Fire and Life Safety Analysis Bonderson Engineering Projects Center

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FPE 596

Cal Poly, SLO

Presentation Overview

- Building Introduction
- Code Summary
- Prescriptive Code Analysis
 - Egress
 - Structural
 - Fire Detection and Alarm
 - Fire Suppression
- Performance Based Design
 - Fire Scenario 1
 - Fire Scenario 2
- Recommendations

Building Introduction

- Built for students (clubs, projects, labs, etc)
- Completed in 2007 (~ \$8 million)
- Two story building (18,575 ft²)
 - Atrium lobby
 - 8,110 ft² Covered Work Area
- Concrete and steel frame
- Fully sprinklered (automatic wet-pipe system) / Ionization Smoke Detection

Building Introduction

- Location: Cal Poly Campus, Engineering Plaza, Building 197

Codes and Standards

- Built Under:

- California Building Code, 2001
- California Code of Regulations, w/ Title 19 & 24
- Uniform Building Code, 1997
- Americans with Disabilities Act

- Project Analysis:

- International Building Code, 2009
- NFPA 101: Life Safety Code, 2012
- NFPA 13: Installation of Sprinkler Systems, 2010
- NFPA 72: National Fire Alarm and Signaling Code, 2010

Egress Systems

Occupancy Classification

- Classifies as a Multiple Occupancy Building
- Analyzed under the IBC/LSC Mixed Use Classification

- Features
 - Assembly
 - Business
 - Industrial
 - Storage

LSC Occupancy Classification	LSC Occupant Load Factors (ft ² /Pers)
Assembly Use - Less Concentrated Use, Without Fixed Seating	15 Net
Business Use	100 Gross
Industrial Use - General Industrial Occupancy	100 Gross
Storage Use - Ordinary Hazard Contents	500 Gross
Shops, Laboratories, or Vocational Rooms	50 Net

Occupancy Classification

First Floor Layout

Assembly
Business
Industrial
Storage/
Service Space

Occupant Load: 285 People

Occupancy Classification

Second Floor Layout

Assembly
Business
Industrial
Storage/
Service Space

Occupant Load: 98 People

Egress Systems

- Atrium lobby
- Single primary corridor on both first and second floors
- Three 72" exits along corridor
- Three 36" exits from Covered Work Area

Egress Systems

- Second floor – open to lobby
- Two 48" stairways provide a means of egress for occupants

Egress Capacity

All rooms and areas meet individual requirements for

- Egress capacity
- Location
- Remoteness

Location	Occupant Load	Exit Width	Exit Capacity	Meets Req.
Second Floor / Vertical Exits	98			
Stair 1		48"	160	Yes
Stair 2		48"	160	Yes
First Floor (Public Way Exits)	285			
Exit 1		72"	360	Yes
Exit 2		72"	360	Yes
Exit 3		72"	360	Yes
Exit 4		36"	180	Yes
Exit 5		36"	180	Yes
Exit 6		36"	180	Yes

Exit Arrangement

- Originally Business Occupancy
- Assembly classification
- Requires two exits (IBC/LSC)
- Meets separation requirements (7.5.1.3.2)
- Does not meet door swing direction or panic hardware (7.2.1.4.2 / 12.2.2.2.3)

Other Egress Factors

Consideration	Applicable Sections	IBC				LSC				Meets Req.?
Travel Distance	IBC 1016.1 / LSC A.7.6	250/300/250				250/300/250				Yes
Dead End	IBC 1018.4/LSC A.7.6	20/50/50				20/50/50				Yes
Common Path	IBC 1014.3/LSC A.7.6	75/100/100				(20/75)/100/100				Yes
Egress Illumination	IBC 1024 / LSC 7.8, 7.9	1 ft/can – emergency light, etc				1 ft/can – emergency light, etc				Yes
Interior Finishes	IBC Chapter 8 / LSC 10.2	A B F	Exit A/B A/B/C	E Acc A/B A/B/C	Other A/B/C A/B/C A/B/C	A B I	Exit A A/B A/B	E Acc A/B A/B A/B/C	Other A/B A/B/C A/B/C	Yes

Structural Systems

Structural Fire Protection

- Concrete and steel frame building
- Type II-B construction: Unprotected, Non-Combustible
- First Story: 12,240 ft² with 8,110 ft² Covered Work Area
- Second Story 6,335 ft²
- Height: 14' – 1' Second floor, 29' – 0" Roof

Structural Fire Protection

No fire resistance required
for any structural member

Exterior non-bearing walls
also require no fire
resistance (Table 602) –
based on separation
distance

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	Ad	B	Ad	B	HT	Ad	B
Primary structural frame ^d (see Section 202)	3 ^a	2 ^a	1	0	1	0	HT	1	0
Bearing walls Exterior ^{d, f} Interior	3 3 ^a	2 2 ^a	1 1	0 0	2 1				
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior ^d	0	0	0	0	0				
Floor construction and secondary members (see Section 202)	2	2	1	0	1				
Roof construction and secondary members (see Section 202)	1½ ^b	1b, c	1b, c	0c	1b, c

Building Materials

- Structural frame includes wide flanged I-beam columns and beams: W16x26 – W21x50
- Roof is constructed of 20-gauge steel decking
- Floors are light weight concrete poured over steel decking
- Walls: Gypsum/steel studs, glass curtain, reinforced concrete

Fire Rated Construction

- Originally built with 1-hour rated walls around laboratories and shops as per 2001 CBC 304.2.2.1:

Adjacent occupancies	IBC Required Separation	LSC
Assembly from Business	1 hour (sprinklered)	Not Required
Business from Industrial/Factory-Moderate	Not Required	1 hour (sprinklered)

- Would meet IBC, but not LSC, requirements for Separated Occupancy

Rated Separation – First Floor

- IBC requires 1-hr between control areas
- LSC requires 1-hr between Industrial and business
- Atrium is required to be separated from surrounding occupancies

Rated Separation

Second Floor

Corridors not required
to be rated due to
sprinkler system

Rated Separation

- Rated walls are constructed of 5/8" Type X Gypsum wall board
- Where rated separation exist, separation is continuous
 - Doors
 - Penetrations
 - IBC 713.3.1

Detection and Alarm Systems

- Part of a proprietary, campus wide, supervising system
- Features a building wide ionization detection system
- Additional detection/initiation through heat detectors and manual pull stations
- Ample alarm and notification appliances

Detection and Notification

Detection/Initiating Devices

First Floor	Second Floor
Ionization Det. - 16	Ionization Det. - 20
HARSH Ionization Det. - 10	HARSH Ionization Det. - 2
Manual Pull Station - 3	Duct Smoke Detector - 2
Heat Det. - 1	Heat Det. - 1
Water Flow - 1	Pull Station - 1

Notification Appliances

First Floor	Second Floor
Strobe - 11	Strobe - 6
Horn/Strobe - 10	3 Horn/Strobe
1 Bell	2 Horn

Detection and Notification – First Floor

Detection and Notification – Second Floor

Spacing Requirements

- NFPA 72

Ceiling Type	NFPA 72 Required Spacing
Smooth Ceiling	30 feet between detectors / 15 feet perp. to walls (1/2 listed spacing)
Solid Joist, $D < 0.1H$	30 feet between detectors / 15 feet perp. to walls (1/2 listed spacing)
Strobe Type	Maximum Spacing
15 CD Wall	20 x 20
30 CD Wall	28 x 28
30 CD Ceiling	30 x 30
75 CD Wall	45 x 45

Fire Suppression System

- Fully automatic, wet-pipe sprinkler system
- 4" Rise in Room 108
- 6" Double check valve

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Fire Sprinkler System

271 total sprinklers

Quick Response Sprinklers (besides single sidewall)

Sprinkler Type	Finish	K-Factor	Degree	Quantity
1/2" Tyco TY-FRB Upright, 28 " Sprig	Brass	5.6	200	208
1/2" Tyco TY-FRB Upright	Brass	5.6	200	38
1/2" Tyco TY-FRB Pendant, 1" Drop	Chrome	5.6	155	24
1/2" Tyco TY-FRB Horiz. Sidewall	Brass	5.6	155	1

Hydrant Number	I-05-06
Test Date	9/3/2002
Static Pressure	80 PSI
Residual Pressure	60 PSI
Observed Flow	1210 GPM
Calculated Flow (20 psi)	2190 GPM

System Demand

Hydraulic calculations preformed using the density/area method of NFPA 13, Chapter 11 and 23

Two cases considered:

- 1) Hydraulically remote Light Hazard Occupancy (2nd floor)
- 2) Ordinary Hazard Group-2 Machine Shop (first floor)

System Demand

Light Hazard Occupancy, 2nd Floor

Number of Sprinklers	11
Design Area	990 ft ²
Design Density	0.10 gpm/ft ²
Calculated Flow	159 gpm
Calculated Pressure (B.O.R.)	64.2 psi

Ordinary Hazard Group-2, 1st Floor

Number of Sprinklers	12
Design Area	990 ft ²
Design Density	0.20 gpm/ft ²
Calculated Flow	263 gpm
Calculated Pressure (B.O.R.)	54.4 psi

System Demand

Occupancy	Hose Stream Allowance	Duration
Light Hazard	100 gpm	30 min
Ordinary Hazard	250 gpm	60 min

Prescriptive Overview

- **Egress:** Prescriptive requirements largely met besides issues relating to room 104
- **Structural:** Prescriptive requirements met
- **Detection and Alarm:** Minor coverage gaps, mostly insignificant compared to overall coverage. Average ambient sound levels should be properly measured in order to gauge audible notification system
- **Suppression:** Prescriptive requirements met

Two vertical bars, one dark green and one olive green, are positioned on the left side of the slide.

Performance Based Design

Was performed following the guidance of Chapter 5, LSC 101

Overarching criteria: Any occupant who is not intimate with ignition shall not be exposed to instantaneous or cumulative untenable conditions

Life safety is the primary focus. Other performance criteria (structural failure/mission continuity or environmental damage) not evaluated

Two vertical bars, one dark green and one olive green, are positioned on the left side of the slide.

ASET vs RSET

Computer modeling was performed in order to evaluate the Available Safe Egress Time and Required Safe Egress Time for the given scenarios

Fire Dynamics Simulator was primarily used in order to calculate ASET

Pathfinder was primarily used in order to help determine RSET

Tenability Criteria

Visibility	
Unfamiliar	> 10 m
Familiar	> 5 m
Temperature	< 60 °C
CO Concentration	< 1600 ppm

Fire Scenario 1 – Entrance Lobby Atrium

First design fire scenario considered: Acetone spill

Basis: LSC Design Fire 2 – ultra-fast developing fire in primary means of egress

Used as an industrial solvent for machine shop

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Acetone

- Chemical Formula: C_3H_6O
- Flash Point: $-17.8\text{ }^{\circ}\text{C}$
- Boiling Point: $56\text{ }^{\circ}\text{C}$
- Explosive Limits: 2.6 – 12.8 %
- Heat of Combustion: 25,800 kJ/kg
- Mass Burning Rate: $0.041\text{ kg/m}^2\text{-sec}$
- Density: 791 kg/m^3
- Flammable Liquid Class IB

HRR Modeling

Fuel spill of 5 gallons

Spill area extrapolated from data produced by NII – Flammable and Combustible Liquid Spill/Burn Patterns (25 ft²)

A short haired nylon carpet was one of the test materials used

United States Nuclear Regulatory Commission's "Chapter 3: Estimating Burning Characteristics of Liquid Pool Fires, Heat Release Rate, Burning Duration, and Flame Height" Excel tool

Used to calculate peak heat release rate based on spill area

25 ft² -> ~ 2,363 kW fire burning for 157 seconds (2.62 min)

HRR Modeling

- Information from Gottuk and White (SFPE Handbook) on gas phase flame spread vs liquid phase flame spread – Acetone will most likely experience rapid flame development

HRR Modeling

- Data from a NIST report, “Quick Response Sprinklers in Chemical Laboratories”
- Testing of Acetone fires in laboratory settings
- Free burn Acetone base test with recorded HRR and growth data
 - 4 liters over 13 ft²
 - 1 MW @ 35 seconds
 - 1.5 MW @ 50 seconds
 - 2MW (peak) @ 68 seconds

HRR Modeling

Figure 2. Laboratory bench heat release rate (free burn)

HRR Modeling

- Similar growth rate to the NIST data
- Initial run with 990 kW @ 30 s, 1.58 MW @ 50s, 2.36 MW @ 70 s
- Sprinkler activation time was recorded
- HRR remodeled
 - Controlling and partial suppression
- FDS modeling showed sprinkler activation at 37 s
- Fire was allowed to keep growing for ~ 10 s before being limited
- Restricted to 25% peak HRR (590 kW)

Modeled HRR

Fire Scenario 1 Fire Growth and HRR

By-Products

- SFPE Handbook, 4th Edition, Table 3-4.16 Yields of Fire Products
 - CO Yield: 0.003 g/g
 - Soot Yield: 0.014 g/g

FDS Model

Additional Doors Open Justification

Smoke Condition at Sprinkler Act. (37 s)

Visibility Tenability Reached – 71.5 s

Temperature Tenability Reached – 81.1 s

Thermocouple Array at Corridor Exit

Carbon Monoxide Tenability – Not Reached

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RSET – Detection Time

Ionization smoke detector modeled in FDS (Cleary Model)

Specs: 0.5 – 2 %/ft obscuration

1%/ft chosen as activation limit (conservative)

Detection Time = 19 seconds

RSET – Notification Time

Assumed to be nearly instantaneous with modern alarm system

Notification Time = 1 second

RSET – Pre Movement Time

Delay/Pre-movement time taken from NFPA Handbook:

Mid rise office building is closest occupancy match

Lower median value rather than average due to Bonderson building characteristics – less of a delay time

TABLE 4.2.1 Delay Times (Minutes) Derived from Actual Fires and Evacuation Exercises Reported in the Referenced Literature

<i>Event Description</i>	<i>N</i>	<i>Min</i>	<i>1st Q</i>	<i>Median</i>	<i>3rd Q</i>	<i>Max</i>	<i>Mean</i>	<i>Factors</i>
High-rise hotel ¹⁴	536	0	3.3	60.0	130.9	290.0	NA*	MGM Grand Hotel fire, no alarm notification, grouped data from questionnaires
High-rise hotel ¹⁵	47	0	2.0	5.0	17.5	120.0	NA	Westchase Hilton Hotel fire, no alarm in early stages, grouped data from questionnaires
High-rise office building ¹⁶	85	0	2.0	5.0	10.0	245.0	11.3	World Trade Center explosion and fire, no alarm notification (building closer to explosion)
High-rise office building ¹⁶	46	0	4.5	10.0	31.5	185.0	28.4	World Trade Center explosion and fire, no alarm notification (building further from blast)
High-rise office building ¹⁷	107	1.0	1.0	1.0	1.0	~6.0	NA	Fire incident, no alarms, data from interviews with occupants of four floors of building (11 interviewees were trapped)
High-rise office building ¹⁸	12	0.5	NA	1.0	NA	2.3	1.2	Unannounced drill on three floors; data for first person to reach each of four stairwell doors to wait for voice instruction; trained staff; data from video recordings
Mid-rise office building ¹⁹	92	0	0.4	0.6	0.8	<4.0	0.6	Unannounced drill, good alarm performance; fire wardens; warm day
Mid-rise office building ¹⁹	161	0	0.5	0.9	1.4	<5.0	1.1	Unannounced drill, good alarm performance; fire wardens; cool day

RSET – Movement Time

- Modeled in Pathfinder using imported CAD drawings
- Full occupant load assumed (383 persons)
- Steering and SFPE models tested
 - Only Steering data used
- Steering: 125 s
- SFPE: 137 s

RSET

- RSET
 - Detection Time = 19 s
 - Notification Time = 1 s
 - Pre-movement Time = 36 s
 - Movement Time = 125 s

RSET = 181

ASET = 71.5 s Visibility (81.1 Temperature)

RSET > ASET, performance objective fail

Recommendations

Scenario solidifies IBC, LSC, and IFC requirements towards prohibiting high combustible materials and finishes within atrium spaces

Continue/improve administrative control over lobby space

While the chance of a Acetone spill/fire is low, other combustibles frequently are transported and sometimes temporarily stored within the space (cushioned chairs for engineering expos outside the building, etc)

Fire Scenario 2

- Modeled off of LSC Design Fire 1; occupancy specific fire
- Fuel considered: Stack of metal framed, soft segment polyester based thermoplastic polyurethane chairs

HRR Modeling

- Lack of data for this fuel source
- Data from SFPE Handbook for metal framed polypropylene chairs used instead
- Polypropylene Heat of Combustion: 38.6 kJ/g
- Polyester Heat of Combustion: 20.0 kJ/g

HRR Modeling

Fuel Source

HRR Modeling

- Fast – Medium growth rate fire
 - $\alpha = 0.035 \text{ kW/s}^2$.
- Initial run to determine sprinkler activation time
 - FDS: 1st @ 149 seconds, 2nd @ 167 seconds
 - DETACT Model: 154 seconds
- HRR adjusted, fire held at 450 kW

HRR Modeling

Fire Scenario 2 Heat Release Rate

By-Product Modeling

- SFPE Handbook, 4th Edition, Table 3-4.16 Yields of Fire Products

• Sample	CO Yield (g/g)	Soot Yield (g/g)
• Polyester 1	0.07	0.091
• Polyester 2	0.08	0.089

Since data is so close, choose higher values to stay conservative

By-product data: CO Yield: 0.08 (g/g) Soot Yield: 0.091 (g/g)

FDS Model

Control Logic

Pyrosim control logic built into the model

Open/close doors at start and end of occupant egress

RSET data points determined before FDS simulation

Open: 37 seconds

Close: 107 seconds

Visibility Tenability Reached – 135.8 s

Temperature Tenability – Not Reached

Carbon Monoxide Tenability – Not Reached

RSET – Detection Time

- Ionization detector modeled in FDS (Cleary Model)
- Manufacturers specification: 0.5 – 2.0 %/ft obscuration
- Conservative 1%/ft chosen as activation limit
- Detection Time: 26 seconds

Fire Plume at Detector Activation – 26 s

Two vertical bars of different shades of green are positioned on the left side of the slide.

RSET – Notification Time

- Assumed to be almost instantaneous for modern day alarm systems
- Notification Time = 1 second

RSET – Pre-movement Time

Set at 10 seconds

Occupants will quickly realize severity of the situation

RSET – Movement Time

Modeled in Pathfinder

Steering: 67 seconds

SFPE: 69 seconds

RSET vs ASET

- Detection Time: 26 seconds
- Notification Time: 1 second
- Pre-movement Time: 10 seconds
- Movement Time: 67 seconds
- RSET = 104 seconds
- RSET + 15% F.O.S. = 119.6 seconds
- Performance criteria achieved

ASET = 135.8 seconds (Vis)

RSET vs ASET

Second iteration of fire scenario 2

72" door unusable

Egress through 36" door only

Control logic programmed to open 36" door at 37 seconds and close it at 171 seconds (predetermine RSET times)

Pathfinder Queuing

RSET

Detection Time: 26 seconds (same)

Notification Time: 1 second (same)

Pre-movement Time: 10 seconds (same)

Movement Time:

Steering: 134 seconds

SFPE: 166 seconds

Visibility Tenability – Reached at 135.8 s

Smoke Spill into Corridor (171 seconds)

RSET vs ASET

- $RSET = 26\text{ s} + 1\text{ s} + 10\text{ s} + 134\text{ s}$
- $RSET = 171\text{ seconds}$
- $ASET = 135.8\text{ seconds}$
- Performance criteria not met

Smoke Layer at RSET

Two vertical bars, one dark green and one olive green, are positioned on the left side of the slide.

Recommendations

Fix the 36" door so it meets swing direction and panic hardware requirements

Changing the quick response sprinkler heads for the lower 155 F models instead of the 200 F devices would enable quicker sprinkler activation and potentially quicker suppression of the fire source

Performance Based Overview

- Performance based design has shown the importance of maintaining administrative control over the materials allowed within the atrium space
- Room 104 should have its door components upgraded to facilitate egress under any future fire conditions

Questions?