

Design and Implementation of a Fire Fighting System for a High-Rise Residential Building: A Case Study of SAMA Tower

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Abstract—This paper describes the design and installation of a fire-fighting system in a high-rise building, the SAMA Residential Tower. A sprinkler system, a standpipe system, a fire hose cabinet, a landing valve, hydrants externally connected, and a Siamese connection are all included in this system. Additionally, it complies with the codes of NFPA 13, 14, and 20, as well as those of the Palestinian and Jordanian governments. A hydraulic calculation was performed manually and then confirmed using Elite Fire Protection software. The layouts were developed using AutoCAD, and the 3D modeling was created in Revit in order to optimize the placement of the components. All zones of the building will be protected by this integrated approach, which ensures reliable flow, sufficient pressure, and code compliance.

Keywords—*Fire-fighting system, High-rise residential building, NFPA standards, Fire protection design.*

I. INTRODUCTION

High-rise residential buildings pose unique challenges in ensuring occupant safety and minimizing property damage during fire incidents [1]. These challenges necessitate specialized design approaches that prioritize safety and efficiency. Among the most critical elements in such designs are fixed fire protection systems [2], which must be meticulously engineered to meet specific pressure, flow, and accessibility requirements. This study offers an in-depth exploration of a comprehensive fire-fighting system design for the SAMA Tower, adhering to both international and local standards. The design process encompasses detailed fire risk analysis, precise hydraulic calculations, careful selection of components, and advanced layout simulations, providing a robust framework for fire safety in high-rise structures.

II. BACKGROUND AND FUNDAMENTALS OF FIRE PROTECTION SYSTEMS

A. Fire Safety Principles

To effectively combat fire, it is essential to understand the fundamental principles of how fire ignites and sustains itself. Fire requires three critical components to start and burn: heat, fuel, and oxygen [3]. This combination is commonly called the fire triangle. Removing any one of these elements whether by cooling the heat source, eliminating the fuel, or cutting off the oxygen supply will extinguish the fire [4].

In addition to the fire triangle, a fourth element, the chemical chain reaction, plays a crucial role in sustaining a fire. This reaction perpetuates the combustion process, transforming the fire triangle into a fire tetrahedron [5]. The inclusion of this chemical chain reaction highlights the dynamic and self-sustaining nature of fire.

Effective fire protection systems are designed to address and control these elements. By targeting heat reduction, fuel removal, oxygen deprivation, or disruption of the chemical chain reaction, such systems prevent fires from starting or spreading, ensuring safety and minimizing damage.

B. Types of Fire Protection

Fire protection is categorized into two types [6]: passive fire protection, which includes fire-resistant walls, doors, and barriers to prevent fire spread, and active fire protection, which involves systems like sprinklers, fire cabinets, hydrants, and pumps to directly combat fires.

C. Fire Suppression Methods

The most common method of extinguishing fires is with water. Sprinklers are widely used due to their speed and reliability [7]. Additional methods include water mist (fine droplets), foam (for fuel-based fires), and gas systems (ideal for sensitive environments like server rooms). In this study, we focused on a water-based sprinkler system because it is simple, cost-effective, and compliant with local regulations.

III. BUILDING ANALYSIS AND FIRE RISK ASSESSMENT

A. Building Type

The SAMA Tower is a high-rise residential building featuring multiple floors of apartments, corridors, garages, and technical rooms. It is classified as a residential occupancy according to building codes.

B. Fire Hazard Class

According to NFPA 557 and NFPA 13, buildings are categorized into hazard groups. SAMA building is classified as Ordinary Hazard Group 1 due to the presence of standard furniture, electronics, storage, and electrical areas.

C. Fire Load Calculation

The fire load indicates the quantity of combustible material present within a building. It is calculated using equation (1):

$$\text{Fire Load} \left(\frac{\text{MJ}}{\text{m}^2} \right) = \frac{\text{Mass} \times \text{Calorific value}}{\text{Area}} \quad (1)$$

The estimated materials include 500 kg of wood, 200 kg of plastic, 100 kg of paper/textiles, within a floor area of 1,250 m², resulting in a fire load of approximately 13.2 MJ/m², which falls within the range for Ordinary Hazard Group 1 (10–20 MJ/m²) [8].

IV. FIRE SYSTEM DESIGN AND COMPONENTS

A. Sprinkler System

A wet-pipe sprinkler system was selected instead of a dry system because it keeps the pipes constantly filled with water, making it the most common and straightforward system to install. Sprinklers are heat-activated; when the glass bulb breaks (typically at 68°C), water flows immediately. The sprinkler type used is standard spray, pendent type, with a K-factor of 5.6. Each sprinkler covers an area of 12 m², and the layout follows a tree distribution with simple, direct branches.

Adherence to NFPA 13 spacing requirements, as shown in Table I, was maintained. The sprinkler spacing was set at 3 m by 4 m, with a maximum of 8 sprinklers per branch. According to the code, sprinklers must be at least 1.8 m apart, and the distance between each sprinkler and walls or obstacles should not exceed half the spacing between sprinklers or be less than 10 cm [9].

TABLE I. PROTECTION AREA AND SPACING [10]

Construction Type	System Type	Protection Area		Spacing (maximum)	
		ft ²	m ²	ft	m
All	All	130	12,1	15	4.6

B. Fire Hose Cabinets (FHC)

Fire hose cabinets (FHCs) enable untrained individuals to combat fires before firefighters arrive, equipped with a hose, nozzle, and valve. In the used design [10], FHCs are strategically placed near exits, stairs, and garages, ensuring coverage of 25 m in all directions. The cabinets are semi-recessed (partially in the wall), provide a flow rate of 125 GPM, and require a pressure of 65 psi.

C. Landing Valves

Landing valves supply water to firefighter teams, strategically placed at stairwells for use by trained personnel only, as their high-pressure outlets are unsafe for public use. In the current design, one landing valve is installed on each floor.

D. Hydrants and Siamese Connections

Hydrants are positioned outside the building, spaced less than 30 m apart, to facilitate firefighting from fire trucks. A Siamese connection, featuring at least two 2.5" ports with a flow capacity of 250 GPM each, enables fire trucks to pump water into the building when necessary [9]. The hydrant flow rate

aligns with the overall system flow, and the Siamese connection is located near the main entrance and hydrants.

E. Pumps and Piping

Three pumps were selected for the system [11]: the main pump, an electric pump that handles normal operation and supplies total system demand; the jockey pump, a small pump that maintains system pressure to prevent frequent activation of the main pump; and the diesel pump, a backup pump that matches the main pump's flow and pressure in case of power failure. Pipes are made of Schedule 40 carbon steel, with diameters chosen to maintain velocities of 6–8 ft/s for sprinklers and fire hose cabinets (FHCs) and 10–15 ft/s for hydrants and Siamese connections. Sprinkler mains are 6 inches, FHC pipes are 4 inches, and Siamese/hydrant lines are 6 inches [9, 12, 13].

F. Valves

The fire-fighting system employs various valves to control water flow and facilitate maintenance. Gate valves isolate sections of the system, while check valves prevent backflow. Alarm check valves activate alarms when sprinklers are triggered, and test and drain valves enable system testing and water removal [11]. Pressure gauges monitor water pressure at critical points, and butterfly valves are used in confined spaces. Zone control valves divide the building into zones and signal alarms. Flexible connections between pumps and pipes minimize stress and vibration. Ball check valves provide backflow prevention with minimal pressure loss, and anti-vortex plates at pump inlets prevent air entry, ensuring smooth water flow [11].

V. HYDRULIC CALCULATIONS

A. Sprinkler Flow

NFPA 13 was used to determine the design area and required density for ordinary hazard, as shown in Figure 1.

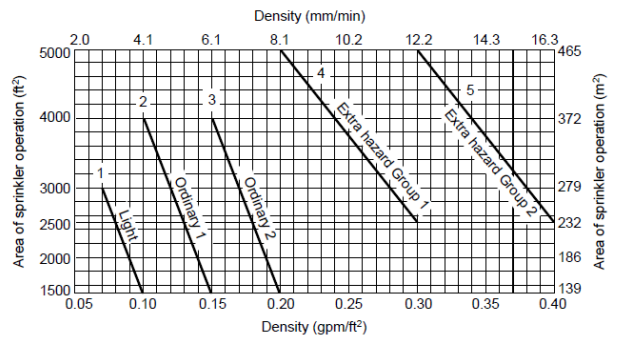


Fig. 1. Area of Sprinkler-Design Density [10].

The flow is calculated using Equation 2:

$$\text{Flow} (Q) = \text{Density} (D) \times \text{Design Area} (A) \quad (2)$$

where $D = 0.15 \text{ gpm/ft}^2$ and $A = 1500 \text{ ft}^2$. Thus:

$$Q = D \times A = 0.15 \times 13 = 19.5 \text{ GPM/Sprinkler}$$

The design area is 1500 ft² and each sprinkler cover 130 ft².

Therefore:

$$\text{Number of sprinklers} = \frac{\text{Design Area (A)}}{\text{Protection Area}} \quad (3)$$

$$\text{Number of sprinklers} = \frac{1500 \text{ ft}^2}{130 \text{ ft}^2} = 11.53 \approx 12 \text{ sprinklers}$$

Thus, the design area (A) requires: $19.5 \times 12 = 234 \text{ gpm}$

B. Fire Hose Cabinet (FHC) Flow

Each fire hose cabinet (FHC) requires 125 GPM, and the design must account for two cabinets at the farthest point, resulting in a total FHC flow of $2 \times 125 = 250 \text{ GP}$. The required pressure is 65 psi at the outlet.

C. Total Flow and Pressure

1) Total Flow (GPM):

The total designed flow combines the sprinkler and FHC flows as shown in equation (4).

$$\text{Total Flow} = \text{Sprinkler Flow} + \text{FHC Flow} \quad (4)$$

This is calculated as $\text{Total Flow} = 234 + 250 \approx 500 \text{ GPM}$. This calculation assumes an ideal flow pattern without considering the pressure losses that affect the flow. The flow is modeled using Equation (5):

$$Q = \frac{K}{\sqrt{P}} \quad (5)$$

where Q is the flow (GPM), K is the water flow coefficient (GPM $\text{psi}^{0.5}$), and P is the pressure at the sprinkler (psi).

2) Total Pressure (Psi):

The total pressure (psi) can be expressed using Equation (6):

$$P_{\text{Total}} = P_{\text{FHC}} + P_{\text{Elevation}} + P_{(\text{Friction} + \text{Fittings})} \quad (6)$$

where $P_{\text{FHC}} = 65 \text{ psi}$ is the pressure at the cabinet outlet, P_{Friction} represents the frictional pressure loss due to flow through pipes, $P_{\text{Elevation}}$ accounts for pressure loss due to elevation differences, and P_{Fittings} includes additional losses from valves, elbows, tees, etc.

The Hazen-Williams equation, shown in Equation (7), is used to calculate frictional pressure losses due to pipe length and fittings:

$$h_f = 4.52 \cdot \frac{Q^{1.85} L}{C^{1.85} D^{4.87}} \quad (7)$$

where h_f is the frictional pressure loss (psi), Q is the total flow rate in the pipe (GPM), L is the pipe length (ft), C is the roughness coefficient (unitless, typically 120 for steel), and D is the pipe diameter (inches).

The equivalent length method is used to account for pressure losses from elbows, tees, and valves by representing the length of straight pipe that would cause the same pressure drop. Therefore:

$$L_{\text{Total}} = L_{\text{Pipe}} + L_{\text{Fittings}} \quad (8)$$

where L_{Total} is the total length that is calculated as the sum of the longest pipe length L_{Pipe} and the equivalent length of the fittings L_{Fittings} .

By applying these equations, the total pressure for the system can be determined, which affects the total flow. The flow is expected to exceed 500 GPM, as demonstrated in Elite software.

VI. SOFTWARE SIMULATION WITH ELITE FIRE

Elite Fire Protection Software was used to simulate the hydraulic performance of the system, calculating the pressure and flow alongside the effects of losses on them.

A. Input Data

In the software, the following inputs were entered:

- 1) Building height and floor levels.
- 2) Hazard classification (Ordinary Hazard Group 1).
- 3) Type of system: Sprinkler and Standpipe.
- 4) Pipe materials and diameters.
- 5) Elevation of each node (floor or component).
- 6) Fittings, lengths, and K-factors.

B. Simulation

Two simulations were run in the software:

- 1) Sprinkler system simulation.
- 2) Fire hose cabinet system simulation.

C. Results Summary

The simulation results, as detailed in Table II, highlight the key characteristics of the fire components.

TABLE II. FIRE COMPONENT CHARACTERISTICS

Component	Hydraulic Calculations		
	Flowrate (GPM)	Pressure (psi)	Pipe Diameter (m)
Sprinklers	314.85	75	6
Fire Hose Cabinets	284.81	127.3	4
Landing Valves	250	65	6
Hydrants	600	127.3	6
Siamese	500 – 600	12 bar (from truck)	6

The total system flow is approximately 600 GPM under worst-case conditions. These results confirm the hand calculations and demonstrate that the design is reliable.

D. Fire Water Capacity

The amount of water required for Ordinary Hazard Group 1 for 60 minutes can be calculated using Equation (9):

$$C = \frac{Q_T \times 3.78 \times \text{Time}}{1000} \quad (9)$$

where Q_T is the total flow rate and $Time$ is the duration for extinguishing the fire. Substituting the values, the calculation is:

$$C = \frac{600 * 3.78 * 60}{1000} = 136.08 m^3$$

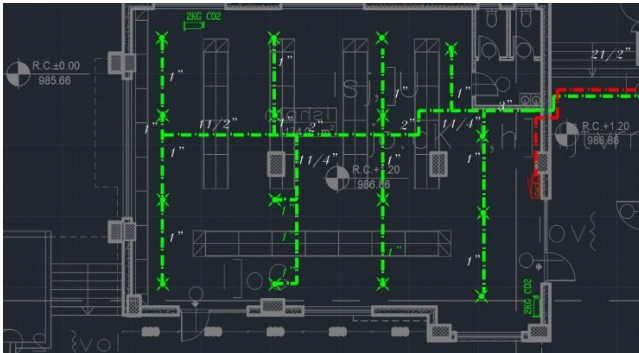
Therefore, the required water volume is 136.08 cubic meters.

VII. CAD AND REBIT MODELING

AutoCAD was used for creating 2D plans, while Revit was used for developing 3D models to prepare the system for real construction.

A. AutoCAD Layouts

AutoCAD was used to draw pipe paths, connections, and risers, show the positions of pumps, cabinets, and sprinklers, and measure pipe lengths needed for hydraulic calculations, as illustrated in Figures 2. Figure 2(a) shows the sprinkler distribution over the mezzanine, while Figure 2(b) illustrates the riser connection with pumps.



(a) Sprinkler Distribution Over the Mezzanine



(b) Raiser Connection with Pumps

Fig. 2. AutoCAD 2D Modeling.

B. Revit 3D Models

Revit allowed for the creation of realistic 3D views of the system, avoiding conflicts with structural or architectural elements, showing riser connections and vertical pipes between floors, and presenting the system visually to others, as shown in Figure 3. Figure included 3D sprinklers, risers, pumps, valves, and pipe networks in garages and apartment floors where Figure 3(a) illustrates FHC at garage, 3(b) pipe distributions over the garage, 3(c) raiser distributions, 3(d) sprinkler head at mezzanine, 3(e) sprinkler head on the line, 3(f) landing valve, 3(g) hydrant and Siamese, and 3(h) pump rooms.



(a) FHC at Garage



(b) Pipe Distributions Over the Garage



(c) Raiser Distributions



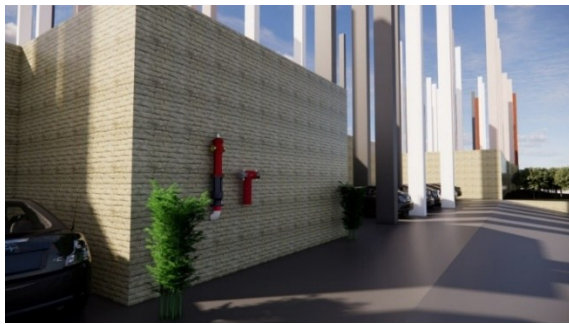
(d) Sprinkler Head at Mezzanine



(e) Sprinkler Head on the Line



(f) Landing Valve



(g) Hydrant and Siamese



(h) Pumps Rooms

Fig. 3. Revit 3D Modeling.

VIII. RESULTS AND DISCUSSION

A. System Performance

The system meets all fire protection goals. Water reaches all zones at the appropriate pressure, thus ensuring adequate

coverage. The sprinkler system and fire cabinet meet code demands, while pipe diameters maintain recommended velocities (6–15 ft/s). Additionally, pressure losses due to elevation and fittings are effectively managed, ensuring optimal system functionality.

B. Code Compliance

The system adheres to multiple standards, ensuring safety and reliability. It complies with NFPA 13 for sprinkler layout, density, and K-factor requirements. NFPA 14 standards for standpipe and fire hose cabinet pressure and flow are met, as are NFPA 20 requirements for pump types, valves, and backup systems. The system is also aligned with Palestinian and Jordanian codes, which specify component locations, spacing, and system zoning.

IX. CHALLENGES AND IMPROVEMENTS

A. Challenges

In this study, several challenges were encountered as follows:

- 1) Pressure at Top Floors: Achieving adequate pressure at the highest levels required careful pump selection and accurate pipe sizing.
- 2) Fitting Losses: Elbows, tees, and valves introduced pressure losses, which were addressed by including equivalent pipe lengths in the calculations.
- 3) Complex Inputs for Elite: Detailed data entry for each pipe section, node, and fitting was necessary, as even minor errors could significantly impact results.
- 4) Local Code Integration: Balancing NFPA standards with local Palestinian and Jordanian codes required additional checks and adjustments to ensure compliance.

B. Recommendations for Future Improvement

Several recommendations for future improvements are as follows:

- 1) Smart Monitoring: Install sensors to monitor water flow, pump status, and pipe pressure in real-time during a fire.
- 2) Scheduled Maintenance: Conduct regular tests and inspections to ensure the system remains operational and ready for emergencies.
- 3) CPVC Pipes: Utilize lightweight CPVC pipes in concealed areas to reduce costs and overall weight.
- 4) Pressure-Reducing Valves: Install PRVs on lower floors to protect Fire Hose Cabinets (FHCs) from excessive pressure.
- 5) Building Information Modeling (BIM): Implement a comprehensive BIM model to optimize system distribution, including sprinklers and hydrants, improving overall efficiency.

X. CONCLUSIONS

This work successfully designed a comprehensive fire-fighting system for the SAMA Residential Tower, adhering to NFPA 13, 14, 20, and local fire codes, incorporating essential components such as sprinklers, fire cabinets, landing valves, hydrants, and Siamese connections, and ensuring comprehensive coverage of all areas inside and around the building, adequate water flow and pressure to all fire-fighting components, efficient system distribution without overdesign, and enhanced reliability supported by a backup diesel pump and Siamese connections, achieved through meticulous planning, detailed analysis of the building's requirements, hydraulic calculations validated by Elite software, and precise CAD/Revit modeling, resulting in a well-designed system that not only meets regulatory standards but also provides robust protection, ensuring the safety of the building and its occupants.

XI. RECOMMENDATIONS

According to the experiences learned from this work, the following recommendations are made:

- 1) The future design of the building should include a smart monitoring system using sensors to detect and monitor pressure and flow levels inside the pipes, pumps, and along the valves.
- 2) Scheduled maintenance is essential to prolong the system's life by regularly checking components, testing pressure throughout the system, and ensuring pump operation to guarantee readiness.
- 3) Providing training for occupants, including fire drills and evacuation exercises, will improve evacuation times and enhance safety during emergency situations.

XII. FUTURE WORKS

Key areas for future research include:

- 1) Comparing the performance of wet-pipe and dry-pipe systems in buildings located in mixed climates with both hot and cold weather conditions.
- 2) Developing pipe materials to enhance their strength and resistance to mechanical corrosion and damage.

- 3) Improving water storage and recovery cycle systems to increase the efficiency of fire protection systems in dry and remote areas.

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