

# Fire Safety Engineering Workshop Session II: Technical Methods for Fire Safety

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*Quality Fire Safety Management*

Presented at the Fire Safety Engineering Workshop at Sichuan Fire  
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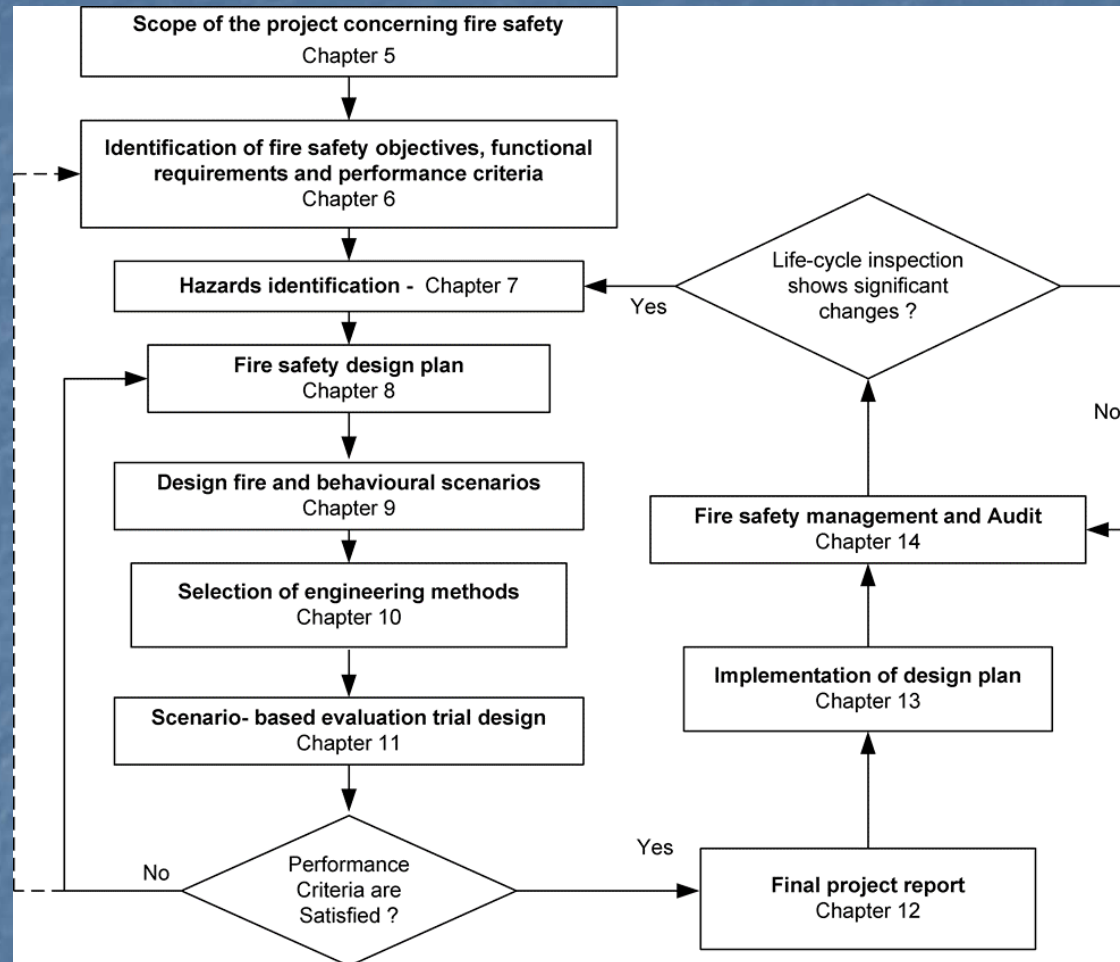
# Plan for Session on Technical Methods

- General procedures for fire safety engineering
- Design fire scenarios & design fires
- Structural response & fire spread beyond enclosure of origin
- Fire calculation methods for fire initiation, movement, & impact on structures

# Plan for Session – Cont'd

- Methods for assessing suitability of calculation methods for specific applications
- Verification & validation of fire calculation methods

# Fire Safety Engineering Process

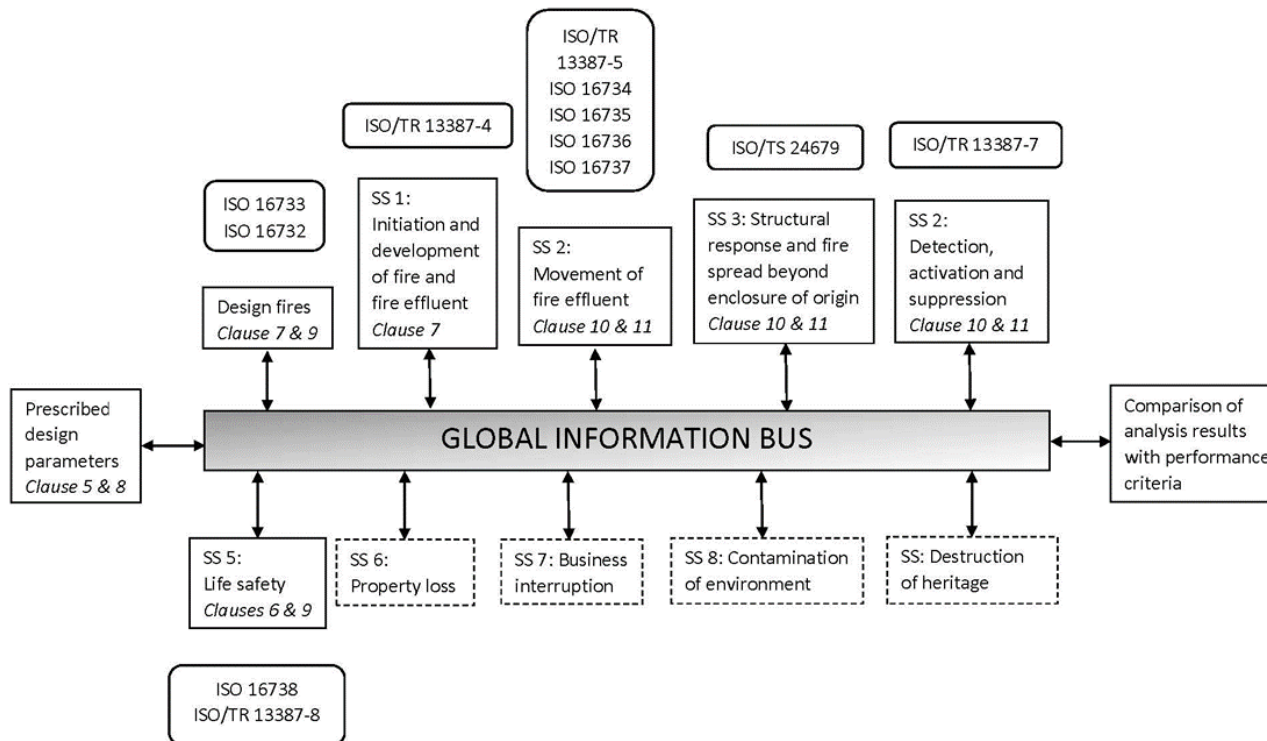


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# Safety Objectives

- Life safety
- Conservation of property
- Continuity of operations
- Preservation of heritage
- Protection of environment

# Global Information Bus



Global Fire Safety Engineering Analysis and Information System

# General Procedures for Fire Safety Engineering

- Contained in ISO 23932
- Provides procedures & requirements for a fire safety engineering design
- Standard under revision in ISO TC 92 SC 4
  - Link all SC 4 FSE standards to design process
  - Emphasize quality safety management & audit



# Current Core FSE Standards

Chapter in ISO 23932	List of standards available	Comments
<b>Scope of the project concerning fire safety – Chapter 5</b>	-	Provided by architect to fire safety engineer
<b>Identification of fire safety objectives, functional requirements and performance criteria – Chapter 6</b>	<a href="#">ISO/NP 29761</a>	The standards cover the life safety objective. Other safety objectives have not yet been elaborated.
<b>Hazard Identification - Chapter 7 and Design scenarios – Chapter 9</b>	<a href="#">ISO 16733</a> , <a href="#">ISO 16732</a> , <a href="#">ISO/NP 29761</a>	<a href="#">ISO 16733</a> covers design scenarios generically, <a href="#">ISO 16732</a> includes risk methods for scenario selection, and <a href="#">ISO/NP 29761</a> covers the life safety objective.
<b>Scenario based evaluation of trial design – Chapter 11</b>	-	
<b>1. Movement of fire effluents</b>	<a href="#">ISO 16734</a> , <a href="#">ISO 16735</a> , <a href="#">ISO 16736</a> , <a href="#">ISO 16737</a>	1. Covers fire plumes, smoke layers, ceiling jet flows, and vent flows, respectively.
<b>1. Structural response and fire beyond enclosure of origin</b>	<a href="#">ISO/TS 24679-1</a>	
<b>1. Detection, activation, and suppression</b>	<a href="#">ISO/TR 13387-7</a>	
<b>General to ISO 23932</b>	<a href="#">ISO 16732-1</a> , <a href="#">ISO 16730-1</a>	<a href="#">ISO 16732-1</a> is used for a fire risk assessment approach. <a href="#">ISO 16730-1</a> is for verifying & validating methods used for <a href="#">Chapter 11</a> .

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# Current Core FSE Standards

ISO 23932 *Fire Safety Engineering -- General Principles*

ISO/TS 16733:2006, *Fire safety engineering -- Selection of design fire scenarios and design fires.*

ISO 16732-1:2012, *Fire safety engineering -- Fire risk assessment -- Part 1: General.*

ISO 16734:2006, *Fire safety engineering -- Requirements governing algebraic equations -- Fire plumes.*

ISO 16735:2006, *Fire safety engineering -- Requirements governing algebraic equations -- Smoke layers.*

ISO 16736:2006, *Fire safety engineering -- Requirements governing algebraic equations -- Ceiling jet flows.*

ISO 16737:2012, *Fire safety engineering -- Requirements governing algebraic equations -- Vent flows.*

ISO/TS 24679:2011, *Fire safety engineering -- Performance of structures in fire.*

ISO/TR 13387-7:1999, *Fire safety engineering -- Part 7: Detection, activation and suppression.*

ISO/NP 16730-1, *Fire safety engineering -- Assessment, verification and validation of calculation methods -- Part 1: General.*

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# Scope of Project

- New built environment or modification of existing built environment
- Built environment includes buildings & other structures/systems, including tunnels, underground stations, etc.
- Application of FSE to limited section of built environment or whole part

# Scope – Cont'd

- Design plan:
  - Purpose/function
  - Dimensions
  - Location of fixtures, furnishings, equipment
- Preliminary plan for new built environment or refurbishment project

# Safety Objectives, Functional Requirements & Performance Criteria

- Objectives: what are required outcomes of foreseeable fires?
- Functional requirements: how outcomes achieved by design?
- Performance criteria: how adequacy of design measured?

# Comparison with Prescriptive Regulations

- Prescriptive provide "*acceptable solutions*"
- Safety design "*deem to satisfy*"
- Derive mandatory objectives & functional requirements, or use intent of regulations
- Performance criteria can be relative to performance of "*acceptable solution*"

# Examples

- Life safety objective: “occupants not intimate with fire will not be injured”
- Functional requirements for high rise building: “no design fire scenario should result in structural damage; or result in injury before evacuation for occupants not intimate with fire”

# Examples – Cont'd

- Performance criteria: “quantitative criteria for structural fire resistance; & visibility & concentrations of narcotic & irritant gases before evacuation is completed”
- Performance criteria can be derived for prescriptive design requirements
- More examples later



# Design Fire Scenarios & Design Fires

- Hazard identification:
  - Internal & external
  - Combustible materials
  - Natural hazards
- Use of fire incidence data
- Develop manageable group of fire scenarios to test fire safety system

# Selection of Engineering Methods

- Algebraic equations
  - Quick & simple
  - Can provide conservative results
- Zone models
  - Appropriate for most applications
  - Provides average conditions
- CFD models
  - Use for specialized cases only

# Scenario-Based Evaluation of Trial Design

- Development of input data
- Analysis of fire behavior
- Analysis of human behavior
- Determine if quantitative performance criteria are met for design fires
- Uncertainty of input data and analysis methods

# Safety Factors & Uncertainty

- Sources of uncertainty
  - Choice of fire scenarios and design fires
  - Functioning of fire protection features
  - Predictive capability of fire calculation method
  - Input data for fire calculations
- Safety factors should consider uncertainty in overall analysis

# Quality Safety Management – Conformity Assessment

- Develop final project report
- Conduct regulatory reviews & approvals from authorities
- Implement design plan
- Fire safety management & audit
- Life cycle inspection & reviews
- Importance of fire safety management

# Examples of Safety Objectives, Functional Requirements & Performance Criteria

- France:
  - Safety Objective (OBJ): Health and life safety of occupants
  - Functional requirement (FNR)1: No sudden change in tenability conditions before evacuation from room of fire origin
  - FNR 2: Adequate tenability conditions in the egress route

# OBJ, FNR, PR - France

- FNR 3: Adequate tenability conditions in waiting area within the building
- FNR 4: Adequate tenability conditions in place of refuge
- Performance criteria (PR) for FNR 1-4
  - Criteria 1: Maximum gas temperature of 60°C (references given)
  - Criteria 2: Maximum incident heat flux of 2 kW/m<sup>2</sup>

# OBJ, FNR, PR - France

- Criteria 3 : Maximum radiative dose of 3 ? kW per m<sup>2</sup>
- Criteria 4: Maximum Fractional Effective Dose (FED) of 0.3
- Criteria 5: Minimum visibility of 10 m (as calculated within ISO 13571)



# OBJ, FNR, PR - New Zealand

- Systematic review conducted over several years lead to performance-based Building Code & Verification Method C/VM2
- New Building Code (2012) specifies safety objectives (OBJ), functional requirements (FNR) & performance criteria (PR)

# OBJ, FNR, & PR – New Zealand

- OBJ: safeguard people from unacceptable risk of injury or illness caused by fire
- Clauses provide FNRs & PRs for:
  - C2: Prevention of fire:
    - FNR: Fixed appliances using controlled combustion must be designed in a way that reduces likelihood of illness or injury due to fire occurring
    - PR e.g. Maximum surface temp. of combustible building materials near appliances < 90°C

# OBJ, FNR, PR – New Zealand

- C-3: Fire affecting areas beyond fire source – covers flame spread & specifies material performance (PRs) determined by standard tests (e.g. ISO tests)
- C-4: Movement to place of safety: Buildings must provide means of escape so probability of occupants suffering injury is low (FNR) (performance-based design)

# OBJ, FNR, PR – New Zealand

- Evacuation should occur such that occupants not exposed to (PRs):
  - FED of CO  $> 0.3$
  - FED of thermal effects  $> 0.3$
  - Visibility  $< 10$  m
- Above can be calculated with fire calculation methods

# OBJ, FNR, PR – New Zealand

- C5: Fire fighter operations
- C6: Structural stability
- Verification method C/VM2 provides details on conduct of fire modeling for design fires:
  - Obtain uniformity in application for fire safety
  - Provides means for conformity assessment

# OBJ, FNR, PR - Japan

- Prescriptive standards prescribe acceptable solutions in terms of permissible materials, structures fire resistance ratings, equipment designs, dimensions of spaces
- Development of the Comprehensive Fire Safety Design Method of Buildings – 1986
  - Identified OBJ, FNR of prescriptive regulations

# OBJ, FNR, PR - Japan

- Equivalency concept for PB design
- Technical standards (PRs) provide numerical values or formulas to facilitate conformity assessment without ambiguity
  - Included in Building Standards Law (BSL)
- OBJ 1: Prevention of Fire Occurrence
- OBJ 2: Exclusion of Hazardous Materials
- OBJ 3: Assurance of Life Safety

# OBJ, FNR, PR - Japan

- OBJ 4: Assurance of The Third Parties' Property
- OBJ 5: Assurance of Fire Brigade Operation
- Predictive calculation methods for fire behavior specified in BSL
  - Simple & conservative



# OBJ, FNR, PR - Japan

- PRs: Numerical values contained in BSL
- OBJ 3: Assurance of Life Safety - ensure safety from fire for the entire occupants
  - FNRs: Evacuation plans
  - FNRs: Limitation of hazardous materials
  - FNRs: Assurance of safe refuge: *Evacuees shall be free from danger due to fire, smoke, flame, radiant heat, damage or collapse of the building*

# OBJ, FNR, PR - Japan

- FNRs: Assurance of safe evacuation route:  
*evacuation route shall be free from fire hazards, smoke, flame, radiant heat, collapse and breakage etc.*

# OBJ, FNR, PR - Japan

- Formulas used which include performance criteria (PRs) to verify compliance:
  - Smoke - indoor & outdoor
  - Radiant heat
  - Falling debris
  - Structural stability
  - Fire spread to other buildings
- Transparent approach

# OBJ, FNR, PR

## Recommended Approach

- Develop OBJ which are qualitative & contain policy and societal goals
- Develop FNR as more detailed statements that can specify certain requirements
  - Implemented as prescriptive requirements; e.g. material test specifications
  - Through performance-based analysis, e.g., evacuation analysis

# OBJ, FNR, PR

## Recommended Approach

- Develop PR which determine if functional requirements are met
- Include OBJ, & FNR in law & regulations as mandatory requirements
- Include PR, calculation methods & input data as part of verification method

# Design Fire Scenarios & Design Fires – ISO 16733-1

- Step 1: Establish design fire scenarios for a specific objective
  - Life safety, property loss, heritage
  - Describes sequence of events & conditions
- Step 2: Establish design fires for that objective
  - Defines specific heat release rate

# Design Fire Scenarios – Options for Development

- I - Prescribed scenarios for built environment and safety objective
- II – Qualitative approach
- III – Quantitative & risk-based approach

# Design Fire Scenarios – Qualitative Approach

- Identify safety objective & challenges
  - Type of built environment
  - Safety challenge
- Location of fire
  - Fire statistics
  - Experience



# Design Fire Scenarios – Qualitative Approach

- Type of fire
  - Ignition source
  - Growth of fire
- Complicating hazards
  - Common cause events, e.g. earthquakes
  - High hazard materials

# Design Fire Scenarios – Qualitative Approach

- Systems interactions
  - Passive systems, e.g. doors
  - Active systems, e.g. suppression systems
- Occupant actions
- Initial selection
- Modification based on system unavailability
- Final selection

# Design Fire Scenarios – Example from New Zealand Building Code

- Fire blocks exit
- Fire in normally unoccupied room threatens occupants in other rooms
  - ASET/RSET analysis or provide separation
- Fires in concealed spaces
  - Provide separation

# Design Fire Scenarios – Example from New Zealand Building Code

- Smoldering fire
  - Provide automatic detection & alarm
- Fire spread in internal linings
  - Use suitable materials proven by tests
- Challenging fire for evacuation & life safety
  - ASET/RSET analysis

# Design Fire Scenarios – Example from New Zealand Building Code

- Robustness check
  - ASET/RSET analysis assuming fire safety system unavailable
- Horizontal fire spread to other buildings
  - Radiation calculation
- External vertical fire spread
  - Use suitable materials proven by tests

# Design Fires – Example from Swedish Building Regulation

Fire Scenario	Occupancy	Growth rate	HRR (MW)	Heat of Combustion (MJ/kg)
1 & 2	Office/School	Medium	5.0	16
1 & 2	Dwellings, hotels & healthcare facilities	Fast	5.0	20
1 & 2	Assembly halls	Fast	10.0	20
3	All occupancies	Fast	2.0	20
1 = high stress scenario	2 = Hidden fire	3 = Robustness scenario		

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# Design Fires – Example from Swedish Building Regulation

Fire scenario	Soot production	CO production (g/g)	CO2 production (g/g)
1 & 2	0.10	0.10	2.5
3	0.06	0.06	2.5

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# Design Fires – Recommended Approach

- Develop prescribed design fire fires for specific types of built environment & safety objectives, & include in regulation
- Design fires will then be fixed for use by designers in different projects

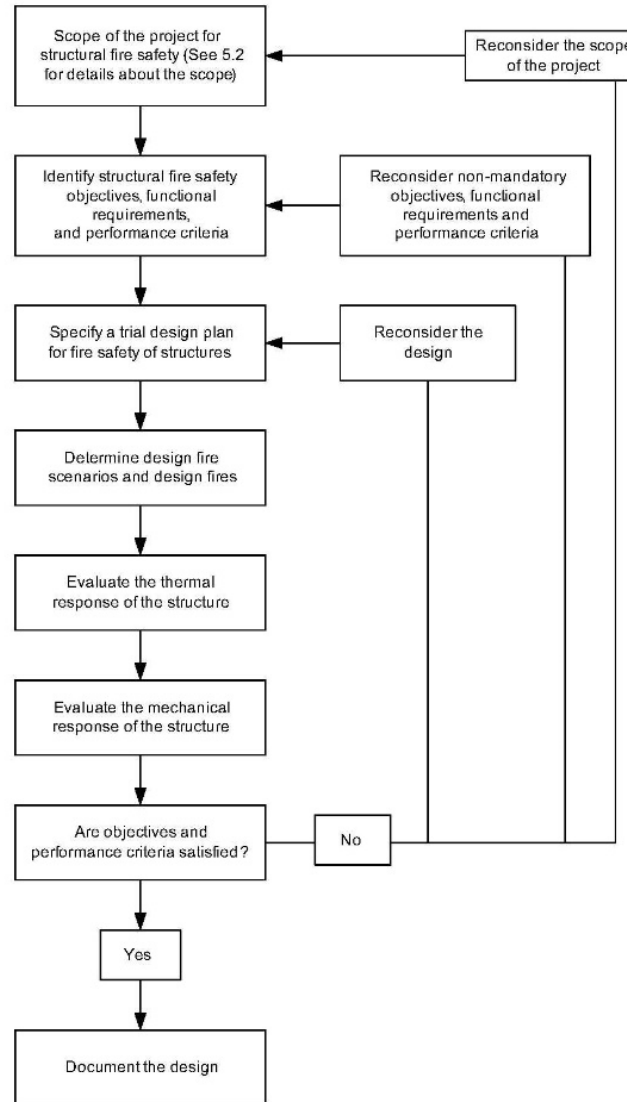


# Structural Response & Fire Spread

- ISO/TS 24679: Performance of structures in fire
  - Thermal response of structures & boundaries
  - Mechanical response of boundaries
  - Fire spread
  - Structural collapse

# Structural Response & Fire Spread

- Prescriptive regulation
  - Fire *resistance* tests for single fire & isolated elements & assemblies determine acceptability
- Performance-based design
  - Analyze real fires
  - Examine behavior of whole structural system
  - Consider realistic loads & cooling phase



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From ISO/TS  
24679:2011

# Structural Response & Fire Spread - FNR

- Functional requirements stated in terms of compartmentation, integrity & stability
  - Compartmentation
    - Prevent or limit fire spread within & outside built environment
    - Maintain integrity of separating elements
  - Integrity & stability of structure
    - Prevent failure
    - Limit deformation

# Structural Response & Fire Spread - PR

- Limit harm due to fire spreading
  - Criterion for limiting heat transfer, thermal radiation to materials in non-fire room
  - Criterion to limit spread of hot gases, e.g. leakage rate to non-fire room
- Limit harm due to collapse of structure
  - Criterion for load bearing elements
  - Criterion for critical elements
  - Criterion for progressive & global failure

# Structural Response & Fire Spread

- Calculation methods:
  - Simple formulas (Japan)
  - One-zone model for flashover conditions
  - Two-zone models
  - CFD models
- Thermal calculations:
  - Heat transfer from hot gases
  - Heat transfer within element (conduction)

# Structural Response & Fire Spread

- Mechanical response – Assess:
  - Load bearing capacity
  - Deformation of structure
- Representation options:
  - Temp. dependent/thermal expansion between elements
  - Temp. independent/expansion within element

# Structural Response & Fire Spread

- Required input data for calculations:
  - Thermal properties:
    - Specific heat, thermal conductivity, density, moisture content
  - Mechanical response:
    - Stress-strain relationship
    - Expansion or contraction at high temp.
- Consideration of uncertainties important



# Structural Response & Fire Spread

- Limited number of validated calculation methods
- Limited capability to model some phenomena, e.g. spalling
- Lack of thermal properties at elevated temperatures

# Structural Response & Fire Spread Recommended Approach

- Use of simple formulas and performance criteria have an advantage
- Examine and validate calculation methods for thermal & mechanical response
- Conduct tests to gain:
  - Further understanding of phenomena
  - Develop & validate calculation methods

# Questions

- Comments and discussion
- Thank you
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