moveable ceiling mechanisms from extreme conditions.

The ductwork required for the data collection and air emissions control systems is a maze of ducts varying in diameter and weights, all contained within the attic level above the test areas. The architect, mechanical engineer, structural engineer, and construction manager all worked in close cooperation to conceive of an optimal layout for the ductwork, to avoid conflicts and to minimize the cost of the trusses. After several iterations, the team settled on a truss design that allowed for stacked ducts to pass through an open "vierendeel" panel at the truss center.

The barrel vault shape of the truss top chord provides maximum depth at the center of the truss (maximizing efficiency of the chords and minimizing forces in the vierendeel panel) where the highest concentration of ductwork is located, and also provides a defining architectural feature for the project.

Fire Endurance Ratings and ASTM E119

ASTM recently released the latest version of Standard E119, *Standard Test Methods for Fire Tests of Building Construction and Materials*.

The standard, which was first approved in 1917, is the most widely recognized procedure for the establishment of fire endurance ratings of structural members (walls, floors, roofs, beams, and columns) in the United States, and is referenced by all of the major building codes.

ASTM E119 testing is performed at numerous laboratories throughout the world, including Underwriters Laboratories (UL). (*See on-line reference 2*). Although FM Global has a high temperature furnace used to test fire resistive coatings, the various products listed in the FM Approval Guide (*see on-line reference 3*) are typically tested at partner labs under supervision of FM Global personnel.

Photograph courtesy of Brenda Schwartz

Key elements of ASTM E119 of interest to structural engineers include:

- ASTM E119 specifies a standard fire, in the form of a *time-temperature* curve. Test assemblies are normally subjected to the standard fire in a special furnace. The standard fire in ASTM E119 does not represent an actual building fire, but instead provides a benchmark for the comparison of different assemblies.
- The testing criteria in the standard establish the ability of the test assembly to contain a fire and/or retain its structural integrity. Test endpoints are based on heat transmission through the assembly, transmission of gases hot enough to ignite combustible materials above the assembly, the ability of the test assembly to carry load and withstand restraining forces, and the temperature of steel in some cases.
- Test specimens are to be constructed as closely as possible to the representative construction in the field. The specimens are required to be loaded during tests to the maximum required by nationally recognized design criteria.
- Typical lab tests are limited by the size and geometry of the furnace, thus tests are often performed on representative assemblies and extrapolated for application to different spans and lengths. For example, most test labs can only test up to 16-foot long specimens. However, the somewhat conservative practice of applying full loading to test specimens during a fire provides a greater level of confidence in the extrapolation of test results to longer span systems.
- In addition to the standard fire test, walls and partitions with ratings greater than 1 hour must also undergo a *hose stream* test. The hose stream tests the cooling and erosion impact of a water stream on the wall or partition. The requirement of the hose stream test on floors and roofs from previous editions has been removed due to impracticality and possible damage to test furnaces (See ASTM E119, commentary section X.5.9.1)
- Columns are tested with all four sides exposed to fires. Previous editions of ASTM E119 required pinned connections at top and bottom of columns to simulate the most critical condition, but this criterion has been removed. (See ASTM E119, X.5.10.1)
- The standard has recognized that thermal restraint of assemblies can be beneficial to the performance of a specimen (although it can also be detrimental in some circumstances). The commentary section of ASTM E119 (section X3), states that "While it has been shown that certain conditions of restraint will improve fire endurance, methodologies for establishing the presence of sufficient restraint in actual constructions have not been standardized." National model building codes (e.g., Reference 6) allow the use of restrained assembly fire endurance ratings when evidence of sufficient restraint is provided by the design professional. ASTM E119 table X3.1 provides guidance to engineers and architects in determining the conditions of restraint for typical building construction types. An excellent discussion of this issue is provided on-line (*References 4 and 5*), supporting the argument that composite steel beam floor systems framing into steel columns can be considered as "restrained construction" regardless of the beam to column connection types.

The standard can be downloaded or ordered from the ASTM website at **www.astm.org**.▪

The erection of the trusses, attic floor, and roof framing was carefully sequenced to allow for the installation of the large ducts. Each truss was laid out and assembled on the ground and could be lifted into place by a single crane. Once the trusses were erected, the attic floor framing was erected. The large ducts were placed on the attic floor and moved into position using cranes on the ground.

The composite slab attic floor was designed to support all of the mechanical loads within the attic. The large stainless steel ducts, which weigh up to 200 pounds per linear foot, sit on frames spaced evenly along the length of the duct. The composite steel framing and slab allowed for some flexibility and tolerances as to the locations and anchorage of the duct supports.

The process of incorporating such a sophisticated system within a structure was only possible by coordinating all of the mechanical and structural systems at an early phase, and through constant communication between the architect, engineers, steel fabricator/erector, and owner. The design-build structure of the project fostered a team-oriented approach that greatly facilitated this effort.

Summary

A creative, yet cost-effective structural system was successfully employed by the design-build team to meet the many challenges of the new Fire Technology Laboratory at the FM Global Research Campus. By forging a collaborative working relationship with FM Global's scientists and engineers, the team first identified the important design criteria. These criteria formed the basis of innovative solutions to the unique loading and operational requirements of the facility. The team then used careful coordination to integrate complex mechanical infrastructure into the structural and architectural design, and executed construction on an aggressive fast-track schedule. These accomplishments have set the stage for FM Global to use this world-class facility for innovative property loss-prevention research and product testing to meet the ever-changing needs of its clients for decades to come.▪

For more information on the FM Global Research Campus, as well as access to other data referenced in this article, visit **www.fmglobal.com**.▪

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