Fire and Life Safety Evaluation of Christopher Cohan Center

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Keywords: International Building Code, Stage Fire Hazards, Fire Modelling, Fire Dynamics Simulator (FDS), Emergency Evacuation.

Contents

Abstract

A prescriptive and performance-based fire and life safety evaluation for Christopher Cohan Center is performed. The results and findings of the evaluations are conveyed in this report.

Christopher Cohan Center was built in accordance with California Building Code (1992 Edition) and California Fire Code (1992 Edition). The current version (2015) of International Building Code is consulted for prescriptive evaluation. The protection requirements set forth in IBC are intended to limit the threat from stage fires to an audience, to reduce the likelihood of a large fire in the stage area and to reduce the possibility of irrational mass response. These objectives have been identified as primary parameters to evaluate the fire and life safety systems of the building.

Christopher Cohan Center was constructed of Type IB construction with a sprinkler system throughout the building. Legitimate stage is completely separated from seating by a proscenium wall of 2-hour fire-rated construction with the main proscenium opening protected by an automatic closing fire protection curtain in accordance with IBC 410.3.5. A wet pipe, hydraulically calculated automatic sprinkler system is provided throughout the building. A hydraulic calculation was performed in accordance with NFPA 13, which shows that, the city water supply is not adequate for the sprinkler system and hose stream demands. The main exit of the Sydney Harman Hall accommodates a total occupant load of 1,440, which is more than the total occupant load of the hall, 1,289. This arrangement complies with IBC section 1029.2. In addition to having access to a main exit, Christopher Cohan Center is provided with additional exits from the balcony level, gallery level, orchestra stage, and entry lobby. These exits provide an egress capacity of 5,280 persons from orchestra stage and entry lobby levels and 960 persons from balcony and gallery levels, which are more than the total occupant loads served by an

individual level. In the event of an alarm, Christopher Cohan Center Ushers are required to assist in the evacuation process.

A fast-growing fire is modeled in FDS, which shows activation of gravity vents between 349 and 436 seconds, fire protection curtain activation at 440 s, and first sprinkler activation at 498 second after ignition. The tenability criterion is established to be the smoke layer descend within 2 m. above any means of egress. This criterion is predicted to occur at 210 s. in the zone model. FDS model does not predict smoke layer to descend within 2 m. above any means of egress, within the simulation time (570 s.). FDS model also shows that, the proscenium structure can contain the smoke until 300 s. FDS predicts the smoke detector will activate at 274 second. The notification of the fire event is expected to be triggered by the rapid descend of smoke layer, possibly shading or obscuring lighting effects dropped from the grid-iron, or by occupants, present in the fly gallery, sensing the presence of smoke, can initiate the notification of the fire event by activating manual fire alarm, long before the automatic detection devices detect the fire cues and initiate activation of the fire alarm.

Based on the evaluation of the building and stage construction, the stage construction and fire separation play key-role in limiting the threat from a stage-fire to the audience due to its containment of smoke long enough for the audience to evacuate the hall. It can also be confirmed that the installed systems will not perform to meet the performance criteria. The building would be relying on human actions to detect fire, to annunciate, and to suppress the fire. To reduce the likelihood of a large fire in the stage area human intervention would be a crucial factor. Also, the collective effort of the egress system and human-assistance play a crucial role in evacuation process, which contributes to ensure minimal exposure to the fire environment. Due to effective

evacuation and egress system, the possibility of irrational mass response is expected to be minimal.

Recommendations include the incorporation of a fire pump based on the hydraulic demand for the most challenging design area. Proper inspection, testing and maintenance of the suppression systems is required, in accordance with specified standards. Additional requirements specified in the fire safety management plan must be included in the 'Emergency Management Plan' for Christopher Cohan Center. This includes engaging dedicated fire watch personnel and crowd managers during events, and incorporating specified employee training and response procedures along with all the emergency management procedures that are currently in place.

Fire and Life Safety Evaluation of Christopher Cohan Center

A comprehensive fire and life safety evaluation for Christopher Cohan Center is performed. Relevant fire safety codes, standards and regulations are identified, the fire safety performance objectives and criteria associated with these documents are comprehended, and these fire safety objectives and criteria are applied on the evaluation process. Construction, egress systems, smoke management systems, fire detection and alarm systems and fire suppression systems are analyzed to achieve specified performance objectives. The flammability characteristics of ignitable materials used to create sets and sceneries are analyzed and the fire hazards associated with these materials are evaluated. The dynamics of fires inside the building is analyzed through the application of fundamental principles and state-of-the-art computer based fire simulation models. How people interact with fire conditions in the building is discussed and evacuation times are calculated through the application of fundamental principles of people movement and state-of-the-art computer-based evacuation model. The results and findings of fire and life safety evaluations for the building are conveyed in this report.

General Building Information

Widely known as the Performing Arts Center, San Luis Obispo is a state-of-the-art performance facility located on the campus of California Polytechnic State University (Cal Poly). Open since September of 1996, the Performing Arts Center incorporates two main venues: The Christopher Cohan Center, including the majestic 1,289-seat Sidney Harman Hall, the 180-seat classroom Philips Hall, and the multi-purpose Pavilion that holds various capacities up to 453 people; and the 498-seat Davidson Music Center. The Christopher Cohan Center is a three-story assembly building with a legitimate stage theatre. It was constructed immediately adjacent to a portion of Davidson Music Center. This report only evaluates Christopher Cohan Center and excludes Davidson Music Center from evaluation. Figure 1 shows the external view of the building. Table 1 and 2 describes different occupancies in the building and floor usage at different levels.

Number of stories below / above grade: 1 / 3

Highest occupied floor level / height: Gallery level / 39 ft.

Date of construction: 1996

Figure 1. View of Christopher Cohan Center from Grand Avenue.

Occupancy Classification:

Table 1. Occupancies Classifications of Christopher Cohan Center

Occupancy Classification		Occupant Load
1. Legitimate theatre	Group A-1	1714
2. Classroom	Group A-3	180
3. Office Spaces	Group B	83
4. Multipurpose Pavilion	Group A-3	453
5. Lobbies	Group A-3	683
6. Storage	Group S-2	8

Table 2. Usage and occupant loads per floor.

Floor	Use	Occupant Load
Trap Room – Lift Pit Level	Stage, Storage, Equipment rooms.	224
Orchestra – Stage Level	Main hall, Loggias, Piano, Stage, Food-handling, Green room, Dressing rooms, Offices, Storages, Laundry, Classroom, Rehearsal Pavilion.	1885
Main Entry Level	Lobby, Dress-circle, Concession, Office.	602
Balcony Level	Balcony, Lounge, Lobby	463
Gallery Level	Gallery	155
Catwalk Level	Gridiron, Catwalk	36

Fire and Life Safety Objectives and Criteria

In this section, relevant fire safety codes, standards and regulations are identified that specify the fire and life safety objectives and criteria that Christopher Cohan Center is expected to perform.

Fire safety codes, standards and regulations

Below is a list of major standards listed in the construction document that were used for fire and life safety design of Christopher Cohan Center.

1. Title 24, Part 2; California Building Code (1992 Edition)
2. Title 24, Part 9, California Fire Code (1992 Edition)

Current version (2015) of International Building Code is consulted to identify relevant codes applicable to Christopher Cohan Center.

IBC Chapter 4: Special detailed requirements based on use and occupancy

The protection requirements set forth in section 410 are intended to limit the threat from stage fires to an audience and reduce the likelihood of a large fire in the stage area. These provisions include construction restrictions, automatic sprinkler systems, ventilation, separation of the stage from the audience and compartmentalization of appurtenant rooms to the stage.

Special allowances are provided for galleries, gridirons, catwalks and other technical production areas. Based on historical events and the expertise of a broad range of professionals with experience in theater design, operations and fire events, a set of principles guides the requirements for theaters. These principles are summarized as follows:

1. The fire hazards of stages are not necessarily a function of type but rather area and height. Accordingly, the stage area of 4,000 square feet and a height of 80 feet represents a significant potential for fuel load due to scenery and drops.

2. The stages requires a means of emergency ventilation.

3. The stages requires automatic sprinkler protection.

4. The stage is like floor construction; therefore, the type of construction should be consistent with that of the floor construction in the building.

5. Separation of the stage from the seating area, dressing rooms and similar spaces is critical to provide a degree of fire containment.

Section 410.3 contains provisions for the construction of the stage and gallery. Stage openings, decorations, equipment and scenery are addressed in Sections 410.3.3 through 410.3.6. Stage ventilation is required in accordance with Section 410.3.7. The construction of auxiliary stage spaces is addressed in Section 410.5. Special means of egress requirements for the stage and technical production areas are established in Section 410.6. Sections 410.7 and 410.8 contain the requirements for automatic sprinkler systems and standpipes, respectively.

IBC Chapter 5: General building heights and areas.

Table 3 shows an extraction from IBC Table 504.3, which provides limitations on the height, in feet, based on the occupancy classification, type of construction (IB) and equipment of sprinkler system. The height in feet is the distance from grade plane to the average height of the highest roof surface. The building is Occupancy Classification A-1.

Table 3. IBC Table 504.3 showing height allowances based on occupancy and type of construction.

TABLE 504.3[a]
ALLOWABLE BUILDING HEIGHT IN FEET ABOVE GRADE PLANE

OCCUPANCY CLASSIFICATION	TYPE OF CONSTRUCTION									
	SEE FOOTNOTES	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
A, B, E, F, M, S, U	NS[b]	UL	160	65	55	65	55	65	50	40
	S	UL	180	85	75	85	75	85	70	60

Table 4 shows an extraction from IBC table 504.4, which provides height limitations, in stories, based upon the occupancy classification, the type of construction, and equipment with the automatic sprinkler system. The height is in number of stories above grade plane.

Table 4. IBC Table 504.4 showing allowable number of stories based on occupancy and type of construction.

TABLE 504.4[a, b]
ALLOWABLE NUMBER OF STORIES ABOVE GRADE PLANE

OCCUPANCY CLASSIFICATION	TYPE OF CONSTRUCTION									
	SEE FOOTNOTES	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
A-1	NS	UL	5	3	2	3	2	3	2	1
	S	UL	6	4	3	4	3	4	3	2

IBC ection 506.2.3 provides no limitations on the area of Christopher Cohan Center based on occupancy classification A-1, type of construction IB and equipment with a sprinkler system throughout.

IBC Chapter 9: Fire protection systems

Because of the potentially large fuel load and three-dimensional aspect of the fire hazard associated with the stage which is 4,000 square feet in area, Class II standpipes are required on each side of the stage. The IBC section 905.3.4 exception recognizes the benefit of Christopher Cohan Center being sprinklered. So, only a single $1\frac{1}{2}$-inch standpipe connection is required. This hose connection is intended to be used by the fire department and apply less water from the hose because of the suppression activity of the sprinkler system. Hose threads are required to be compatible with those of the fire department as required in IBC Section 903.3.6.

In a fully sprinklered building it is acceptable to supply the hose connections through the same standpipe as the sprinklers, which is reflected in the reference to both NFPA 13, which acknowledges this concept, and NFPA 14, which contains similar provisions. Although the standpipe is wet and Class II in its installation, the design of the water supply and interconnection of systems is required to be in accordance with the requirements for Class II as well as for Class III standpipes.

Christopher Cohan Center is typically occupied by a significant number of people who are not completely familiar with their surroundings. The provisions of International Building Code section 907.2.1 addresses situations regarding the application of the alarm requirements which applies for this building.

The exception specified on 907.2.1 allows the omission of manual fire alarm boxes in Christopher Cohan Center, which is equipped throughout with automatic sprinkler system. Activation of the sprinkler system will activate the building evacuation alarms associated with the manual fire alarm system.

The exception does not eliminate the fire alarm system and occupant notification system, but rather permits them to be initiated automatically by the sprinkler water flow switches instead of by the manual fire alarm boxes. It also reduces the possibility of mischievous or malicious false alarms being turned on by manual fire alarm boxes in Christopher Cohan Center where large numbers of people congregate.

To afford authorized personnel, the ability to selectively evacuate or manage occupant relocation, IBC section 907.2.1.1 requires the fire alarm system to operate through an emergency voice/alarm communications system. The exception allows the automatic alarm signals to be overridden for live voice instructions if the live voice instructions do not exceed 3 minutes. The

location from which the live voice announcement originates must be constantly attended and approved by the fire code official. In terms of the applicability of this section, it is not as specific as Section 907.2.1. More specifically, the concept of fire areas does not apply to this code.

IBC Chapter 10: Means of Egress

Sydney Harman Hall, Philips Hall, Rehearsal Pavilion and adjacent lobby areas are used for assembly purposes and contain elements that would affect the path of travel for the means of egress. These spaces require special consideration because of the larger occupant loads and possible low lighting, which can possibly lead to slower fire recognition and crowd concerns.

Sections 1029.2 through 1029.5 deal with number and dispersement of exits. Christopher Cohan Center, just as any assembly space presents unusual life safety problems that includes frequent higher occupant densities and, therefore, large occupant loads and the opportunity for irrational mass response to a perceived emergency. For this reason, the code requires a specific arrangement of the exits. Studies have indicated that in any emergency, occupants will tend to egress via the same path of travel used to enter the hall and building. Therefore, a main entrance to the building is required to be designed as the main exit to accommodate this behavior, even if the required exit capacity might be more easily accommodated elsewhere. The main entrance must be sized to accommodate at least 50 percent of the total occupant load of the structure and is required to front on a large, open space, such as a street, for rapid dispersal of the occupants outside the building or hall. The remaining exits must also accommodate at least 50 percent of the total occupant load from each level. The total occupant load includes those within the theater seating area, the lobby and other spaces.

In Christopher Cohan Center, people might arrive and wait for the next show while another group has yet to exit. In every case, the main entrance and all other exits are to be constantly available for the entire building occupant load.

Because of the queuing of large crowds, particularly in Sydney Harman Hall where a performance may be in progress and people must wait to attend the next one, standing space is provided. For reasons of safety, these spaces should not interfere with established paths of egress from the assembly areas. While the facility might choose to separate the route for means of egress using partitions or railings from the general lobby space to allow for easy traffic flow through the lobby to the street, it is not required to designate these areas.

Section 1029.5 states the threshold where two means of egress are required based on the occupant load of the interior balcony and gallery. This requirement would ensure that at least one path of travel is always available and occupants face a minimum number of hazards.

The means of egress width for spaces used for assembly is to be in accordance with section 1029.6 and the referenced sections instead of the criteria specified in Section 1005 when dealing with the means of egress within the seating area. The width factors in Section 1029.6 and its subsections apply to those doorways, passageways, stepped aisles, ramped aisles and level aisles that are within the assembly seating areas.

The Board for the Coordination of Model Codes (BCMC) issued a report on means of egress dated June 10, 1985. The provisions in Section 1029 are based on this report. This report limits the application of these provisions to aisles and aisle access ways that provide exit access within the room or space with the assembly seating. The primary concern for occupant safety would be that where the different provisions for the capacity requirements in Sections 1005 and 1029 were utilized, there would not be a bottleneck in the path of travel for means of egress. In

Sydney Harman Hall, commonly the occupants leave the seating area for a concourse or lobby area that leads to exit stairways between floor levels. In this situation, the capacity requirement in Section 1005.3 would be applicable for the exit stairway.

Different means of egress width criteria are also specified for assembly seating where smoke protection is provided versus areas where smoke protection is not provided. The egress width for smoke-protected seating can be less than for areas where smoke protection is not provided, since the smoke level is required to be maintained at least 6 feet above the floor of the means of egress, per Section 1029.6.2.1.

Application of codes at Christopher Cohan Center

In this section, structural fire protection, egress systems, fire suppression systems, fire detection and alarm systems and smoke management systems of Christopher Cohan Center analyzed to evaluate the performances.

Construction.

Christopher Cohan Center is constructed of Type IB construction with sprinkler system. The building is constructed to a height above grade plane of 90 feet. The building is constructed to height of three stories above grade plane. The building is Occupancy Classification A-1.

The area of each floor is as follows:

Floor	Square Footage
Orchestra Pit	1,898 s.f.
Basement Level	5,325 s.f.
Electrical Room / Chillers	1,645 s.f.
Orchestra Stage Level	42,979 s.f.
Entry Lobby Level	18,517 s.f.
Balcony Level	13,045 s.f.
Gallery Level	7,672 s.f.
Catwalk Level	357 s.f.
Total	91,438 s.f.

Typical floors are of 2-hour fire-resistive construction. The finish floor of the stage is of wood on a resilient mounting upon heavy timbers (Figure 2). Section 410.3 permits, in all types of construction, the finished floor of the stage can be constructed of wood or approved noncombustible materials.

Figure 2. Stage floor construction

Exterior Walls

Exterior load bearing walls throughout the structure are 4-hour fire resistive construction. Exterior load bearing walls fronting on Tahoe Road, Grand Avenue and the Service Yard have unprotected openings.

The exterior wall of the Davidson Music Center immediately adjacent to the Christopher Cohan Center is of 4-hour fire-resistive construction (10” concrete) with no openings. This wall, which includes a minimum 30-inch parapet, is serves as an area separation wall from the building.

Exterior non-bearing walls fronting on Tahoe Road, Grand Avenue and the Service Yard are of non-combustible, non-fire-rated construction with unprotected openings.

The exterior wall opposite the metal canopy on the Davidson Music Center is of 4-hour fire-resistive construction. No openings are provided in this wall.

Fire-resistive separations.

Stage to accessory rooms such as dressing rooms and store rooms are separated by 2-hour construction and 90-minute fire rated doors in accordance with IBC Section 410.5 (Figure 3). Legitimate stage is completely separated from seating by a proscenium wall of 2-hour fire-rated construction. In addition to the main proscenium opening, there is one opening at the orchestra pit level and two openings into the seating area at the stage floor level. Except the main proscenium opening, all openings in the proscenium wall of the legitimate stage is protected by fire assemblies having ratings of $1\frac{1}{2}$ hours which meets the criteria specified in IBC 410.3.4. The main proscenium opening has an automatic closing fire protection curtain in accordance with IBC 410.3.5.

Interior load bearing walls of Christopher Cohan Center are made of 2-hr fire rated walls. Opening in the walls are protected by 90-minute fire rated assemblies. These interior load bearing wall assemblies divide the building in six (6) separate ‘fire areas’ (Figure 4).

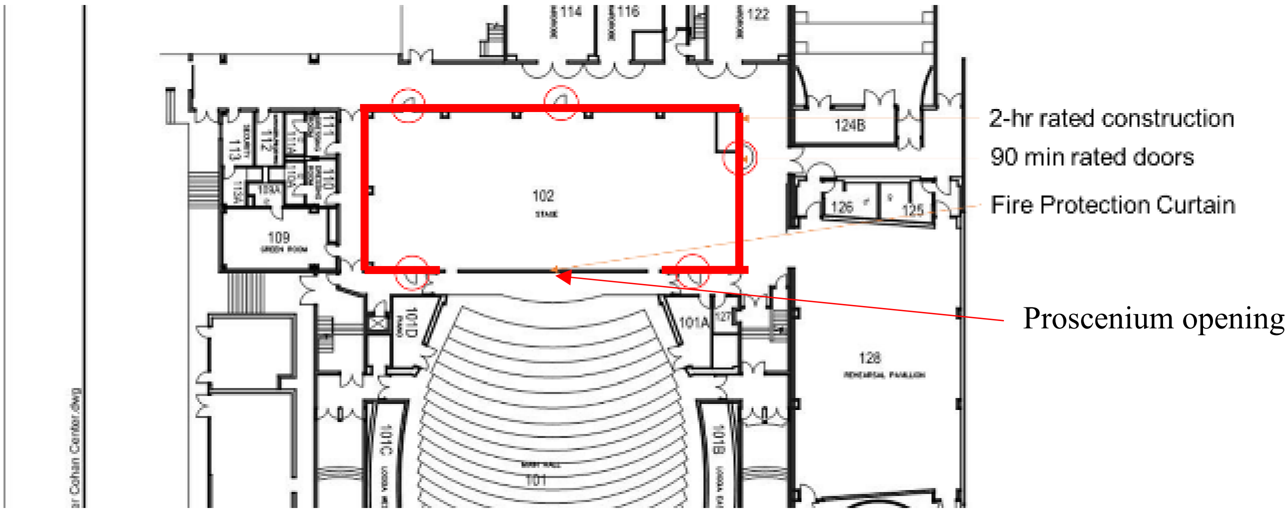

Figure 3. Fire resistive separation used to separate stage from adjacent spaces.

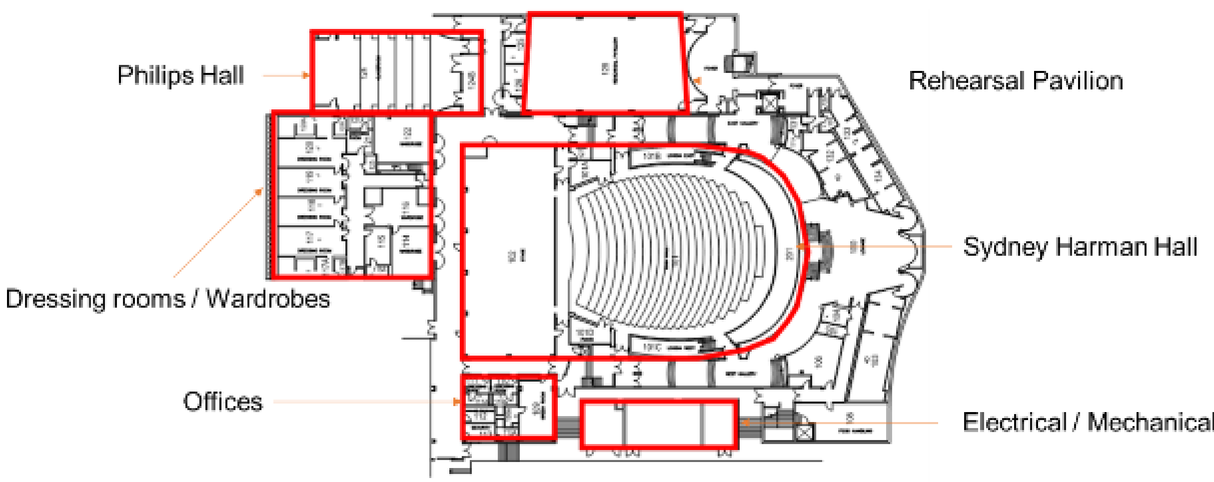

Figure 4. Orchestra Stage level plan showing different fire areas.

Structural Frame

Columns and the girders, beams, trusses and spandrels having direct connections to the columns and all other members essential to the building stability are of 2-hour fire-resistive construction. Floor members and roof panels which have no connection to the columns are considered secondary members.

The construction of Christopher Cohan Center and its legitimate stage was built to meet the prescriptive requirements and in some cases, exceed the minimum requirements with liberal margin of safety. The stage and proscenium plays an important role in limiting threat from stage-

fire to the audience due to its containment of smoke and heat long enough for the audience to evacuate the hall. In ‘Predicting Behavior of Fire in the Stage’ section, this criterion is evaluated to understand the comprehensive performance of the building structure along with emergency ventilation and fire protection curtain systems.

Egress

The main exit of the Sydney Harman Hall accommodates total occupant load of 1,440, which is more than the total occupant load of the hall which is 1,289 complying with IBC section 1029.2 (Figure 6).

IBC Section 1029.3 requires, in addition to having access to a main exit, each level of Christopher Cohan Center, shall be provided with additional means of egress that shall provide an egress capacity for not less than one-half of the total occupant load served by that level and shall comply with section 1007.1. In addition to having access to a main exit, Christopher Cohan Center is provided with additional exit stairs from balcony and gallery levels and additional exits from orchestra stage and entry lobby levels that provides egress capacity of 5,280 persons from orchestra stage and entry lobby levels and 960 persons from balcony and gallery levels which are more than the total occupant loads served by individual level (Figure 5 and 7).

North side of the legitimate stage have three marked exits. There are two exits on the south side and one on the east side. These exits open directly to exit passageways leading to public ways. Section 410.6 requires, no fewer than one exit or exit access doorway shall be provided on each side of the stage.

Both balcony and gallery have two exits which leads directly to enclosed exit stairs. Section 1029.5 requires, for balconies and galleries having seating capacities of 50 or more used

for assembly purposes, not less than two means of egress shall be provided, with one from each side.

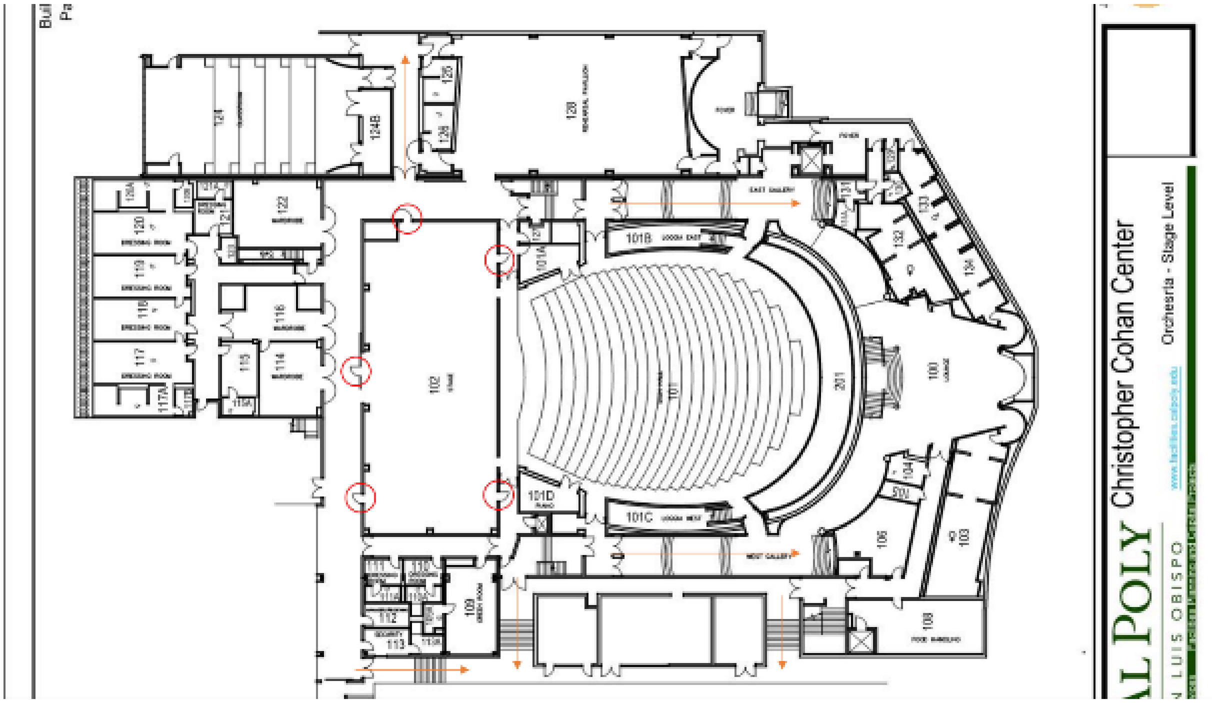

Figure 5. Orchestra stage level plan showing means of egress from assembly areas and stage.

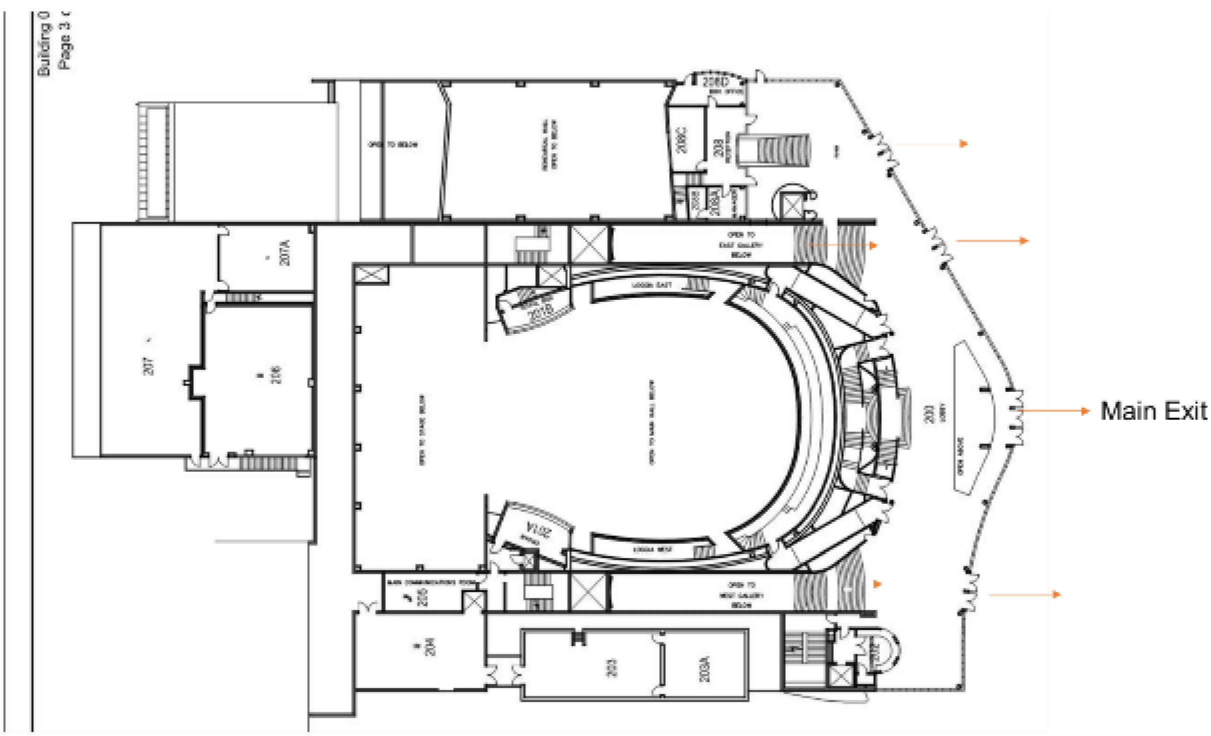

Figure 6. Entry lobby level plan showing the main exit and additional exits.

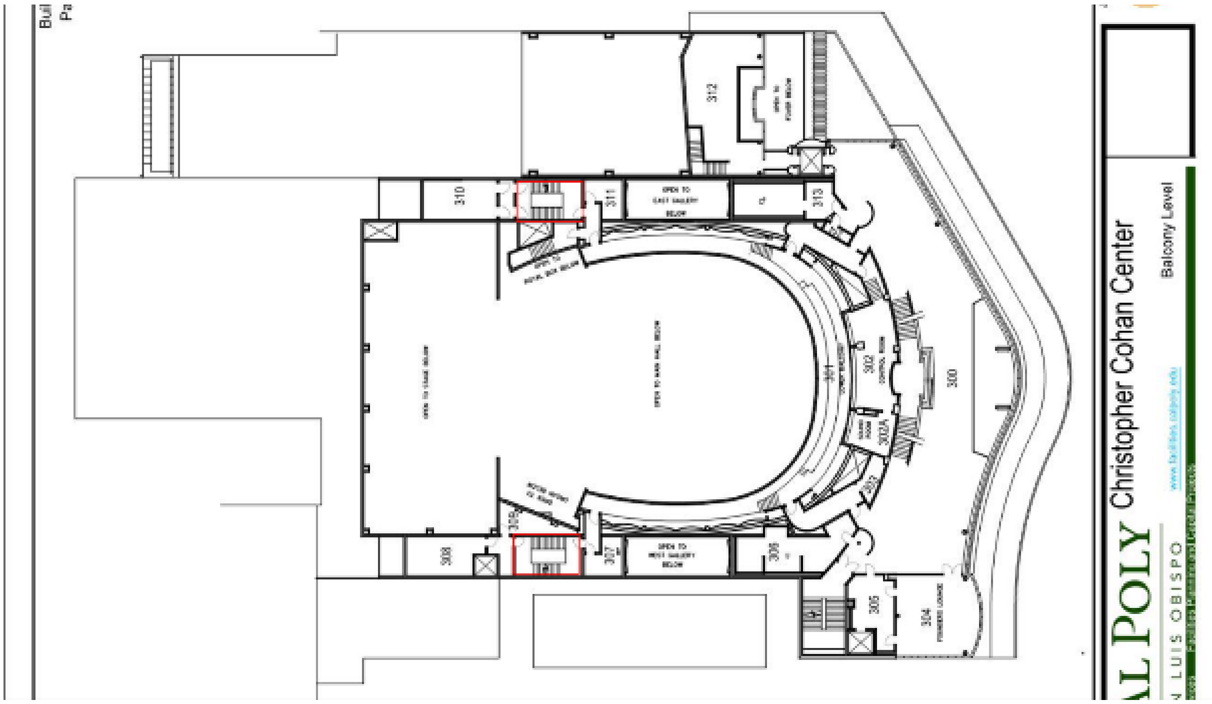

Figure 7. Balcony level plan showing the location of enclosed exits stairs connected directly to the balcony and gallery level.

Egress from the Orchestra pit level is provided by two (2) 48 in. wide exit stairs. Egress from the Orchestra – Stage level is provided by four (4) exit access stairs (one (1) 86 in., one (1) 89 in. and two (2) 148 in.) and seven (7) exits. Egress from the Entry lobby level is provided by three (3) exit stairs (two (2) 48 in., one (1) 73 in.) and six (6) exits. Egress from Balcony and Gallery level is provided by three (3) exit stairs (two (2) 48 in., one (1) 73 in.) and two exit access stairs of 72 in. each. The floor to floor height of the floors served by the stairs is 13 ft. There are 36 in. clear width doors at south stairway entrances and a 75.6 in. wide exit discharge. There are 36 in. wide doors at entrances to north exit stairs and 92 in. and 72 in. wide doors at exit discharge from North West and north east exit stairs respectively.

Occupant load and exit capacity calculations

Table 5. Occupant loads and exit capacities of each level.

Floor	Spaces	Use	Occupant Load Factor (sq. ft. per person) *	Area (sq. ft.)	Occupant Load on each space	Total width of egress (in.)	Capacity Factor (in./ person) **	Exit Capacity (person) = Total width of egress / Capacity Factor	Occupant load per floor	Total number of exits	Total width of egress (in.)	Exit Capacity* **
Trap room Lift Pit level	11	Storage Area	300	3270	11	168	0.2	840	19	2	96	330
	12	Storage Area	300	236	1	36	0.2	180				
	012A	Storage Area	300	97	0	36	0.2	180				
	13	Storage Area	300	86	0	36	0.2	180				
	14	Equipment Room	300	403	1	36	0.2	180				
	15	Equipment Room	300	99	0	72	0.2	360				
	16	Equipment Room	300	74	0	36	0.2	180				
	17	Equipment Room	300	421	1	72	0.2	360				
	18	Equipment Room	300	671	2	84	0.2	420				
	19	Equipment Room	300	393	1	72	0.2	360				

Orchestra Stage Level	Lounge and galleries	Circulation	Number of f	5095		390 in. stair and 72 in. door	0.2 and LSC 7.3.3.2	1984	1883	11	244 in. doors and 622 in. stairs	3797
	Main Hall	Fixed Seating	Number of fixed seats	878	878	354	0.2	1770				
	101A	Stage	15	166	11	72	0.2	360				
	Loggia East	Fixed Seating	Number of fixed seats	9	9	45	LSC 7.3.3.2	151				
	Loggia West	Fixed Seating	Number of fixed seats	10	10	45	LSC 7.3.3.2	151				
	Piano	Stage	15	172	11	72	0.2	360				
	Stage	Stage	15	4049	270	180	0.2	900				
	104	Equipment Room	300	95	0	36	0.2	180				
	105	Business	100	63	1	36	0.2	180				
	106	Business	100	724	7	36	0.2	180				
	Food Handling	Business	100	653	7	36	0.2	180				
	Green Room	Business	100	513	5	36	0.2	180				
	Dressing Room 110	Business	100	171	2	36	0.2	180				
	Dressing Room 111	Business	100	149	1	36	0.2	180				
	Technical Services Manager	Business	100	107	1	36	0.2	180				
	House Production Office	Business	100	198	2	36	0.2	180				
	House Storage 114	Storage	500	453	1	96	0.2	480				
	Dressing Room 115	Business	100	257	3	36	0.2	180				
	Laundry Room	Equipment Room	300	609	2	192	0.2	960				
	Dressing Room 117	Business	100	679	7	36	0.2	180				
	Dressing Room 118	Business	100	393	4	36	0.2	180				
	Dressing Room 119	Business	100	393	4	36	0.2	180				
	Dressing Room 120	Business	100	678	7	36	0.2	180				
	Dressing Room 121	Business	100	192	2	36	0.2	180				
	House Storage 122	Storage	500	586	1	96	0.2	480				
	123	Business	100	41	0	36	0.2	180				
	Classroom	Fixed Seating	Number of fixed seats	180	180	108	0.2	540				
	124B	Equipment Room	300	339	1	168	0.2	840				
	127	Business	100	59	1	36	0.2	180				
	Rehearsal Pavillion	Concentrated use, without fixed seating	7	3179	454	140	0.2	700				
	129	Storage	500	39	0	36	0.2	180				
	130	Equipment Room	300	53	0	36	0.2	180				
	131	Business	100	60	1	36	0.2	180				
	131A	Business	100	62	1	36	0.2	180				

Entry Lobby Level	Lobby	Waiting Space	15	8889	593	657	0.2	3285	643	9	657 in. doors and 169 in. stairs	3895
	Balcony Left	Fixed Seating	Number of fixed seats	17	17	36	0.2	180				
	Royal Box	Fixed Seating	Number of fixed seats	17	17	36	0.2	180				
	Concession	Business	100	263	3	36	0.2	180				
	Main Communications Room	Business	100	341	3	36	0.2	180				
	Reception / Manager / Box Office	Business	100	1014	10	108	0.2	540				
Balcony Level	Lower Balcony	Fixed Seating	Number of fixed seats	138	138	144	0	720	197	4	293	1123
	Control and Sound Room	Business	100	669	7	36	0.2	180				
	303	Storage	500	78	0	36	0.2	180				
	Founder's Lounge	Less concentrated use, without fixed seating	15	662	44	144	0.2	720				
	307	Storage	500	122	0	36	0.2	180				
	308	Business	100	287	3	36	0.2	180				
	309	Storage	500	144	0	36	0.2	180				
	310	Business	100	290	3	72	0.2	360				
	311	Storage	500	121	0	36	0.2	180				
	312	Storage	500	876	2	48	LSC 7.3.3.2	165				
	314	Storage	500	28	0	36	0.2	180				
Gallery Level	Gallery	Fixed Seating	Number of fixed seats	152	152	144	0.2	720	156	5	300	1100
	402	Equipment Room	300	355	1	36	0.2	180				
	403	Storage	500	79	0	36	0.2	180				
	404	Storage	500	123	0	36	0.2	180				
	405	Equipment Room	300	293	1	36	0.2	180				
	406	Equipment Room	300	347	1	36	0.2	180				

* Occupant load factor is selected based on LSC Table 7.3.1.2

** Capacity factor is selected based on LSC Table 7.3.3.1

*** As all the stairs are wider than 44 in. and subject to the 0.3 in. (7.6 mm) width per person capacity factor, the capacity is increased using the equation provided in LSC 7.3.3.2

Each floor has an adequate number of exits with sufficient exit capacity based on occupant load (Table 5).

Number and arrangement of means of egress

Table 6 has been extracted from LSC Table A.7.6, which provides us with the values of allowable common path, dead-end and travel distances limits by occupancy.

Table 6. Common paths of travel, dead-end and travel distance allowances per the Life Safety Code.

Table A.7.6 Common Path, Dead-End, and Travel Distance Limits (by occupancy)

	Common Path Limit				Dead-End Limit				Travel Distance Limit			
	Unsprinklered		Sprinklered		Unsprinklered		Sprinklered		Unsprinklered		Sprinklered	
Type of Occupancy	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m
Assembly												
New	20/75	6.1/23[a]	20/75	6.1/23[a]	20	6.1[b]	20	6.1[b]	200	61[c]	250	76[c]
Existing	20/75	6.1/23[a]	20/75	6.1/23[a]	20	6.1[b]	20	6.1[b]	200	61[c]	250	76[c]

The cases of highest travel distances on each floor are demonstrated on the figures below.

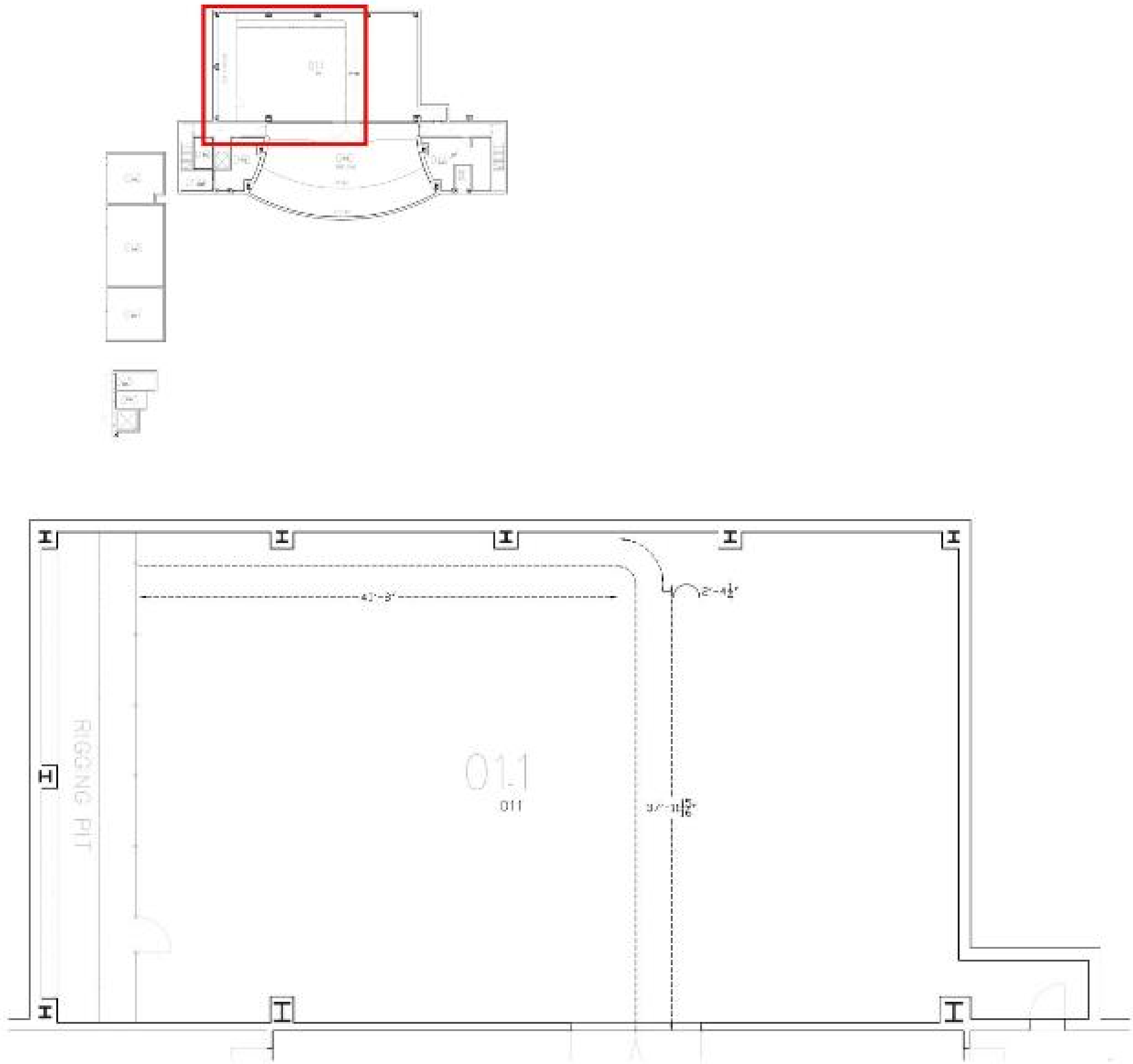

Figure 8. Plan of the lift pit level showing highest travel distance scenario

The highest travel distance is found on room 011. The highest travel distance is 80 ft. which is below the allowable travel distance limit of 250 ft. for sprinklered Assembly occupancies (Figure 8).

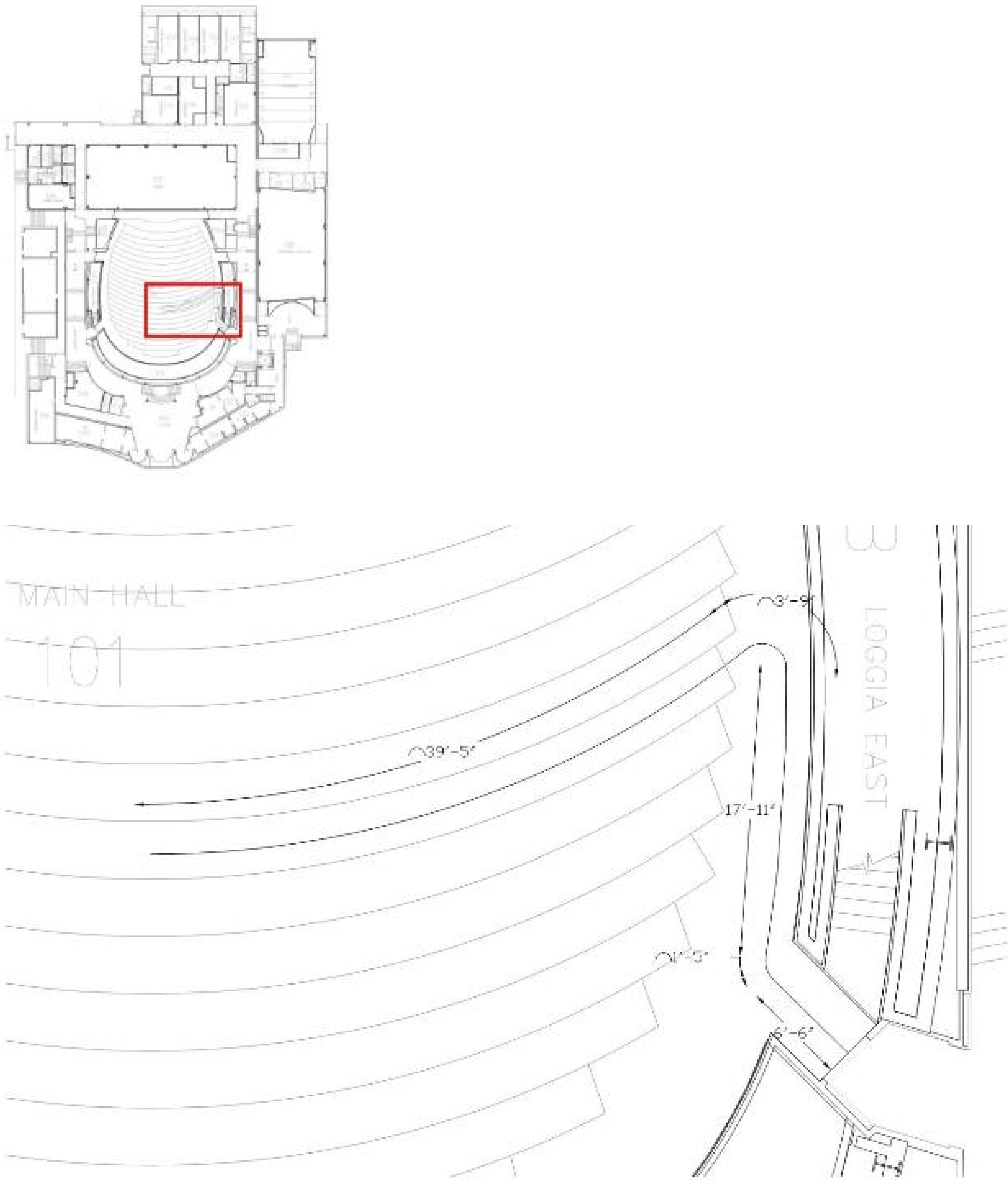

Figure 9. Highest travel distance scenario in the Sydney Harman hall

The highest travel distance scenario at the Sydney Harman Hall is 70 ft., which is below the allowable travel distance limit of 250 ft. for sprinklered Assembly occupancies (Figure 9).

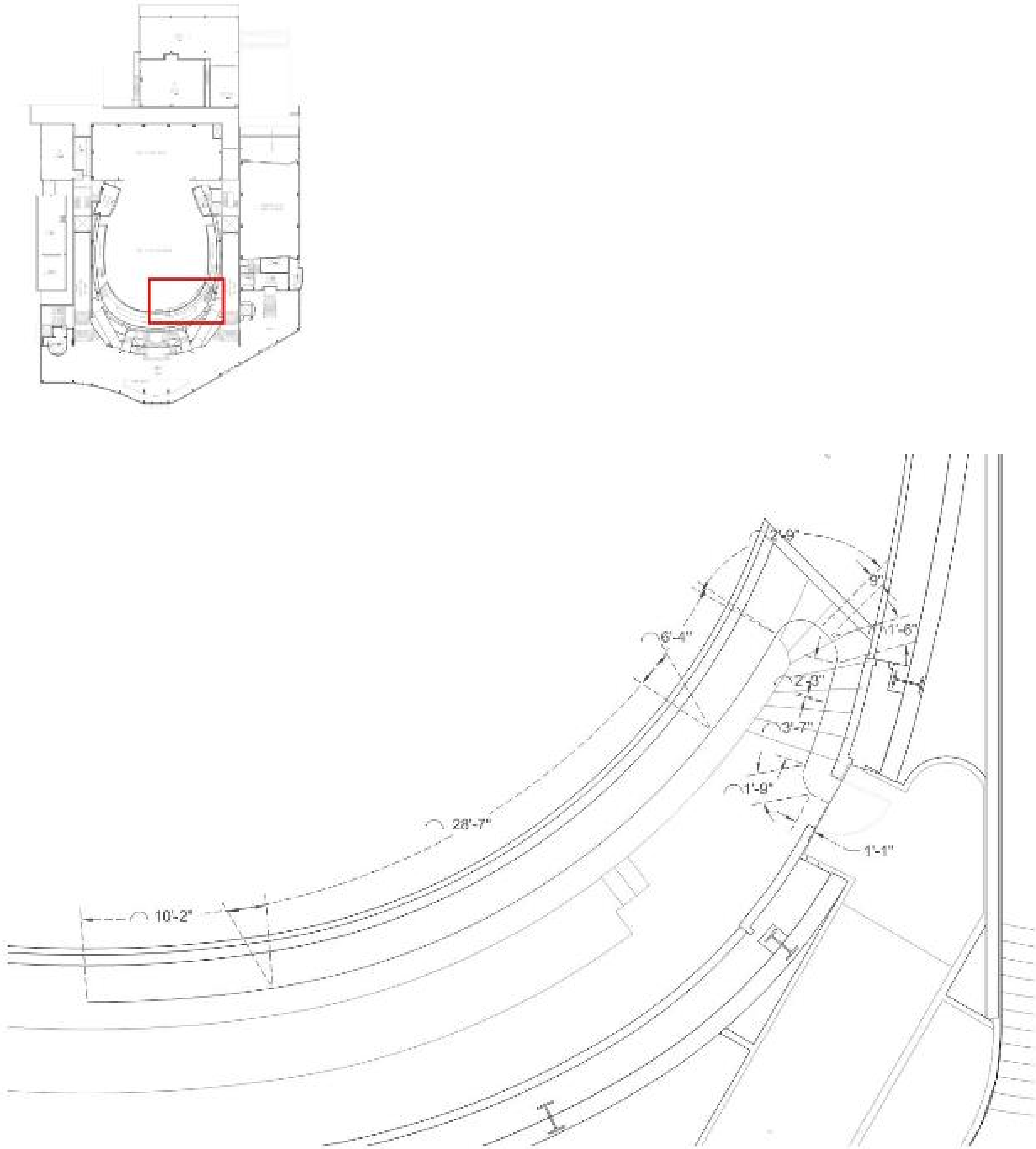

Figure 10. The highest travel distance scenario at the Dress circle

The highest travel distance at the Dress Circle is 59 ft., which is below the allowable travel distance limit of 250 ft. for sprinklered Assembly occupancies (Figure 10).

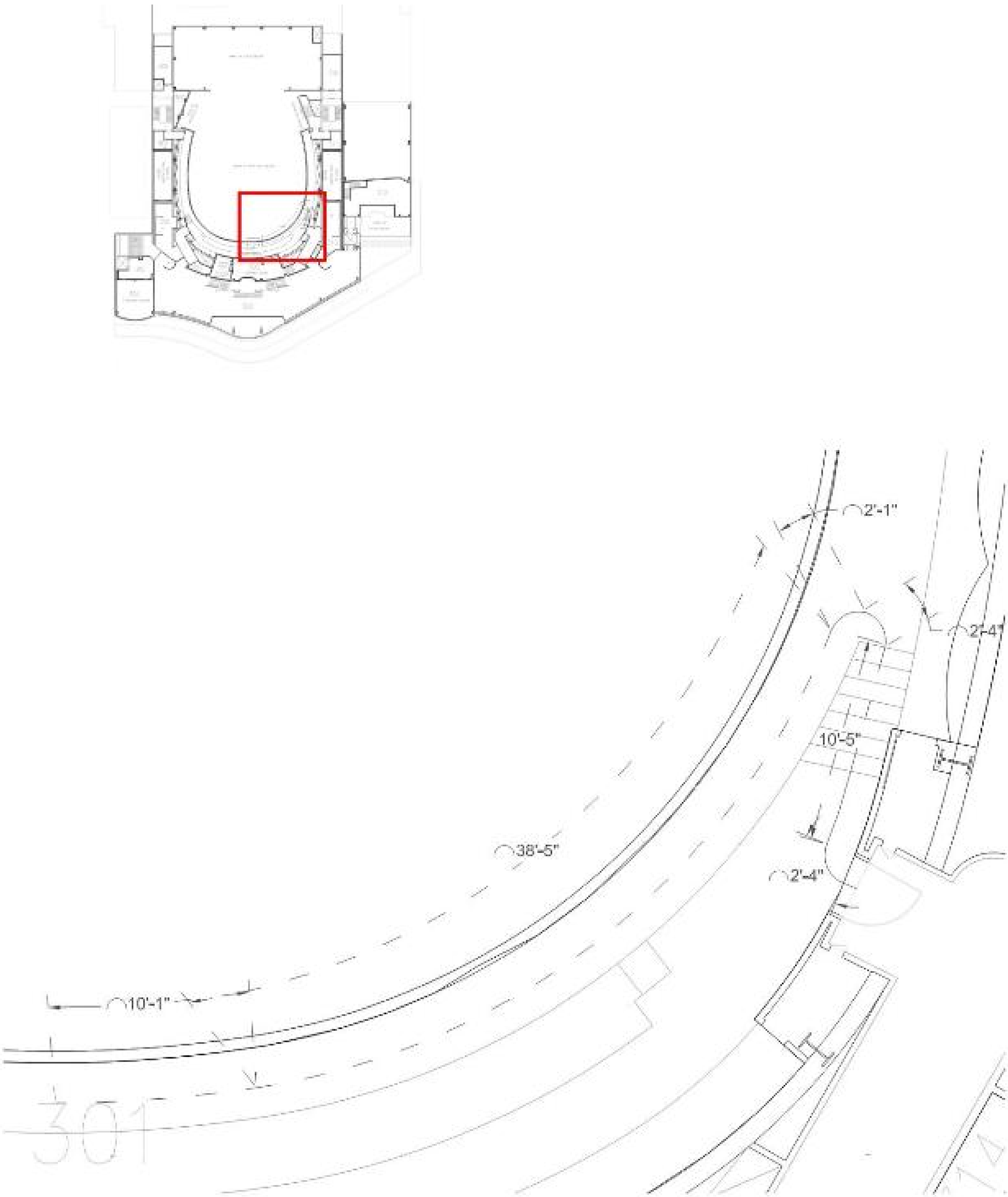

Figure 11. Highest travel distance at the balcony level

Highest travel distance at the Balcony level is 66 ft., which is below the allowable travel distance limit of 250 ft. for sprinklered Assembly occupancies (Figure 11).

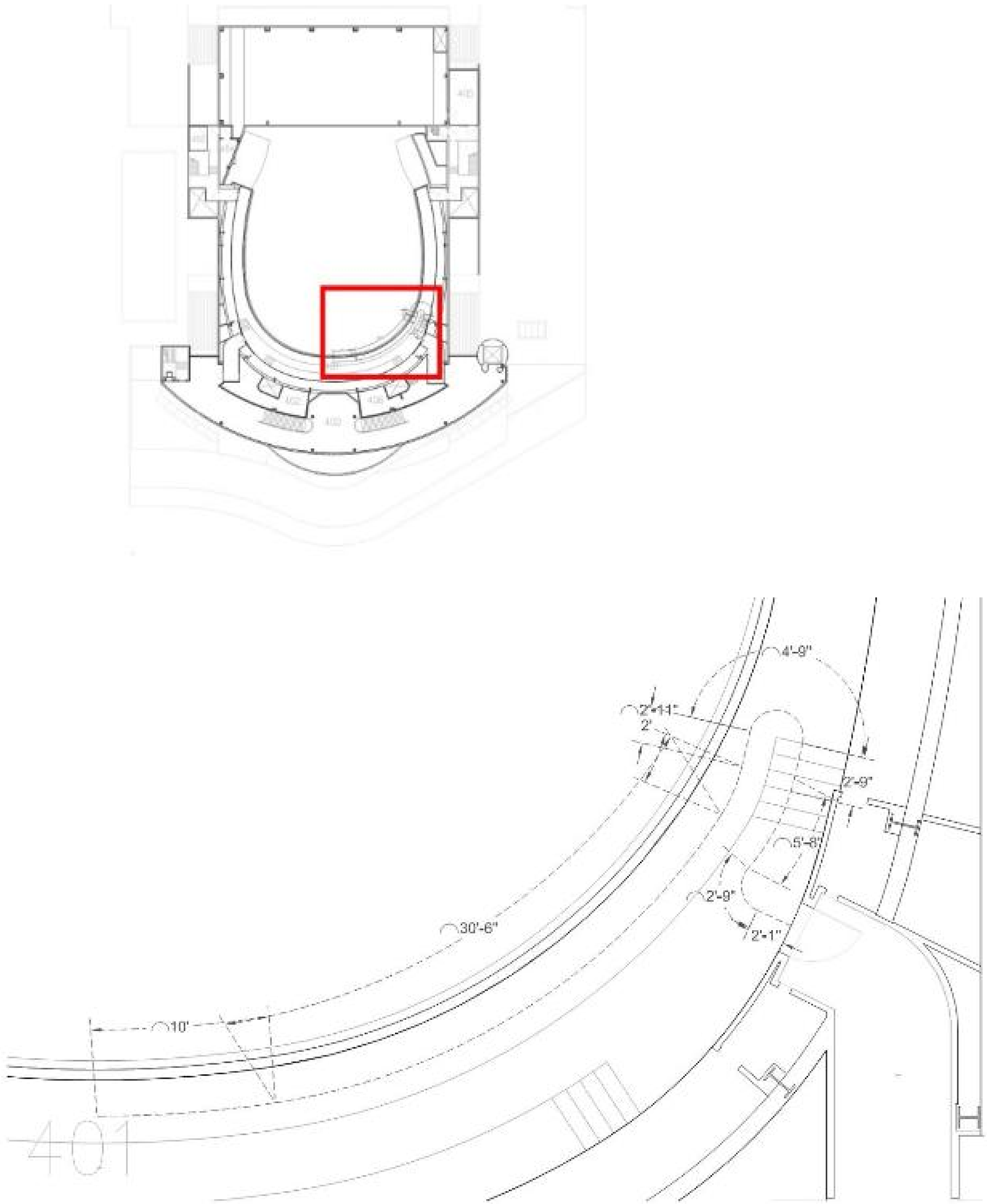

Figure 12. Highest travel distance scenario at the Gallery level

Highest travel distance at the Gallery level is 64 ft., which is below the allowable travel distance limit of 250 ft. for sprinklered Assembly occupancies (Figure 12).

All exits, except the North-east exit stair, discharged to the exterior of the building. The South stair on all floors is open due to unenclosed stairwell. All other exit stairs are provided with 90-min fire-rated doors.

Common paths of travel and dead ends are not present in the building. Exit access corridors are provided with the proper fire protection and fire separation. Emergency evacuation plans and occupant load signs are located adjacent to the exits. Stair designation signs are provided inside the exit stairs.

The egress system meets the prescriptive requirements of IBC. The collective role of egress system along with the evacuation agents still requires a performance-based analysis to be performed, which is discussed in the Evacuation section in the later part of the report.

Suppression

A wet pipe, hydraulically calculated automatic sprinkler system is provided throughout Christopher Cohan Center. Offices and auditorium seating areas are classified as Light Hazard Occupancies. System covering these areas are designed with a density of 0.1 gpm/square foot over the most remote 1,500 square feet. Coverage per sprinkler does not exceed 225 square feet. Storage areas, kitchen and mechanical equipment areas are classified as Ordinary Hazard Group 1. Systems covering these areas are designed with a density of 0.15 gpm/square foot over the most remote 1,500 square feet. Coverage per sprinkler does not exceed 130 square feet in area. Stage and orchestra pit is classified as Ordinary Hazard, Group 2. Systems covering these areas are designed with a density of 0.2 gpm/square foot over the most remote 1,500 square feet. Coverage per sprinkler does not exceed 130 square feet in area. The hazard classification, design density and coverage meets the requirements of NFPA 13.

Water Supply Analysis

For Christopher Cohan Center, city water main is the only water supply serving the fire suppression systems installed in the building. The static pressure was 130 psi; residual pressure was 60 psi at a flow of 1100 gpm at the point of connection to the water supply system, per the flow test information that was conducted on November 9, 1994. This flow test was conducted at the water hydrant located at Tahoe road.

Sprinkler system calculations

Per the occupancy classification provided in NFPA 13, different parts of the building are classified as Light hazard, Ordinary hazard Group 1 and Group 2. Per NFPA 13 section 5.3.2.1, ordinary hazard (Group 2) occupancies shall be defined as occupancies or portions of other occupancies where the quantity and combustibility of contents are moderate to high, and fires with moderate to high rates of heat release are expected. Examples of ordinary hazard (group 2) are cereal mills, distilleries, dry cleaners, feed mills, horse stables, mercantile areas, post offices and repair garages. The assessment of the quantity and combustibility of the contents and expected rates of heat release warrants the stage to be classified as an Ordinary Hazard Group 2. Per section 11.2.3.2.1.2, calculations shall satisfy any single point on the appropriate density / area curve (Figure 13). Due to the higher density requirements for the sprinklers protecting the stage, the required flow and pressure on the system is determined by the flow and pressure calculated for the most remote heads, which are located 81 feet above the stage (node 1-17 of Figure 14).

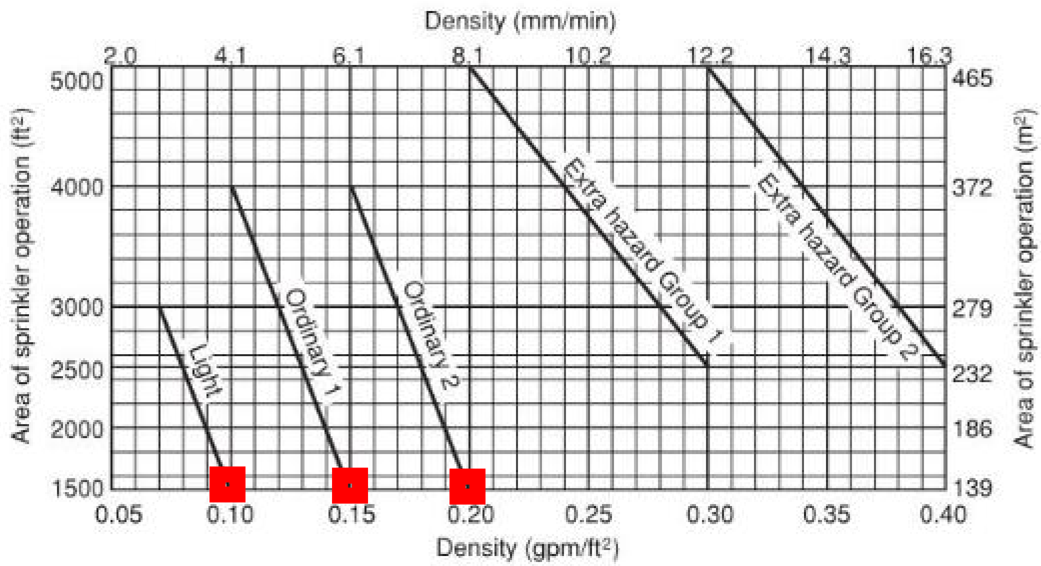

Figure 13. Density/Area Curves for different hazard groups.

$$Number\ of\ sprinklers\ in\ design\ area\ (Ns) = \frac{Area\ of\ operation}{Area\ per\ sprinkler}$$

$$Area\ of\ operation = 1500\ sq.ft.$$

Per NFPA 13 section 23.4.4.1.1.1, for density/area method, design area shall be a rectangular area with the dimension parallel to the branch lines (BL) at least 1.2 times the square root of the area of sprinkler operation (A) used, for A = 1500 sq. ft., L > 46.48 ft. As sprinklers are 11.25 ft. apart, five (5) sprinklers are required along each BL. But each BL contains four (4) sprinklers. So, all four (4) sprinklers along the BLs are incorporated in the calculation area. Four (4) BLs cover an area of 1375.31 sq. ft.

Note that the design area is not a perfect rectangle. The 1500 sq. ft. requirement can be met with an additional sprinkler on the fifth BL, so there is no need to include the additional three (3) sprinklers of the fifth BL (Figure 14).

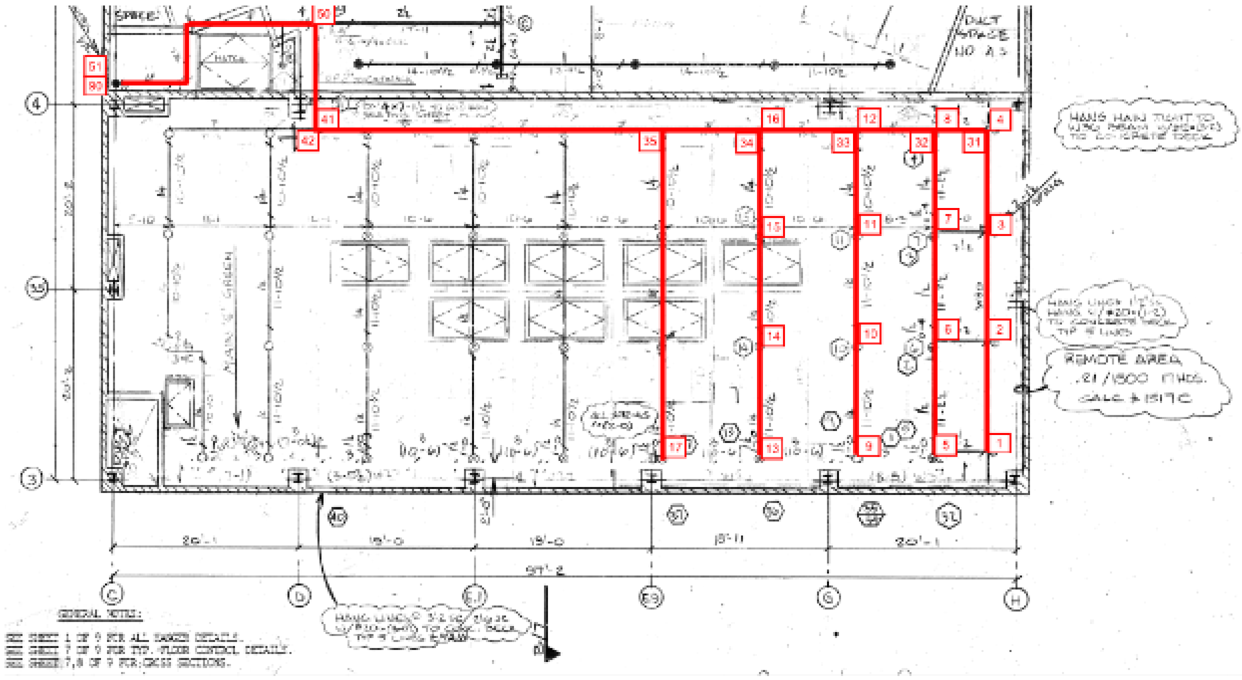

Figure 14. Sprinkler layout at Grid-iron level showing hydraulic nodes 1 - 90.

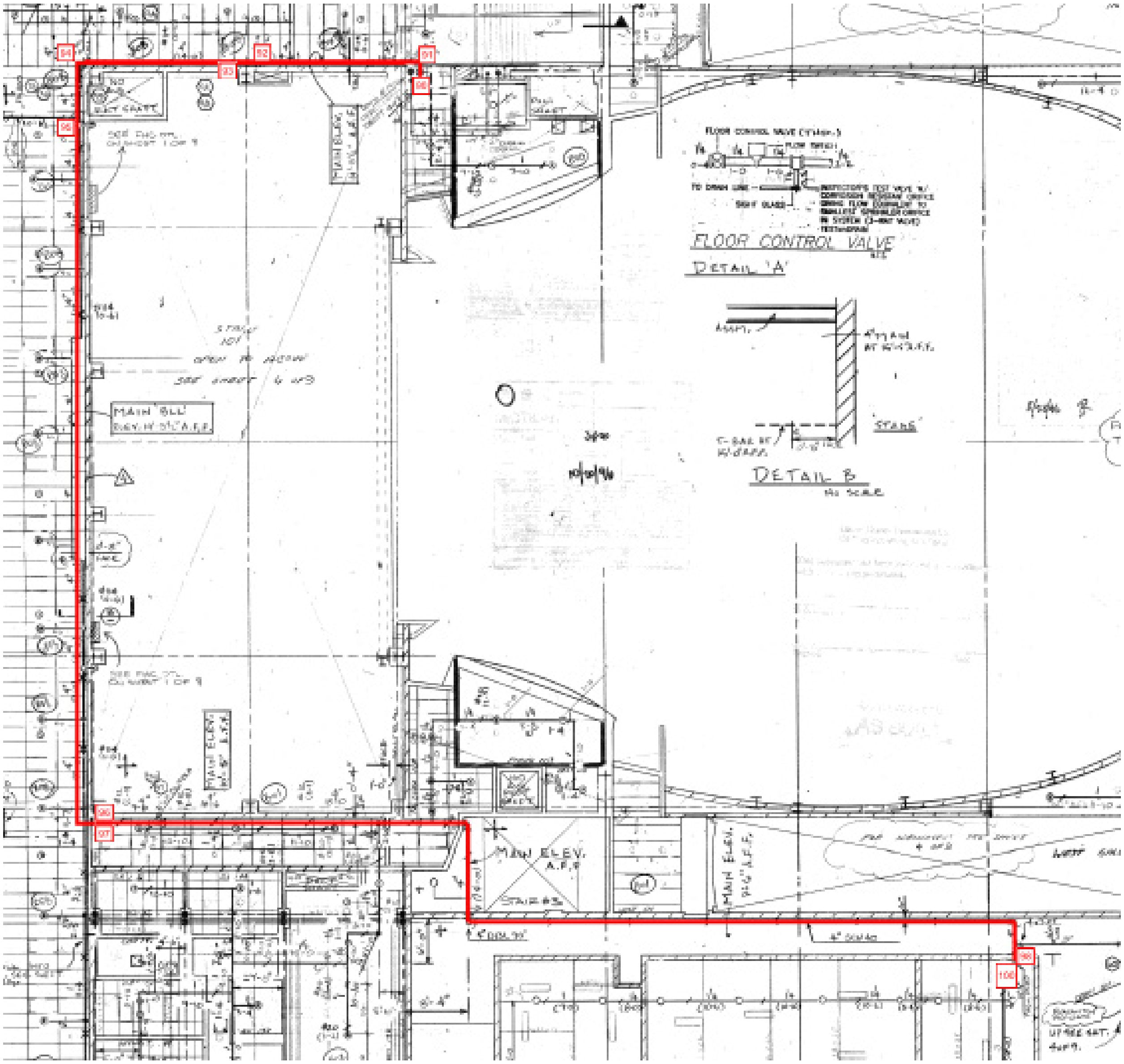

Figure 15. Orchestra stage level plan showing hydraulic calculation nodes 91 - 100.

Node Analysis. Flow and pressure at the most remote sprinkler can be determined by

$$Flow, Q\ (gpm) = density * area\ per\ sprinkler = 0.2\frac{gpm}{sft} * 112\ sft = 22.4\ gpm.$$

$$Pressure, P = 7\ psi\ or\ \left(\frac{Q}{K}\right)^2, whichever\ is\ greater.$$

$$(\frac{Q}{K})^2 = (\frac{22.4}{5.5})^2 = 16.6\ psi$$

K-factor for BL is calculated as $K_{BL} = Q_{BL}/(P_{BL})^{1/2}$. The hydraulic calculation form (Table 7) along with the piping layouts (Figure 14 and 15) are provided to follow the pressure loss and flow requirements calculation in the pipes.

Table 7. Node analysis data

Step No.	Nozzle Ident and Location		Elev (ft)	K-Factor	Flow in gpm		Pipe size	Pipe Fittings and	Equivalent Pipe Length		Friction loss (psi/ft)		Pressure Summary	
	1		456	5.5	q	22.4			L	12	C=	120	Pt	16.6
1		BL-1					1.38		F				Pe	0.0
	2		456		Q	22.4			T	12	pf	0.042	Pf	0.5
	2		456	5.5	q	22.8			L	12	C=	120.00	Pt	17.1
2		BL-1					1.38		F				Pe	0.0
	3		456		Q	45.2			T	12	pf	0.154	Pf	1.9
	3		456	5.5	q	24.0			L	12	C=	120	Pt	19.0
3		BL-1					1.38		F				Pe	0.0
	4		456		Q	69.1			T	12	pf	0.339	Pf	4.1
	4		456	5.5	q	26.4			L	2	C=	120	Pt	23.1
4		BL-1					1.38	E	F	4			Pe	0.9
	31		454		Q	95.5			T	6	pf	0.618	Pf	3.7
	31		454	0	q	0.0			L	7	C=	120	Pt	27.6
5		CM					3.068	T	F	15			Pe	0.0
	32		454		Q	95.5			T	22	pf	0.013	Pf	0.3
	5		456	18.2	q	96.0			L	36	C=	120	Pt	27.9
6		BL-2					1.38	E	F	4			Pe	0.9
	32		454		Q	96.0			T	40	pf	0.623	Pf	24.9
	32		454	0	q	0.0			L	8	C=	120	Pt	27.9
7		CM					3.068	T	F	15			Pe	
	33		454		Q	191.5			T	23	pf	0.046	Pf	1.1
	9		456	18.2	q	97.8			L	36	C=	120	Pt	29.0
8		BL-3					1.38	E	F	4			Pe	
	33		454		Q	97.8			T	40	pf	0.645	Pf	25.8
	33		454	0	q	0.0			L	10.5	C=	120.0	Pt	29.0
9		CM					3.068	T	F	15			Pe	0.0
	34		454		Q	289.3			T	25.5	pf	0.098	Pf	2.5
	13		456	18.2	q	101.9			L	36	C=	120	Pt	31.5
10		BL-4					1.38	E	F	4			Pe	0.9
	34		454		Q	101.9			T	40	pf	0.696	Pf	27.9
	34		454	0	q	0.0			L	10.5	C=	120	Pt	31.5
11		CM					3.068	T	F	15			Pe	0.0
	35		454		Q	391.3			T	25.5	pf	0.171	Pf	4.4
	17		456	5.5	q	32.9			L	36	C=	120	Pt	35.8
12		BL-5					1.38	E	F	4			Pe	0.0
	35		456		Q	32.9			T	40	pf	0.086	Pf	3.4
	35		454	0	q	0.0		T	L	35	C=	120	Pt	39.3
13		CM					3.068	L	F	20			Pe	0.0
	41		454		Q	424.2			T	55	pf	0.199	Pf	10.9
	41		454	0	q	0.0		E4	L	120	C=	120	Pt	50.2
14		R					4.026	T6	F	150.8			Pe	21.2
	90		405		Q	424.2		L2C1	T	270.8	pf	0.053	Pf	14.3
	90		405	0	q	0.0		E4	L	380	C=	120	Pt	85.8
15		FM					4.026	T6	F	188			Pe	13.0
	100		375		Q	424.2		LC	T	568	pf	0.053	Pf	30.1
													Pt	**128.8**
					Q	**424.2**								

Hose Stream Allowance. Per NFPA 13 minimum water demand requirements for a sprinkler system shall be determined by adding the hose stream allowance (HSA) to the water demand for sprinklers (NFPA 13 section 11.1.4.2). Per Table 11.2.3.1.2 of NFPA 13, total hose stream allowance of 250 gpm is required to be supplied for the duration of minimum 60 minutes. Table 8 shows the result of the hydraulic analysis.

Table 8. Sprinkler design data for Grid-iron level.

Occupancy classification:	Ordinary hazard, group 2
Density:	0.2 gpm/sq. ft. [NFPA 13 section 11.2.3.2.1.2]
Area of application:	1500 sq. ft. [NFPA 13 section 11.2.3.2.1.2]
Number of sprinklers calculated:	17 sprinklers
Total sprinkler water flow required:	424.2 gpm
Total Hose Stream Allowance at Source:	250.0 gpm
Total water required (including hose):	674.2 gpm
Required pressure	128.8 psi
Available pressure at total demand	100 psi
Sprinkler orifice size:	½ inch.

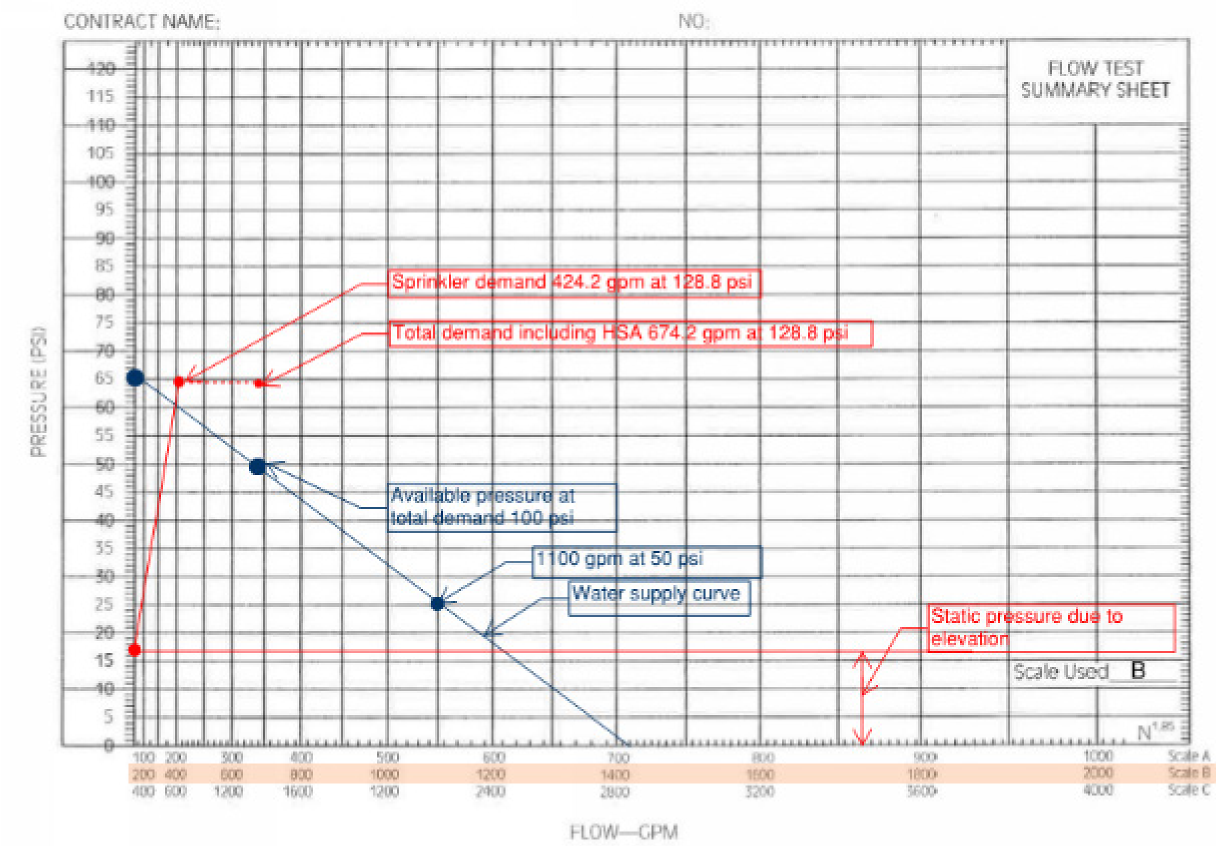

Figure 16. Hydraulic graph showing supply and demand curve. The values on the y-axis are doubled.

Figure 16 shows the total water demand for the sprinkler system. The city water supply is not adequate for the sprinkler system and hose stream demands. The total demand for the system is 674.2 gpm at 128.8 psi. From the graph, we can see, at 674.2 gpm flow rate the available pressure is 100 psi, hence not meeting the demand.

Supervision

Water flow detection devices are provided at lateral connections to the riser (Figure 17). Valve supervision devices are provided on all sprinkler water valves. Central station monitoring is provided for all valve supervision and water flow detection devices.

Figure 17. A flow detector and supervision device connected to a riser and control valve.

Standpipes.

Standpipe risers are combined with automatic sprinkler risers. Class II standpipe are located on each side of the stage. Figure 18 shows one of the standpipe connection located at the stage.

Figure 18. Class II Standpipe system with a fire extinguisher.

Inspection, Testing and Maintenance Requirements

Maintenance procedures are critical, such as those required by NFPA 25; Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems includes evaluation of the factors that affect system performance.

Frequency and Timing of Testing and Inspection. NFPA 25 requires testing of representative samples of installed sprinklers periodically to verify continued performance. Testing and inspection should comprise 1% of the total number of sprinklers installed in the facility and never be less than four sprinklers. Replacement is necessary of any sprinkler that shows signs of: contamination (loading), corrosion and paint (other than the paint applied by the manufacturer).

Dust. Light dust may be found on sprinklers which are less serious than hard deposits. Dust may delay the operation of sprinklers but not prevent the eventual discharge of water. Dust can be blown or brush off. Compressed air may create dust explosion or ignition hazard. Brushes should be soft to avoid possible injury to sprinkler parts.

Advance Preparations before Shutoff. It is dangerous when water supply is shut off (protection is interrupted). Effort must be made to limit the extent and duration of the interruption. Notify the fire department whenever impairment exists. Plan to work for a time when the least hazard exists. Work should be done on a weekend or another idle period. Utilize special guard service if required, to help in detection of any fire that might develop while the systems are shut off. Sectional valves, rather than main values, should be used to reduce to a minimum the number of shutoff systems and to take advantage of multiple water supplies. For underground mains tapping machines should be used when possible to avoid shutting off the water. During shutoff maintain the maximum possible water supply. When repair or modifications are necessary, a fire protection system may need to be taken out of service. It is Ideal to appoint an impairment coordinator familiar with the operation of the system. During any equipment shutdown, a lockout and/or tag out procedure should be in place. A tag should be posted on any valve that is closed.

Control Valves and Meters. Tightness of check valves should be determined periodically by proper tests arranged and located in accordance with the appropriate NFPA standards. Valves should be readily accessible and unobstructed. Valves must be able to be operated promptly and examined. Pits for gate valves and check valves should be dry and clean. Manhole covers should be kept clear. Each control valve should be numbered, identified, cataloged by location, portion of the system, etc. Locations should be posted at a central point known to public fire officials. Check valves should have a sign showing what it controls; with the legend "Must Be Open at All Times". Underground valve sites should be shown by location and by distance markings on nearby buildings and on accurate plans of the property. Wrenches should be kept at post indicator valves or at locations where they are readily accessible.

Sprinklers and Sprinkler Piping. Clearance of sprinklers should be reviewed. Obstructions by high-piled stock, walls, or partitions that might prevent free and proper water distribution. Clear space of 18 in. below the deflectors of the sprinklers is required.

Position of Deflectors. Distance of deflectors from the ceiling or the bottom of beams or joists should conform to NFPA 13. Items should never be stacked close to fire sprinklers. Tops of storage or furniture should be at least 18" below fire sprinklers.

Support of Piping. Loose hangers and loose, unsupported pipes should be looked for. Sprinkler piping and hangers should never be used for purposes unrelated to its function.

System Water Flow Tests. NFPA 13 requires a water supply test of pipe and pressure gauges to be provided at locations that will permit flowing tests to be made to determine whether water supplies and connections are in order. A 2-in. diameter drain at the sprinkler riser may suffice as a water supply test pipe. The valve of the water supply test pipe must be installed so that the valve may be opened wide for a sufficient time to ensure a proper test, without causing

water damage. At each inspection, an individual flow test should be made for each water supply and each connection from a supply. System water flow test shall be accomplished by closing all water supplies temporarily, except the one under test. To make sure that there is free flow at good pressure and to test the water flow alarm system water flow tests shall be operated atleast twice a year. Two tests, the Main Drain Test and the Inspector's Test, should be conducted to ensure sprinkler systems and sprinkler water flow alarms are operational and water supplies are not impaired.

Inspector's Test. The area around the inspector's test discharge should be checked to determine that the water released during the test will drain away safely and not cause damage. The inspector's test valve should be opened fully and allow the water to run for a minimum of 90 seconds or until the audible alarm on the premises operates. The time the valve was opened should be recorded for confirmation with the alarm monitoring company receipt of the alarm. An audible alarm on the premises should operate within five minutes of opening the inspector's test connection and water flow begins. The inspector's test valve should be closed. The time the valve was closed should be recorded for confirmation with the alarm monitoring company receipt of the alarm. Water flow alarms should be restored on the local fire alarm control unit (panel).

Main Drain Test. Check the area around the main drain discharge pipe should be checked to ensure that water will drain away safely and not cause damage. The main control valve should be unlocked so that it can be shut quickly if a problem develops during the test. The valve should be closed two or three turns, and then the valve should be returned to the fully open position. This should send a tamper signal to the alarm company. The static pressure should be recorded on the supply side pressure gauge prior to the test. The main drain valve should be opened slowly

until it is fully open. The water should be allowed to flow until the pressure stabilizes, then the residual pressure should be recorded using the same gauge. The main drain valve should be closed slowly to avoid water hammer. When it is closed, the static pressure should be recorded on the supply side pressure gauge.

Fire Department Connections. It should be ensured that the caps are in place, threads are in good condition, ball drip or drain is in order and check valve is not leaking. Hydrostatic test should be conducted periodically on older FDC piping to ensure that it will withstand the required pressure.

Automatic sprinkler protection is provided in Christopher Cohan Center as required by IBC. No records or assertions of regular testing or maintenance of the automatic sprinkler system were collected. A Class II standpipe system is provided in the building. As an assembly occupancy building with a legitimate stage, Christopher Cohan Center requires a Class II standpipe system. No records or assertions of regular testing or maintenance of the standpipe system were collected. These systems are supplied from city water main having a reported static pressure of 130 psi and residual pressure of 60 psi when 1100 gpm flowing, which does not meet the hydraulic demand, calculated for the most challenging design area. There was no fire pump connected to the system. A fire pump appears to be needed for the standpipe system and automatic sprinkler system demand.

Fire detection and alarm systems

A fire alarm system is provided in accordance with provisions of IBC. The fire alarm system consists of initiation devices, both manual and automatic; a fire alarm control panel to process incoming alarm, supervision and trouble signals and activate desired output devices; an

occupant notification system, consisting of both audible and visual devices, and a connection to a central station monitoring service.

The alarm system receives alarm signals from manual pull stations, automatic sprinkler water flow indicators, automatic smoke detectors and automatic heat detectors. A manual alarm system is provided. Manual pull stations (Figure 19) are provided adjacent to exit stair doors, adjacent to required stage exits and wherever additional stations are required along the exit path to not exceed a 200-foot travel distance to the nearest station.

Figure 19. Standard UL-listed manual pull stations used at Christopher Cohan Center.

Occupant notification system

The occupant notification system is an approved public address system. The activation of any alarm signal automatically activates the voice alarm system. An approved pre-recorded message announcement is played. Manual controls for activating the voice alarm system or making general announcements are provided adjacent to the fire alarm control panel. Table 9 provides the model number for different types of anunciation devices that are installed at the Christopher Cohan Center. Figure 20 shows an exemplar speaker-strobe installed in the premise.

Table 9. Model numbers of the notification devices used in Christopher Cohan Center

	Model#	CSFM #
Speaker strobe (wall mounted) (Figure 20)	ET-1070-LSM-24-VFR	7125-0785125
Speaker strobe	ET-1070-LSM-24-VFR	7125-0785.125
Speaker only	4902-9702	7320-0026199
Visual only	4904-9135	7125-0026198
Remote Lamp	2098-9808	7300-0026150

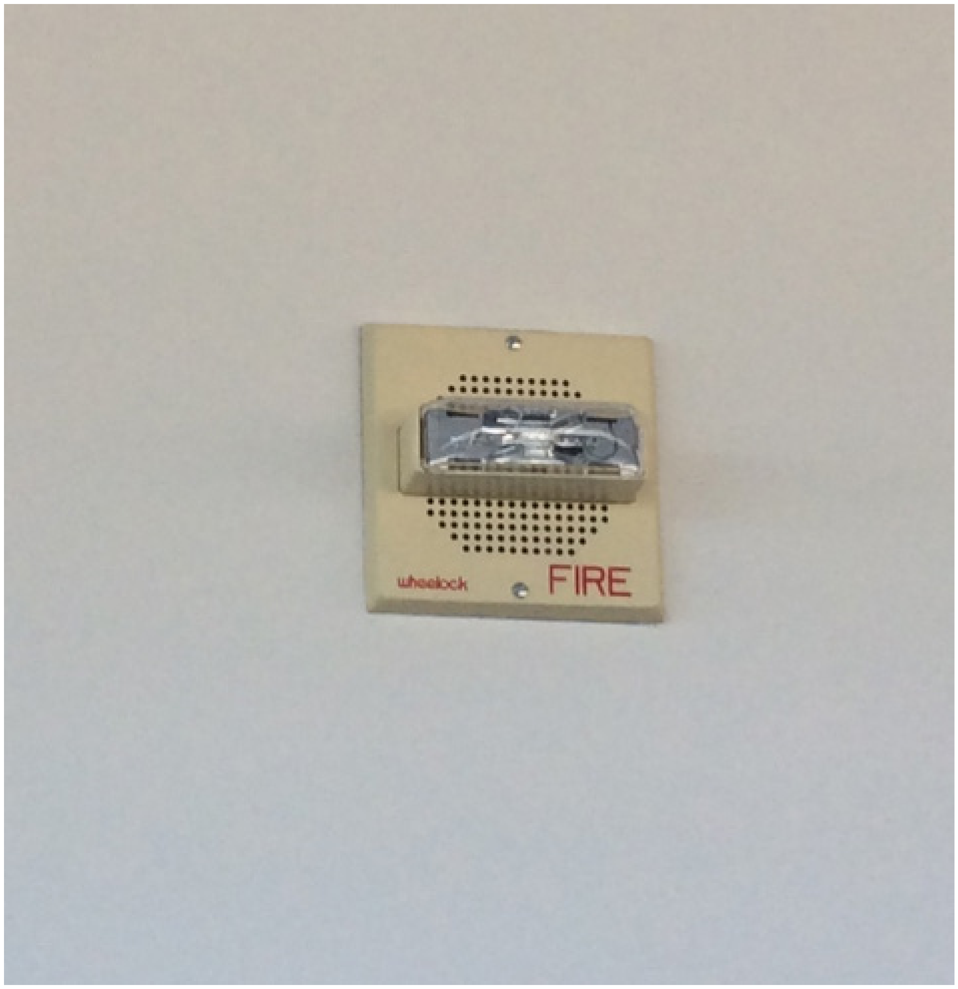

Figure 20. Standard UL-listed speaker-strobe used at Christopher Cohan Center.

Fire Alarm Control Panel

The location of the Fire Alarm Control Panel is at the Security Room on the Lower Level. The model number is 4120-8210. Figure 21 shows the fire alarm control panel. A fire alarm miniplex panel is provided with a model number 4120-8210. The location of the main Fire Alarm Control Panel and the miniplex panel is shown in Figure 22.

Figure 21 Fire Alarm Control Panel

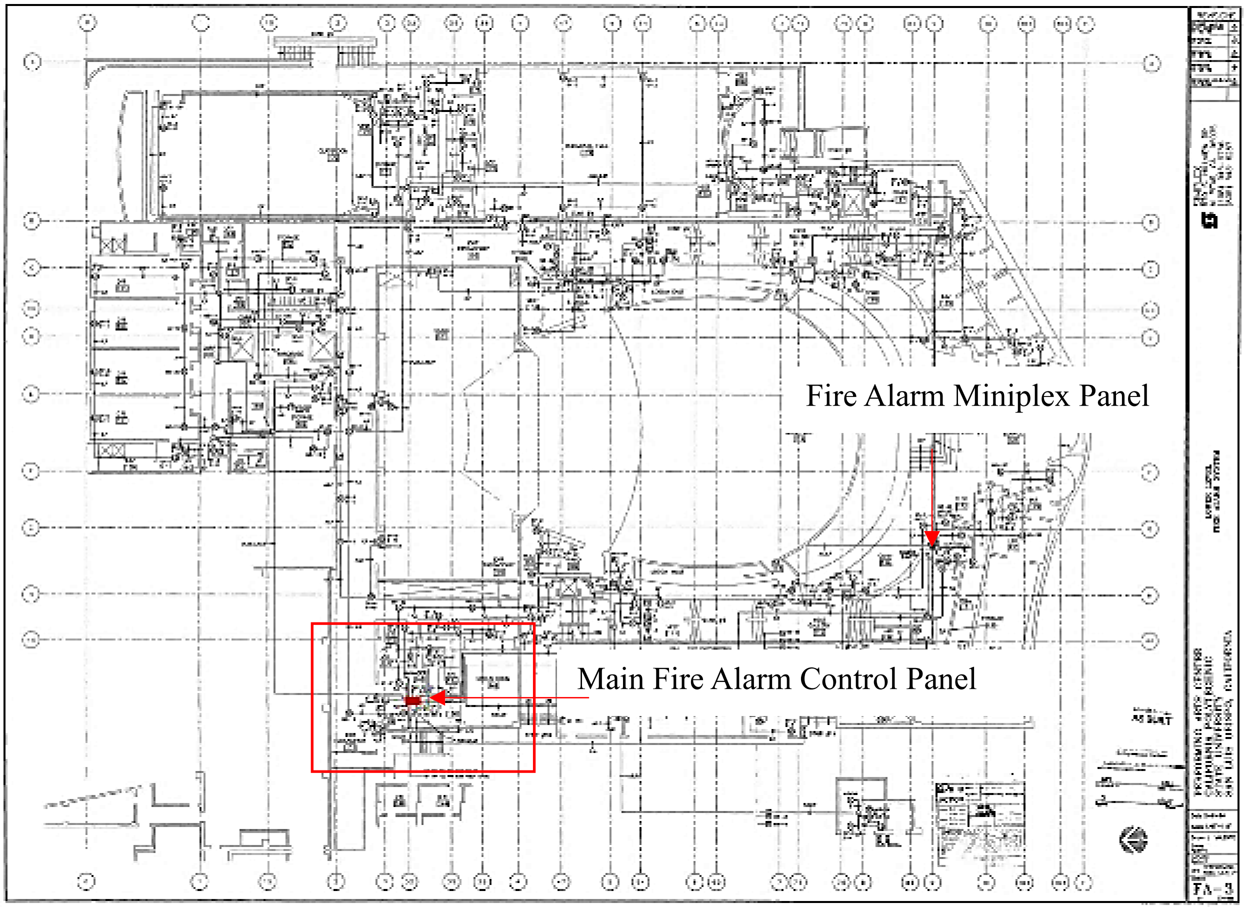

Figure 22 Location of Fire Alarm Control Panel and the miniplex panel.

Fire Signatures and Detection Devices

The types of initiating devices that are installed in the Christopher Cohan Center are as followed.

1. Smoke and Ionization Detectors
2. Rate of Rise Heat Detectors
3. Break Glass, Fire Reporting Stations
4. Break Glass Stations with Bell and Strobe above
5. Connections to Flow Switches
6. Connections to Tamper Switches
7. Connections to Flow and Tamper Switches
8. Smoke and Ionization Detectors with Sampling Tubes

Table 10 provides model numbers of the initiating devices that are installed.

Table 10. Model and CSFM numbers of initiating devices.

	Model #	CSFM#

Smoke Detector	2098-9201 (Head), 2098-9651 (Base)	7272-0026132 (Head), 7300-0026149 (Base)
Smoke Detector	4098-9783 (Base), 4098-9701 (Head), 2098-9737 (Relay)	7300-0026165 (Base), 7272-0026166 (Head), 7300-0026013 (Relay)
Heat Detector	4098-9731 (Head), 4098-9781 (Base)	7270-0026176 (Head), 7300-0026165 (Base)
Manual Pull Station	2099-9795	7150-0026175
Door Holder	2088-9585	3550-0026176
Duct Detector	2098-9702 (Housing), 20988-9201 (Head)	3240-0026159 (Housing), 7272-0026132 (Head)
Tamper Switch		
Water Flow Switch		
Remote Lamp	2098-9808	7300-0026182

Location, spacing and placement of fire detection devices

The locations of initiating devices installed in different levels are shown in Figure 23, 24, 25, 26, 27 and 28.

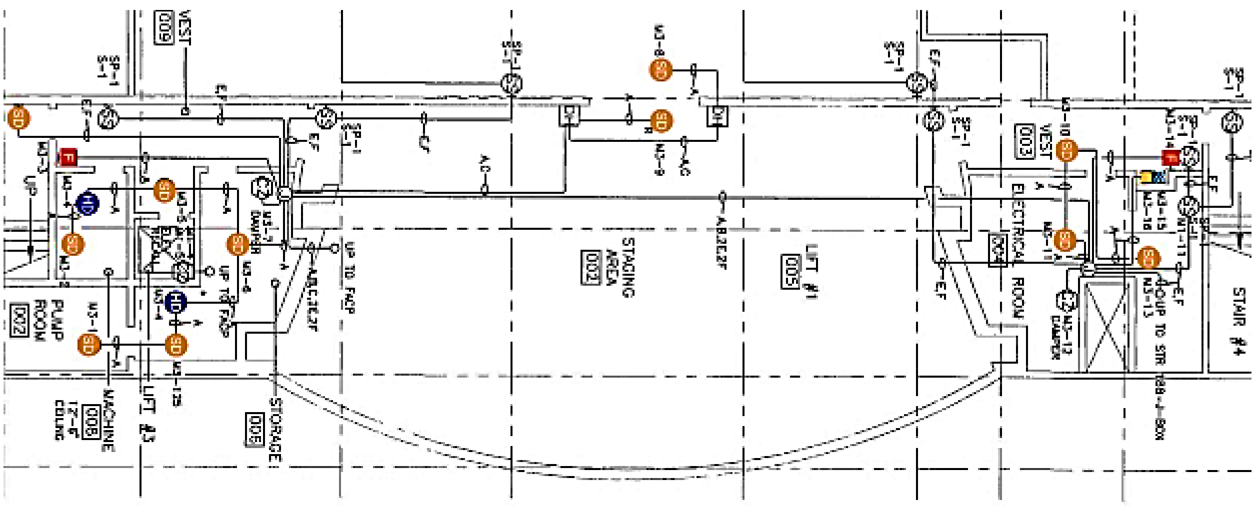

Figure 23. Location of initiating devices on the Basement.

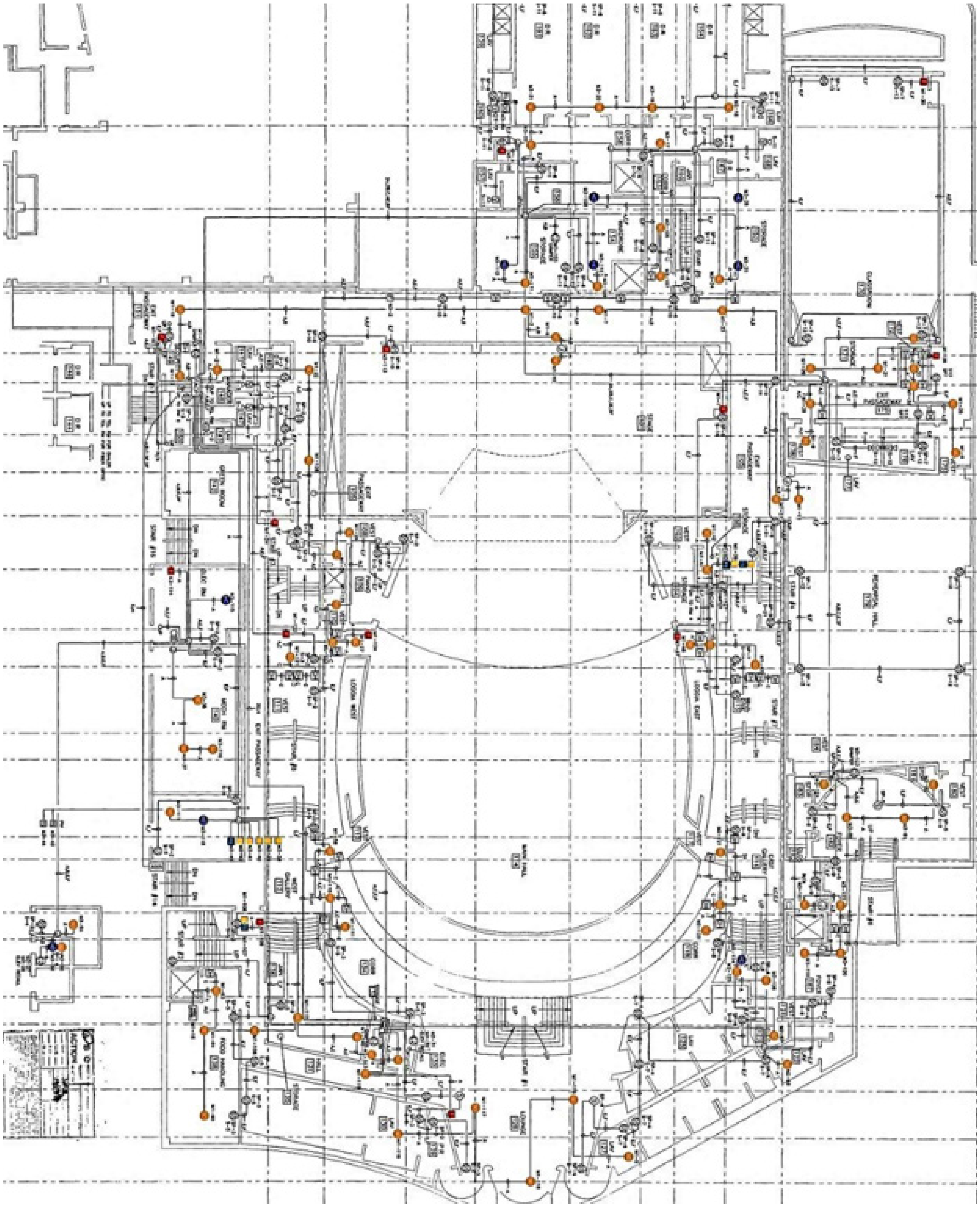

Figure 24. Location of initiating devices on the Orchestra stage level.

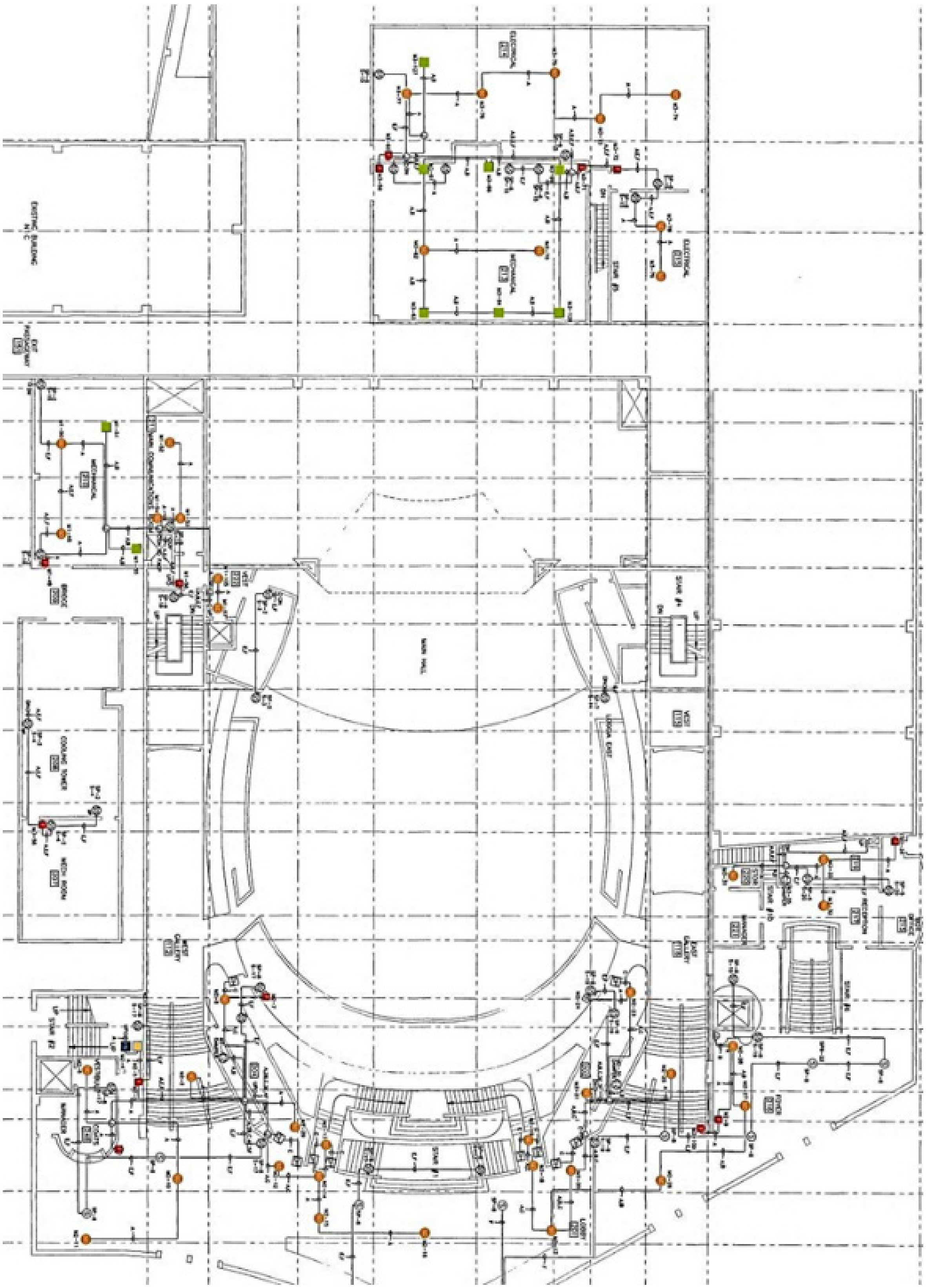

Figure 25. Location of the initiating devices on the Entry Lobby level.

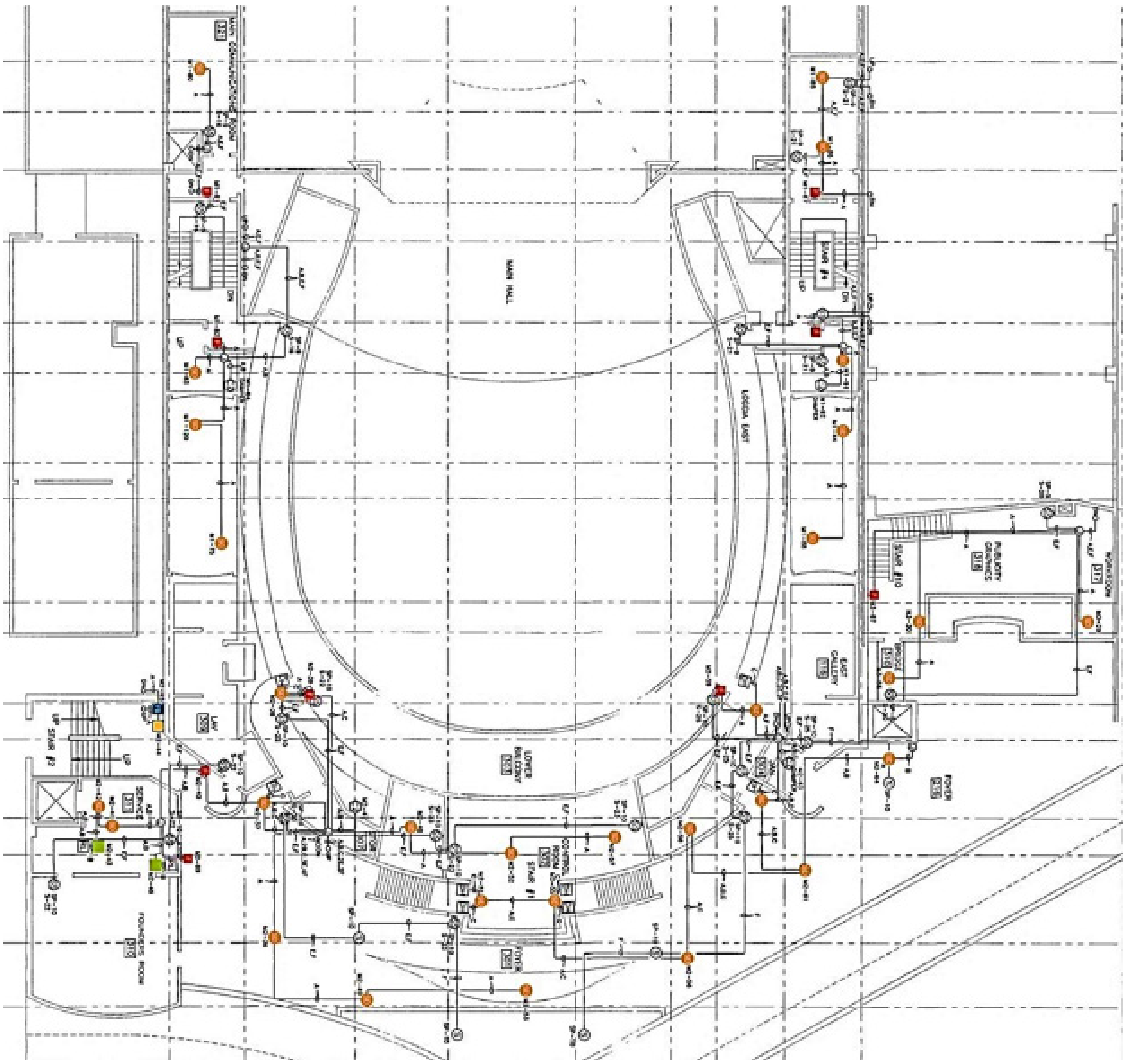

Figure 26. Location of initiating devices on the Balcony level.

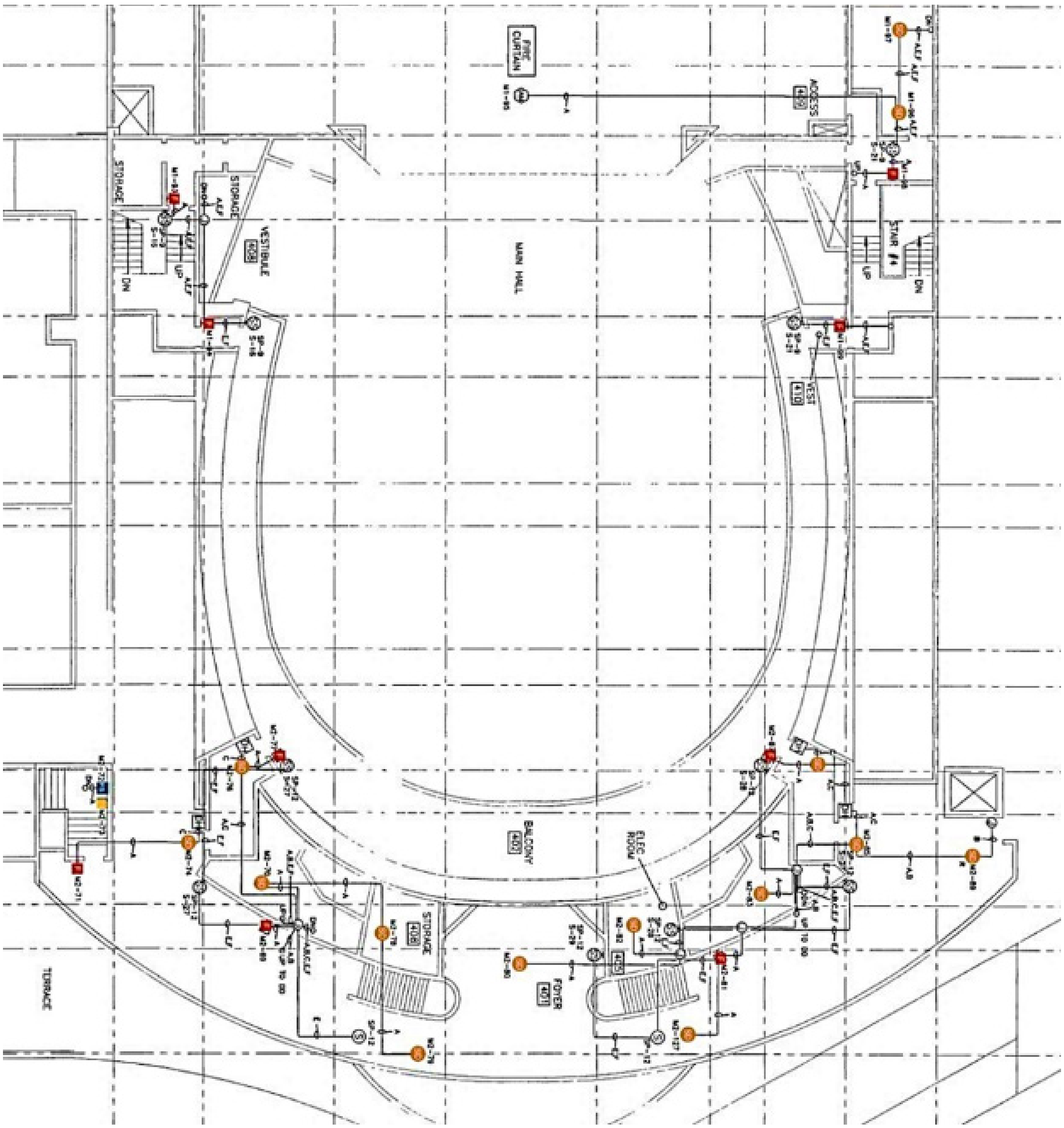

Figure 27. Location of initiating devices on the Gallery level.

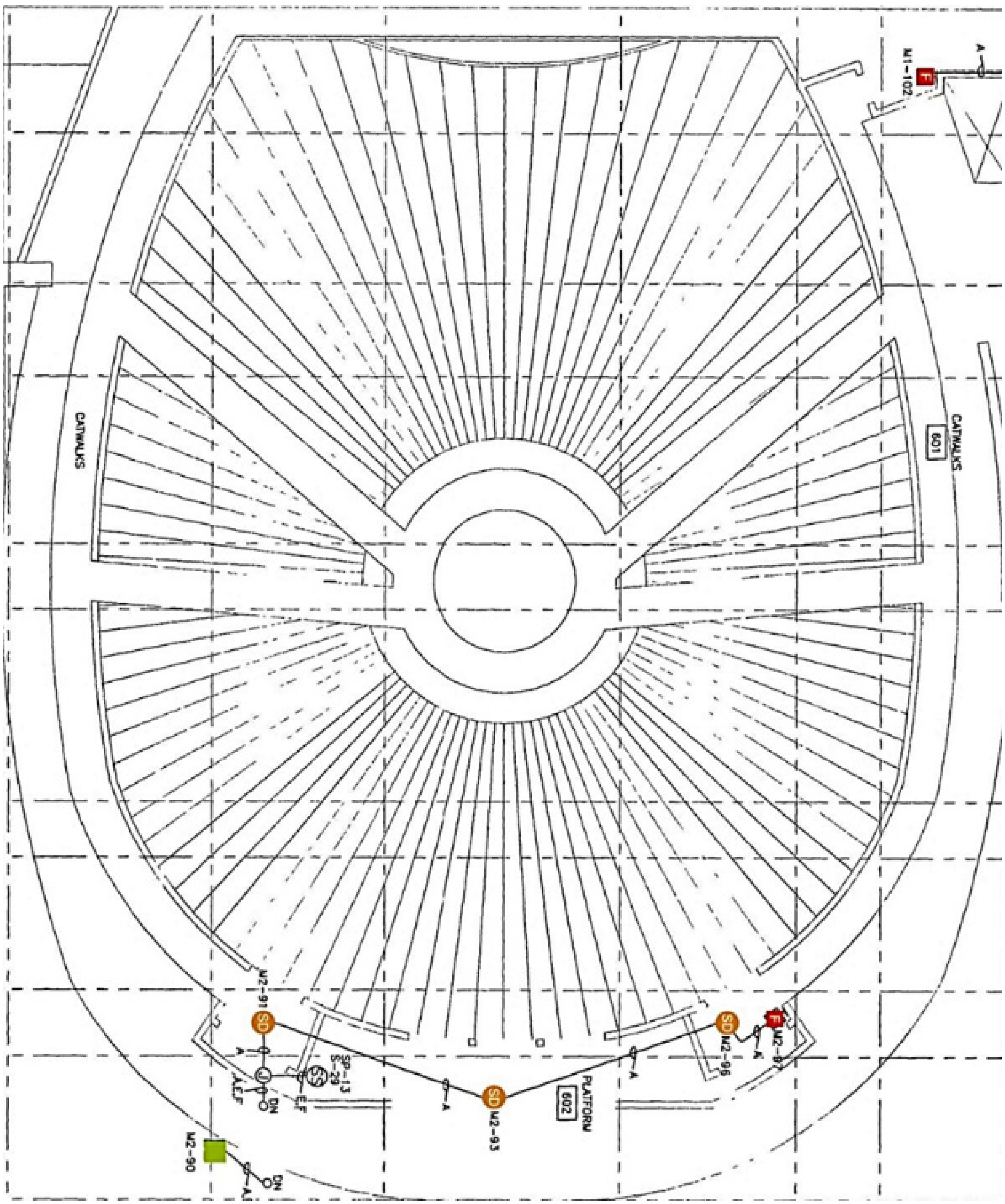

Figure 28. Location of initiating devices on the Catwalk level.

Fire alarm system response requirements

Alarm, supervisory and trouble signals are received at the central station monitoring service. The fire alarm receives alarm signals from manual pull stations, automatic sprinkler water flow indicators, automatic smoke detectors and automatic heat detectors as shown in the sequence of matrix (Table 11).

The fire alarm receives supervisory and trouble signals from sprinkler water supply valve tamper switch, emergency power status and public notification system.

The central station monitoring service is required to perform the following actions upon receipt of an alarm signal:

1. Immediately retransmit alarm to communications center.
2. Dispatch a runner or technician to arrive within 2 hours if equipment needs to be manually reset by prime contractor.
3. Immediately notify the management of the Performing Arts Center.
4. Provide notice to AHJ if required.

The central station monitoring service is required to perform the following actions upon receipt of a supervisory signal:

1. Communicate immediately with the persons designated by the administration of Performing Arts Center and notify the Fire Department when required by the AHJ.
2. Dispatch a runner or maintenance person within 2 hours to investigate.
3. Notify the AHJ when sprinkler systems or other suppression equipment has been out of service for 8 hrs. And provide notice when service has been restored.

The central station monitoring service is required to perform the following actions upon receipt of a trouble signal:

1. Communicate immediately with the persons designated by the administration of Performing Arts Center and dispatch personnel to arrive within 4 hours to initiate maintenance if necessary.

2. Notify the AHJ if required when interruption is more than 8 hrs.

Sequence of operation matrix

Table 11. Sequence of operation matrix.

Device	Activate Speaker / Strobe	Signal CSMS	Trouble indication	Supervisory signal	System to run on battery back-up
Manual pull station	X	X			
Smoke detector	X	X			
Heat detector	X	X			
Duct detector	X	X			
Water flow	X	X			
Tamper switch		X	X	X	
System trouble		X	X	X	
Power failure		X	X	X	X

Battery requirements

Battery requirements are calculated for the miniplex and fire alarm control panel (Table 12, 13, 14, 15, 16 and 17).

Miniplex.

The miniplex panel modules require total 0.82 AH current to stand-by. The field devices require additional 0.185 AH current. For 24-hour standby, the panel needs a total of 24.144 AH capacity. The panel modules and the field devices require a total of 18.7 AH during alarm mode. For five minutes of alarm, the panel needs 1.55 AH. Adding the required current for 24-hr stand-

by and 5-minutes of alarm, the battery requires a minimum of 25.7 AH battery capacity. A 50 AH battery is provided.

Table 12. Panel modules of the minplex panel.

Q	Product ID	Description	Standby		Alarm	
			Each	Total	Each	Total
1	4120-0110	Mapnet II Module	0.47	0.47	0.49	0.49
1	4120-0203	Audio AMP 25W	0.25	0.25	8.75	8.75
3	4120-4331	6 Signal circuit, style Y	0.025	0.075	0.07	0.21
1	4120-3003	8-point aux relay	0.025	0.025	0.28	0.28
		Panel standby current		0.82		
		Panel alarm current				9.73

Table 13. Field devices connected to minplex panel.

Q	Product ID	Description	Standby		Alarm	
			Each	Total	Each	Total
4	2098-9645	Addressable duct detector	0.024	0.096	0.024	0.096
9	2190-9163	Control zam	0.01	0.09	0.04	0.36
2	2098-9808	Remote alarm indicator	0	0	0.115	8.51
74	ET-1070-LSM-24-VFR	Wheelock Audio/visual	0	0	0.115	8.51
		Device standby current		0.186		
		Device alarm current				8.968

Table 14. Total system current for miniplex panel

Description	Standby	Alarm
Control panel	0.82	9.73
Field devices	0.186	8.968
Total standby current	1.006	
24-hour standby	24.144	
Total alarm current		18.698
5 minutes of alarm		1.551934
Total battery requirement		25.695934
Battery supplied		50 AH

Fire alarm control panel

The panel modules require a total of 1.585 AH during stand-by and 21.04 AH during alarm. The field devices require 0.334 AH during stand-by and 11.796 AH during alarm. Total standby current is calculated to be 1.919 amp for 1 hour. So, 46.056 AH capacity is needed for 24-hour stand-by operation. Total alarm current is calculated to be 32.836 amp for 1 hour. So, for five minutes of alarm 2.72 AH current is needed. For 5-minute alarm and 24-hr stand-by operation, a total of 48.78 AH current capacity is required. A battery with 50 AH capacity is provided.

Table 15. Panel modules for the main panel.

Q	Product ID	Description	Standby		Alarm	
			Each	Total	Each	Total
1	4120-0110	Mapnet II Module	0.47	0.47	0.49	0.49
1	4120-0201	Audio AMP 25W	0.15	0.15	2	2
2	4120-0203	100W Amplifier W/P.S 120 V	0.25	0.5	8.75	17.5
1	4120-0210	Single channel audio controller	0.185	0.185	0.185	0.185
1	4120-0301	LED/SW Controller	0.015	0.015	0.26	0.26
1	4120-3002	4 relays	0.015	0.015	0.175	0.175
4	4120-4321	6 signal circuit, style Y	0.025	0.1	0.07	0.28
1	4120-6011	RS-485 Network interface card	0.15	0.15	0.15	0.15
		Panel standby current		1.585		
		Panel alarm current				21.04

Table 16. Field devices connected to the main panel.

Q	Product ID	Description	Standby		Alarm	
			Each	Total	Each	Total
9	4904-9135	Wall-mount strobe	0	0	0.1	0.9
11	2098-9645	Addressable duct detector	0.024	0.264	0.024	0.264
7	2190-9163	Control zam	0.01	0.07	0.04	0.28
2	2098-9808	Remote alarm indicator	0	0	0.001	0.002
90	ET-1070-LSM-24-VFR	Wheelock Audio/visual	0	0	0.115	10.35
		Device standby current		0.334		

Device alarm current	11.796

Table 17. Total system current requirement for main panel.

Description	Standby	Alarm
Control panel	1.585	21.04
Field devices	0.334	11.796
Total standby current	1.919	
24-hour standby	46.056	
Total alarm current		32.836
5 minute of alarm		2.725388
Total battery requirement		48.781388
Battery supplied		50 AH

Voltage drop

Highest percentage of voltage drop is identified at the signal circuit connecting the strobes at the orchestra stage level. The calculation is shown below.

Device	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Gauge wire	12	12	12	12	12	12	12	12	12	12
Distance (ft)	218	68	18	111	30	8	48	7	27	13
AMPs at device	1.12	1.005	0.89	0.775	0.66	0.56	0.46	0.345	0.23	0.115
AMPs developed volt drop	0.776	0.217	0.50	0.273	0.062	0.014	0.070	0.007	0.0197	0.0047

Total CKT VD	1.49786
CKT Voltage	24
% voltage drop	6.24108

Christopher Cohan Center relies primarily on sprinklers and manual fire alarm system for detection and annunciation. Although IBC allows omission of manual fire alarm boxes in the presence of sprinkler system, the Christopher Cohan Center is equipped with both. The exception does not eliminate the provision for occupant notification system, and accordingly, a public-

address system is provided in the building. The public-address system should allow the automatic alarm signals to be overridden for live voice instructions. However, the conjunction of all these systems requires effective sequence of operation matrix in place, which is found to be present.

The building has an addressable fire alarm system built around a Honeywell Notifier alarm panel. The system supported smoke detectors, heat detectors, manual pull stations and speaker-strobe units installed throughout the complex. No functional test was conducted on the system during the inspection. No records or assertions of regular testing or maintenance of the fire alarm system were collected.

Interconnected smoke and heat detectors are in various places throughout the building. These detectors are tied into the fire alarm system. In the event, they detect smoke and heat, they would send a signal to the fire alarm control panel to activate the fire alarm. No records or assertions of regular testing or maintenance of the fire detection system were collected.

Stage Smoke Removal

Gravity vents are located near the center and at the highest point above the stage. The gravity vents are activated by a fusible link. Manual controls are also provided. The total gravity vent area is approximately 224 square feet which exceeds the minimum 5% of stage floor area required by IBC section 410.3.7.1. Figure 29 shows an exemplar gravity vent, which is like the ones installed in Christopher Cohan Center.

Figure 29. A part of the product data sheet of the smoke vent used at Christopher Cohan Center.

Recommended Fire Safety Management Practices

Public Assemblages and Events

Fire watch personnel. Because of the number of persons, and the nature of the performance, exhibition, display, contest and activity, the management, agent and lessee should provide one or more fire watch personnel. It is essential for public safety in Christopher Cohan Center. Fire watch personnel should remain on duty during the times the place is open to the public, and when such activity is being conducted.

Duties. Fire watch personnel should keep diligent watch for fires. They should see if any obstructions or other hazards are present at the means of egress, during the time the building is open to the public and an activity is being conducted. They should take prompt measures for remediation of hazards, extinguishment of fires that occur and assist in the evacuation of the public from the structure.

Crowd managers. Trained crowd managers shall be provided for facilities or events where more than 1,000 persons congregate. The minimum number of crowd managers shall be established at a ratio of one crowd manager to every 250 persons.

Emergency Evacuation Drills

Frequency. Required emergency evacuation drills shall be held quarterly or more frequently if necessary to familiarize all employees including the volunteers with the drill procedure.

Leadership. Responsibility for the planning and conduct of drills shall be assigned to competent persons designated to exercise leadership.

Time. Drills shall be held at unexpected times and under varying conditions to simulate the unusual conditions that occur in case of fire.

Record keeping. Records shall be maintained of required emergency evacuation drills and include the following information:

a. Identity of the person conducting the drill.

b. Date and time of the drill.

c. Notification method used.

d. Staff members on duty and participating.

e. Number of occupants evacuated.

f. Special conditions simulated.

g. Problems encountered.

h. Weather conditions when occupants were evacuated.

i. Time required to accomplish complete evacuation.

Initiation. Emergency evacuation drills shall be initiated by activating the fire alarm system.

Accountability. As building occupants arrive at the assembly point, efforts shall be made to determine if all occupants have been successfully evacuated or have been accounted for.

Recall and reentry. An electrically or mechanically operated signal used to recall occupants after an evacuation shall be separate and distinct from the signal used to initiate the evacuation. The recall signal initiation means shall be manually operated and under the control of the person in charge of the premise or the official in charge of the incident. No one shall enter the premise until authorized to do so by the official in charge.

Employee Training and Response Procedures

General. Employees shall be trained in the fire emergency procedures described in their fire evacuation and fire safety plans.

Frequency. Employees shall receive training in the contents of fire safety and evacuation plans and their duties as part of new employee orientation and at least annually thereafter. Records shall be kept and made available to the fire code official upon request.

Employee training program. Employees shall be trained in fire prevention, evacuation and fire safety in accordance with the following:

Fire prevention training. Employees shall be apprised of the fire hazards of the materials and processes to which they are exposed. Each employee shall be instructed in the proper procedures for preventing fires in the conduct of their assigned duties.

Evacuation training. Employees shall be familiarized with the fire alarm and evacuation signals, their assigned duties in the event of an alarm or emergency, evacuation routes, areas of refuge, exterior assembly areas and procedures in the event of an emergency lockdown.

Emergency lockdown training. Employees shall be trained on their assigned duties and procedures in the event of an emergency lockdown.

Fire safety training. Employees assigned fire-fighting duties shall be trained to know the locations and proper use of portable fire extinguishers or other manual fire-fighting equipment and the protective clothing or equipment required for its safe and proper use.

Use and Occupancy-related Requirements

Announcements. In Christopher Cohan Center, an audible announcement shall be made not more than 10 minutes prior to start of each program to notify the occupants of the location of the exits to be used in the event of a fire or other emergencies.

Performance-based analysis

The SFPE Engineering Guide to Performance Based Fire Protection defines performance based design as "an engineering approach to fire protection design based on (1) agreed upon fire safety goals and objectives, (2) deterministic and/or probabilistic analysis of fire scenarios, and (3) quantitative assessment of design alternatives against the fire safety goals and objectives using accepted engineering tools, methodologies, and performance criteria."

This definition identifies three key attributes of performance-based design. The first is a description of the desired level of fire safety in a building (or other structure) in the event of a fire. The second attribute includes definition of the "design basis" of the building. The "design basis" is an identification of the types of fires, occupant characteristics, and building characteristics for which the fire safety systems in the building are intended to provide protection. In the vernacular of performance-based design, these fires are referred to as "design fire scenarios." The third element involves an engineering analysis of proposed design strategies to determine whether they provide the intended level of safety in the event of the design fire scenarios.

In the process of evaluating Christopher Cohan Center, these three attributes of performance-based design are used. The desired level of safety in the building in the event of a fire would thought to be achieved if the performance objectives set by the International Building Code are fulfilled. The performance objectives that are specified in the International Building Code commentary, which are applicable to the context of Christopher Cohan Center are –

1. limit the threat from stage fires to an audience
2. reduce the likelihood of a large fire in the stage area
3. reduce the opportunity for irrational mass response to a perceived emergency.

Deterministic analysis of fire scenarios in Christopher Cohan Center

In a deterministic analysis, scenarios that are expected to occur with a frequency above a threshold value are analyzed to determine their consequences. If the consequences of those scenarios are within the design objectives, then the design is acceptable.

Design Fire Scenarios

Per NFPA 101 section 5.5.3 design fire scenarios should comply with the following:

(1) Scenarios selected as design fire scenarios shall include, but shall not be limited to, those specified in 5.5.3.1 through 5.5.3.8.

(2) Design fire scenarios demonstrated to the satisfaction of the authority having jurisdiction as inappropriate for the building use and conditions shall not be required to be evaluated fully.

NFPA 101 5.5.3.1 Design Fire Scenario 1. It is an occupancy-specific fire representative of a typical fire for the occupancy. It explicitly accounts for the occupant activities, number and location of occupants, room size, contents and furnishings, fuel properties and ignition sources, ventilation conditions, identification of the first item ignited and its location.

NFPA 101 5.5.3.2 Design Fire Scenario 2. Design Fire Scenario is an ultrafast-developing fire, in the primary means of egress, with interior doors open at the start of the fire. It addresses the concern regarding a reduction in the number of available means of egress.

NFPA 101 5.5.3.3 Design Fire Scenario 3. Design Fire Scenario 3 is a fire that starts in a normally unoccupied room, potentially endangering many occupants in a large room or other area. It addresses the concern regarding a fire originating in a concealed space that does not have either a detection system or a suppression system and then spreading into the room within the building that potentially holds the greatest number of occupants.

NFPA 101 5.5.3.4 Design Fire Scenario 4. Design Fire Scenario 4 is a fire that originated in a conceal wall or ceiling space adjacent to a large occupied room. It addresses the concern regarding a fire originating in a concealed space that does not have either a detection system or a suppression system and then spreading into the room within the building that potentially holds the greatest number of occupants.

NFPA 101 5.5.3.5 Design Fire Scenario 5. Design Fire Scenario 5 is a slowly developing fire, shielded from fire protection systems, near a high occupancy area. It addresses the concern regarding a relatively small ignition source causing a significant fire.

NFPA 101 5.5.3.6 Design Fire Scenario 6. Design Fire Scenario 6 is the most severe fire resulting from the largest possible fuel load characteristic of the normal operation of the building. It addresses the concern regarding a rapidly developing fire when occupants are present.

NFPA 101 5.5.3.7. Design Fire Scenario 7. Design Fire Scenario 7 is an outside exposure fire. It addresses the concerns regarding a fire starting at a location remote from the area of concern and either spreading into the area, blocking escape from the area, or developing untenable conditions within the area.

NFPA 101 5.5.3.8. Design Fire Scenario 8. Design Fire Scenario 8 is a fire originating in ordinary combustibles in a room or area with each passive or active fire protection system independently rendered ineffective. It addresses concerns regarding the unreliability or unviability of each fire protection system or fire protection feature, considered individually. It is not required to be applied to fire protection systems for which both the level of reliability and the design performance in the absence of the system are acceptable to the authority having jurisdiction.

Historically, most significant theater fires originated on the stage. The 1903 Iroquois Theater fire in Chicago serves as a vivid example of a stage fire and its potentially tragic effects—602 people lost their lives. Hazards associated with the stage include: combustible scenery and lighting suspended overhead; scenic elements, contents and acoustical treatment on the back and sides of the stage; technical production areas including dressing rooms located around the stage perimeter; and storage areas located underneath the stage. Design fire scenario 1 and 6 are applicable in evaluating the fire hazards in Christopher Cohan Center originating on the stage, as these two scenarios talks about occupancy-specific fire representative of a typical fire with the concern regarding a rapidly developing fire when occupants are present.

IBC section 410.3.6 recognizes that scenery and sets used in the stage are decorative materials. As such, combustible materials used in sets and scenery are required to meet the fire propagation performance criteria in accordance with the provisions of NFPA 701 Standard Methods of Fire Tests for Flame Propagation of Textiles and Films, Section 806 and the IFC. Section 806 references Section 2604 for specific requirements for foam plastics used as trim. The materials when tested in accordance with NFPA 701 must comply with the performance criteria of one of the two identified test methods.

Curtains, draperies, and wall coverings can ignite from such ignition sources as electrical malfunction. It has been shown that large differences exist between the potential of various curtain materials to the production of heat and smoke. Curtains in public occupancies are regulated by local authorities and conforming materials do not seem to present major problems during the initial stages of a fire. NFPA 701 recently addressed that, even if single layers of curtain fabrics pass the requirements of the standard, the combination of two or three layers, may burn vigorously.

Flammability characteristics of materials used in sets and scenery

Materials that are used to create sets and sceneries are divided into two major classes: (1) flexible materials, such as textiles and cushioning; and (2) structural materials, which can include wood or engineered wood composites and synthetic thermoplastics and plastic foams (Figure 30). For both classes of materials there is a variety of tests to determine their susceptibility to ignition. However, since ignition requires the volatilization of some of the solid fuel, ignition behavior is strongly dependent on the amount of heat applied to the surface. Therefore, different ignition tests often give different results, depending on the size of the ignition source. The same principle applies to tests that attempt to measure flame spread over small samples. The larger the amount of sample burning, the greater the heat transferred to the unburned area ahead of the flame and a large sample will appear to have a higher flame spread rate than a small one.

The ignitability, flame spread and heat release rates, total heat produced, heat shrinkage, and ease of fire extinction in textile materials depend on the type of fibers used, their percent content, the configuration of the fabric, its weight, and its construction. The finish generally does not alter these properties significantly, unless the fabric is treated with a flame retardant. Flame-retardant treatments can be either durable or nondurable. Normal laundering and dry cleaning may reduce flame retardancy.

All common natural fibers contain organic compounds and the elements carbon and hydrogen and often also oxygen and nitrogen. Coating added to textile fabrics can greatly alter their combustibility. Several coatings are commonly applied to fabrics or bonded to fabrics to create laminates. Coated or laminated fabrics exhibit combustibility characteristics of the coating or film and the fiber used. Chlorine is found in vinyl-coated fabrics.

Thermoplastics are hard to ignite. There are, however, many situations in which thermoplastics can burn readily, especially when they are stiffened by finishes or heavy dye application, causing them to lose their ability to evade flames and ablate. It also occurs in blends of thermoplastic and char-forming fibers, for example, in the popular polyester/cotton blends, which burn more like 100 percent cotton than 100 percent polyester. A thermoplastic fiber fabric in contact with a char-forming fabric, for example, a polyester curtain in contact with a foam lining, can burn readily. Finally, if an ablated thermoplastic fabric still flames when it falls, it can ignite garments or furnishings near it.

The ranges of decomposition, melting, ignition, and the burning temperatures of the flames are often quite wide for any one fiber because of the differences in methods for measuring such temperatures, as well as the variety of polymer compositions used in each fiber group for various end uses. In the case of nylon, there are two major types, Nylon 6 and Nylon 66, which vary in the structure of the base molecule. For the ignition temperature of cotton, one finds two values in the literature, that is, 490 and 750°F (255 and 400°C); it is possible that the lower value was obtained with aged cotton. The ignition temperature of blends tends to be like that of the component with the lower ignition temperature. Thus, measured by one method, the ignition temperature for 14 different fiber types ranged from 750°F (400°C) for cotton to 1110°F (600°C) for wool; 50/50 blends of cotton and another fiber ranged from 770 to 860°F (410 to 460°C).

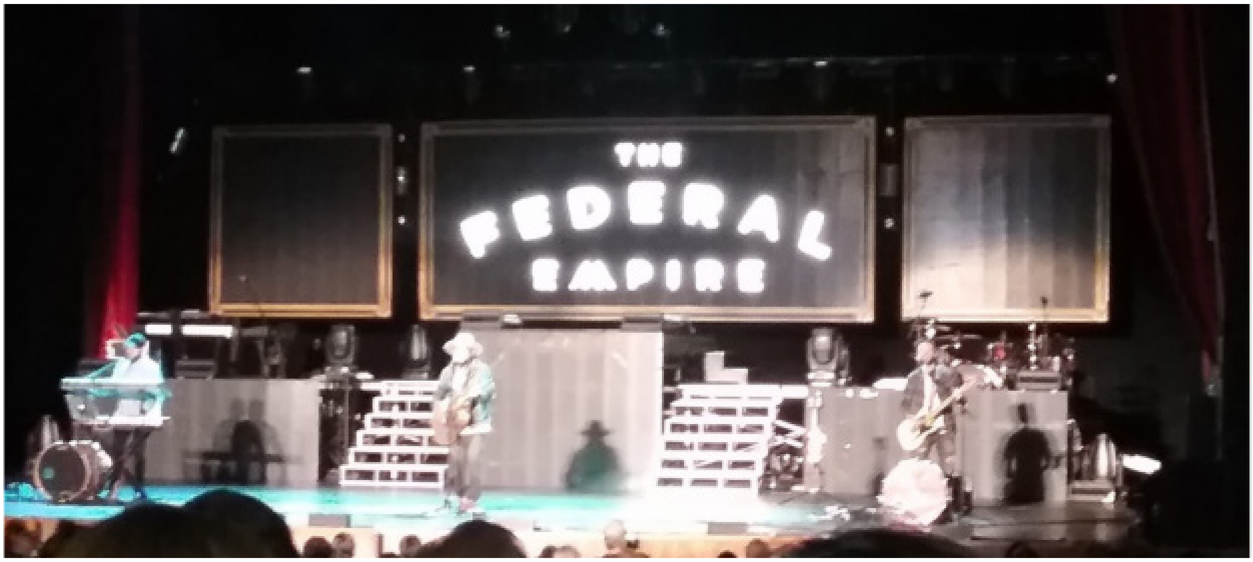

Figure 30. A set made of flexible and structural materials on the stage of Christopher Cohan Center.

Effect of orientation

Vertical configuration is quite common in the stage, as seen on Figure 31. Fabrics generally burn faster in the vertical position than in the horizontal position. The edge of the fabric will also ignite much more easily than the surface, given the ability of the flame to contact more than one side. Some fabrics melt when burned, form a pool, and require other combustibles to act as a wick before their full combustibility can be exhibited.

Fire established on vertical combustible surfaces are especially dangerous because of the potential for rapid upward fire spread. Such surfaces are common in the stage environment. Flames on vertical burning surfaces transition from a steady laminar flow to a turbulent flow near the flame base. With increasing height on the vertical surface, flame thickness increases proportionally, which results in increased thermal radiation both to the material surface and outward to potential targets.

Upward flame spread is driven by heat transfer in the region between the top of the active burning zone and the flame tip. Because of the heat transfer in this region, ignition occurs after a time controlled by thermal inertia. For a combustible surface that can support upward flame

spread, the rate of increase of flame height is proportional to the current flame height, which translates into an exponential increase in flame height with time or a constant time to doubling of flame height. Therefore, vertical surface burning is so hazardous.

On a vertical surface, the heat flow to the lowest 6 to 10 in. of the surface from the flames is dominated by convective heat transfer, but the remainder of the burning surface above this level is primarily subject to thermal radiation heat transfer. The burning vertical surface receives a roughly constant 10 kW/m^2 of convective heating, a low level partly due to the cooling effect of the flow of fuel vapors from the surface. In contrast to convection, levels of radiant heat flux incident on the burning material surface increase steadily with height until flames become optically thick. The layer of cool soot-laden vapor near the material surface is less effective in blocking the incident radiation for a wall fire. And so, heat fluxes over 100 kW/m^2 are possible.

Figure 31. Verticality is used to visually connect with the full audience of the hall.

Smoke hazard

Smoke is usually the primary threat to life safety. Three major effects of smoke can be identified: light obscuration, toxicity, and post fire impact. The first two effects are closely

related: smoke can reduce visibility, thereby slowing escape and making one more vulnerable to its toxic properties. The third can include any toxic effects encountered by fire fighters during overhaul, but it is more usually interpreted as a property issue in situations where smoke deposition can affect the behavior of sensitive equipment and circuitry.

Predicting Behavior of Fire in the Stage

This section discusses the dynamics of fire in the stage through the application of fundamental principles and state-of-the-art computer based fire simulation models.

Design fire scenario

An assembly occupancy-specific fire representative of a typical stage fire is selected as a design fire scenario. It explicitly accounts for the following:

Occupant activities

Occupants are classified as (1) performers, (2) patrons, (3) ushers and (4) technical crews. It can be assumed that the performers are focused on executing performance and the patrons are involved in experiencing the performance at the stage (Figure 32). Ushers are volunteers serving the front-of-house needs of the Performing Arts Center. In the event of an alarm, they are required to assist in evacuation. Technical crews are occupants, who are executing the technical requirements of the performance. It can be assumed that the patrons and performers may not have a comprehensive conception of the egress arrangement of the building and will be dependent on the ushers and in-house technical crews for assistance in evacuating due to emergency.

Figure 32. A stage performance in progress showing the audience and performers.

Number and location of occupants

For the fire scenario number of occupants is assumed to be 2,651 out of which 1,289 are patrons seated in the Sidney Herman Hall, 1,289 occupants are assumed waiting in the entry lobby to watch the next show, 41 performers in the stage, 15 occupants are assumed as technical crews located at different levels of the fly gallery and grid iron and 32 occupants at the cat-walk (Figure 33).

Room size

The size of the stage is modeled as 30 m. x 12.65 m. x 25 m. The hall is modeled as 30 m. x 35 m. 19 m. in the zone model. In CFD model, the shape of the hall is modeled as ovular fitted inside volume measuring the same as the zone model.

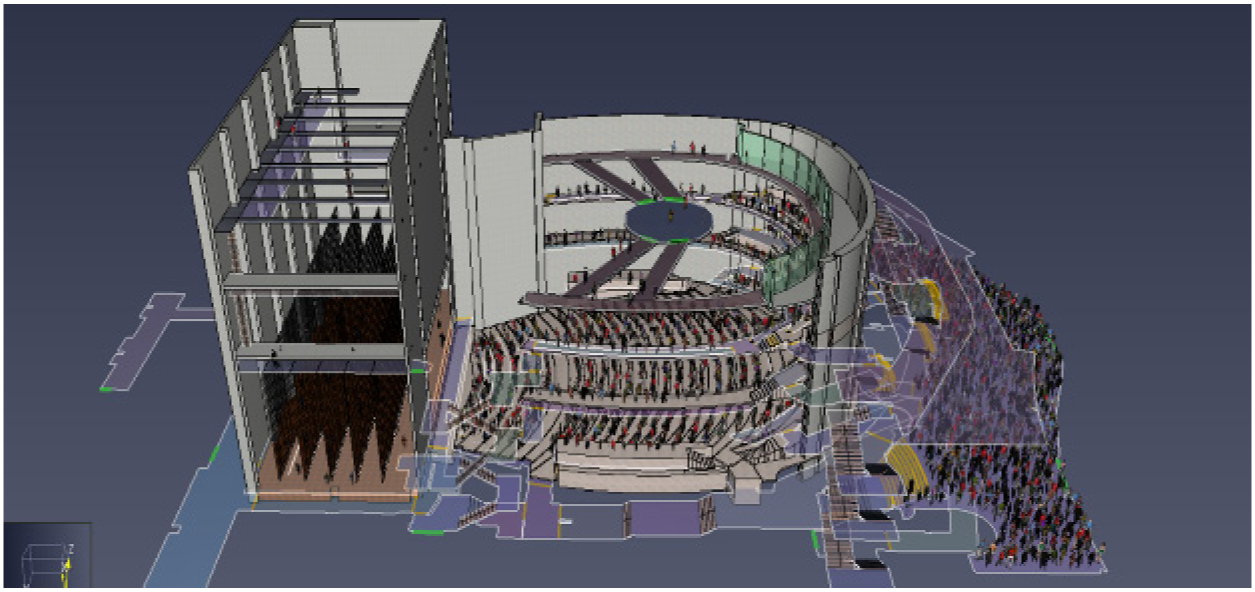

Figure 33. A cut-out 3D view of the geometry showing the occupants at different location in the model.

Contents and furnishings

The following materials are used in modeling the compartment linings;

Component	Material	Conductivity (W/m-K)	Specific Heat (kJ/kg-K)	Density (kg/m^3)	Thickness (m)	Emissivity
Stage floor	Wood	0.15	2.6	700	0.05	0.9
Walls	Concrete	1.35	0.815	2,250	0.3	0.9
Hall floor	Carpet	0.24	1.87	1,170	0.025	0.9

Fuel properties and ignition sources:

Ignition source is assumed to be electrical or lighting equipment igniting drapes, stage curtains, which are mostly made of cotton and polyester. The fuel is also assumed to be composed of cellulosic and other petrochemical materials. Cellulosic materials include wood, MDF, particle boards, ply-wood and so on. Petrochemical materials, in general, refer to plastics used to create customized sets and scenery by the process of thermoforming. Some of these materials contain styrene, Acrylonitrile Butadiene Styrene (ABS), Polyethylene terephthalate (PETG) and Polycarbonate. The fuel properties are conceived as an average heat of combustion

value for these materials and a higher CO and soot yield value for well-ventilated fire scenario. The following values are selected for modeling the design fire scenario.

Heat of combustion: 28,000 kJ/kg

Soot yield: 0.1 g/g of air

CO yield: 0.034 g/g of air

Ventilation conditions

Gravity vents are located near the center and at the highest point above the stage. The gravity vents and fire protection curtain are activated by fusible links with RTI of 240 $(m/s)^{1/2}$ and melting temperature of 74 C, which are standard values for UL-listed fusible links. The total gravity vent area is approximately 224 square feet.

Duct smoke detectors are installed in the return and supply ducts of HVAC system in Christopher Cohan Center to prevent smoke from fire being spread throughout the building by its recirculating HVAC system. The detection of duct smoke is difficult for a number reasons. First, the location of the return air duct is under the stage which makes it difficult for products of combustion to be detected by the duct detectors if the fire is above the stage. And, the dilution with return air from other spaces e.g. dressing rooms and possibly with outside fresh air makes the modeling of detection difficult. For this reason, HVAC system was not considered in the modeling.

Identification of the first item ignited and its location

The first item to be ignited is one of the stage curtain located at the back stage. The location of the fire is 6 m. from the proscenium wall and 7.5 m from the wall in the west side of the stage.

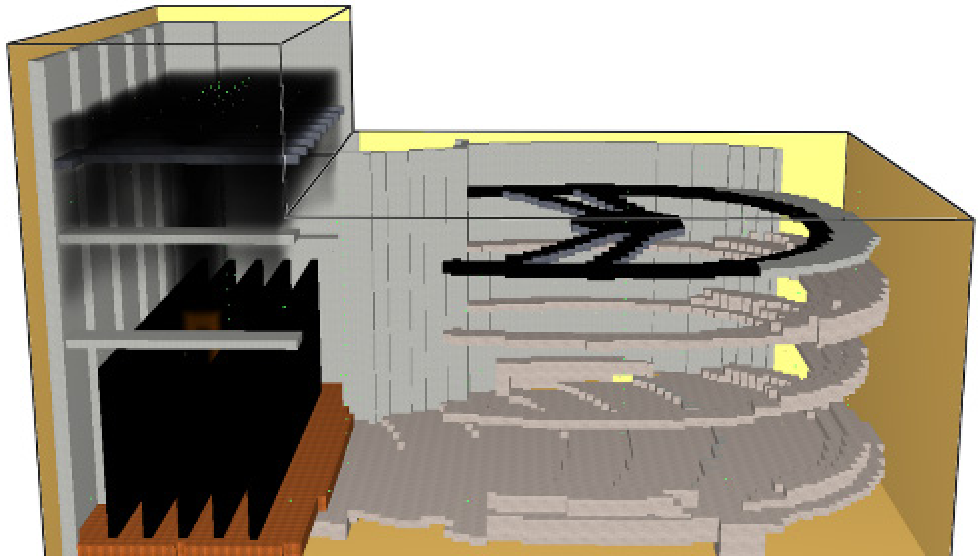

Figure 34. Smoke View rendering showing the location of fire at 100 s.

Rate of growth

A t-squared fire can be characterized for the design fire scenario by the following equation.

$$\dot{Q} = \alpha t^2$$

Where

$\dot{Q} = Heat\ release\ rate$

$\alpha = Fire\ growth\ constant = 0.05\frac{kW}{s^2}$ [rounded from 0.0469 which accounts for a fast-growing fire].

$t = Time$

The peak HRR can be considered as HRR needed for flashover which is dependent on the openings of the proscenium stage and can be generally predicted using the following equations.

$$Babrauskas'\ equation: \dot{Q}_{fo} = 750 A_o \sqrt{H_o}$$

$$Thomas' equation: \dot{Q}_{fo} = 7.8A_T + 378A_O\sqrt{H_o}$$

Where

$A_0 = Area\ of\ opening = 1188sf + 8 * 32sf = 134\ m^2$

$H_o = Height\ of\ the\ proscenium\ opening = 26\ ft. = 8\ m$

$A_T = Total\ area\ of\ stage\ enclosing\ surfaces$

$$= 2 * (98\ ft\ *\ 42\ ft\ +\ 98\ ft\ *\ 80\ ft\ +\ 42\ ft\ *\ 80\ ft)\ -\ 1444\ ft^2$$

$$= 29{,}188\ ft^2 = 2712\ m^2$$

$$\dot{Q}_{fo} = 750 * 134\ m^2 * \sqrt{8\ m.} = 284{,}257\ kW\ or\ 7.8 * 2712\ m^2 + 378 * 134\ m * \sqrt{8\ m}$$

$$= 164{,}419\ kW$$

Fire Models

FDS is used to model this fire scenario along with Fire Dynamics Spreadsheet and CFAST zone model. FDS allows for “Direct Numerical Simulation” or “Large Eddy Simulations (LES)” of fire effects. LES uses a low Mach number approximation for the Navier-Stokes equations and a formulation of the complex governing equations to provide a very efficient solution. Under the LES mode, the inputs parameters of the fire are heat release rate and species generation. Although FDS includes algorithms for flame spread, burning rate, and suppression, these have not been developed and validated to allow their application to problems in these areas. FDS calculates the temperature, pressure, species concentrations, and flow field in relation to the prescribed fire. FDS provides for calculating the activation of sprinklers. In addition, the sprinklers can dispense droplets, which yield evaporative cooling and prewetting. The model supports prediction of multiple sprinkler activations. The major geometric limitation of FDS is its exclusive use of rectilinear computational meshes, which effectively limits the model to “stair stepped” approximations for curved or sloped geometries. Although there are commercial CFD

packages that allow better definition of realistic geometries, these are much less efficient and there has been limited validation of commercial CFD codes for use in fire applications. Heat transfer is treated as one-dimensional and is calculated by using thermally thick elements only, but heat is not conducted through wall portions to other parts of the domain. The model also supports heat-activated vents that "open," allowing flow through the vent. Smokeview is the companion software that is designed to visualize the numerical predictions generated by FDS.

Modelling the fire

Instead of modeling by specifying relevant properties via the MATL namelist group, the fire of a given heat release rate (HRR) is specified. The specified fire is basically modeled as the ejection of gaseous fuel from a surface of the set and scenery. This is essentially a burner, with a specified Heat Release Rate Per Unit Area, HRRPUA, in units of kW/m^2.

&SURF ID='FIRE', HRRPUA=50. /

applies 50 kW/m^2 to the surface with the attribute SURF_ID='FIRE'.

To simulate the fire growth through sets and scenery, the planar surfaces are fragmented, and individual fragment has been provided with different ignition time. To prescribe the initial fire, heat release rate ramp, the TAU_Q parameter is defined as a negative value (t-squared growth rate), which results in a time-dependent heat release rate as

$\dot{Q}(t) = \dot{Q}_O(\frac{t}{\tau})^2$ if TAU_Q is negative

Here $\dot{Q}_0$ is the heat release rate. As the fire ramps up following a t-squared curve, then it remains constant after TAU_Q seconds. The subsequent fires are defined as RAMP_T equal to a character string designating the ramp function to use for that surface type. Nine subsequent fires with different ignition time and heat release rate ramps are specified to different fragments of the

vertical stage curtains to model the full duration of the fire and sequential fire spread along the stage curtains.

1. &SURF ID='Burning Curtain 1', COLOR='BLACK', HRRPUA=50.0, TAU_Q=-100.0/
2. &RAMP ID='Burning curtain 2_RAMP_Q', T=100.0, F=0.0/
   &RAMP ID='Burning curtain 2_RAMP_Q', T=173.0, F=1.0/
3. &RAMP ID='Burning Curtain 3_RAMP_Q', T=173.0, F=0.0/
   &RAMP ID='Burning Curtain 3_RAMP_Q', T=224.0, F=1.0/
4. &RAMP ID='Burning Curtain 4_RAMP_Q', T=224.0, F=0.0/
   &RAMP ID='Burning Curtain 4_RAMP_Q', T=265.0, F=1.0/
5. &RAMP ID='Burning Curtain 5_RAMP_Q', T=265.0, F=0.0/
   &RAMP ID='Burning Curtain 5_RAMP_Q', T=330.0, F=1.0/
6. &RAMP ID='Burning Curtain 6_RAMP_Q', T=330.0, F=0.0/
   &RAMP ID='Burning Curtain 6_RAMP_Q', T=387.0, F=1.0/
7. &RAMP ID='Burning Curtain 7_RAMP_Q', T=387.0, F=0.0/
   &RAMP ID='Burning Curtain 7_RAMP_Q', T=436.0, F=1.0/
8. &RAMP ID='Burning Curtain 8_RAMP_Q', T=436.0, F=0.0/
   &RAMP ID='Burning Curtain 8_RAMP_Q', T=480.0, F=1.0/
9. &RAMP ID='Burning Curtain 9_RAMP_Q', T=480.0, F=0.0/
   &RAMP ID='Burning Curtain 9_RAMP_Q', T=557.0, F=1.0/
10. &RAMP ID='Burning Curtain 10_RAMP_Q', T=557.0, F=0.0/
    &RAMP ID='Burning Curtain 10_RAMP_Q', T=625.0, F=1.0/

The resultant fire growth rate curves are shown in Figure 35. The fire reaches 1 MW within 141 s., which is a characteristic of fast growing fire. And continues to grow exponentially following a t-squared growth rate.

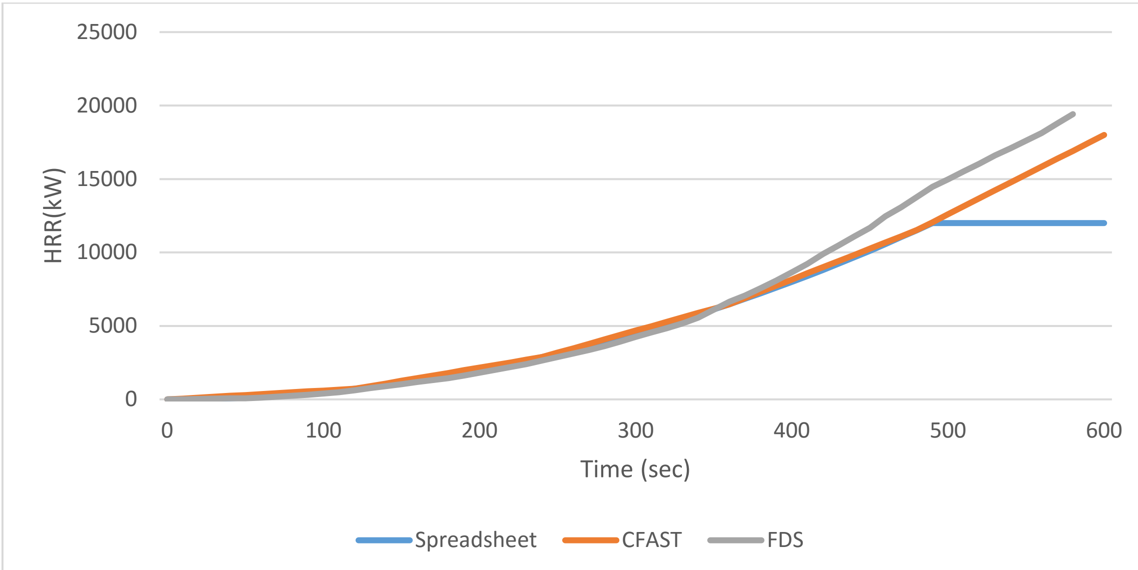

Figure 35. Heat Release Rate curve attained in the spreadsheet, CFAST and FDS.

Results

Figures 36-40 demonstrate the type of approximation that are expected. Results from two different models and empirical correlations are used to produce the behavior of the fire in the stage. Although the type of approximation produced by the FDS model is more accurate than other methods of estimation, the results must still be recognized as engineering approximations. In Figure 36, the curves using yellow plots the average upper layer temperature computed from FDS model. The other curves graph the predictions by a zone model and a Fire Dynamics Spreadsheet. In the case of this simulation, the FDS model followed the same growth curve as the spreadsheet calculation until the activation event of the gravity vents at 349 s., but the zone model gave a lower prediction of temperature and did not show any sprinkler, gravity vent and

fire protection curtain activation events. All the models used to produce the results in Figure 36 are classified as zone models; that is, they predicted a single "upper layer" (smoke) temperature.

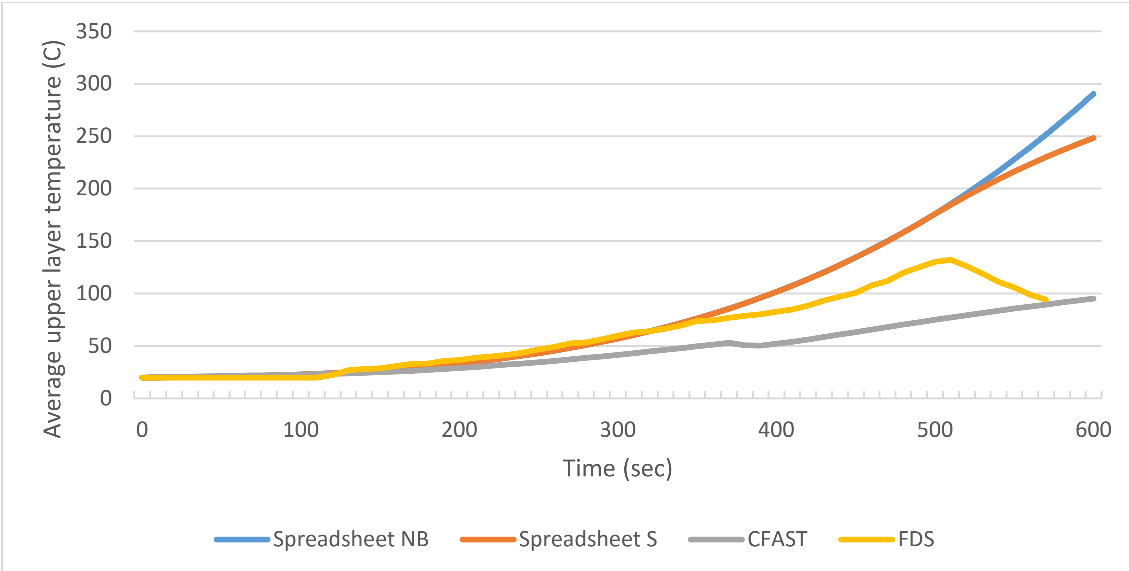

Figure 36. Predicted layer temperature in the stage by Fire Dynamics spreadsheet, zone model (CFAST) and FDS model.

Figure 37 plots the smoke layer interface calculated by the models. FDS layer device that is used to calculate smoke layer interface position, does not recognize any smoke built-up until 110 s. This is the time when the smoke keeps dissipating until it reaches the end of the ceiling. After 110 s., as fire continues to grow, the smoke-layer interface plunges rapidly. The smoke interface reaches within 2 m. above the stage at 520 s. The spreadsheet calculation and the zone model both shows a conservative smoke layer descend, reaching 2 m. above the stage at 390 s.

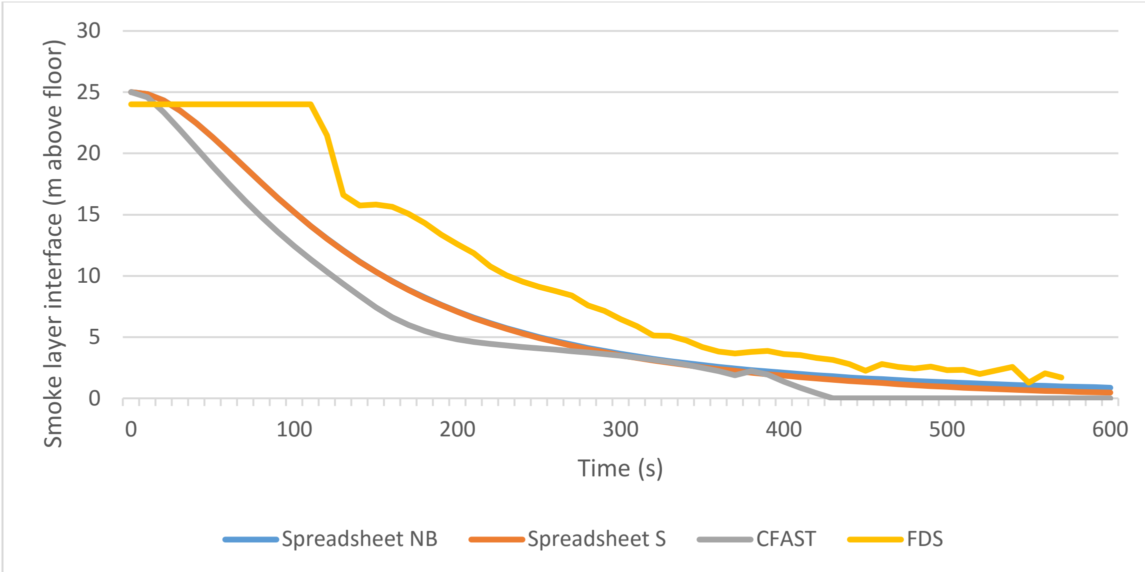

Figure 37. Prediction of Smoke Layer in the stage by Fire Dynamics Spreadsheet, zone model (CFAST) and FDS model.

Figure 38 shows the total mass flow through the gravity vents as calculated by the FDS model. The first vent activates at 349 s., followed by others. There were total eight (8) vents on the ceiling. Each vent was modelled separately with individual heat detector activation control logic. All the vent opened within 436 s. After initial spikes in flow due to pressure differences, the flow tends to stabilize. The flow is seen to rescind, into the enclosure, after sprinkler activation at 498 s.

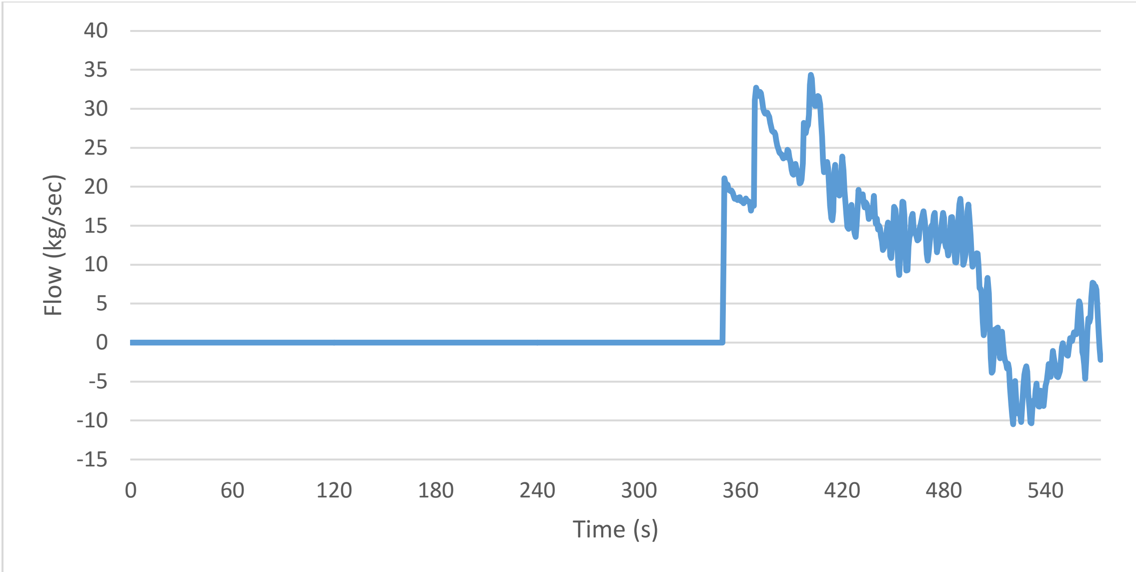

Figure 38. Prediction of Mass Flow Through Gravity Vents by FDS Model.

Figure 39 and 40 shows temperature changes and smoke layer descend in the seating hall. Only the zone model and FDS was used to model the fire environment inside the seating hall. Zone model predicts smoke spilling and flow into the compartment at early stage of the fire, starting from 150 s. Three separate layer devices, namely Layer 1, Layer 2 and Layer 3 were used in FDS to understand the complete scenario. Data from these three devices are shown in Figure 39 and 40. Layer 1 and Layer 2 are situated at 2-m. and 15 m. distance from the proscenium opening. Layer 3 is located at the farthest end of the seating hall. Layer 1 detects smoke spilling through the proscenium opening at the onset of 310 s. First discontinuation of smoke flow is observed after 340 s. It can be assumed that the operation of gravity vents changes the pressure profile, which changes the direction of the smoke flow. As the heat release rate increases, second wave of smoke is seen to spill to the auditorium, which eventually gets discontinued by operation of fire protection curtain at 440 s.

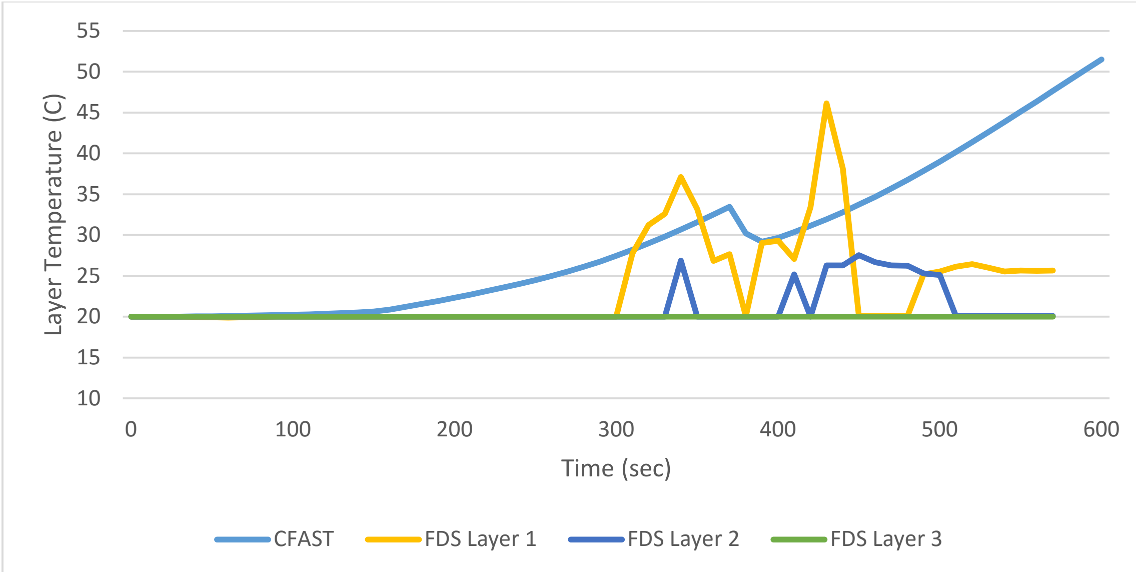

Figure 39. Predicted layer temperature by zone model versus FDS model inside Harman Hall.

From Figure 40, the smoke layer descended within 6 m. above the stage level seating at 500 s, as seen from the data collected by Layer 1. Layer 3 which lies at the end of the hall room does not show any formation of smoke layer, which possibly can be a modelling error.

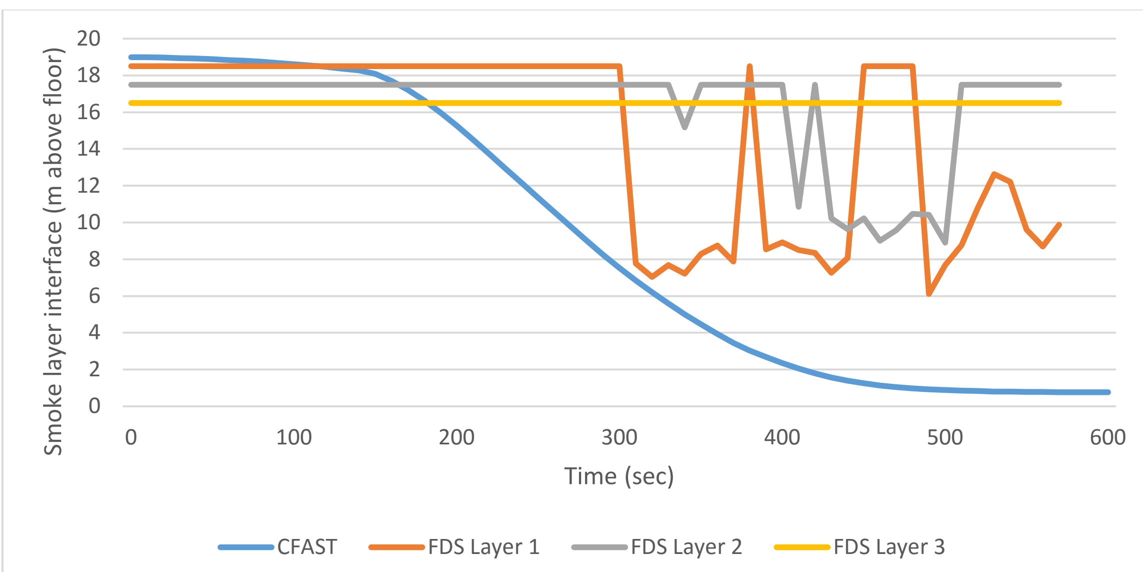

Figure 40. Prediction of smoke layer in the Harman Hall by zone model versus CFD model.

When using models for analyzing the dynamics of the fire, it is important to be aware of the differences between underlying assumptions and limitations of the models that governs the

fire effects. As the zone model under predicts the temperature of the hot gas layer at the ceiling, the estimated time of operation of the gravity vents, safety curtain and the sprinklers are delayed compared to the FDS model. This delay gives the impression of a delayed warning what is observed in the FDS model. In the FDS model, all the gravity vents activated between 349 and 436 seconds, fire protection curtain activated at 440 s. and first sprinkler activated at 498 second. On the other hand, zone model predicts the smoke layer to reach 2 m. above the top aisle of the gallery level at 210 s. FDS model does not predict smoke layer descend within 2 m. above any means of egress, within the simulation time (570 s.). Although in FDS model, the smoke is observed to spill in to the hall through the proscenium opening right after 300 s. until the fire protection curtain is activated at 440 s.

Evacuation

This section discusses, the emergency management protocol maintained by the management of Performing Arts Center to interact with fire conditions in the Christopher Cohan Center. Also, evacuation times are calculated through the application of fundamental principles of people movement and state-of-the-art computer-based evacuation models.

Human interaction with fire condition

In the event of an alarm, Ushers are required to return immediately to their original post and await further instructions. The floor captain would signal them if the alarm is false or a true emergency. If the evacuation is halted, a general announcement would be made over the public-address system or from the stage and the event will continue.

Normal Evacuation Route

Main Lobby Ushers are required to immediately return to assist in the opening of all Main Lobby doors. All patrons would exit through the same doors that they entered through and leave the facility through the main lobby doors.

Once the patrons have exited the building, the Ushers would direct them away from the building so they do not block the doors or prevent emergency personnel or vehicles from entering the Center. Even if this is not an emergency, the Fire Department would still report to the location and they are required to not have patrons blocking their access to the building. When emergency personnel determine, it is safe to re-enter the building, the House Manager would let the ushers and patrons know if the performance would continue or be cancelled.

If this is a true alarm, the Ushers are required to check their designated exit route. If there is no obvious threat (smoke, flames or debris) they should proceed with the normal evacuation route (Figure 41).

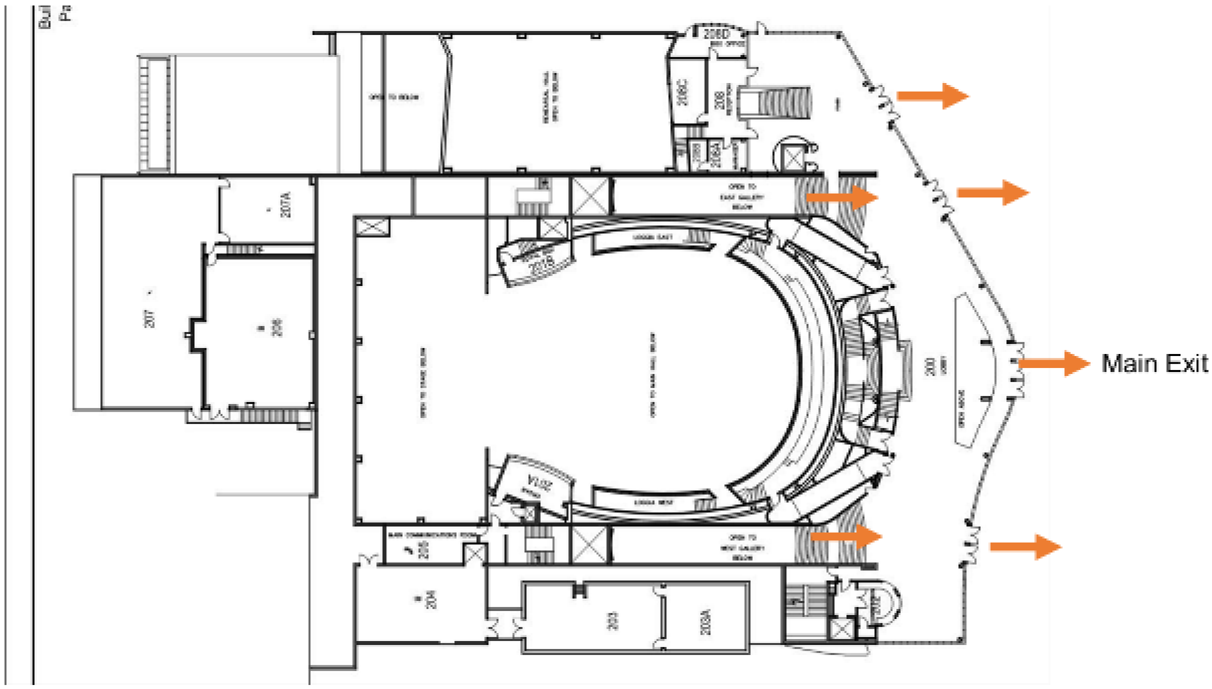

Figure 41. Entry Lobby level plan showing the normal evacuation route.

Alternate Evacuation Route

If the Ushers' exit route is blocked or otherwise congested, they would direct patrons to an alternate path (Figure 42). Patrons seated in the orchestra section would exit through the side doors and be guided toward the back-stage area and through the closest exit doors to outside of the building. Patrons seated in the Balcony and Gallery areas would be directed down the right and left sides to the Exit doors leading to the stairwells or the Balcony or Gallery lobby emergency stairwells on House Left.

No one can use the stage as an escape route. Patrons are directed away from stage to avoid injury.

"House right Orchestra" patrons and "Dress Circle right" patrons would proceed through the doors leading to the backstage, past the Pavilion. The exit paths are well marked with wall signs and a fluorescent stripe along the lower wall. They would exit the building through the exit

doors next to the classroom. Once patrons have left the building, Ushers would direct them to the grass area outside of the Spanos Theatre.

“House left orchestra” and “Dress Circle left” patrons would exit through the doors leading to backstage closest to the Green Room. Patrons would travel up a few steps to exit doors on left. These doors open to loading dock area. Once patrons have left the building, the Ushers would direct them to the sidewalk along Tahoe Road around the Music Department Building.

Patrons seated in the Balcony and Gallery levels would be guided toward the exit doors leading to the backstage stairwells. Once these patrons have left the building, Ushers would direct them to the sidewalk along Tahoe Road via the loading dock area or if they exit through the classroom doors, to the grass area outside Spanos Theatre. Dress Circle patrons would need to exit through original entry doors but may be guided down stairway to back exits or to the emergency stairway on House Left near the Catering area if Main Lobby doors are blocked.

Patrons with special needs would be escorted to the designated “sanctuary” area near the elevator on each level. If possible, they would remain with them until they can be safely removed.

Under certain circumstances, patrons in wheelchairs in the orchestra level would be escorted through the lower lobby into the Men’s restroom and out through the Pavilion exit doors. The technical crew would evacuate performers on stage, in the dressing rooms and Green Room per their plan.

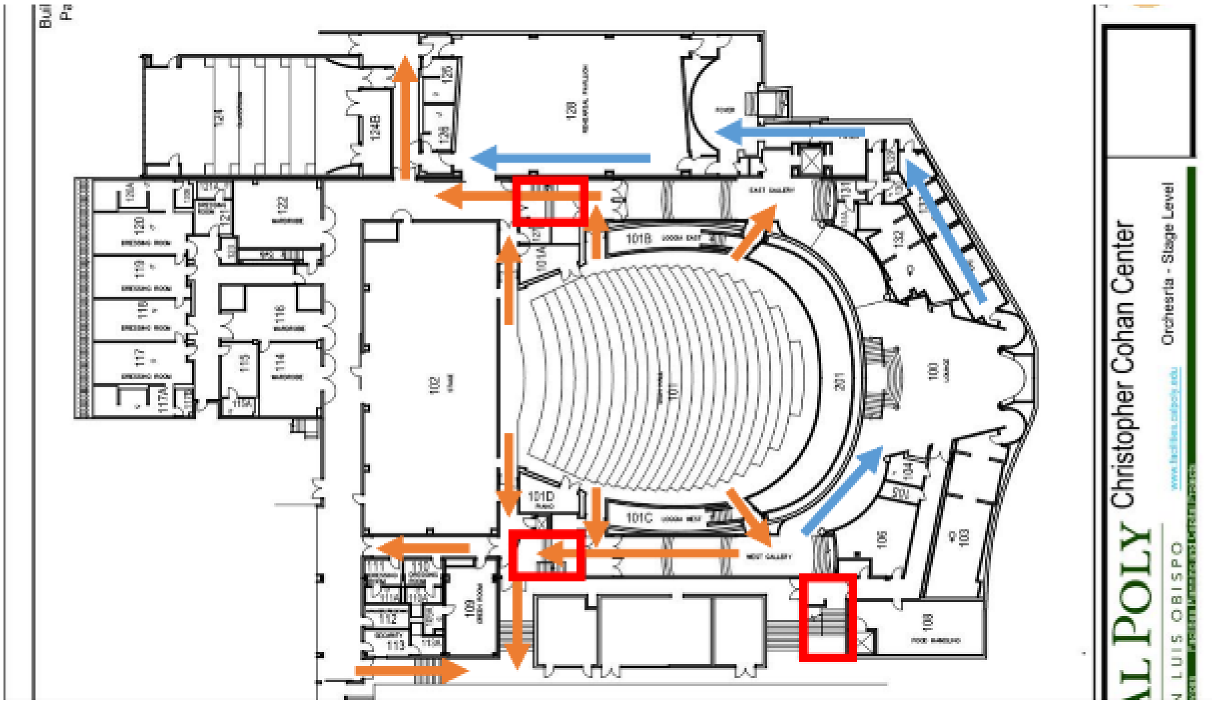

Figure 42. *Alternate route for evacuation. Blue lines are showing the evacuation route for patrons in wheel-chair.*

Ushers do not fight the fire, if the fire is spreading beyond the spot where it started, or if the fire could block their exit or if they aren't sure how to operate the fire extinguisher. Usher's may fight the fire if they have alerted the Floor Captain and the House Manager has been notified to call the Fire Department 911 and patrons are out of the area. If the fire is small and they can fight it with their back to an exit and if the fire extinguisher works properly and they know how to use it and they know enough to get out fast if their effort is failing.

Evacuation time calculation

Evacuation times are calculated through the application of fundamental principles of people movement and state-of-the-art computer-based evacuation models.

Principles of people movement

The evacuation time for an individual is the entire span of time that elapses from the ignition of the fire until the occupant emerges from the building or arrives at a location of safety. It consists of four components, all of which must be taken into consideration: (1) Time to

notification, (2) Reaction time, (3) Pre-evacuation activity time, (4) Travel or movement time. The first three components are often grouped together and referred to as “delay time” or “premovement time.”

Evacuation time = Delay time + Travel time

= Time to notification + Reaction time + Pre-evacuation activity time + Travel time

It is very important not to underestimate the contribution that the delay time can make to total evacuation time. Studies have shown that, the response in an assembly building could be expected to be slow, and in some instances, occupants may completely ignore the signal and pursue their activities. Therefore, the selection, estimation, and calculation of premovement times is extremely important to obtain valid results.

Time to Notification. In the evaluation of Christopher Cohan Center, evacuation time begins when ignition occurs. Some period, the time to notification, will elapse before conditions develop to the point where an alarm sounds or where people begin to sense the cues of the fire itself. The fire cues that reach occupants can be the site or smell of smoke, heat, the sight of flames, or the sound of an alarm signal from a smoke detector, a duct detector, a heat detector, the fire curtain or a sprinkler system. The time to notification is modeled, and is estimated using judgment.

Fire growth and smoke transport models are used with detector/sprinkler activation models to estimate this period. Models that are used are DETACT, which models fire curtain and sprinkler activation and FDS (Fire Dynamics Simulator), which predicts the transport of heat and smoke from the fire.

Per the DETACT model, fire curtain and sprinkler is estimated to be activated at 370 and 490 s respectively. FDS predicts the smoke detector, fire curtain and sprinkler to be activated at 274, 439 and 498 seconds, respectively.

The fire cues such as site or smell of smoke and the sight of flames can be sensed by the occupants if they are adjacent to the fire source. If the fire is obscured, abrupt change in the environment such as, temperature rise, smoke layer descending, change in air pressure and velocity etc. might act as notification cues. Figure 43 and 44 shows such an event when the smoke layer descends 10 m. from the ceiling to the upper level of fly gallery from 110 s. to130 s. This change possibly can shade or obscure lighting effects that are dropped from the grid-iron, or if occupants are present in the fly gallery, they would be able to sense the presence of smoke.

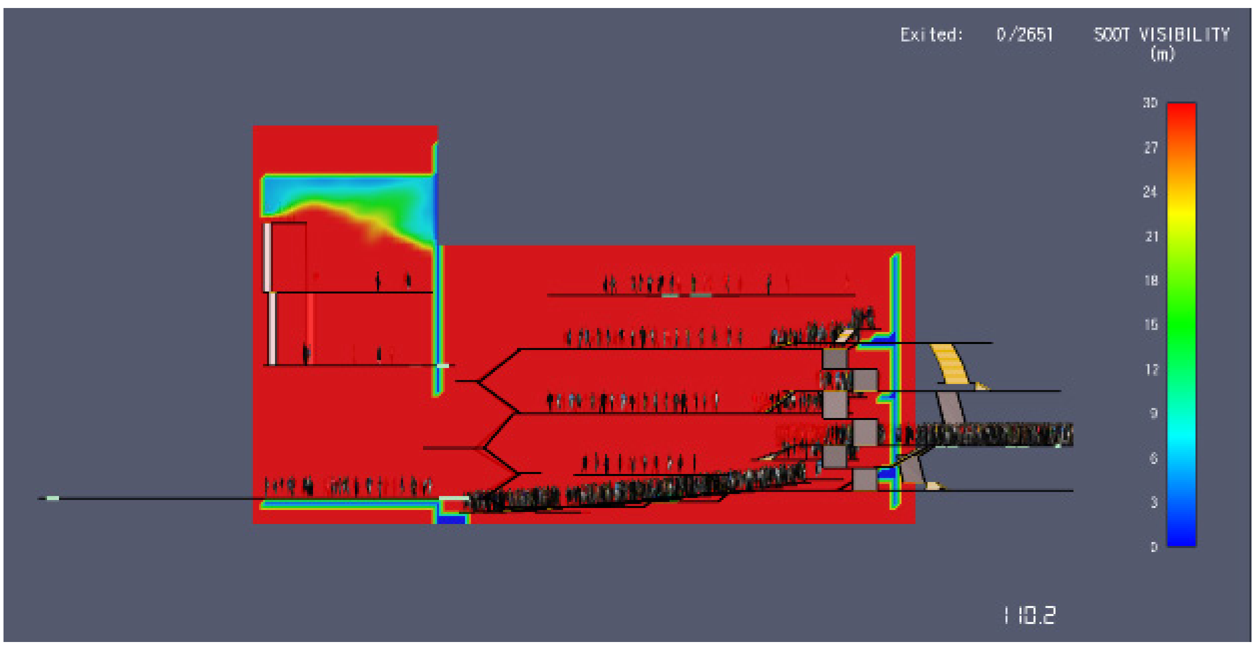

Figure 43. Section through Sydney Harman Hall showing soot visibility condition at 100 s after ignition.

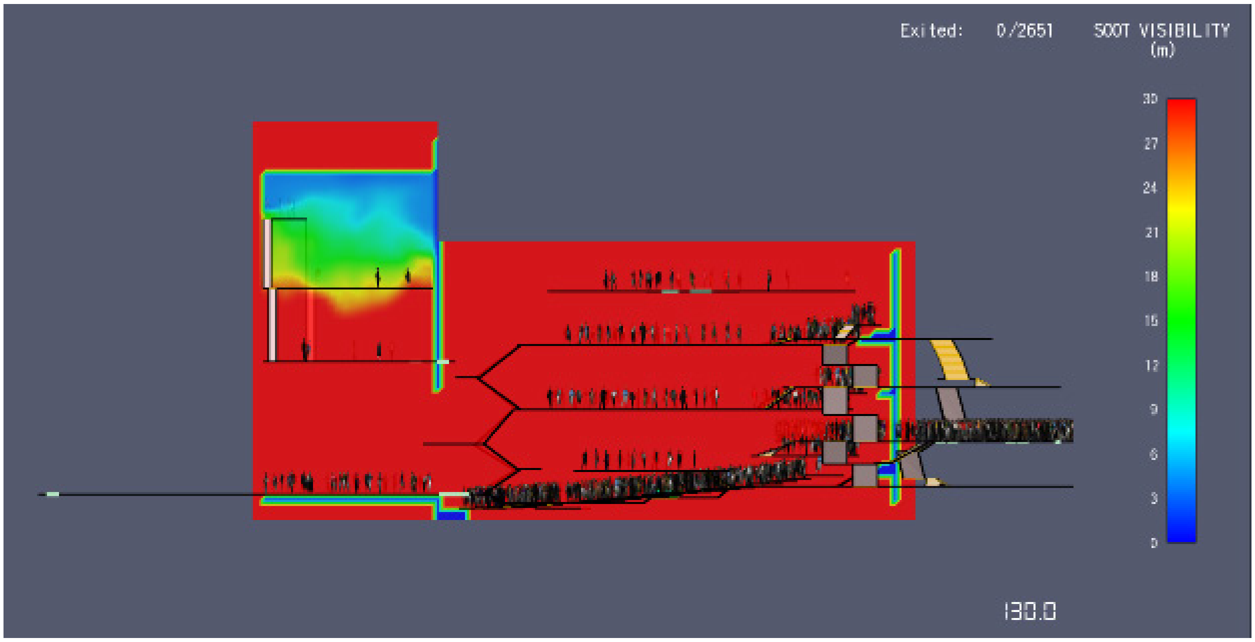

Figure 44. *Section through Sydney Harman Hall showing soot visibility condition at 130 s after ignition.*

Reaction Time. Reaction time is the time it takes an occupant to perceive the alarm or fire cue and decide to act. In the event of an alarm, Ushers are required to return immediately to their original post and await further instructions. The floor captain would signal them if the alarm is false or a true emergency. It will take some period for the person to walk to their post, to identify the sound as the smoke alarm, and to wait for further instructions. There is currently no generally accepted modeling technique available to predict reaction time. The time used in an analysis may depend on observations or judgment.

Pre-Evacuation Activity Time. Pre-evacuation activity time includes the time that elapses while the occupant is preparing to leave or seek refuge. Pre-evacuation activities involve all the activities in which an occupant will engage from the time when he or she makes the decision to leave until the time he or she starts to travel toward an exit or an area of refuge. Ushers might take the time to deliver proper direction to the patrons. As with reaction time, there are no generally accepted modeling techniques available for pre-evacuation activity time, and the time used in an analysis may depend on observations or judgment.

Reaction time and pre-evacuation activity time are often considered together. Combined time from notification to the time that movement toward the exit begins can be estimated by the data on pre-evacuation delays that have been obtained from postfire behavior studies and evacuation drills presented in NFPA Fire Protection Handbook. The short delay times observed in the two office building evacuation drills demonstrated the combined effect of “good” alarms, training of occupants, and the use of fire wardens to assist in the evacuation. The delay times in the two drills averaged 0.60 minute and 1.05 minutes. The lower of these two data is used for the current analysis, which is 36 s. The pre-evacuation movement time is a total of 130 + 36 = 166 s. Figure 45 shows, the smoke layer formation above the stage and containment by the proscenium wall.

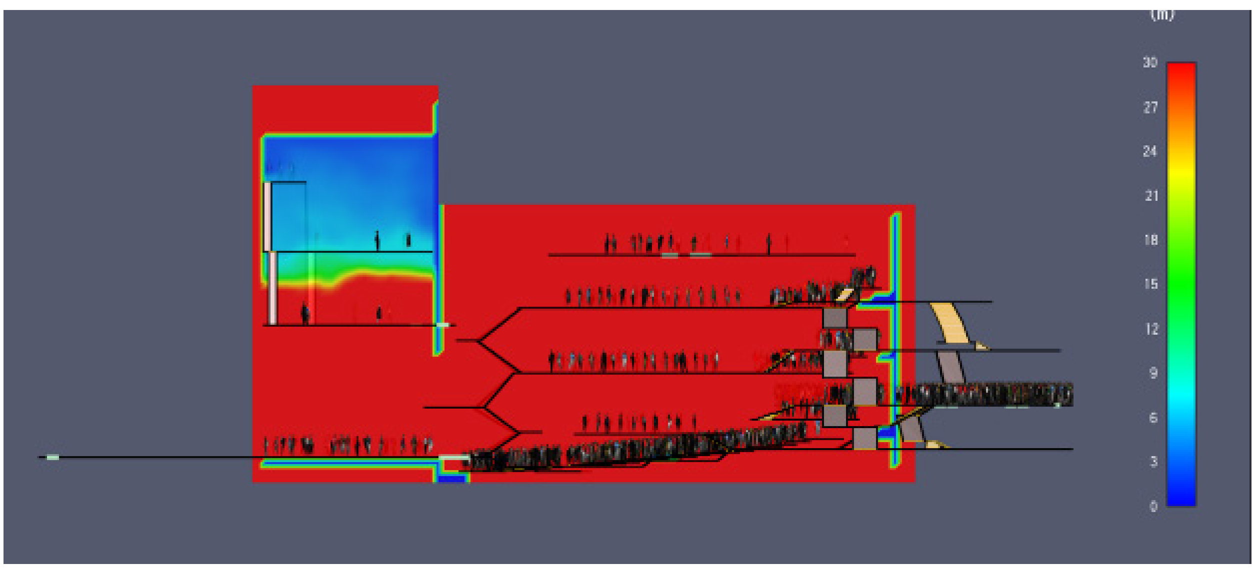

Figure 45. Section through Sydney Harman Hall showing soot visibility condition at 166 s.

Travel Time. Travel time is the final component in the calculation of evacuation time. It is defined here as the time to move to a location of safety. There are various calculation or estimation techniques available for travel time based on some of the hand calculation methods described in the NFPA Fire Protection Handbook.

Behavioral simulation models. Behavioral simulation models consider more of the variables related to occupant movement and behavior. They treat occupants as individuals with unique characteristics. Occupants can move at different speeds in reaction to the conditions in their surroundings. Because they are tracked individually, their exposure and reaction to toxic conditions while evacuating can be estimated by the model or by tenability or toxicity models that analyze the simulation results. This type of model allows a more realistic simulation, but there are concerns with their use related to the lack of available data that would allow the prediction of human behavior in fire.

The evaluation of Christopher Cohan Center requires, a comparison of the fire effects predicted for the scenario with the results of the evacuation model that would predict where and for how long people are dispersed throughout the building. The occupants' potential exposure to the effects of the fire would determine whether the condition is acceptable.

Behavioral Simulation Model Pathfinder uses the PLOT3D data output from FDS to create time history data for each occupant as they move throughout the simulation. FDS PLOT3D output data is collected for CO Volume Fraction, CO_2 Volume Fraction, and O_2 Volume Fraction; Pathfinder also output FED for each occupant specified.

FDS data integration is a measurement only and does not alter the movements or decision making within the Pathfinder simulation. The figures below show the calculated FED for selected occupants starting from initiation of fire until their exit. For each level, the occupants located farthest from their nearest exit are selected, assuming it would result in the highest FED due to the prolonged exposure to the fire environment.

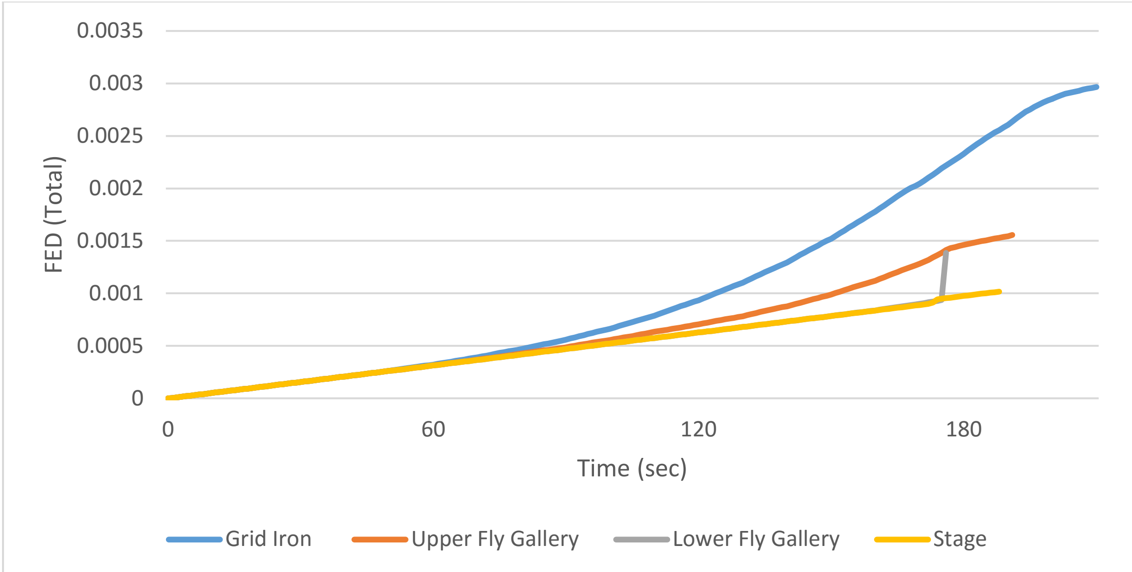

Figure 46. FED (total) calculated in Behavior Simulation model for occupants located in different levels of the stage.

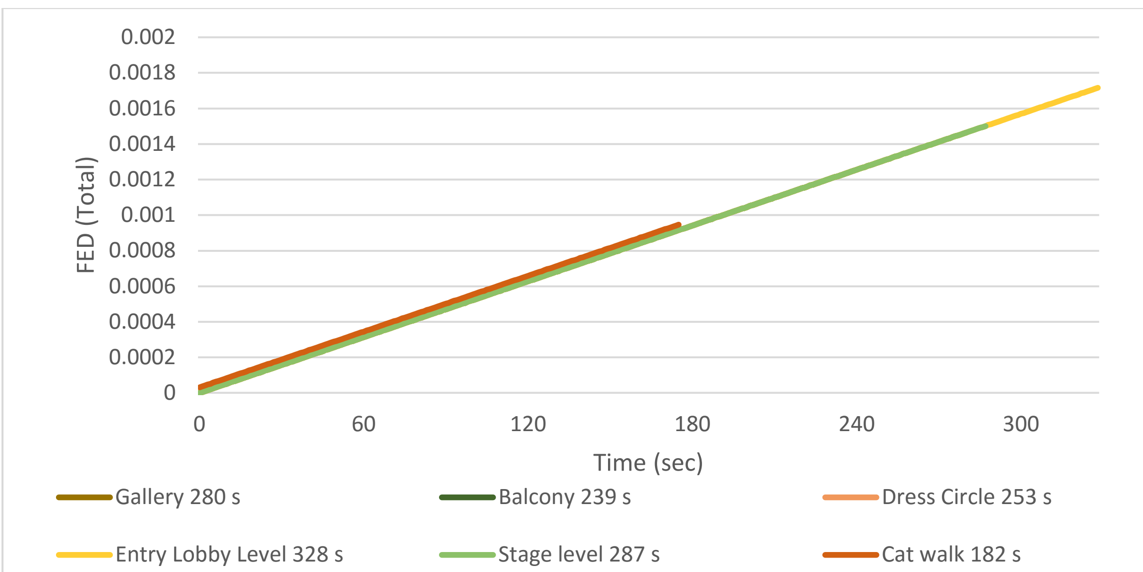

Figure 47. FED calculated in Behavioral Simulation Model Pathfinder for occupants located at different levels of the Sydney Harman Hall.

Calculation of Factional Effective Dose. The Pathfinder calculation of Fractional Effective Dose (FED) uses the equations described in the SFPE Handbook of Fire Protection Engineering, 5th Edition, Vol 3, Chapter 63, pages 2308-2428. The implementation is the same as used in FDS+EVAC, using only the concentrations of the narcotic gases CO, CO_2, and O_2 to calculate the FED value.

$$FED_{tot} = FED_{CO} * VCO_2 + FED_{O_2}$$

This calculation does not include the effect of hydrogen cyanide (HCN) and the effect of CO_2 is only due to hyperventilation. Carbon dioxide does not have toxic effects at concentrations of up to 5 per cent, but it stimulates breathing which increases the rate at which the other fire products are taken up.

The fraction of an incapacitating dose of CO is calculated as:

$$FED_{CO} = 3.17 * 10^{-5}[CO]^{1.036}(V)(t)/D$$

where:

[CO] = Carbon monoxide concentration (ppm v/v 20° C)

V = Volume of air breathed each minute (L/min). Value is 25 L/min for an activity level of light work – walking to escape.

t = Time (minutes)

D = Exposure dose (percent COHb). Value is 30% for an activity level of light work (walking to escape).

Hyperventilation due to carbon dioxide can increase the rate at which other toxic fire products are taken up. The multiplication factor is given by:

$$VCO_2 = \exp(0.1903 * \%CO_2 + 2.0004)/7.1$$

where:

$\%CO_2$ = volume fraction of CO_2 (v/v)

The fraction of an incapacitating dose of low O_2 hypoxia is calculated for oxygen volume fractions less than 20.9% as:

$$FED_{O_2} = \frac{t}{\exp[8.13 - 0.54(20.9 - \%O_2)]}$$

Where:

T = Time (minutes)

$\%O_2$ = volume fraction of O_2 (v/v)

As FED_{O2} is time dependent, for a constant value of O_2 volume fraction under 0.209 with each time step the FED_{tot} increases at a steady rate, hence resulting a straight curve as seen in figure 11. The deviation from a straight curve as seen in Figure 46 for grid irons and fly galleries suggests exposure to increased CO and CO_2 and reduced O_2 concentration in the air. For the occupant egressing from the grid-iron level this condition is observed starting from 80 s.

FED_{tot} values of 1.0 is associated with sub-lethal effects that would incapacitate persons of average susceptibility. In the absence, of information to the contrary, a log-normal distribution of human responses is a reasonable choice, with FED value of 1.0 corresponding to the median value of the distribution. Statistics show that at FED criteria of 0.3, 11.4 percent of the population would be susceptible to less severe exposures and, therefore, be statistically subject to incapacitation. The occupant exiting from the grid-iron level has been exposed to an FED_{tot} value of 0.03.

Evaluation Summary

The summary of fire and life safety evaluations for Christopher Cohan Center is provided in this section.

Objective: Limiting the threat from stage fires to an audience

Christopher Cohan Center was built in accordance with California Building Code (1992 Edition) and California Fire Code (1992 Edition). These codes recognize hazards associated with the stage including combustible scenery and lighting, scenic elements, contents and acoustical treatment on the back and sides of the stage; technical production areas including dressing rooms and storage areas. Protection requirements set forth in IBC is intended to limit the threat from stage fires to an audience and reduce the likelihood of a large fire in the stage area.

Christopher Cohan Center is constructed of Type IB construction with sprinkler system. The finish floor of the stage is of wood on a resilient mounting upon heavy timbers which conforms to Section 410.3. Legitimate stage is completely separated from seating by a proscenium wall of 2-hour fire-rated construction with the main proscenium opening protected by an automatic closing fire protection curtain in accordance with IBC 410.3.5.

A fast-growing fire is modeled in FDS which shows activation event of the gravity vents at 349 s. Though the zone model gave lower prediction of temperature and did not show any sprinkler activation, gravity vent and safety curtain activation occurred. The zone model gives an impression of delayed warning than observed in FDS model, where all the gravity vents activated between 349 and 436 seconds, fire protection curtain activated at 440 s. and first sprinkler activated at 498 second. On the other hand, as the time for the smoke layer to descend, 2 m above the top aisle of the gallery level being evaluated, the tenability criterion is predicted to

occur earlier (210 s) in the zone model than is predicted to occur in the FDS model (not less than 570 s) though the smoke is seen spilling through the proscenium opening after 300 s.

Based on this analysis it can be assumed that the stage construction and separation plays a key-role in limiting the threat from a stage-fire to the audience due to its containment of smoke long enough for the audience to evacuate the hall.

Objective: Reducing the likelihood of a large fire in the stage area

A wet pipe, hydraulically calculated automatic sprinkler system is provided throughout the building. A hydraulic calculation was performed in accordance with NFPA 13, which shows that, the city water supply is not adequate for the sprinkler system and hose stream demands. Central station monitoring is provided for all valve supervision and water flow detection devices. Class II standpipe are located on each side of the stage.

The alarm system receives alarm signals from manual pull stations, automatic sprinkler water flow indicators, automatic smoke detectors and automatic heat detectors. The activation of any alarm signal automatically activates the voice alarm system. The detectors located at the lobby area of the Gallery level does not conform NFPA 72 section 17.7.3.4. The current layout of the visible notification appliances does not satisfy requirements of NFPA 72 and warrants additional visible appliances to be located.

Fire growth and smoke transport models are used with detector/sprinkler activation models to estimate time to notification period. FDS predicts the smoke detector, fire curtain and sprinkler to be activated at 274, 439, and 498 seconds, respectively. The rapid descend of smoke layer possibly can shade or obscure lighting effects that are dropped from the grid-iron, or if occupants are present in the fly gallery, they would be able to sense the presence of smoke initiating the notification of the fire event.

From the analysis, it can be assumed that the installed systems will not perform well to meet the performance criteria. The building would be relying on human actions to detect fire, to annunciate and suppress the fire. To reduce the likelihood of a large fire in the stage area human intervention would be a crucial factor.

Objective: Reduce possibility of irrational mass response

Christopher Cohan Center is typically occupied by a significant number of people who are not completely familiar with their surroundings. The provisions of International Building Code section 907 addresses situations regarding the application of the alarm requirements which applies for this building. It allows the omission of manual fire alarm boxes in Christopher Cohan Center, which is equipped throughout with automatic sprinkler system. The exception permits the alarm system to be initiated automatically by the sprinkler water flow switches instead of by the manual fire alarm boxes, to reduce the possibility of mischievous or malicious false alarms. To afford authorized personnel, the ability to selectively evacuate or manage occupant relocation, IBC section 907.2.1.1 requires the fire alarm system to operate through an emergency voice/alarm communications system.

IBC section 1029 deals with egress in Group A occupancies. Performance objective of this code is to reduce the possibility of irrational mass response to a perceived emergency. In every case, the main entrance and all other exits are to be constantly available for the entire building occupant load. Spaces where ques may form should not interfere with established paths of egress from the assembly areas. Section 1029 also requires that at least one path of travel is always available and occupants face a minimum number of hazards. The primary concern for occupant safety would be that, there would not be a bottleneck in the path of travel for means of

egress. Lastly, the smoke level is required to be maintained at least 6 feet above the floor of the means of egress.

The main exit of the Sydney Harman Hall accommodates a total occupant load of 1,440, which is more than the total occupant load of the hall which is 1,289 complying with IBC section 1029.2. In addition to having access to a main exit, Christopher Cohan Center is provided with additional exit stairs from balcony and gallery levels and additional exits from orchestra stage and entry lobby levels that provides egress capacity of 5,280 persons from orchestra stage and entry lobby levels and 960 persons from balcony and gallery levels which are more than the total occupant loads served by an individual level. Exits from the stage opens directly to exit passageways leading to public ways. Both balcony and gallery have two exits which leads directly to enclosed exit stairs.

In the event of an alarm, Christopher Cohan Center Ushers are required to assist in evacuation process. All patrons are expected to exit through the same doors that they entered through and leave the facility through the main lobby doors. Once the patrons have exited the building, the Ushers would direct them away from the building so they do not block the doors or prevent emergency personnel or vehicles from entering the Center. If there is no obvious threat the occupants should proceed with the normal evacuation route.

If the Ushers' exit route is blocked or otherwise congested, they would direct patrons to an alternate path. No one would be allowed to use the stage as an escape route. "House right Orchestra" patrons and "Dress Circle right" patrons would proceed through the doors leading to the backstage, past the Pavilion. "House left orchestra" and "Dress Circle left" patrons would exit through the doors leading to backstage closest to the Green Room. Patrons seated in the Balcony and Gallery levels would be guided toward the exit doors leading to the backstage

stairwells. Patrons with special needs would be escorted to the designated “sanctuary” area near the elevator on each level. Under certain circumstances, patrons in wheelchairs in the orchestra level would be escorted through the lower lobby into the Men’s restroom and out through the Pavilion exit doors. Ushers would not fight the fire, if the fire is spreading beyond the spot where it started, or if the fire could block their exit or if they aren’t sure how to operate the fire extinguisher.

The Pathfinder calculation of Fractional Effective Dose (FED) shows that the occupant egressing from the grid-iron level are exposed to increased CO and CO_2 and reduced O_2 environment starting from 80 s. At the end of evacuation process the occupant has been exposed to an FED_{tot} value of 0.03, which is lower than the values considered as threshold for susceptibility to less severe exposure.

Based on the analysis, it can be assumed, the collective effort of the egress system and human-assistance plays a crucial role in evacuation process, which contributes to ensure minimal exposure to fire environment. Due to effective evacuation and egress system, possibility of irrational mass response is expected to be minimal.

Conclusion

A prescriptive and performance-based fire and life safety evaluation for Christopher Cohan Center is performed. The results and findings of the evaluations are conveyed in this report.

Christopher Cohan Center was built in accordance with California Building Code (1992 Edition) and California Fire Code (1992 Edition). The Current version (2015) of International Building Code is consulted for the prescriptive evaluation. The protection requirements set forth in IBC are intended to limit the threat from stage fires to an audience, to reduce the likelihood of a large fire in the stage area and to reduce the possibility of irrational mass response. These objectives have been identified as primary parameters to evaluate the fire and life safety systems of the building.

Christopher Cohan Center was constructed of Type IB construction with a sprinkler system throughout the building. Legitimate stage is completely separated from seating by a proscenium wall of 2-hour fire-rated construction with the main proscenium opening protected by an automatic closing fire protection curtain in accordance with IBC 410.3.5. A wet pipe, hydraulically calculated automatic sprinkler system is provided throughout the building. A hydraulic calculation was performed in accordance with NFPA 13, which shows that, the city water supply is not adequate for the sprinkler system and hose stream demands. The main exit of the Sydney Harman Hall accommodates a total occupant load of 1,440, which is more than the total occupant load of the hall, 1,289. This arrangement complies with IBC section 1029.2. In addition to having access to a main exit, Christopher Cohan Center is provided with additional exits from the balcony level, gallery level, orchestra stage, and entry lobby. These exits provide an egress capacity of 5,280 persons from orchestra stage and entry lobby levels and 960 persons

from balcony and gallery levels, which are more than the total occupant loads served by an individual level. In the event of an alarm, Christopher Cohan Center Ushers are required to assist in the evacuation process.

A fast-growing fire is modeled in FDS, which shows activation of gravity vents between 349 and 436 seconds, fire protection curtain activation at 440 s, and first sprinkler activation at 498 second after ignition. The tenability criterion is established to be the smoke layer descend within 2 m. above any means of egress. This criterion is predicted to occur at 210 s. in the zone model. FDS model does not predict smoke layer to descend within 2 m. above any means of egress, within the simulation time (570 s.). FDS model also shows that, the proscenium structure can contain the smoke until 300 s. FDS predicts the smoke detector will activate at 274 second. The notification of the fire event is expected to be triggered by the rapid descend of smoke layer, possibly shading or obscuring lighting effects dropped from the grid-iron, or by occupants, present in the fly gallery, sensing the presence of smoke, can initiate the notification of the fire event by activating manual fire alarm, long before the automatic detection devices detect the fire cues and initiate activation of the fire alarm.

Based on the evaluation of the building and stage construction, it is affirmed that the stage construction and separation play a key-role in limiting threat from a stage-fire to the audience due to its containment of smoke long enough for the audience to evacuate the hall. Response time of the sprinklers and smoke-detectors are excessively long, which confirms that the automatic systems will not meet the performance objective of limiting likelihood of a large fire in the stage area. The building would be relying on human actions to detect fire, to annunciate and to suppress the fire. To reduce the likelihood of a large fire in the stage area, human intervention would be a crucial factor. Also, the collective effort of the egress system and

human-assistance would play a crucial role in the evacuation process, which would contribute to ensure minimal exposure to fire environment. Due to effective evacuation and egress system, the possibility of irrational mass response is expected to be minimal.

Recommendations

Following recommendations are provided to address the major fire safety issues identified in the Christopher Cohan Center.

- A fire pump needs to be provided in accordance with NFPA 20 and IBC 913. The fire pump system must be inspected, tested and maintained and written records should be kept on-site, in accordance with NFPA 20.
- The automatic sprinkler system needs to be inspected, tested and maintained and written records must be kept on-site, in accordance with NFPA 25.
- The Recommended Fire Safety Management Practices must be added to the current Emergency Management Protocol, to create a comprehensive guideline for fire and life safety.
- Dedicated fire watch personnel and crowd managers must be engaged during events for immediate detection of fire or smoke and safe evacuation from the building.
- All employees and volunteers must receive training on response procedures as described in the Recommended Fire Safety Management Practices.