

FIRE PROTECTION Engineering

1ST QUARTER 2011

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Fire Engineering in RAIL PROJECTS in Australia

Fixed Fire Fighting Systems in Road Tunnels

Behavior of FRP-Strengthened Reinforced Concrete Members Under Fire Conditions

The Evolution of Storage Sprinkler Design



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From the **TECHNICAL DIRECTOR**

SFPE's Guidelines for Substantiating a Fire Model for a Given Application

In December, 2010, the Society of Fire Protection Engineers published the *Guidelines for Substantiating a Fire Model for a Given Application*. Publication of these guidelines culminated a three-and-a-half year development effort that began in 2007. For additional background, refer to this column in the first quarter, 2010 issue of *Fire Protection Engineering*.

The guidelines establish a five-step process for determining the suitability of a fire model. These steps include defining the problem, selecting a candidate model, verifying and validating the model, determining the impact of uncertainty and user effects on the model results, and finally, documentation of the model evaluation.

The first step described in the guide is to define the problem of interest. The problem of interest should be defined by identifying the relevant phenomena and key physics, collecting available information and determining the analysis objectives. Identification of relevant phenomena and key physics requires knowledge of the details of the problem of interest as well as the underlying chemical and physical processes involved.

Prior to using a fire model, there will be information available that might influence the model that is chosen. This information includes the geometry to be modeled, the timeline for the problem of interest, events that might occur during the period modeled (such as ignition of objects, opening of doors or windows, or activation of fire protection systems), the materials relevant to the problem of interest and their material properties, the initial and boundary conditions, and the objectives of the analysis.

The next step identified in the guide is to select a candidate model. The guide recommends considering a number of factors before selecting a particular model, including available model inputs, desired model outputs, computational resources, time limitations, required level of accuracy, and most importantly, whether or not the governing equations and assumptions in the model are appropriate for the problem of interest.

The guide notes that there is often more than one model available that may provide a sufficiently accurate solution to a problem. In such cases, model selection can be based upon the resources that are available to run the model. While a CFD model may provide benefits, such as the ability to more exactly represent the geometry of a space and better visualization tools than a zone model, it may not always provide a more accurate solution to a problem. If time constraints and lack of computer resources prohibit a thorough sensitivity analysis using CFD, then for some problems it might be more appropriate to use a zone model or algebraic model in order to more thoroughly address uncertainty.

Prior to using a model for a particular problem, the guide recommends that the model user determine if the model is capable of generating a useful result. The formal process by which this is demonstrated is verification and

validation. Model verification serves two purposes. First, it ensures that the mathematical equations have been properly implemented. Second, it ensures that the model user understands the assumptions of the model. Verification ensures that the model is working as designed, i.e., that the equations are being properly solved. It essentially is a check of the mathematics.

Validation is a check of the physics, i.e., whether the equations are an appropriate description of the fire scenario. Most often, validation takes the form of comparisons with experimental test data. Validation does not mean that a model makes perfect predictions, only that the predictions are good enough for its intended use. The meaning of "good enough" is up to the model user, and to say a model has been validated only means that an end user has decided that the model is sufficiently accurate for a particular application.

Once the verification and validation have been conducted, the guide recommends addressing the uncertainty that arises in model predictions. In addition to uncertainty that exists within the model, the input data can introduce uncertainty into the model calculation. The resolution of the model can also affect the analysis outcome. The guide suggests several methods of dealing with uncertainty introduced through the use of models.

Finally, the results of the evaluation should be documented so that other people can understand how it was determined that the model is appropriate for its intended use.

The guide concludes with an appendix that identifies fire-related phenomena that might be modeled. The following phenomena are addressed in the guide: gas layer temperature and depth, ceiling jet temperature and velocity, flame height, heat flux, target response to heat flux, gas concentration, room pressure, heat release rate, ventilation, visibility, detector and sprinkler response, explosions and gas dispersion.

SFPE developed the *Guidelines for Substantiating a Fire Model for a Given Application* to provide a standard of care for model users and to address the concerns of consumers of model results, such as enforcement officials. Ordering information can be found on page 48.

Morgan J. Hurley, P.E., FSFPE
Technical Director
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Fire Protection Engineering welcomes letters to the editor. Please send correspondence to engineering@sfpe.org or by mail to *Fire Protection Engineering*, 7315 Wisconsin Ave., #620E, Bethesda, MD 20814.

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By David A. Charters, Ph.D.

"Shortly after the evening rush hour had passed its peak on Wednesday 18 November 1987 a fire of catastrophic proportions in the King's Cross Underground station claimed the lives of 30 people and injured many more. A further person was to die in hospital making the final death toll 31."

These are some of the opening words of the Investigation into the King's Cross Underground fire in London in the UK.¹ The investigation called 150 witnesses, took 12 months to publish its findings, ran to more than 250 pages and made no less than 157 recommendations.

The fire started in the grease and detritus on the running tracks of an escalator and spread to the escalator's wooden skirting board. Although smoking was not allowed in underground stations, it is thought that a match was the cause of the fire.

The escalator's wooden decking and balustrades were preheated by the fire and, once ignited, the flames spread up the escalator trench and caused a flashover in the ticket hall. Evacuation of the lower levels of the station was underway at the time of the flashover, though unfortunately the escape route taken was up a separate set of escalators and through the ticket hall where the flashover occurred.

The changes in fire safety on London Underground were wide ranging and included:

- Replacement of wood on escalators with metal
- New emergency and evacuation procedures
- Increased familiarization for emergency services
- New systems for the management and audit of safety
- A range of training programs for all station staff
- Improved communication systems

In addition, existing building fire safety legislation was extended to cover underground stations.

The wider changes to fire safety were perhaps more subtle and far-reaching and included:

- Fire dynamics and the trench effect
- Reaction to fire and toxicity testing
- Human behavior in fire
- Fire safety management and safety culture
- The probabilistic nature of fire

Awareness of the importance of fire dynamics was increased, and in particular the trench effect was discovered. When both balustrades and the floor of the escalator trench

became involved in the fire, the flames, in entraining air on the up-hill side, lay down in the escalator trench. The trench effect was initially identified by researchers applying a (then) relatively new approach to fire modelling called Computational Fluid Dynamics. A similar effect had been observed before and is illustrated in *An Introduction to Fire Dynamics*.²

There was also a greater awareness of the importance of the reaction of fire of station and rolling stock linings and materials. Consequently, existing standards were further developed and continue to be enhanced, including standard test methods for toxicity testing.

The importance of human behavior in fire was also recognized. For example, some passengers did not act on instructions from station staff because they did not perceive them to be authoritative. This perception had developed during normal operation and has important implications for the training of staff. Other passengers responded to police officers who happened to be on the scene and used their initiative, but had little or no knowledge of the station or its emergency procedures.

Fire safety management, and in particular the importance of a safety culture, gained greater recognition. After the fire, there was a radically different approach to near-misses and internal inquiries into accidents were undertaken.

There was also a wider appreciation of the probabilistic nature of the risk of ignition and fire. London Underground had operated for over 100 years without a similar fire event, yet this did not necessarily mean that such a fire could not occur. Subsequently, the legislation for railways now requires a safety case informed by quantitative assessment of risk. The fire safety legislation for existing buildings is now also based on an assessment of risk.

Following the King's Cross fire, there have been major changes to fire safety on underground transport systems. Just as significantly, there have also been more subtle and far-reaching changes in the understanding of fire safety, and this can only have helped improve safety over the last 23 years and continues improving fire safety into the future.

David A. Charters is with BRE Global.

References:

- 1 Fennell, D., 'Investigation into the King's Cross Underground Fire', Department of Transport, London, 1988.
- 2 Drysdale, D., *An Introduction To Fire Dynamics*, 2nd Edition, Wiley, 1998.

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The SFPE Corporate 100 Program was founded in 1976 to strengthen the relationship between industry and the fire protection engineering community. Membership in the program recognizes those who support the objectives of SFPE and have a genuine concern for the safety of life and property from fire.

Symposium Highlights Elevator Use in Building Emergencies

Ten firefighters selected and sponsored by the National Fire Protection Association (NFPA) Metro Chiefs were among the 120 attendees who in December attended a two-day symposium on the use of elevators during building emergencies.

The symposium offered presentations on the progress of the ASME/A17 Task Groups on Use of Elevators by Firefighters and Use of Elevators for Occupant Egress. Speakers described the current requirements as well as new code changes under development that affect Elevator, Building, Life Safety, Electrical and related codes.

The themes at the core of this effort will involve a combination of changes to codes and standards, development of new hardware components for elevators, establishing a protocol for occupants to follow, integrating an operating procedure for the fire department to use the elevators and reconfiguring building floor designs to accommodate these new features.

"The work of these Task Groups is by no means done," says NFPA Principal Life Safety Engineer Ron Coté. "In fact, 2011 is shaping up to be another active year as we look at a hazard analysis for other than fire scenarios and for more types of high-rise buildings. A great deal of information has been collected, reviewed, and developed in the last six years since the inaugural symposium on this topic was held."

Major NFPA codes including NFPA 1, NFPA 101, and NFPA 5000 have a number of proposed changes for the 2012 editions to reflect the latest information for both the occupant evacuation and firefighter elevators. These changes will be considered at the 2011 NFPA Conference & Expo scheduled for June 12-15 in Boston.

For more information, go to www.nfpa.org

WPI Among Best Colleges for Women in STEM Fields

Forbes.com has ranked Worcester Polytechnic Institute (WPI) 11th in the nation among "Best Colleges for Women and Minorities in Science, Technology, Engineering, and Mathematics (STEM)." The Princeton Review also recently recognized the school by naming it one of the top five in the nation for women studying business and management.

"WPI has been able to attract outstanding female students and faculty in the STEM disciplines by making our interest in and commitment to their value and success explicit through pipeline, recruitment, and support programs, and through a campus culture that values collaboration, innovation, curiosity, and exploration," says WPI President and CEO Dennis Berkey.

Upon their arrival on campus, women find support, advocacy, and development services through the WPI Office of Diversity and Women's Programs. Berkey chairs the institute's task force in support of women and minority faculty and staff.

WPI is attracting women in record numbers. Over the last five years the number of women enrolling in WPI as first-year students has increased 83 percent; today there are 1,110 women on campus, comprising 30 percent of the student population. A record-breaking 34 percent of the Class of 2014 will be women.

For more information, go to www.wpi.edu

Nuclear Plant Shifts to Automated Fire Detection System

According to a December 29, 2010 Associated Press report, the Shearon Harris nuclear power plant in Hill, N.C., is "shifting to a new model of fire safety, replacing teams of human fire patrols with an automated fire-detection system." The change is near completion. The Oconee nuclear plant in South Carolina is expected to make the same switch over the next two years.

"They were really pilot projects so the U.S. Nuclear Regulatory Commission (NRC) and the industry could see how this works," NRC spokesman Roger Hannah said.

According to the Associated Press report, these plants will be followed by 50 of the nation's 104 nuclear reactors that will adopt the new approach to fire safety.

The changes have not been met without criticism. Concerns have been forwarded to the NRC's inspector general. Despite those concerns, the 44 changes costing \$30 million made at Shearon Harris are expected to make the plant safer, said David Lochbaum, director of the nuclear safety project at the Union of Concerned Scientists in Washington.

For more information, go to <http://bit.ly/fN8oaR>

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FIRE ENGINEERING IN RAIL PROJECTS IN AUSTRALIA

By Joe Paveley, Ph.D., ARUP

BACKGROUND

In Australia, a major expansion of the rail network is underway, with new routes and upgrades to existing facilities. Much of the investment has been in improving and expanding city services, including increasing the capacity of existing lines. Most rail lines are above ground; however, there is increasing demand for underground routes in dense, urban areas.

A recently completed underground rail line, the Chatswood to Epping Rail Link in Sydney, is a 12 km-long twin tunnel with three new stations connecting two existing stations. Further expansion has been planned for Sydney, with new lines above and below ground. Other cities, including Melbourne, Brisbane and Perth, are also expanding their networks.

Australia uses heavy rail systems in urban areas, with timetabled train operations and trains suited to suburban commuting. Metro services have been proposed for the more densely populated city centers – either as completely new systems or by changing the train car design and operations to increase passenger load and reduce the transfer time at platforms.

SAFETY ASSURANCE IN THE AUSTRALIAN RAIL INDUSTRY

In Australia, the safety assurance process is now a fundamental part of rail system design and operations. This is a risk-based process that covers all design aspects that affect safety, including signals, track design, occupational health and safety, security (including terrorist risks) and fire protection engineering. Rail regulators typically review risks as a whole, so they are keen to keep fire safety risks low. Fire protection engineers can expect their fire strategies to be challenged in detail. Prescriptive codes may give some direction for fire strategy, but reliance on these alone may not demonstrate that the required level of safety has been achieved.

The ALARP (As Low as Reasonably Practical) and related risk processes are generally used to assess safety. Hazards are identified and risks assessed for design, construction and operational safety. The risks are ranked using consequence and probability descriptors to inform the design team of the key risks. A generic example of a risk ranking matrix is shown in Table 1. Table 2 shows the required actions for the risk rankings.

	Likelihood or frequency					
	Once every 1000 yrs	Once every 100 yrs to 1000 yrs	Once every 10 yrs to 100 yrs	Once every 1 yr to 10 yrs	One to 10 times a year	More than 10 times a year
	Incredible	Improbable	Rarely	Occasional	Probable	Frequent
Consequence	>10 Fatalities	High Risk	High Risk	Extreme	Extreme	Extreme
	2-12 Fatalities	Moderate	High Risk	High Risk	Extreme	Extreme
	1 Fatalities 2-10 Major Injuries	Moderate	Moderate	High Risk	High Risk	Extreme
	1 Major Injury	Risk Acceptable	Moderate	Moderate	High Risk	Extreme
	1 or more minor injury	Risk Acceptable	Risk Acceptable	Moderate	Moderate	High Risk
	Minor First aid or no treatment required	Risk Acceptable	Risk Acceptable	Risk Acceptable	Moderate	High Risk

Table 1. Example Probability and Consequence Risk Matrix for Life Safety

Risk Ranking	Action
Extreme	Not acceptable. Improve design and management.
High Risk	Not acceptable. Improve design and management as much as practicable.
Moderate	Only tolerable if ALARP
Risk Acceptable	Acceptable but monitor risk

Table 2. Risk Rankings and Required Actions



FIRE SAFETY IN THE AUSTRALIAN RAIL INDUSTRY

There have been few fatal rail fires in Australia, and none of the same severity as King's Cross, London, 1987.¹ There are several reasons for this, but an important factor is operational staff acting quickly to prevent the escalation of fires. The challenge is to maintain an acceptable level of fire safety with changing operations, greater passenger numbers, and an expanding rail network.

In Australia, buildings must comply with the Building Code of Australia (BCA).² The prescriptive provisions do not address stations adequately, particularly platforms with large travel distances and escalators used for egress, nor do they address other issues such as electrical hazards and train operations.

For tunnels, a new draft Australian Standard³ was issued in 2009 for comment. This generally adopts a risk-based approach, providing high level guidance, but avoiding prescriptive requirements.

NFPA 130⁴ is often used as guidance for station and tunnel fire safety design in Australia, although it must be adapted carefully to suit local rail operations and fire safety industry practice.

Rolling stock fire safety design is typically addressed through a range of fire safety standards

and guides, including in-house standards, ad hoc tests, and references to other standards such as BS 6853.⁵ Some rail authorities are now updating these standards to take into account developments in materials testing and fire protection engineering methodologies generally.

The International Fire Engineering Guidelines (IFEG)⁶ set out the fire protection engineering process, with some adaptation to align with the safety assurance process. A risk-based approach is often adopted for the fire safety issues in rail projects, with codes providing supporting guidance for design solutions.

THE ROLE OF THE FIRE PROTECTION ENGINEER

Fire protection engineering, as a discipline, is new to the rail industry. Prior to its involvement, various disciplines would develop fire safety designs, often in isolation of others, and not always with specialist fire safety knowledge. This led to repeating previous designs, without understanding the background. Code interpretation was often carried out independently, with parties using different assumptions. Often, the rolling stock, tunnel and station designs were developed in isolation of each other. There was coordination of some key design elements, such as the kinematic envelope for trains, but with

less integration for fire safety. With this approach, some fire hazards may have been left uncontrolled for some elements or overdesigned in others.

There has been performance-based design on infrastructure projects for nearly 15 years; an earlier example is Sydney Olympic Park, which opened in 1998. The scope for fire protection engineering has expanded, becoming the means to integrate fire safety design solutions, as well as solving specific design problems. This has occurred in parallel with new investment in the rail industry and the introduction of the safety assurance process, as well as the introduction of performance-based fire safety design. Many clients see the value in fire protection engineering to develop a fire strategy early, setting the parameters for the design of the tunnels, rolling stock and stations.

DEFINING THE OBJECTIVES FOR FIRE PROTECTION ENGINEERING

An essential part of the process is defining the fire protection engineering objectives. These include safeguarding people from injury due to a fire, avoiding fire spread to adjacent property and facilitating emergency services' activities. A 'safety-by-design' approach is adopted for all design elements to include consideration to installation,

operation and maintenance risk. Other objectives include operational continuity and reliability, which can involve maintaining operations after a relatively small fire, maintaining operations in degraded mode after a significant fire, and implementing a process to avoid escalation of a fire. These operational objectives require early detection and response to incidents, including a robust communication strategy.

The following sections present examples where fire protection engineering has been used to meet these objectives.

RISK-BASED FIRE SCENARIOS

A risk-based approach has been used for the selection of fire scenarios, categorising the scenarios as Base Case Design Fires; High Challenge Design Fires; and Extreme Events.

The categories determine the safety margin which is to be applied to the results, as shown in Figure 1.⁷ The fire scenarios can include a combination of fire sizes and occupant numbers.

The identified scenarios are assessed in terms of the 'Sub-Systems' defined in the IFEG, namely:

- Fire initiation and development and control.
- Smoke development and spread and control.
- Fire spread and impact and control.
- Fire detection, warning and suppression.
- Occupant evacuation and control.
- Fire brigade intervention.

ROLLING STOCK AND OPERATIONS

Rail fire safety is part of a dynamic system. In a fire or other emergency, the number of passengers on a train, number of trains in a tunnel and initial response of the rail operator depend on the system operation. The best place for evacuation is the station, where there is the capacity for the safe, rapid evacuation of a train. Evacuation of passengers from tunnels can be hazardous, even without a fire; therefore, it is better if a train with a fire can keep moving to a station. Until the train arrives, reasonable conditions in the cars are required by limiting fire and smoke spread. In Australia, specification of material fire performance varies, although is typically by

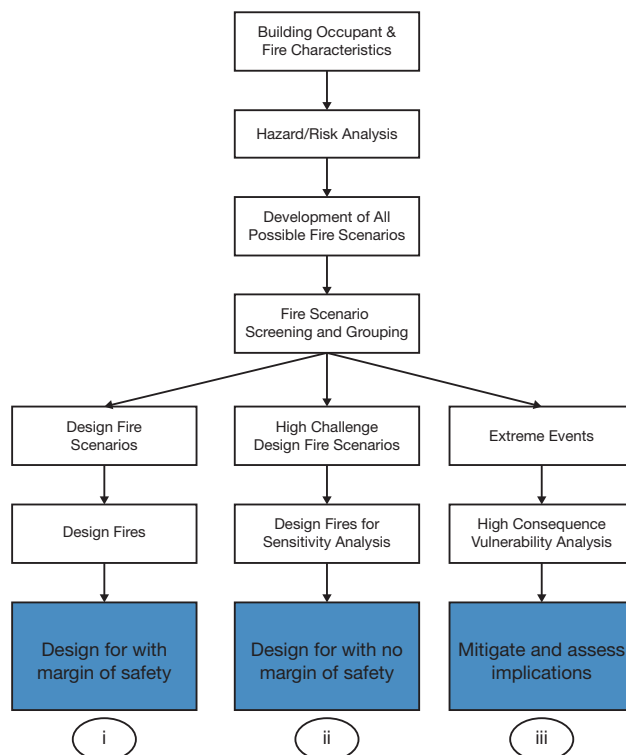


Figure 1. Fire Scenarios⁷

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reference to BS 6853 with additional local requirements. Newer international codes, such as EN 45545,⁸ are beginning to be adopted. The Duggan method⁹ is often used as a simplified method to limit the train car interior heat output. This can over predict the actual maximum fire size, but in the absence of more detailed analysis, provides a fire size as a common point of reference for train material specification and smoke ventilation design. A more detailed analysis of fire growth in existing rolling stock was conducted by Coles, Wolski and Taylor.¹⁰

The resilience of other train systems can improve fire safety, for example:

- Fire rated floor to the passenger compartment, to protect passengers from an undercar traction or brake fire;
- Two cars to have independent power connection via fire rated (or fire separated) cables to power transmission units;
- Multiple motor units, so that a train can continue to the next station, even with failure of one or two units.

These features are important in allowing a train to continue safely to the next station, even with a severe fire affecting one car.

New rolling stock generally has automatic fire detection (in car and under car), CCTV to all areas of the car interior, and various communications systems, such as public address, passenger information displays, and passenger emergency information systems.

A difficulty often encountered is older rolling stock that is run through tunnels that have fewer fire safety features and less robust power and communications systems. Older trains, or trains not specified for underground use, may not have the fire safety features described above. In these cases, it is less certain that a train could reach the next station, or that reasonable tenability could be maintained in the passenger cars, while travelling to a station.

On some systems, reviews have been conducted on whether staffing numbers can be reduced, including operating the trains without an attendant or driver. In these cases, emergency egress response needs to be assisted or directed by a remote operator in a central control room. This requires robust communications, with levels of redundancy in the train, tunnel and station. The fire protection engineer must understand how these systems interact to be able to develop fire scenarios.

For tunnels, a new draft Australian Standard³ was issued in 2009 for comment. This generally adopts a risk-based approach, providing high level guidance, but avoiding prescriptive requirements.

When a fire-affected train travels on to the next station, a reasonable degree of safety must be provided. The omission of inter-car doors has been examined to varying degrees by many operators, who are keen to have an open train car design, in part for better security. This can lead to greater smoke spread between cars. This could impact tunnel egress design if there is a significant risk due to smoke while a train continues travel or due to a train halting in

a tunnel. The rail tunnel systems in Australia are urban, with less than 6 minutes travel time between stations; therefore, the risk is generally low.

ESCAPE VIA THE STATION

There are many factors that affect safe egress from stations, including smoke control and occupant behavior. A key design issue is predicting the occupant load numbers in an emergency and acceptable evacuation times; typically, the methodologies in NFPA 130⁴ are used. Passenger numbers vary with different scenarios, and this is addressed in NFPA 130. NFPA 130 requires calculation of the occupant load with one missed headway; however, beyond that, there are a variety of assumptions used – such as crush-loaded trains arriving from both directions, rather than train loads based on patronage estimates. This can lead to differences in occupant load estimates. There is also much discussion about the 4-minute and 6-minute target evacuation times. There is often a dogmatic attitude towards these targets, even with open air stations, despite NFPA 130 allowing these time periods to be varied.

The occupant loads and fire scenarios can be categorized into design basis, sensitivity and extreme. The evacuation time can be better assessed using levels of service, with maximum time limits for individuals to be held in a queue at restricted points along the egress route. This is also compared against the conditions achieved by the smoke control system. This provides a better means to design and assess evacuation strategies than attempting to interpret the exact meaning of four clauses in NFPA130.

One of the challenges with evacuation analysis has been to understand the effect of stations at depth. Some stations have been planned up to 40 m deep. This can lead to challenges on the movement speed of occupants if they need to

climb fire stairs or if using long escalator runs. A reduction in speed is likely, and stairs are likely to become crowded, possibly crush-loaded, as the flow slows or people stop to rest at upper levels. There is limited information for movement speeds during continuous climbs at depth.

Solutions can involve factoring in reduced flows and providing extended landings to provide resting spaces. Proposals have been developed for the use of lifts as a large-capacity system for general evacuation, as an alternative to stairs and escalators. This is allowed in NFPA 130, and has been adopted for some station designs internationally; however, in Australia this has only been used for disabled passengers.

Egress analysis can use spreadsheets using flow and walking speed data from various sources or computer modeling. The computer modeling can be used to demonstrate overall flow through the evacuation routes. It can also be used to visualise the effects of some design options.

Smoke analysis at platform level can be done by computational fluid dynamics modeling.

The design and the modeling become more difficult when platform screen doors (PSD) are introduced. In a fire, there can be confusion, crowding on the platform, and smoke in the train cars. It can be unclear if all passengers are off the train, and whether the PSDs can be closed to contain smoke.

The smoke control system design must allow for the PSDs to be open during the fire. The gaps between the PSDs and the train are narrow, less than 100 mm typically; therefore, the over track exhaust (OTE) system will extract little smoke via this gap. Any smoke from a train is likely to enter the station platform area, and a larger smoke extraction system is required at a high level over the platform.

Design options are available to make better use of the OTE, such

as openable dampers above the PSDs to draw some smoke from the platform area into the trackway OTE; however, these can conflict with other design requirements, for example the damper opening conflicting with deep beams over the PSD. This issue needs careful attention to provide a practical design solution.

ESCAPE VIA THE TUNNEL

The probability of a train failing in a tunnel due to fire is low, although the consequences are high if it were to involve a major fire involving a car interior.

Walkways and equipment must be kept to a safe minimum width to avoid

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increasing the tunnel diameter as part of an economic design. Evacuation of a crowded train in a tunnel can be slow.

In rail tunnels, a longitudinal smoke control system can be provided to protect passengers upstream of a fire. Typically, the downstream condition is taken to be untenable and ignored. This may be deemed acceptable if the most likely scenario is considered to be an undercar fire. With a fire-rated floor, passengers would be able to walk over the fire in an upstream direction.

A major fire involving a car interior has a lower probability; however, usually, there will be people downstream of a fire. Consideration should be given to this scenario. If a serious train fire involves a car interior, then occupants are unlikely to be able to walk past the fire. They would need to escape through the downstream smoke. In Australia, this issue requires assessment as part of the safety assurance process. This requires a more detailed assessment than simply using 10 m or 7 m visibility as acceptance criteria. The effects of visibility on egress need to be assessed, but tenability must be assessed based on the effects of temperatures and gases using a range of fire sizes. The risk may be determined to be low through detailed analysis; however, if the risk is significant,

then additional measures are required.

A practical risk-reduction measure is reducing the spacing of the cross passages, thus reducing the distance required to travel through smoke. Cross passages provide an alternative path for passengers to move away from the incident tunnel to the non-incident tunnel and provide additional means for fire brigade personnel to reach the incident. Australian Standards do not have particular requirements for cross passages, although cross passages every 240 m have been used as adapted from NFPA 130. This tunnel standard requires a smoke control system for tenable conditions along the egress route. Typically, this is with a longitudinal smoke control system to avoid backlayering. A longitudinal smoke control system will normally generate air flow at less than 2 m/s upstream of the train. It is not intended to maintain tenable conditions downstream of the fire, but may dilute smoke sufficiently to protect occupants from smaller fire sizes.

With increasing cross passage distances, it becomes more difficult for the occupants downstream of a fire to reach safety and for firefighters to access, or retreat from, a fire. However, with well designed rolling

stock, there can be reduced probability of the failure of a train leading to passengers needing to escape downstream of a fire.

In Australia, it is unlikely that a distance between exits or cross passages greater than 240 to 300 m in a passenger rail tunnel would be accepted unless it can be conclusively demonstrated that tenable conditions are possible downstream of a fire up to the maximum size. Smoke temperatures would need to be limited to enable occupants to travel the distances required without injury. Large cross passage spacing could lead to a significant change in smoke control, possibly even a smoke extraction system similar to that now provided in road tunnels in Australia.

Joe Paveley is with Arup.

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By Andreas Häggkvist

Using any type of Fixed Fire Fighting Systems (FFFS) in road tunnels has, in many parts of the world, been a controversial issue and still is today. An overview is presented regarding the current research, standards, debates, and attitudes regarding FFFS in road tunnels. This overview shows that there is a general negative viewpoint at using FFFS from the decision makers, which to a large part contradicts from the findings of research, results and experience from actual tunnel fires.

INTRODUCTION

The purpose of a FFFS in a road tunnel is determined by the fire protection objectives, which can be simplified to either fire suppression or fire control. The differences between the two objectives are the amount of water needed to be used, the possible use of a foam agent, the positioning of the sprinklers and the principle of the activation system.¹

The fixed fire fighting systems used in road tunnels are generally water based. The different kinds of water-based FFFS can be divided into three groups: traditional sprinklers/water spray systems, water mist systems and systems with an added foam agent. In principle, it can be said that smaller droplets will attack the flames and the smoke plume while larger droplets will attack the fire base and solid objects. However, adding a foam agent to the FFFS will create a film of foam which will separate the burning fuel from the oxygen and thereby suffocate the fire.

USEFUL STANDARDS

Two standards that can be used when engineering FFFS in road tunnels are NFPA 502² and *Engineering Guidance for Water-Based Fire Fighting Systems for the*



Protection of Tunnels and Subsurface Facilities.³ As the title implies, the NFPA 502 is not exclusively intended as a standard for road tunnels and FFFS.

During the European Research Project UPTUN, the *Engineering Guidance for Water-Based Fire Fighting Systems for the Protection of Tunnels and Subsurface Facilities* was written. It provides information on design, installation and maintenance of water-based Fixed Fire Fighting Systems to be used in tunnels.

ROAD TUNNELS WITH FFFS

Japan has suffered from accidents involving tunnel fires, and this has resulted in a unique experience using

Country	Location of Tunnel
Austria	Mona Lisa Tunnel Felbertauern Tunnel
France	A86 Tunnel
Italy	Brennero Tunnel Virgolo Tunnel
The Netherlands	Roermond Tunnel
Norway	Vålreng Tunnel Fløyfjell Tunnel
Spain	M30 Tunnels Vielha Tunnel
Sweden	Tegelbacken Tunnel Klara Tunnel

Table 1. A compilation of road tunnels with FFFS in Europe.^{1, 2, 5}

Location	Name of Tunnel
Boston, Massachusetts	CANA Northbound* CANA Southbound*
Seattle, Washington	Battery Street I-90 First Hill Mercer Island* Mt. Baker Ridge* I-5 Tunnel*
Vancouver, British Columbia	George Massey Tunnel

Table 2. A compilation of road tunnels with FFFS in North America. Tunnels with FFFS that has an added foam agent are marked with an asterisk.²

Name of Tunnel
Adelaide Hills Tunnel
City Link Tunnel
Eastern Distributor
Graham Farmer Tunnel
Lane Cove Tunnel
M4 Tunnel
M5 East Tunnel
Mitcham/Frankston Tunnel
North/South Busway Tunnel
North/South Tunnel
Sydney Harbour Tunnel

Table 3. A compilation of road tunnels with FFFS in Australia.²

FFFS for a period that has extended over more than four decades.⁴ They have approximately 80 road tunnels equipped with FFFS.⁵

Some road tunnels in the rest of the world equipped with FFFS are shown in Tables 1 to Table 3.

LARGE-SCALE FIRE TESTS

The main objective of the UPTUN project⁵ was to find new methods for fire safety in existing tunnels, and during this project, tests with water mist systems were performed. The large-scale fire tests were focused on fire control rather than fire suppression, and they were conducted with low pressure and high pressure water mist systems. Two different fire scenarios were used in the tests: pool fires and solid fuel fires in the form of a stack of wood pallets. The fires had a potential severity on the order of 10 MW to 20 MW under free burning conditions. Some results from the UPTUN project were as follows:

- Both types of systems tested were able to reduce the heat release rates of the fires in the range of 40% to 70%. It was not possible to determine whether or not one type of system performed better than the other.
- After the activation of the systems, gas temperatures were reduced rapidly downstream the fire.
- Backlayering was reduced after the activation of the system, which resulted in better visibility upstream the fire.
- The efficiency of the system was dependent on the fire size, nozzle type, water discharge density and the location of the fire.
- The visibility downstream the fire did not initially improve; however, when the fire size was reduced by the water mist system, the visibility also increased.

In 2005, a series of tests was conducted in the Runahamar Tunnel in Norway in order to evaluate the

...it is more vital to protect the evacuees from the high temperatures and the high HRRs generated than a potentially explosive environment...

effectiveness of FFFS using compressed air foam (CAF).⁶ The first fire test consisted of solid fuel in the form of wood pallets with a volume of 100 m³ and with a heat release rate (HRR) up to 300 MW. The second test fire was a diesel pool fire with an area of 100 m² and a HRR of 200 MW.

The FFFS successfully extinguished the large pool fire and controlled the solid fuel fire, but did not extinguish it. Upstream of the fire, the air temperature was cooled down to 50°C and downstream the temperature was cooled to below 100°C. Thus, preventing fire spread and generating

an acceptable working environment for firefighters. The visibility in the tunnel was completely lost before the discharge of the FFFS.

RESERVATIONS AGAINST THE USAGE OF FFFS IN ROAD TUNNELS

There are numerous reservations against the usage of FFFS in road tunnels. These reservations have been made in the past and are still used today.



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One concern has been that using FFFS in road tunnels could worsen the conditions for the evacuating tunnel users. This is because the FFFS will generate steam that may injure them or that the cooling effect of the FFFS could cause destratification of the smoke. Other concerns have focused on the effectiveness of FFFS in road tunnels. Fires that start in the engine or in the compartment may be difficult to protect using a FFFS. Another concern has been that petroleum fires may continue to produce combustible gases after they have been extinguished by a FFFS, and an explosive environment will be created.

Current research shows that FFFS lowers temperatures in the tunnel

considerably, even close to the fire. A free burning fire can reach 1000°C at relatively long distances from the fire source. Steam can, in some cases, be found in the close proximity of the fire but the cooling effect of a FFFS outweighs any danger that might be caused by this.³

Concerning the potential destratification of the smoke, research shows that the smoke will reach the tunnel floor when using these kinds of systems. However, tests conducted within the UPTUN project have shown that the smoke remains stratified only for relative short distances even when FFFS are not used due to thermal effects and ventilation.

The FFFS also reduce the production of smoke, and the water droplet itself can bind particles – thereby reducing the toxic effects and increasing visibility conditions.³

Concerning the effectiveness of FFFS, the general view today on FFFS is that they are used to suppress or control the fire, stopping it from spreading, and to reduce temperatures in the tunnel. The main reason for installing a FFFS is, therefore, not to extinguish a fire. The intention is that the fire is later extinguished by the rescue services.

If a fire in a vehicle is not suppressed or controlled, it will in a very short time overtake the vehicle and start spreading itself to adjacent vehicles. Furthermore, it is more vital to protect the evacuees from the high temperatures and the high HRRs generated than a potential explosive environment after a petroleum fire has been extinguished by the rescue services. In most cases, people who can escape have done so.

Andreas Häggkvist is with Luleå University of Technology.

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BEHAVIOR OF FRP-STRENGTHENED

REINFORCED CONCRETE MEMBERS

UNDER FIRE CONDITIONS

By Venkatesh Kodur, Ph.D., P.E. and Aqeel Ahmed

INTRODUCTION

Reinforced concrete (RC) structures can deteriorate due to poor maintenance, corrosion of steel reinforcement as well as aging related problems. In addition, the need for strengthening of existing structures due to natural and man-made disasters (seismic, hurricanes and blasts) is ever growing. Fiber reinforced polymers (FRP) have emerged as an alternative for retrofitting and strengthening of concrete structures due to properties such as light weight, corrosion resistance, and high strength.

Fire represents a hazard for built infrastructure, and thus provision of an appropriate fire resistance for structural systems is a design requirement. The fire safety provisions for structural members are specified in terms of fire resistance ratings. The fire resistance rating requirements depend on the type of structural member, occupancy and other factors.

When an RC member is strengthened with FRP, the resulting fire resistance will depend on the properties of the original concrete member as well as the properties of FRP. Currently, FRP is mainly used in bridges and parking garages where the fire hazard is not a major consideration in design. However, when used in buildings, FRP-strengthened structural members have to meet stringent fire resistance requirements specified in building codes and standards.

FRP UNDER FIRE

Currently, little is known about the performance of FRP-strengthened

concrete structures under fire conditions. This knowledge gap has emerged as a primary reason that limits widespread application of FRP in building applications.

When used in buildings, structural members have to satisfy flame spread, smoke generation, and fire resistance ratings prescribed in building codes.¹ The flame spread and toxic smoke generation, largely depend on the type of FRP formulation (composition). The third requirement to be satisfied by FRP-strengthened structural members is the fire resistance rating specified in building codes. Fire resistance is the actual duration during which a structural member exhibits resistance with respect to strength, integrity, and stability. Fire resistance depends on many factors, including structural geometry, material used in construction, and fire characteristics.

Concrete performs well under fire because of its low thermal conductivity, high thermal capacity, and slower loss of strength and stiffness

Fire resistance is the actual duration during which a structural member exhibits resistance with respect to strength, integrity and stability.

Fire resistance depends on many factors, including structural geometry, material used in construction, and fire characteristics.

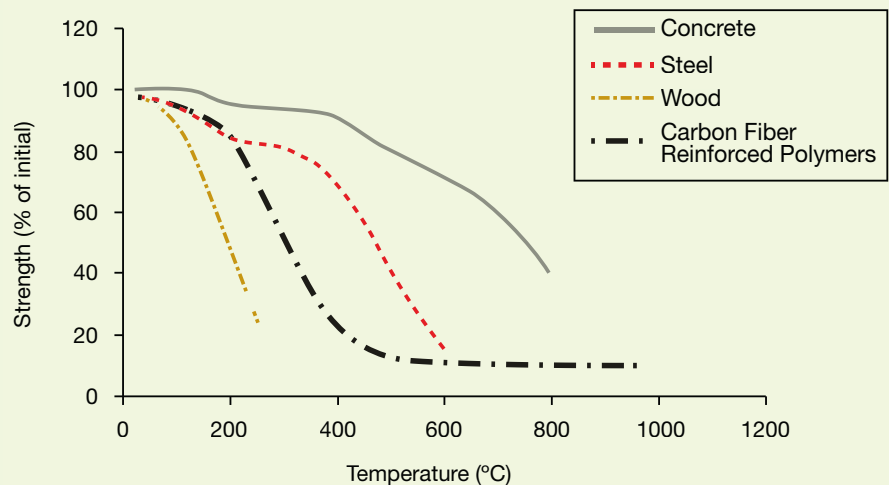


Fig. 1. Strength variation for concrete, steel, wood and FRP with temperature⁴

Table I. Summary of Test Parameters and Results⁹

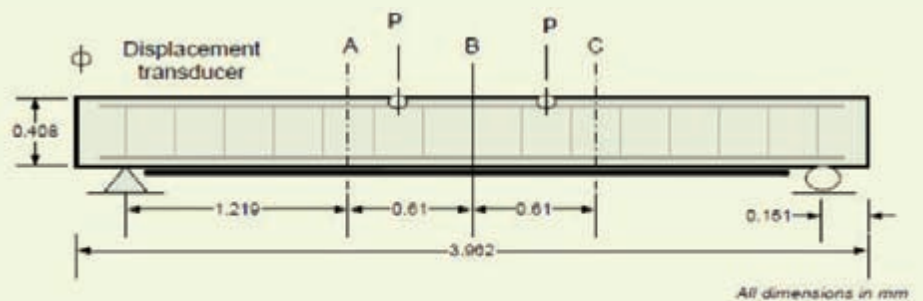
Beam designation	FRP strengthening	Insulation type	Insulation thickness (mm)		Fire scenario	Support condition	Failure time (min)
			Vermiculite	Epoxy			
B1	2 layers of 203 mm wide	Tyfo® WR AFP-Type A	25	0.1	Design fire	SS	NF*
B2		Tyfo® WR AFP-Type B	25	0.1	Design fire	SS	NF*
B3		Tyfo® WR AFP-Type A	25	0.1	ASTM E119	SS**	NF*
B4		Tyfo® WR AFP-Type A	25	0.1	ASTM E119	AR***	NF*

* NF – No failure ** Simply supported *** Axially restrained

properties. Therefore, concrete structures often satisfy fire resistance ratings without the need for external fire protection. However, when concrete members are strengthened with an external FRP system, the fire response of the whole system can alter from that of the original concrete member. Thus, the fire response of an FRP-strengthened RC member is influenced by many factors, including strength, stiffness and bond properties of the FRP in addition to the properties of concrete and reinforcing steel.

Like other construction materials, FRP loses its strength and stiffness properties with temperature. However, the degradation in FRP properties is faster as compared to concrete or steel since the properties of the FRP matrix start to deteriorate even at modest temperature. Figure 1 illustrates the degradation in strength of FRP as compared to concrete, steel, and wood. Also, bond degradation is another concern with externally bonded FRP. FRP is a combustible material. Thus, it is susceptible to loss of bond strength and stiffness above its glass transition temperature (T_g).

The glass transition temperature is the temperature at which a material changes from relatively stiff material to viscous, leading to a drop in strength and stiffness. Typically, the glass transition temperature for commonly used polymers (adhesive) varies between 60 to 82°C.² In



(a): Elevation

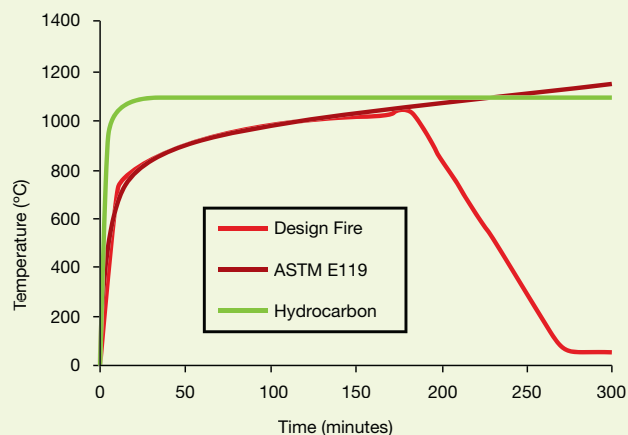
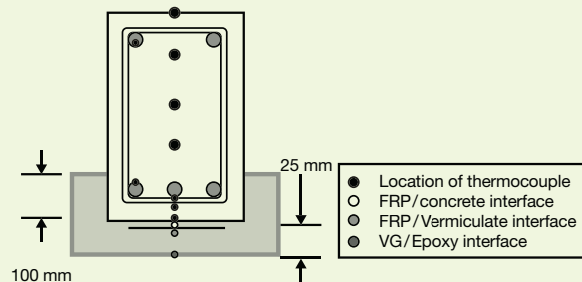


Fig. 2. Elevation and cross-sectional details of tested FRP-strengthened RC beam, together with fire scenarios

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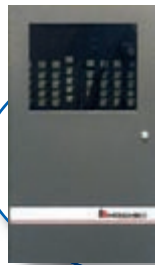
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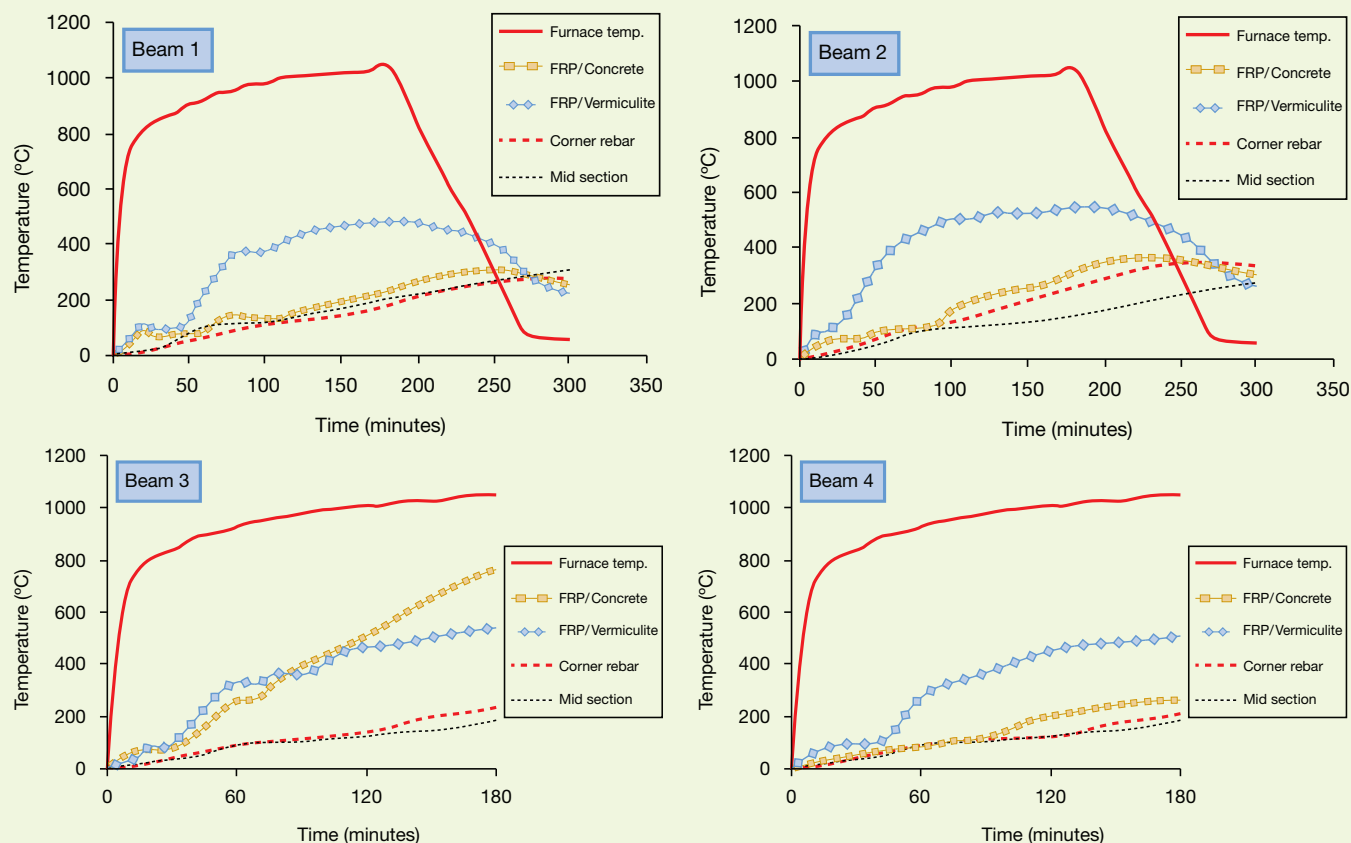


Fig. 3. Measured temperatures as function of time

FRP-strengthened members, the main load carrying mechanism is through transfer of stresses from the concrete substrate to the FRP reinforcement. This transfer of forces to FRP reinforcement occurs through development of shear stresses at the interface of FRP and concrete. However, when the temperature at the interface reaches T_g , the bond properties of the adhesive (shear modulus and bond strength) deteriorate considerably and introduce bond-slip at the interface.³ This bond-slip reduces force transfer from the concrete to the FRP composite, and subsequently leads to debonding of the FRP.

FIRE RESISTANCE EXPERIMENTS

In the last decade, there have been limited studies to investigate the fire behavior of FRP-strengthened concrete members.

The notable experimental studies on FRP-strengthened RC beams were conducted by Kodur et al.,¹ and Deuring,⁵ Blontrock et al.,⁶ Barns and Fidell,⁷ Kodur et al., and Williams et al.⁸ Most of these tests have been conducted under the standard fire exposure without any consideration to realistic fire, loading, and restraint scenarios. All these studies recommended use of supplemental insulation for externally bonded FRP to maintain the bond between the FRP and the concrete substrate.

To address shortcomings in previously conducted research and to develop needed test data for validating numerical models, four FRP-RC beams were tested under fire conditions at Michigan State University (MSU). A summary of test parameters and results are tabulated in Table 1.

The four rectangular RC beams were of 3.96 m in span length and designed as per ACI 318¹⁰

specifications to represent typical beams in buildings. The RC beams were fabricated with concrete having a design compressive strength of 42 MPa. The measured compressive strength of concrete at 28 days was 52 MPa, while on the day of the test (after 2 years), it was 55 MPa. The beams had three 19 mm dia. rebars as flexural reinforcement and two 13 mm rebars as compressive reinforcement. The RC beams were strengthened with FRP sheets (2 mm thick and 203 mm width) to enhance the flexural strength capacity by 50%. The resin used was two-component epoxy material with a glass transition temperature (T_g) of 82°C. For Beams B1 and B2, FRP was applied on the entire unsupported length of the beam terminating at a distance d (352.4 mm) from the supports to study the influence of anchorage zone on fire response of FRP-strengthened RC beams. While for Beams B3 and B4,

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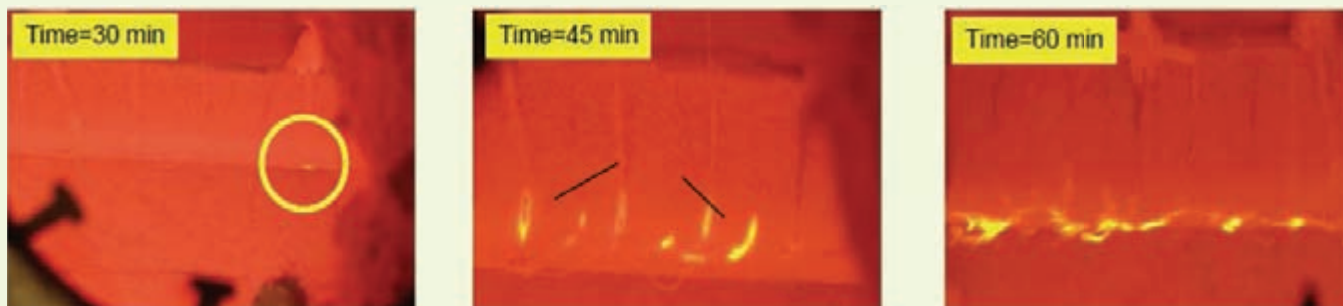


Fig. 4. Crack development in insulation of FRP-strengthened beam

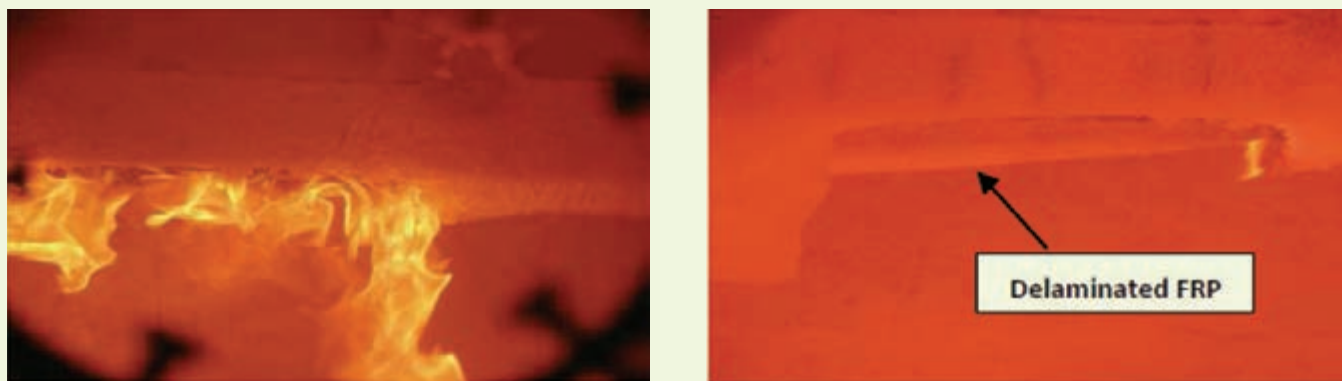


Fig. 5. A portion of beam B3 exposed to fire after delamination of FRP and insulation

fire exposed beam length (central 2.44 m) was retrofitted with FRP sheets to evaluate the effect of debonding on fire resistance FRP-RC beams. Unlike in previous studies,^{6, 8, 11} no shear strengthening was provided in these beams to study the failure patterns under flexural strengthening effect only. The beams were insulated with a vermiculite-based insulation (VG insulation) and epoxy coating. The insulation layout comprised of 25 mm of insulation at the bottom surface of the beam extending 100 mm on the two sides (refer to Fig. 2).

The beams were instrumented at various locations: Type K thermocouples to measure temperature distribution throughout the cross section, high temperature foil strain gauges to measure strain in the reinforcing steel and FRP and electro-mechanical displacement gauges to measure overall beam deflection. The thermocouples were distributed throughout the beam cross-section at three different sections along the span (cross-sections A, B, C in Fig. 2 (a)) and also at several points along the unexposed face of the beam, as required by ASTM E119.¹²

Beams B1 and B2 tested under a design fire that comprised of a growth phase followed by a cooling phase, while Beams B3 and B4 were tested under the ASTM E119 standard fire. The beams were subjected to two point loads (P in Fig. 2(a)), each of 70 kN, which represents 50% of the strengthened beam's nominal capacity according to ACI 440.² Data generated from

these fire tests was valuable in developing failure patterns, as well as in developing numerical models for tracing the fire response of FRP-strengthened RC beams.



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RESULTS FROM FIRE TESTS

Data from fire tests can be used to illustrate the fire behavior of FRP-strengthened RC beams. The time-temperature progression at various locations of tested FRP-strengthened RC beams is shown in Fig. 3. It can be noticed that

temperature at various beam cross sections, including in rebar and concrete, increases throughout the test duration for beams B3 and B4, which were exposed to the standard fire. However, in beams B1 and B2, which were exposed to a design fire, the measured temperatures increase to a maximum value and then start

to decrease. This decrease in temperature can be attributed to the decay (cooling) phase in time-temperature curve of the design fire. For both types of insulation (Type A and B), cracks appeared in early stages of the fire exposure that allowed transfer of heat flux (refer to Fig. 4). This led to a temperature increase in the FRP and resulted in localized burning of epoxy, since T_g for epoxies is low ($T_g=82^\circ\text{C}$).

However, the slow temperature increase at FRP/concrete interface is due to formation of a protective char layer as a result of the pyrolysis process of the matrix.¹³ In Beam B3, a sudden increase in temperature at the FRP/concrete and FRP/insulation interfaces is due to delamination of the FRP from the beam soffit around 38 minutes (refer to Figs. 3 and 5).

The insulation played a key role in limiting the temperature rise in the rebars. This is mainly attributed to the low thermal conductivity of the insulation. The average rebar temperature in all the tested beams remained below 400°C for the complete test duration (refer to Fig. 6). Since rebars do not lose any significant strength up to 400°C ,¹⁴ the steel reinforcement maintained full strength capacity for the test duration. This led to achieving high fire resistance in these beams.

Fig. 7 shows the variation of mid-span deflection as function of time for the four tested beams. The mid-span deflections increased slowly up to 20 minutes and then all beams experienced a sudden increase in deflections. This can be attributed to loss of bond at the FRP/concrete interface with temperature, which occurs at T_g (83°C). After debonding of the FRP, the behavior of Beams B1, B2 and B4 was different than that of Beam B3.

At the start of the test, FRP-strengthened RC beams were loaded to 50% of their strengthened nominal capacity at room temperature. This loading corresponds

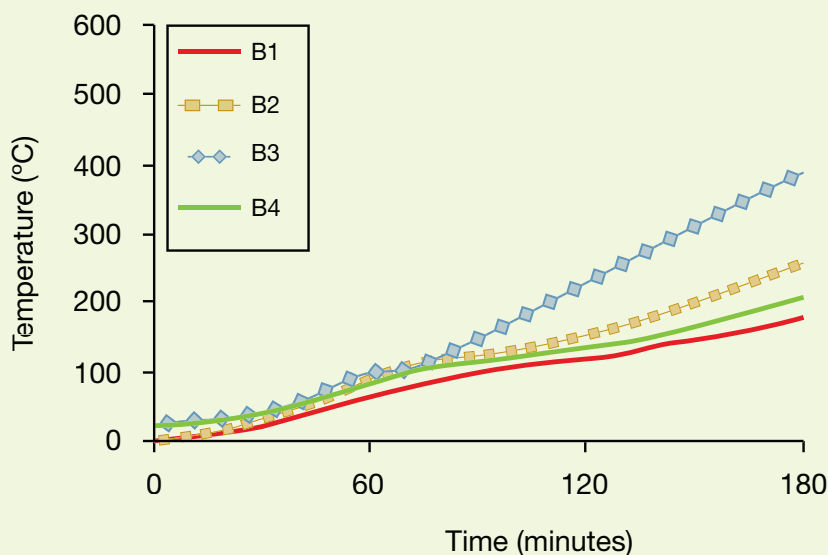


Fig. 6. Corner rebar temperature as function of fire exposure time

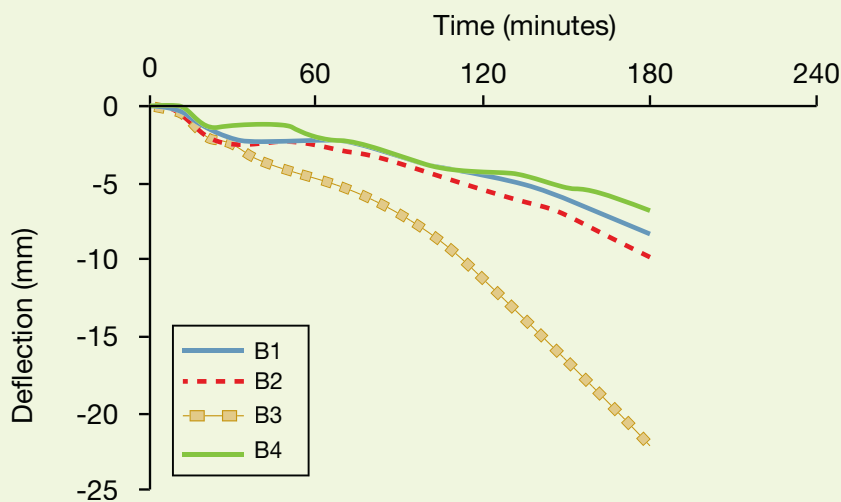


Fig. 7. Variation of mid-span deflections for tested FRP-strengthened RC beams

Fig. 8. Post-fire behavior of FRP



(a) Tested Beam B1



(b) Tested Beam B4

to about 80% load ratio for an unstrengthened RC beam. Therefore, beam B3, which behaved as a reinforced concrete beam after the FRP was lost (debonding), experienced an increase in deflection due to the higher load ratio, as shown in Fig. 7. The factor that contributed towards the lower deflections in beams B1 and B2 after the FRP debonded is the "cable action" (similar to tensile membrane

action is slabs) provided by unbonded continuous carbon fibers at the beam soffit held by a cool anchorage zone towards the end supports (refer to Fig. 8).¹³ In beam B4, development of the axial restraint force mainly limited the deflection increase for the entire duration of the test.

In general, this axial restraint force acts below the neutral axis of the beam section; this leads to the development of an arch action, which counteracts the moment due to applied loading. A closer

examination of Fig. 7 indicates that, similar to cable action mechanism, the fire induced axial restraint force is beneficial in enhancing the fire resistance of FRP-RC beams. It helps to slow down progression of deflections in the beam under a higher load ratio, and this in turn leads to high fire resistance in the beams. Therefore, an effective insulation scheme in FRP-strengthened RC beams is critical for achieving good fire resistance.



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NUMERICAL MODEL

As part of ongoing research at MSU, a numerical model has been developed for tracing the fire response of FRP-strengthened RC beams exposed to fire.¹⁵ The model is based on a macroscopic finite element (FE) approach and uses moment-curvature relationships to trace the response of an FRP-strengthened RC beam. The model accounts for fire induced debonding of FRP, axial restraint, high temperature material properties and various failure criteria. The model has been validated against fire tests on FRP-RC beams.

This fire resistance model takes into account the elevated temperature properties of constitutive materials to generate moment-curvature ($M-k$) relationships for different beam segments at various time steps. These time dependant $M-k$ relationships are utilized to trace the response of FRP-strengthened RC beams up to collapse under fire conditions. A flow chart illustrating various steps in fire resistance analysis of FRP-RC beams is shown in Fig. 9.

The model has been validated against tests performed on rectangular FRP-strengthened RC beams conducted by Blontrock et al.⁶ as well as T-beams by Williams et al.⁸ The thermal and structural response predictions from the model compared well with the measured test parameters throughout the range of fire exposure. Thus, the model can be applied to evaluate fire response of FRP-strengthened RC beams.

PRACTICAL APPLICATIONS

The above developed macroscopic finite element based numerical model can be applied to develop optimum insulation schemes for FRP-strengthened RC beams. To illustrate the usefulness of the model, fire resistance analysis was carried out on an FRP-strengthened RC beam (380 ~ 610 mm). The beam was provided with insulation of varying thicknesses and configuration schemes. On the sides of the beam, 20 mm thick insulation was applied with a depth of 105 mm. The insulation thickness at the beam soffit was varied to be 15, 25, 40, and 50 mm, respectively. The analysis was carried out by exposing the beams to

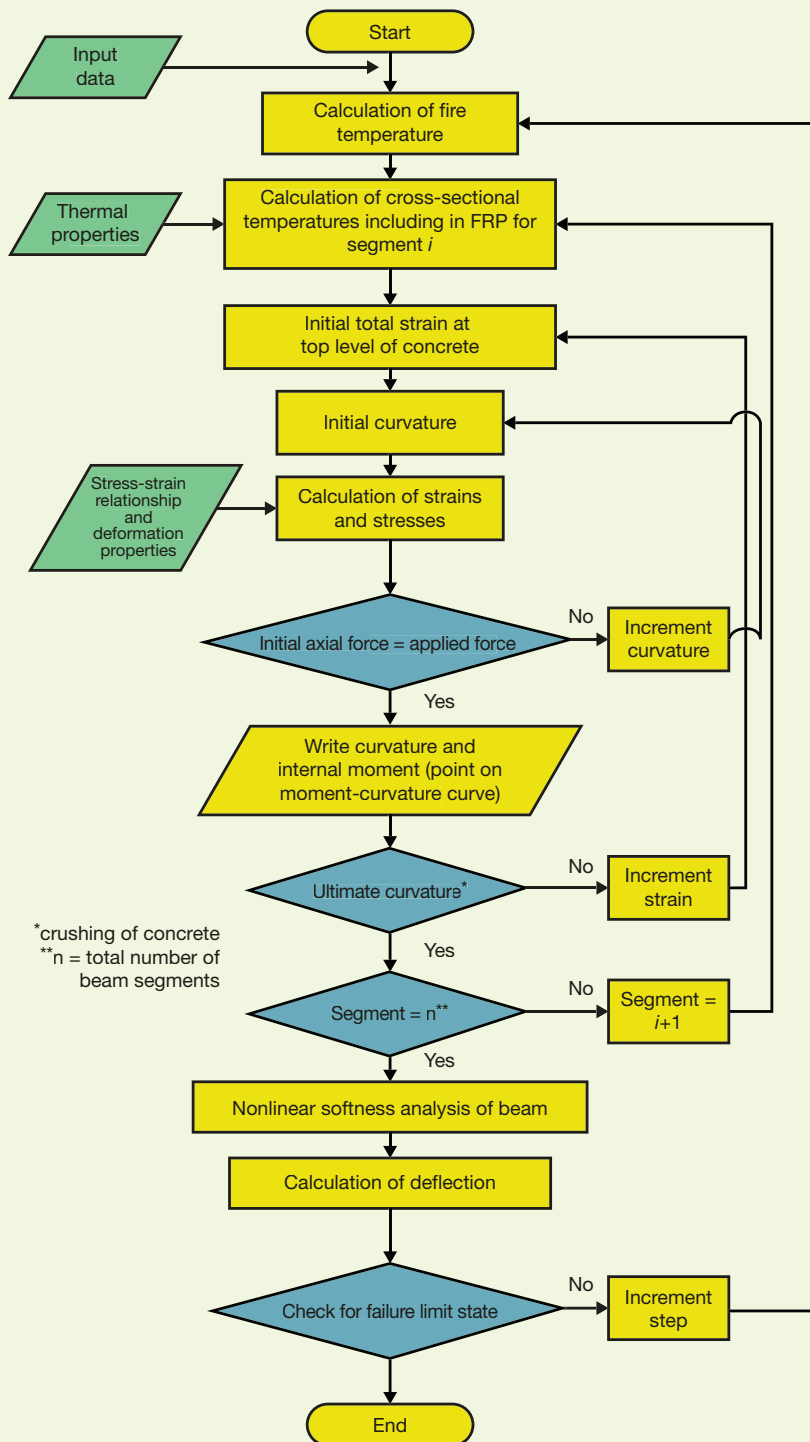


Fig. 9. Flow chart explaining the procedure of numerical model


the standard ASTM E119 fire from three sides. The applied load ratio on the beam was kept constant at 52% for all the cases. Typical results that are generated from fire resistance analysis are shown in Fig. 10.

The failure of the fire exposed beams was computed based on strength, rebar critical temperature and deflection limit states. No failure occurred under deflection or rate of deflection limit states. This can be attributed to lower deflections (resulting from reduced ductility) in the beams when strengthened with FRP. Closer examination of Fig. 10 indicates that increasing insulation beyond an optimum thickness does not contribute much to fire resistance. This can be attributed to the fact that the strength (moment capacity) of the beam, under fire conditions, is controlled by the tension forces in the FRP (up to a certain fire exposure time) and steel reinforcement. Increased insulation thickness helps to reduce temperature in rebars, and this in turn helps to achieve a higher moment capacity at a given fire exposure time. However, beyond the optimum insulation thickness, at which rebar temperatures reach about 400 °C, any further reduction in rebar temperatures does not result in higher tension force or capacity of the beam. This is because the strength loss in rebars occur only above 400 °C¹³ and any measure to decrease temperature below 400 °C, through increased insulation thickness, does not contribute to increased tension force. This is illustrated in Fig. 9, where rebar temperature and corresponding yield strength ratio ($f_{y,r}/f_{y,20}$), obtained from parametric studies was plotted as a function of insulation thickness for 3 hours of fire exposure. It can be seen that increasing insulation thickness from 0 to 15 mm has maximum benefit, and beyond this thickness, the beneficial effect gradually decreases. Beyond the optimum insulation thickness of

40 mm, there is no advantage to increasing the insulation thickness.

The above case study illustrates the usefulness of the model in evolving optimum insulation schemes for FRP-strengthened RC beams for a specified fire resistance. Numerical models, like the one discussed in this article, will help practitioners

to arrive at optimum fire insulation scheme for a given fire resistance application. Typical application of the research presented in this paper for arriving at fire resistance strategies in buildings is illustrated in Fig. 11.



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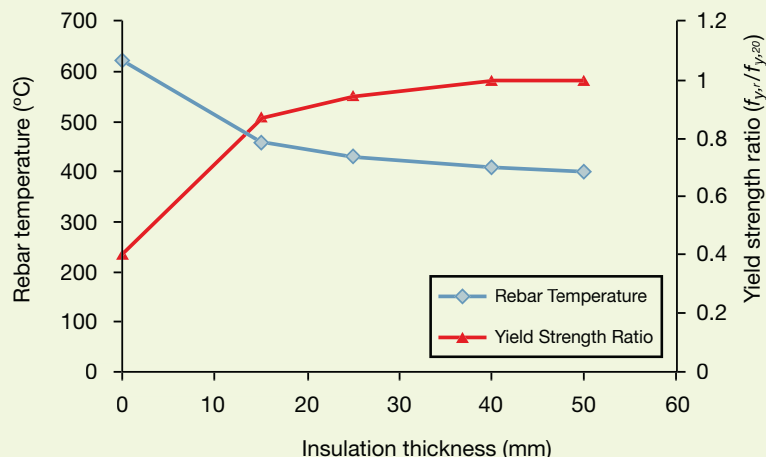


Fig. 10. Corner rebar temperature and yield strength ratio as a function of insulation thickness for 3-hour of fire exposure time

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Fig. 11. Application of Carbon fiber reinforced polymers to strengthen RC beams



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A HISTORICAL PERSPECTIVE ON THE EVOLUTION OF STORAGE SPRINKLER DESIGN

By HC Kung, Ph.D., FSFPE



The automatic sprinkler system is the most commonly used fire protection system for industrial and commercial occupancies. Sprinkler systems were first employed in textile mills in New England in the early 20th Century as a means of protecting the equipment and textile goods stored in those early, multi-story buildings.¹ Ceilings were low and goods were, for the most part, stored in wooden crates. Designed to project approximately half of the water to the ceiling and half toward the floor, an important function of those early sprinkler systems was to wet and protect the combustible ceiling structure.

This design philosophy was changed when Factory Mutual (FM) introduced the "spray" sprinkler in the 1950s. At this time, it was recognized that applying water directly to the ceiling was not necessary provided that high ceiling temperatures could be avoided, and the spray from each sprinkler could be more efficiently distributed over a larger floor area. The new spray sprinkler was designed to project all the water downward. After several years of successful

demonstration of its effectiveness, the spray sprinkler was accepted in 1953 by the National Fire Protection Association (NFPA) as the "standard" sprinkler in the United States. These standard sprinklers, featuring a K-factor (discharge coefficient) of 5.6 gpm/psi^{1/2} (80 l/min-bar^{1/2}) and a nominal orifice diameter of 1/2 inch (12 mm), were used in the industrial occupancies of that time.

DRAMATIC CHANGES IN MANUFACTURING AND STORAGE PRACTICES

Industrial, manufacturing and storage occupancies have undergone changes in the interim decades. The proliferation of plastics, such as "styrofoam", in packaging materials and the increased use of cardboard

cartons created new, unprecedented challenges for fire protection sprinkler systems to overcome. These newer, lightweight storage materials allowed for storage racks to be built to greater heights and changed the dynamic of how storage spaces were designed. Taller storage racks create a "chimney effect" when their contents

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burn, changing the way fires grow and increasing the challenge for adequate sprinkler protection. In addition, plastic materials, now commonly used, generate more heat than previously used manufacturing materials when burned, increasing the hazard.

Overall, fires in a rack storage environment are characterized by fast fire growth, high heat release rate and high plume velocity, and have therefore challenged the standard sprinkler. In some cases, combustibles are stored on solid shelves in rack arrangements, or the storage height and commodity fire challenge are beyond the effectiveness of ceiling-based sprinkler systems. In these instances, in-rack sprinklers are needed to provide sufficient fire protection.

Under these challenging circumstances, a standard sprinkler system is required to supply a relatively large number of sprinklers with sufficient water to control and limit the fire spread within a particular design area by keeping the surrounding combustibles wet enough so that they do not ignite. In the years following the adoption of the spray sprinkler, it became evident that sprinkler system design requirements for each storage condition had to be individually determined.

In 1967, FM built a large sprinkler fire test facility to seek solutions for fire protection challenges of storage environments through large-scale fire tests. Two test programs, rack storage and plastic storage fire test programs, were conducted from 1968 to 1972.

In order to provide the data needed with a reasonable number of fire tests, a concept called “parallelism” was adopted by Factory Mutual, which involved the establishment of a base density (water flux) versus area of demand curve for a standard test commodity and a set of test conditions utilizing a given sprinkler. Additional curves for other stored commodities, storage conditions, and sprinkler variables, such as aisle width, type of storage rack and sprinkler temperature rating, were then constructed by drawing a line parallel to the base curve through a single test point of the new commodity and test variables. All the tests were conducted with the ignition source centered below four sprinklers. By definition, the density/area rule assumes that for a given density, the



performance of all listed sprinklers in a given category would be the same, regardless of their manufacturer, orifice size, spacing, or pressure.

Unfortunately, over the years, test results have shown that different sprinkler models and ignition locations can cause significant differences in area demands.² In addition, the density/area rule, which has been used as the basis of traditional sprinkler system design, is not always appropriate for modern storage protection.

Furthermore, fire tests in the "Plastic Storage Program" at Factory Mutual^{2,3} revealed that rack storage of a plastic commodity over 15 ft (4.5 m) in height could not be protected with a ceiling-based sprinkler system alone, using standard sprinklers. The standard sprinklers at the ceiling needed to be supplemented with in-rack sprinklers in order to adequately control a fire. In-rack sprinkler systems are susceptible to damage by warehouse operators and create inflexibility in warehouse storage reconfiguration. To warehouse owners looking at cost-effectiveness and future expansion or reconfiguration, it is desirable to be able to use "ceiling only" sprinkler protection.

To respond to this need, new sprinkler technologies came into the marketplace. For protection of 20 ft (6 m) high rack storage of cartoned plastic commodities under a 25 ft (7.6 m) high ceiling, large orifice sprinklers with a K-factor of 8.0 (115 l/min-bar^{1/2}) and a nominal orifice of 17/32 inch (13 mm) were developed. As the storage height increases, the fire challenge becomes greater for the ceiling-only sprinkler systems, and more water is required to be discharged from the ceiling sprinklers to protect the stored commodities. With the available pressure from the water source a fixed value, the sprinkler orifice size needs to be increased to provide a higher discharge rate.

MEASUREMENT OF THE EFFECTIVENESS OF STORAGE SPRINKLERS

In response to these ongoing challenges, an additional, more comprehensive series of research programs was conducted by scientists and engineers at Factory Mutual from the 1970s through the 1990s, exploring the principles of sprinkler performance in rack storage fires.² These research programs included sprinkler sensitivity (Response Time Index) measurement, prediction of sprinkler activation, spray penetration ability through fire (Actual Delivered Density, ADD), and fire suppression requirements of rack storage fires (Required Delivered Density, RDD).

Aided by these scientific principles, the desired effectiveness of sprinkler fire protection could be targeted and the optimal use of water quantity could be determined, resulting in optimized, cost-effective sprinkler protection of a range of commodity storage in warehouses.

KEY CONCEPTS:

Response Time Index (RTI):

A measurement of the sprinkler's response sensitivity to the gas temperature and velocity in the vicinity of the sprinkler.⁴

Prediction of Fire Size at Sprinkler Actuation:

Correlations of fire plume, ceiling jet flow, and sprinkler response using RTI and fire plume and ceiling jet correlations.⁵

Required Delivery Density (RDD):

The water flux required to be delivered to the top surface of a burning array to achieve fire suppression.⁶

Actual Delivery Density (ADD):

Measurement of the actual water flux delivered by the sprinkler to the



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top surface of a burning array that penetrates the fire plume. The ADD depends upon water droplet size, spray pattern, discharge rate and fire size.⁷

DEVELOPMENT OF A "LARGE DROP" SPRINKLER

In response to the need to provide fire protection for 30 ft (9.1 m) high warehouses containing storage of cartoned plastic up to 20 ft high (6 m), beyond what a large orifice (LO) sprinkler could deliver, the "large drop" sprinkler was developed in the mid-1970s. This sprinkler had a nominal orifice diameter of 0.64 inch (26 mm) and a K-factor of 11.0 (157 l/min-bar^{1/2}), as compared with the LO sprinklers that featured an orifice diameter of 17/32 inch (13 mm) and a K-factor of 8.0 (115 l/min-bar^{1/2}). At a given discharge pressure, this large drop sprinkler delivered a larger quantity of water and larger droplet sizes than the LO sprinkler and demonstrated the superior performance that was expected.⁷ ADD measurements were used to guide the design of the large drop sprinkler.

The design goal of "large drop" sprinkler systems was to provide a minimum number of sprinklers operating at a minimum pressure for a specific occupancy and commodity class, storage height and storage arrangement. This approach differed from the traditional density/area approach (sprinkler

water flux density over sprinkler operation area), allowing the sprinkler design density (sprinkler discharge pressure) to decrease as the sprinkler operation area increases. As the discharge pressure decreases, ADD of the sprinkler spray may diminish to a level at which the effectiveness of the system can no longer be maintained.

THE ADVENT OF EARLY SUPPRESSION FAST RESPONSE SPRINKLERS

In the 1980s, another new technology was developed: Early Suppression Fast Response (ESFR) sprinklers.⁷ This new class of sprinkler was developed to ensure a higher ADD than RDD while providing hazard protection with cartoned plastic commodity storage as high as 25 ft (7.6 m) under a 30 ft (9.1 m) high ceiling. A fast response link was used in the sprinkler. Therefore, ESFR sprinklers were designed to respond to a fire at its early stage of development and to discharge a large quantity of water over the fire to achieve fire suppression. The first generation of ESFR sprinklers has a nominal orifice diameter of 0.72 inch (18 mm) and a K-factor of 14.0 (200 l/min-bar^{1/2}). ESFR technology became popular, protecting storage of ordinary combustibles (class I - IV commodities and cartoned unexpanded plastic as defined in NFPA 13[®]). In the 1990s, the K14 ESFR sprinkler became a popular technology for storage protection. Shortly after the introduction of K14 ESFR sprinklers, there was a desire to use ESFR technology for protection of greater fire challenges. These challenges resulted from greater ceiling and storage heights, which were beyond the original intended protection objectives of the K14 ESFR sprinkler. Within the next 10 years, ESFR sprinklers with larger K-factors, such as 16.8, 22.4 and 25.2 (240, 320 and 360 l/min-bar^{1/2}) were developed to provide protection for these greater fire challenges. As was expected, the larger the orifice, the larger the drops delivered by the sprinkler. The K25.2 ESFR sprinkler was primarily developed for protection of 45 ft high (13.7 m) warehouses with storages of cartoned plastic commodities up to 40 ft (12 m) high.

CLASSIFICATION OF STORAGE SPRINKLERS

Beyond ESFR, storage sprinkler classifications were further expanded to include control mode (density/area) (CMDA) and control mode (specific application) (CMSA).⁸ CMDA is a system design method based upon the calculation of the density of water discharged in a specified area of coverage (i.e., 0.6 gpm/ft² (24 mm/min) over 3000 ft² (280 m²)). This approach is limited to ceiling heights of 25 ft (7.6 m). K-factors of control mode sprinklers include 5.6, 8.0, 11.2, 14, 16.8 and 25.2 gpm/psi^{1/2} (80, 115, 160, 200, 240 and 360 l/min-bar^{1/2}). With increasing K-factor and orifice size, there is an increase in coverage.

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CMSA sprinkler systems are designed to provide a minimum number of sprinklers operating at a minimum pressure for a specific occupancy. The large drop sprinkler is the first CMSA sprinkler. After creation of this class, other CMSA sprinklers with larger K factors of 16.8, 19.6 and 25.2 gpm/psi^{1/2} (240, 280 and 360 l/min-bar^{1/2}) were developed.

RECENT STORAGE SPRINKLER INNOVATION – FASTER IS NOT ALWAYS BETTER

Today, system designers and contractors typically associate adequate sprinkler suppression performance of rack storage fires only with “fast response” sprinklers. Although a fast-response sprinkler responds to a fire sooner than a standard-response sprinkler (making it easier for water drops to penetrate the fire plume and reach the burning fuel), fast response alone is not necessary and sufficient for a sprinkler system to achieve fire suppression. More importantly, ADD must be greater than RDD. In this situation, superior fire suppression can be expected.

Aided by the scientific principles of studying sprinkler performance in storage fires, a new large K-factor standard-response sprinkler has been developed which can now achieve fire suppression of cartoned plastic commodities under a ceiling up to 40 ft (12 m) high. The sprinkler model is a pendent sprinkler with a nominal one inch (25 mm) diameter orifice and a K-factor of 25.2 (360 l/min-bar^{1/2}). The sprinkler temperature rating is 160°F (71°C), and the sprinkler has a Response Time Index (RTI) of 235 (ft-s)^{1/2} (130 m^{1/2}-s^{1/2}). The large water drops generated from

this large K-factor sprinkler enhance its penetration ability against the fire plume.

A series of fire tests⁹ concluded that the standard-response K 25.2 gpm/psi^{1/2} (360 l/min-bar^{1/2}) sprinkler can be as effective as ESFR sprinklers in providing protection for storage in warehouses with ceiling heights up to 40 ft (12 m), since both ESFR sprinklers and the new sprinkler were evaluated with the same fire scenarios. See Figures 1 and 2. Based on the performance of the new sprinkler, FM Global has treated the sprinkler in the same fashion as ESFR sprinklers, requiring a “12 head” design for the system water demand, identical hose stream demand and water supply duration. The same sprinkler installation rules with regard to physical obstructions and ceiling elements are applied to both the ESFR pendent sprinklers and the new sprinkler. However, the new sprinkler is being classified not as an ESFR sprinkler but as a CMSA sprinkler, because the sprinkler does not use a fast-response link.

This type of technology can offer a reduced end-head pressure as compared to traditional ESFR technology and is poised to replace ESFR as a design choice in storage applications. A low-end head pressure system reduces discharge pressure requirements 25-40% for 30-40 ft (9.1-12.2 m) ceilings and 25-70% for ceilings

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that are up to 30 ft (9.1 m) in height as compared to traditional ESFR products. A benefit of the reduced end-head pressure of this new storage sprinkler is the opportunity to reduce pipe diameters and to even potentially eliminate the need for a pump if the public water supply is strong enough, affording cost savings in material and labor.

THE NEXT DECADE

The broad range and increasing sub-categorization of sprinkler types have made for a confusing palette of fire protection solutions. Complex installation guidelines for each class of sprinklers further complicate the design landscape.

Earlier in 2010, FM Global began an update of its Data Sheets that specify the rules for system design and installation for storage sprinkler systems. The goal is to simplify the variations in sprinkler classes, and base the system design rules on performance of the sprinkler and not on the traditional names of the sprinkler. Hence, greater consistency in system performance can be obtained.

The fire suppression or control performance of sprinklers depends on the combined effects of sprinkler attributes: sprinkler orientation (pendent or upright), sprinkler deflector design, volume median diameter of the spray, sprinkler sensitivity (RTI) and temperature rating. FM Global's new Data Sheets base the system design rules on performance of the sprinkler rather than the traditional name associated with the sprinkler. This sprinkler performance is predictable, based upon the parameters of the system.

As storage space design continues to evolve, new technologies continue to be introduced into the marketplace to meet increasing challenges.

H.C. Kung is with Victaulic.



Figure 1. Fire involvement of a 35 ft (10.7 m) high rack storage array of cartoned plastic commodity under a 40 ft (12.2 m) high ceiling at the time of standard-response sprinkler activation.



Figure 2. The same plastic cartoned commodity one minute after the first K-factor standard-response sprinkler operation.



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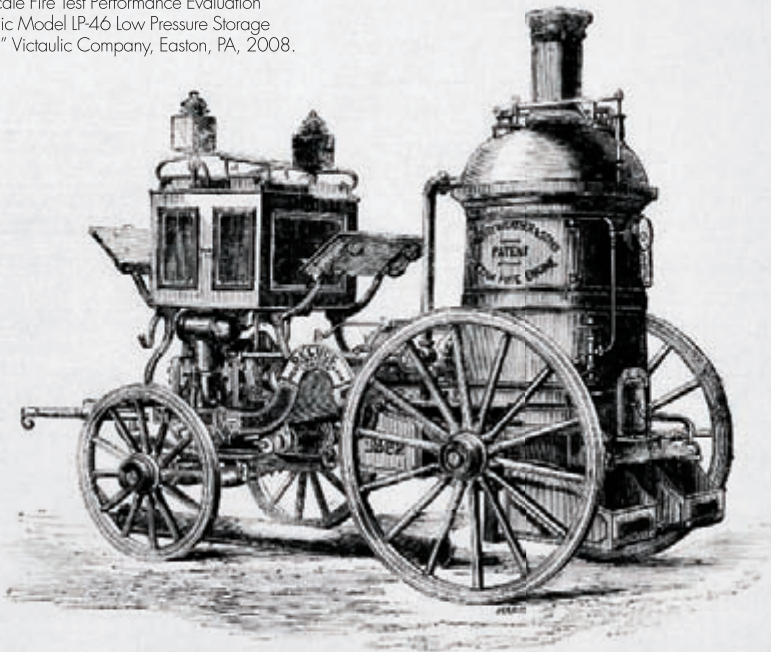
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[A Historical Perspective on the Evolution of Storage Sprinkler Design]

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DETECTION OF FOREST AND WILDLAND FIRES



Setting Standards for Excellence

Forest fires; wildfires; wildland fires – these are all different names for unwanted, nonstructural fires that occur in landscape settings. The destructive power and the need for rapid detection, containment, control and suppression of wildfires has been well recognized since before the birth of Smokey the Bear. More recently, the outward expansion of the urban environment and the commingling of living communities in natural forest settings has given rise to the term “urban wildland interface” and the realization of the greater economic impact and threat to life caused by some wildfires. But the problem does not stop there. The combination of population increase, climate change – whether a natural cycle or man-made – and any form of deforestation, is likely to have a major impact on watershed conservation and, hence, fresh water availability as well as soil erosion and wildlife habitats. So, the need for protecting undeveloped lands, particularly forests, is greater today than it has ever been in the recent past.

For centuries, people have relied on human detection of forest fires. It should not be a surprise that the 21st century is bringing some technological – and even biological – systems to bear on the problem. This article is an introduction to the concept of automated forest/wildland fire detection and a summary of some of the work being done by scientists and engineers.

In addition to the possibility of more rapid detection, other potential needs, problems and solutions are driving technological developments. These include:

- the need for near real-time data input for wildland fire spread models;
- the need for fire ground mapping to aid in resource allocation and deployment;
- the need for vector modeling to manage evacuations and relocations using emergency communications systems (ECSs);

- the need to project or model possible impact on critical infrastructure components, including remotely located cellular communications facilities used as part of an ECS; and
- the need to automatically activate exterior structural defense systems, such as structural foam applications and urban-wildland interface spray systems.

All of these “needs” give rise to potential technological solutions.

Many efforts to automate forest and wildland fire detection have focused on image-based systems. Some image systems use fixed cameras or sensing units similar to those used in many of today’s video-based fire and smoke detection systems. These may use visible or infrared bandwidths for image processing. Geostationary satellites using both visible and infrared imagery have also been investigated and found to have a detection resolution comparable to human detection, but over larger areas.^{1,2}

Improvements have been proposed that will increase resolution and decrease detection time. In addition to using satellites and fixed towers as sensor platforms for these technologies, the use of unmanned aerial vehicles (UAVs) is also possible.³ Other remote sensor-based systems have been tested using radar, light detection and ranging (LIDAR) and sound detection and ranging (SODAR). Radio-acoustic sounding systems have also been tested as ways for remote measuring of crown and surface temperatures.⁴

Infrared wavelength sensors have a disadvantage in that smoke, dust and fog all absorb some of the infrared emissions from a fire. The use of detectors sensitive to longer wavelengths has been investigated and shown to be promising.⁵

The use of fiber optic cables, gas sensors and other opto-electronic sensor networks have also been tested in actual forest settings.⁶ While promising, these systems might have scale limitations due to power requirements and sensor installation and distribution requirements. Also, long term resiliency and survivability of equipment and systems deployed in remote forest and wildland locations has not yet been demonstrated.

As is often the case, innovation often originates outside of a discipline and, frequently, Mother Nature is the inspiration. Entomology is the study of insects. Scientists at several European Universities and organizations have collaborated to study the Black Jewell Beetle (*Melanophila acuminata*) and the Australian Pyrophilic Beetle (*Merimna atrata*). Entomologists have known for some time that both of these beetles need freshly burnt wood to survive. Consequently, both have evolved antennae organs that are very sensitive to certain volatile organic compounds (VOCs) released by burning wood.⁷ In addition, the Black Jewell Beetle has a pair of very sensitive infrared (IR) arrays, each with approximately 90 IR receptors.⁸ These VOC and IR sensors guide the migration of these beetles towards forest fires. Researchers have worked

to isolate and understand how these insect olfactory and IR sensors work. They have also begun to replicate the sensors using electronic “noses” and “eyes”.

In addition to research on wildfire detection, work is being done on how to best communicate and manage the available information. Many communities that regularly experience wildfires have some form of centralized wildfire command center or network. The use of standard Geographical Information Systems (GIS) can permit real-time data sharing among different agencies. Commanders can quickly look at satellite imagery overlaid with road maps, real estate information and fire progress maps. They can switch to or overlay views showing power transmission lines, cell towers and other fixed infrastructure elements. GPS location data permits real time viewing of resource deployments.

These are just some of the ways that technology and biology are being used to manage forest and wildland fire risks through the development and use of detection, signaling and information management systems.

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The fourth edition of the **Fire Alarm Signaling Systems Handbook** was updated to reflect the many changes in the design of fire alarm systems that have occurred over the last seven years. New chapters have been added on mass notification, communications strategies and on fire department interfaces. As with the last edition, the fourth edition was written by **Wayne Moore, P.E., FSFPE** and **Richard Bukowski, P.E., FSFPE**.

The handbook also provides information on how to:

- Establish fire protection goals, match the fire alarm system to the goals, and know system limitations
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Pressure impregnated fire retardant treatments do not prevent wood from being destroyed by fire, but when

added to wood, provide passive protection and slow down the decomposition to such an extent that the wood structurally out performs most other building materials during actual fire conditions.

When temperatures reach a point slightly below the kindling point, the chemicals react with each other. Nonflammable gases and water vapor are formed and released at a slow persistent rate which envelope the wood fibers insulating them from temperatures that cause the wood to decompose. The inflammable gases and tars are reduced and an insulating char forms on the surface of the wood, further slowing down the process of decomposition.

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Table 1. Allowable uses of FRTW in NFPA 5000 and NFPA 101

Uses of fire-retardant-treated wood	2009 NFPA 5000	2009 NFPA 101
Architectural trim, exterior.	37.2.1	NFPA 101 is an exits code. Consult building code for construction requirements.
Awnings & Canopies.	32.4.2.1&3	
Balconies and similar appendages	37.2.2.1	
Bay and oriel windows.	37.2.2.1	
Combustible Projections.	37.2	
Corridors	7.2.3.2.11.2	7.1.3.1
Exterior bearing and nonbearing walls in Type III construction	7.2.4.2.1	NFPA 220: 4.4.2.1
Exterior bearing and nonbearing walls in heavy timber const.	7.2.5.6.7	NFPA 220: 4.5.6.7
Exterior nonbearing walls in Type I and Type II construction.	7.2.3.2.12.1	NFPA 220: 4.3.2.12.1
Enclosed combustible spaces in sprinklered buildings of all Types of Construction	Sprinklers not required – 8-13.1.1&9 NFPA 13, 1999 edition Sprinklers not required – 8.14.1.2.11 NFPA 13, 2002 edition Sprinklers not required – 8.15.1.2.11 NFPA 13, 2007, 2010 editions	
Fire barriers (see interior partitions Type I and Type II construction)	7.2.3.2.11.2	NFPA 220: 4.3.2.11.2
Fuel dispensing station (marine and motor vehicle).	32.4.5.2	See building code
Grandstands: allowable heights increased	32.7.5.4	12.4.8.3.3
Kiosks in Covered Mall Buildings	27.4.4.12.1	36.4.4.8
Interior finish with flame spread index ≤25 (Class A material).	10.3.2.1	10.2.3.4
Parapet not required when FRTW is used for sheathing:		
Exterior walls	37.1.3.1	See building code
Fire and party walls in Type III, IV, and V.	8.3.3.6.5.2	NFPA 221: 6.6.4
Townhouses, 4 ft. each side of wall.	22.5.4	See building code
Partitions in Type I and Type II construction	7.2.3.2.11.2	NFPA 220: 4.3.2.11.2
Partitions (fixed) establishing corridors in building with one tenant serving no more than 30 people.	7.2.3.2.11.2	See building code
Platforms in Type I and Type II construction	7.2.3.2.7	NFPA 220: 4.3.2.7
Plenums in all types of construction	7.2.3.2.15.8	NFPA 220: 4.3.2.15.8
Ramps		7.2.5.3.1 (2,3)
Roof construction in Type I and Type II construction.	7.2.3.2.9.2	NFPA 220: 4.3.2.9.2
Roof construction in Type I, II, III, VA, no rating when >20ft above floor	7.2.3.2.9.1 (Type I,II)	NFPA 220: 4.3.2.8 (Type I, II)
Roof construction, pedestrian walkways	7.2.3.2.9.2	See building code
Shakes and shingles Class A, B, and C roofs.	38.3.2	
Scenery and stage properties in new construction		12.4.5.11.3
Scenery and stage properties in existing construction		13.4.5.11.3

Dave Bueche, Ph.D. has over 30 years of construction experience in both academia and industry. In addition to his hands-on experience as a carpenter, superintendent, and project manager, he has been a research scientist at Colorado State University, taught college courses in construction technology and forest products, was a field representative for APA – The Engineered Wood Association, and an applications engineer for the American Galvanizers Association. He is active in building code development, serves on NFPA Committees that develop standards on the performance of materials in fire and in building construction, is a member of the Society of Fire Protection Engineers, the Society of Wood Science and Technology and the Forest Products Society.



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BRAINTEASER >

Problem / Solution

Problem

[Find the values of x and N that satisfy the following expression:]

$$x^N = 2x^{(N-1)} - x^{(N-2)}$$

Solution to Last Issue's Brainteaser

You are on the bank of a river with a boat, a fox, a hen, and an ear of corn. You have to get the fox, the hen, and the corn to the other side of the river. If left alone, the fox will eat the hen; the hen will also eat the corn if left alone. The boat is only big enough to take you and one of the other three to the other side of the river. How do you get all three across intact?

First take the hen across the river in the boat and leave it at the other side. Go back across and get the fox; take the fox to the other side. Leave the fox on the other side and take the hen back with you back to get the corn. Leave the hen on the original side and take the corn to the other side. Drop the corn off with the fox, and then go back to get the hen. Bring the hen to the other side.

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In response to the ever-growing rise in special hazard fires, fire safety specialist and inventor David Munroe launched ACAF Systems Inc., a manufacturer of innovative and self contained fire suppression systems. ACAF's patented revolutionary machine from ACAF Systems, Inc. is on the verge of changing the way numerous industries – such as marine, oil & gas, mining, aviation and manufacturing – can effectively combat the inevitable risk of fire effectively, affordably and with minimal risk to people and the environment.

Numerous remarkable innovations make the ACAF Systems, Inc. fire suppression invention so extraordinary, such as: it is self-contained, relying only on stored energy created by nitrogen gas; it is not dependent on a fixed water supply; the unique foam is distributed through fixed pipes with nozzles and an automatic detection system; it comes pre-engineered and assembled; and the special foam is non-toxic, environmentally safe and easy to clean after discharge, among other impressive features.

The company is the sole distributor of the exclusive ESF Extreme AFFF foam solution used in all ACAF System, Inc. machines. ACAF offers ESF Extreme Foam and ESF Universal Extreme Foam, a special mix of AFFF (Aqueous Film Forming Foam) concentrate and water that is environmentally responsible – it contains no solvents, only vegetable-based materials. What's more, ESF Extreme foam is non-corrosive, and is suitable for liquid hydrocarbon fires and all Class A fires. Numerous tests proved it will not deteriorate equipment, apparatus or vehicles used to apply the product.

ACAF Systems, Inc. is presently under review for FM Global approvals. The company will further ensure the quality of their product line by allowing sales, installation and service only by a rigorously selected, extensively trained, and specially licensed team of contractors.

For more information, call 401.828.9787 or visit www.acafsystems.net.

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Pasco, Washington's School District One recently constructed a new \$72 million 324,370 square-foot school to resolve space constraints within its existing high school and accommodate a growing student population.

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The new Chiawana High School is split into wings all linked together by technology. When choosing this high-tech school's fire protection system, life safety was always paramount in the eyes of the facility's management, but operation and maintenance costs had to be kept to a minimum.

"Because this new high school is the largest in the state, and the distances between some locations and the main [fire alarm] control panel are extreme, we needed a system that was cost-effectively expandable and scalable," says Robert Fleshman, project manager for Moon Security Services, Inc.

Due to the job's large scale, the Farenhyt line of IFP-2000 fire alarm systems by Silent Knight were chosen to provide a fast, reliable fire protection network for the entire facility.

"We didn't want a system that required troubleshooting, and the IFP-2000 has exhibited fast and rock-solid communication," says Fleshman. "Because this system is so scalable, we were able to connect additional power modules throughout the school and expand the number of devices without worrying about distance limitations. That makes for a more reliable system while also allowing us to scale back the power for energy efficiency."

The IFP Series control panels are compatible with most types of wire, including shielded, twisted-pair and fiber optic cable. In many retrofit applications, this flexibility allows IFP control panels to utilize existing wiring as well as many conventional and addressable detectors from previous fire alarm systems.

Whether new construction or an existing space, Pasco's School District One took advantage of all the scalable, cost-saving benefits Silent Knight's Farenhyt Series of IFP systems offer to obtain a fast, reliable life safety solution.

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Deaf Message Service

DMS (Deaf Message Service) is a NEW fire safety product that informs deaf or hard of hearing people when the fire alarm sounds in a public place like a supermarket, shopping center or library. It also helps service providers and employers comply with the Disability Discrimination Act (DDA), allowing deaf and hard of hearing people freedom to move around buildings without worry of missing an emergency situation.



When a deaf or hard of hearing person enters a building where DMS is installed, they will see clear signage asking them to text a location code to the DMS number. Once a connection text has been sent, the person will be connected to the DMS service for that location.

In the event of a fire and the fire alarm sounding, the DMS controller unit, which is hardwired into the Fire Panel, will trigger a process that within seconds sends a text message to all people connected to that location.

The advantage of DMS is its simplicity; a DMS controller unit can normally be installed in under half an hour and, unlike pager systems, it allows deaf or hard of hearing people to use what they already have with them: a mobile phone.

www.deafmessageservice.com

—Fireco Ltd.

Wide Lens LED Rocker Switch

This newly engineered LED Rocker Switch for trucking applications is compatible with microprocessor-based electrical/electronic systems and offers exceptionally high visibility and durability, no matter the time of day or weather condition. The wide, wrap-around green and yellow colored lenses



are working parts of the actuator, rather than being separate components inserted into the actuator. This significantly increases the chance of seeing the illumination when viewed from an oblique angle, from a distance, or in the bright sunlight while decreasing accidental risks of on-site areas.

www.colehersee.com

—Cole Hersee Co.

PP-R Pipe for Light Hazard

Polypropylene-random (PP-R), a highly engineered pressure pipe, has been approved by FM Global for use in concealed residential and light hazard fire sprinkler applications. Aquatherm Greenpipe® F and Aquatherm FireStop pipes, manufactured by Aquatherm GmbH of Attendorn, Germany, are FM 1635 listed for use in wet pipe automatic sprinkler systems in light hazard occupancies. Pipes are available in 3/4 in. to 4-in. diameters.



www.aquathermpipe.com

—Aquatherm, Inc.

Linear Heat Detectors

New XCR Series Linear Heat Detectors, developed in cooperation with a leading testing and approval agency for use in extreme environments, are designed to provide superior overall performance. Features include chemical resistance, low flame spread and smoke generation, high impact strength, abrasion resistance, and good weathering properties.



www.protectowire.com

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Backflow Preventers

Wilkins 300AR Series Backflow Preventers are designed with an integral spacer spool, pre-assembled from the factory, fully approved and shipped ready to



drop-in any existing assembly replacement without needing additional external spools or spacers. Wilkins custom fits a grooved spool between the backflow body and downstream shut-off valve to match the length of the old worn-out backflow. Saves on labor costs, mismeasurements, and water system downtime.

www.zurn.com

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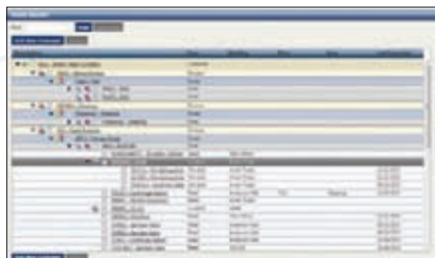
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TISCOR has released InspectNTrack Premium, Version 1.0 — a compliance-based software-as-a-service (SaaS) solution — which is designed to schedule, track, and document inspection activities for equipment or checkpoints that require regular inspection intervals. As a web-based program, it can be accessed at any time from any computer with Internet access. InspectNTrack assists in documenting inspections for fire and life safety equipment, environmental health and safety, facilities, janitorial, property, lab and space, dorm rooms, rodent management, and more.



www.tiscor.com

—TISCOR

Thermo-Activated Shut-Off Device

Viking's new VGS™ grooved piping system, which is cULus Listed and FM Approved, includes grooved couplings, fittings, flanges, mechanical tees, and other products necessary for the installation of complete grooved piping networks for fire sprinkler systems. All products are offered in standard ductile iron as well as galvanized material for use in areas subject to corrosion. Includes sizes up to 12 in. Several coupling gasket types are available, including a version for dry pipe sprinkler systems and freezer applications.



www.vikinggroupinc.com

—Viking Group

Corrosion Inhibiting System

South-Tek Systems' MICBlast® FPS-50 Nitrogen Generation System is designed to effectively inhibit corrosion within small sprinkler systems, 750 gallons or less. This compact system (larger systems available) is identical to another STS Nitrogen Generator: the GSA-approved N2-GEN®, used in combat zones by the U.S. military. The FPS-50 includes an integrated, durable oil-less air compressor; uses 110V; and features a patent-pending leak detection system.



www.southteksystems.com

—South-Tek Systems

Residential Dry Pipe System

Rapid Response Residential Dry Pipe System provides homebuilders with an integrated solution for NFPA 13D applications in areas that are subject to freezing. The system consists of fire sprinklers, CPVC pipe and fittings, and system components including riser assemblies, valves, water flow detectors, alarms, and hangers. Patented design software allows for water delivery times to be determined prior to field installations, ultimately lowering overall system costs. A pre-assembled residential control panel contains pre-programmed controls, an enclosed air compressor, and system performance gauges.



www.tyco-fire.com

—Tyco

Expanded Fire Alarm/MN System

Gamewell-FCI has developed an Addressable Node Expander (ANX) to expand the capacity of its E3 Series® Expandable Emergency Evacuation systems to support up to 122 nodes (for control panels and other modules) and more than 75,000 addressable device points on one network. The ANX can also connect E3 Series networks with FocalPoint® graphic workstations to provide more detailed monitoring and control of additional system functions remotely and at high-speeds.



www.gamewell-fci.com

—Gamewell-FCI

Visual Flame Detector

The Micropack FDS-301 Visual Flame Detector is designed to detect flames in high hazard applications and automatically provide a live video image of the area being protected for situational analysis. Due to the sophisticated algorithms onboard the detector, common nuisance alarm sources that affect conventional flame detectors are ignored. Once an event has been detected the video file is automatically written and stored to a micro SD card, to aid in fire forensics.



www.micropackamericas.com

—Micropack Detection (Americas) Inc.



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FIRE PROTECTION Engineering

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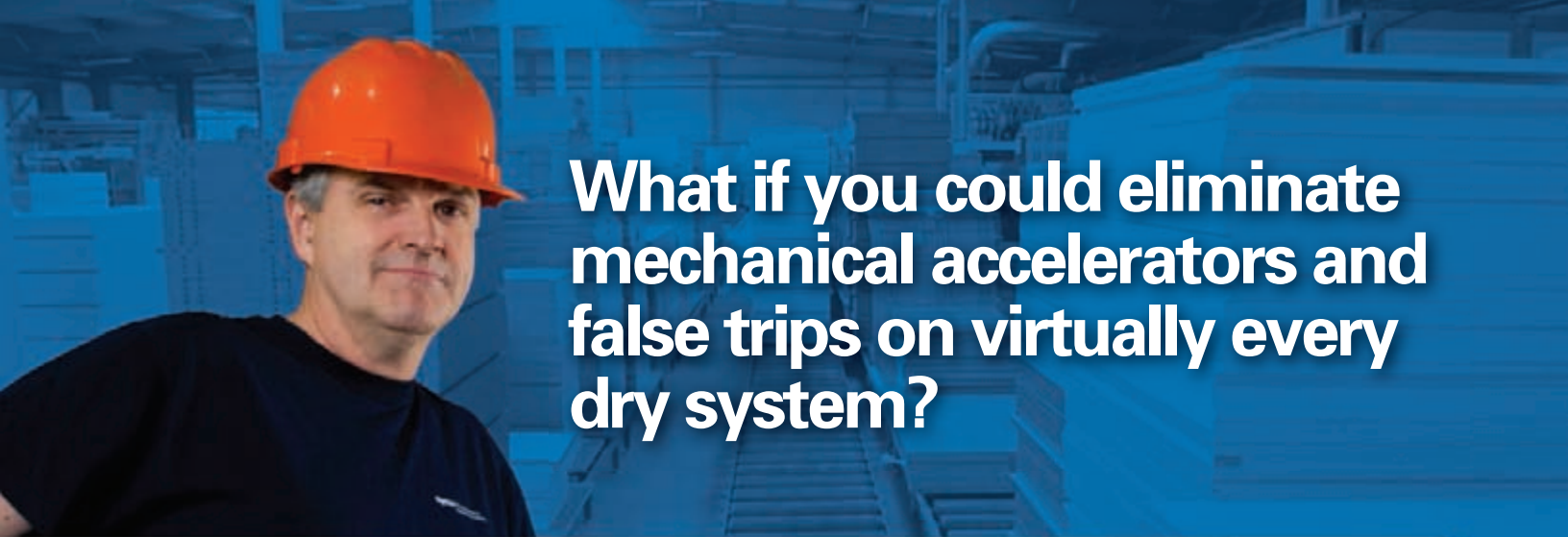


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