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Design and Implementation of an Advanced Firefighting System for Enhancing Outdoor Firefighting Abilities: A Case Study in Residential Project in Egypt

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Abstract – Large-scale outdoor fires pose significant risks to the environment and public safety, especially in residential and urban areas. This study focuses on enhancing outdoor firefighting capabilities in a residential development in New Cairo, Egypt, by designing and comparing two fire safety systems: a fire hydrant-only system and a combined fire hydrant and deluge system. The primary goal is to integrate effective firefighting infrastructure while adhering to the Egyptian Fire-Fighting Code and NFPA guidelines. A mixed-method approach, combining qualitative and quantitative methodologies, was utilized, including design proposals, area layout analysis, technical calculations, and system optimization. The fire hydrant-only system demonstrated a residual pressure of 123.58 psi with a flow rate of 1004.72 GPM, sufficient for sprinkler activation at 4.97 psi. Conversely, the combined system showed a residual pressure of 45.97 psi with a flow rate of 1440.80 GPM, meeting sprinkler activation requirements at 4.26 psi. While both systems meet fire safety standards, the combined system offers greater flow efficiency, making it suitable for high-demand firefighting scenarios. This research emphasizes tailored firefighting designs for landscape areas and highlights the importance of adapting solutions to specific fire safety needs, budgets, and geographical contexts. Integrating a deluge system into the fire hydrant infrastructure enhances fire suppression effectiveness, particularly in high-risk zones. Future research should explore comparative studies across diverse regions and incorporate advanced technologies to further optimize fire safety systems while considering environmental sustainability.

Keywords: Fire Suppression Technology, Fire Safety Standards, Outdoor Firefighting, Fire Hydrant System, Deluge System, Wildfire, Large-Scale Fires

Introduction

Large fires outdoors present a hazard to the built environment. Wildfires that spread into communities, also known as Wildland–Urban Interface (WUI) fires, are a common topic of international media coverage. WUI fires have destroyed communities all over the world and are a growing issue in the field of fire safety science. Large urban fires, including those caused by earthquakes, are additional examples. In recent decades, fire safety science research has devoted a substantial amount of time to comprehending the dynamics of fires within buildings. Research on large outdoor fires and how to mitigate the potential loss of structures in such fire's lags research in other areas of fire safety science.[1].

The most critical aspect of outdoor fires is their rapid and unpredictable spread, driven by several factors such as wind speed, fuel availability, and terrain conditions. These factors contribute to the challenges faced by firefighting personnel, as outdoor fires can increase quickly, two major points of danger to both human life and property. Effective containment and control of Greenland fires require a comprehensive understanding of fire behavior, coupled with quick response strategies and advanced technologies to counteract their unpredictable nature [2].

Table 1: Comparison of firefighting strategies for outdoor area firefighting

Strategies	Advantages	Disadvantages	Limitations
Firebreaks: Creating clear and open spaces between vegetation to prevent the spread of fire	-Effectively prevents fire spread	- Requires regular maintenance and upkeep	- May disrupt the natural aesthetics of the landscape
Water Supply: Creating clear and open spaces between vegetation to prevent the spread of fire	- Provides readily available resources for firefighting	- Dependent on the availability of water sources	- Requires installation of infrastructure
Sprinkler Systems: Installing sprinkler systems that can automatically detect and suppress fires in landscape areas.	- Automated detection and suppression of fires	- Initial setup cost and maintenance requirements	- Limited coverage in large landscape areas
Firefighting Access: Providing proper access for firefighting vehicles and equipment to easily reach different areas of the landscape.	- Enables swift access for firefighting vehicles	- Infrastructure requirements and potential obstructions	- May require modification of the existing layout
Firefighting Equipment: Ensuring the availability of firefighting equipment, such as hoses, nozzles, and fire extinguishers, in strategic locations.	- Equips locations with necessary firefighting tools	- Relies on human intervention to initiate action	- Limited effectiveness if not readily accessible
Training and Planning: Conduct regular training sessions for personnel involved in firefighting and establishing emergency response plans for quick and effective actions.	- Enhances preparedness and coordination	- Requires regular training sessions and planning	- Effectiveness relies on adherence to plans

The specifics of extinguishing fires in buildings and open spaces on the territory all over the World determine that a fire that has taken on a scale that allows it to be attributed to a large one is extinguished with the help of the forces and means of several fire and rescue units. [3]

On Saturday, October 6, 2018, a massive fire broke out in the Egyptian village of Al-Rashda, located in the New Valley Governorate to the west of Egypt. The agency reported that at least 37 people were injured by the fire that broke out near the village of Al-Rashda in the New Valley province on Friday, as shown in Fig. 1, primarily due to smoke inhalation. Authorities declared a high national emergency and evacuated homes as 30 fire trucks, first from Asyut and Sohag governorates, supported by four fire-fighting helicopters, fought the fires for more than 16 hours before gaining control of the blaze. The agency reported that seven firefighters and civil protection staff are among the injured, suffering from oxygen deprivation or minor burns. The governor of New Valley said that the fire had impacted a 100-fedan (104-acre) area of palm plantations and was challenged to spread to the next village. The fire began in a tiny area, but as the wind picked up, it quickly spread to agricultural areas and then to residential areas [4].

Wildfire behavior is crucial for understanding green area fuels and potential green area fuels. Four characteristics describe wildfire behavior: rate of spread, heat per unit area, flame length, and Fireline intensity. The rate of spread affects heat distribution, while a slow-moving fire concentrates more heat on the site. [5,6], Extinguishing agents play a critical role in fire prevention and containment, governed by regulatory standards and legal mandates to ensure effective firefighting strategies. Selecting the right extinguishing agent depends on case-specific variables, fire classification, and material properties. F classification is crucial for identifying effective fire suppression approaches [7,8].

Class A fires encompass fires involving organic solids, including materials such as paper, wood, and plastic. Class B fires pertain to fires involving flammable liquids, while Class C fires involve flammable gases. Electric spark symbols represent fires initiated by electrical equipment. [9,10]. Landscape Firefighting strategies in Egypt according to the Egyptian Fire Protection Code are shown in

Table 1: Comparison of firefighting strategies for outdoor area firefighting. Wildland fire suppression research spans multiple scales, each offering distinct insights into the effectiveness of various strategies. At the flame scale, controlled experiments provide evidence on the performance of suppression chemicals in halting fire spread and reducing fuel consumption, although their applicability to real wildfire scenarios remains limited. Observations at the Fireline scale, encompassing fire perimeter assessments and Fireline construction, yield valuable data on resource productivity, suppression impacts, and the efficiency of hand crews and aerial

resources. Research at the incident scale further emphasizes the importance of accurate productivity models, economic analyses, and case studies to inform decision-making. Moreover, landscape-scale studies utilizing incident databases reveal critical fire outcome variables, but persistent data gaps necessitate expanded datasets and collaboration between researchers and fire managers. The findings of Abdelraouf et al. [11] underscore the necessity of a multi-scale approach to wildfire suppression research, recommending deeper investigations into specific chemicals, resource types, and mop-up activities, alongside the integration of tracking systems and diverse data sources to develop realistic operational datasets and improve wildfire management strategies.[11]

Previous Studies

The Fire Hydrant System is an essential and integral component of modern firefighting infrastructure, designed to provide a readily available and reliable water supply for extinguishing fires in urban and industrial settings. This firefighting equipment consists of a network of underground pipes connected to a series of strategically placed hydrants. These hydrants serve as accessible points for firefighters to connect hoses and access pressurized water, allowing them to respond quickly to fire emergencies. Fire Hydrant Systems are crucial for urban fire suppression, providing immediate water sources, reducing spreading risk, and minimizing property damage. Efficient design and maintenance enable rapid response and effective control in populated areas [12-14].

Hydrants, developed in the 1600s, are crucial for fighting fires and supporting municipal activities. As cities grew, the need for cost-effective fire management systems increased, and strategically placed, high-capacity hydrants became more important. [15,16]

A jockey pump is essential for regulating hydraulic fluid in fire hydrant and sprinkler systems, maintaining consistent water pressure, and preventing damage. It modulates pressure levels, ensuring continuous pump operation, ensuring optimal functionality and durability. [17,18].

Although there has been a global awakening on fire disaster management, and empirical literature with recent issues, Sufiyanto et al [19] study the Application of hydrant piping system design in boiler plants for fire safety systems in papermaking companies, The scope of the research discussion includes hydrant piping systems, hydrant piping calculations, and standards used in hydrant piping systems. The result of the calculation and data processing of this hydrant system design is the number of pillar hydrants needed in an area of 2016 m^2 is 2 pillar hydrants, the required water discharge is 432 m^3 with the assumption that the blackout time is 2 hours, and the pipe diameter required is 6 inches and must have a pipe thickness of 6 mm.

Also, Rahmad Samosir et al [20] confirm that the building fire pump design meets regulatory standards, including DKI Jakarta Governor Regulation No.92/2014 and Indonesian National Standard. It features an integrated parallel pump system, a backup pump for contingency, and a minimum head of 64 meters. The pump meets key specifications, including a minimum water level of 5.82 meters below the pump centerline and a minimum capacity of 171 m^3.

The installation of fire hydrants within water distribution systems serves the crucial purpose of providing firefighters with a means to swiftly connect hoses and combat fires as they arise. The practice of placing hydrants at intervals of 500 ft in the USA, as outlined by Lamm (200), is standard, although various factors such as accessibility, obstructions, proximity to protected buildings, and specific circumstances contribute to practical considerations in their placement. In urban water distribution systems, the quantity of hydrants installed can range from hundreds to thousands, depending on the city's size. Beyond their primary firefighting function, hydrant flow tests serve multiple purposes.[21] These include estimating available fire flow and calibrating hydraulic models using pressure data to identify leakage hotspots Sage, Wu, and Croxton [22]

Shah, Lakin, Singh, Raval, and Grimes, maintaining water quality through pipeline flushing to collect accurate pressure data, guidelines have been developed for selecting hydrants for flow tests [23]. The test Recommendations often include testing hydrants located at the distribution system's outskirts and achieving significant pressure drops of at least 10 psi or 70 kPa during [24]

The study aims to create a mixed fire system for outdoor firefighting, using modern engineering principles. It integrates a deluge system with a hydrant to reduce fire intensity and risks and evaluates its performance.

Methods

This study employs a comprehensive mixed-method approach, which combines both qualitative and quantitative methodologies, to investigate and improve residential outdoor firefighting capabilities. The study's methodology outlines a series of well-defined steps that guide the research procedure as shown in **Figure 1**. All begins with the conception of design concepts, where innovative firefighting system designs are proposed. Then, examine the layout of the designated area., taking into account factors such as landscape area, pipe material, diameter, length, and water flow rate. The subsequent phase entails designing the piping network and installation components of the firefighting system to ensure optimal functionality and effectiveness. To evaluate crucial parameters such as water pressure, flow rates, and hydraulic properties, technical calculations are performed. The crucial question of whether or not the design meets the specified objective is then addressed. This methodology, guided by a structured approach.

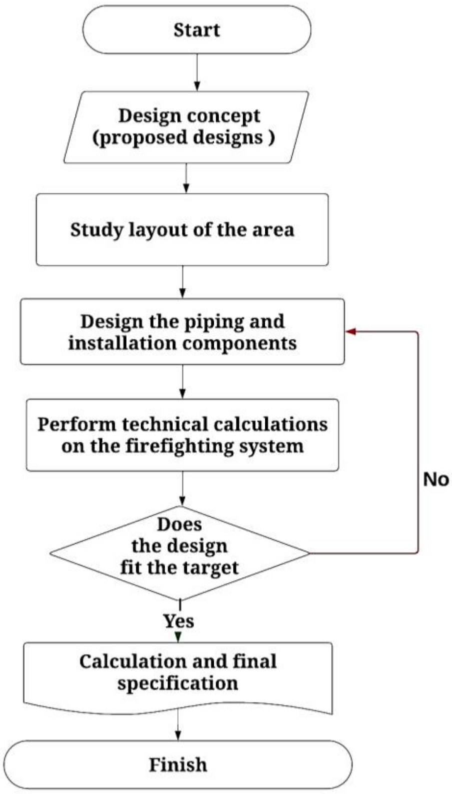


Figure 1: Research methodology workflow

Optimization of technical calculations performed with The Elite Software Fire Program is crucial for managing and optimizing sprinkler systems, utilizing NFPA 13 hydraulic calculations, estimating head requirements, evaluating pipe sizes, and conducting peaking analyses. It assists the design and review procedure by precisely calculating variables such as GPM water flow, velocity, residual pressure, pressure losses, system demand, and total GPM of water. The program ensures data integrity, records project specifics, and provides precise pipe segment and node identification. It offers comprehensive reports, customizable content, and preview options, which significantly contribute to the design and analysis of fire safety systems. [24].

Proposed Designs:

Study Area:

The Dort l'Karz residential project in New Cairo, Egypt, as shown in Figure 2, aims to provide high-quality residential units and integrated facilities. It adheres to quality, safety, and sustainability standards, offering green spaces, schools, recreational facilities, commercial centers, and public transportation. The project aims to meet population needs and improve the quality of life in the area.

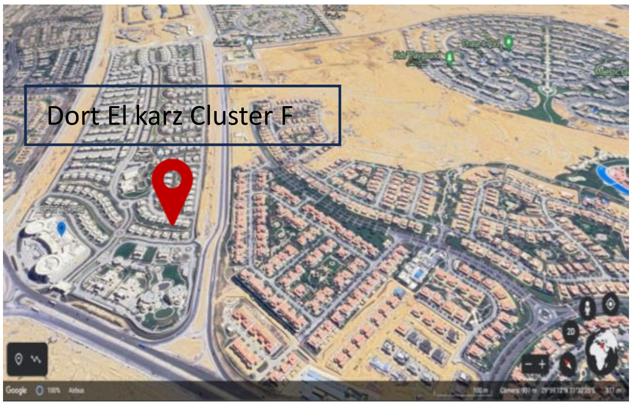


Figure 2: 3D Mapping for the Dort El Karz Project

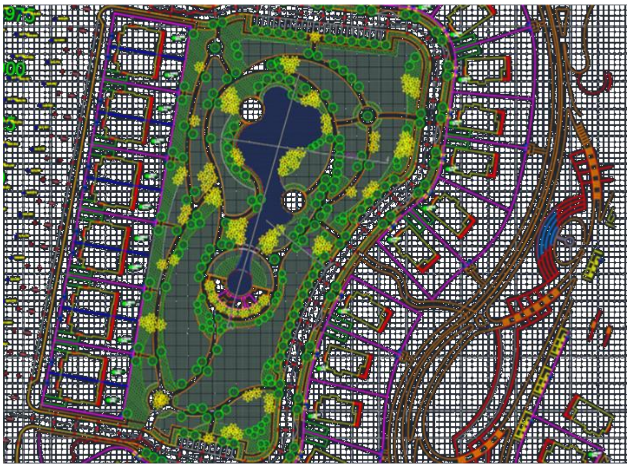


Figure 3: Cluster F AutoCAD Dort El Karz Layout

Fire uses the Hazen-Williams equation. to solve pipe networks, and each pipe is defined to flow according to the Hazen-Williams equation. Calculations can be made for a given water supply pressure or they can be performed such that Fire determines the lowest water supply pressure needed to adequately supply the sprinkler system. Calculations are very fast and accurate. The user manual lists all the pertinent equations to allow for full manual verification.[25]

Hydraulic equations commonly used for the design and analyses of water transmission networks are Darcy–Weisbach equation; and Hazen–Williams equation [26], The design and analysis were worked out by using the most popular Hazen–Williams equation. This equation is the conventionally acceptable equation for the design of a water conveyance system as it is simple to use. Hazen–Williams equation with hydraulic mean depth, slope, and velocity is given by Eq. (1)

$$V = 0.852 C_H R^{0.63} S^{0.54} \qquad (1)$$

Where C_H: Hazen–Williams's coefficient of pipe, .S: Slope of the hydraulic gradient line (m/m) and R: Hydraulic mean depth m, Substituting $V = 4Q(\pi D^2)$, $R = D/4$,$C_H = 100$,$S = h_f\ /L$in Eq. (1), and after some algebraic manipulations, one can obtain equations.

$$h_F = \frac{10.68 L Q^{1.852}}{C_H^{1.852} D^{4.87}} \quad (2)$$

$$h_f = K Q^{1.852} \quad (3)$$

where K = Resistance coefficient of a pipe and given by

$$K = \frac{10.68 L}{C_H^{1.852} D^{4.87}} \quad (4)$$

The Hazen–Williams formula expressed in the forms of the above equations can be used to compute the loss of head in a pipe flowing under pressure.

Fire employs the Newton-Raphson matrix solution technique for pipe network analysis, solving nonlinear equations governing flow in pipes. This iterative numerical technique linearizes equations and improves until convergence. The Hardy-Cross method, suitable for smaller networks and simpler systems, balances flows and head losses in closed-loop pipe networks. The choice between these methods depends on network complexity, computational efficiency, and desired accuracy level.

The Newton-Raphson method can be represented by the following equation for a single pipe in a network [21]

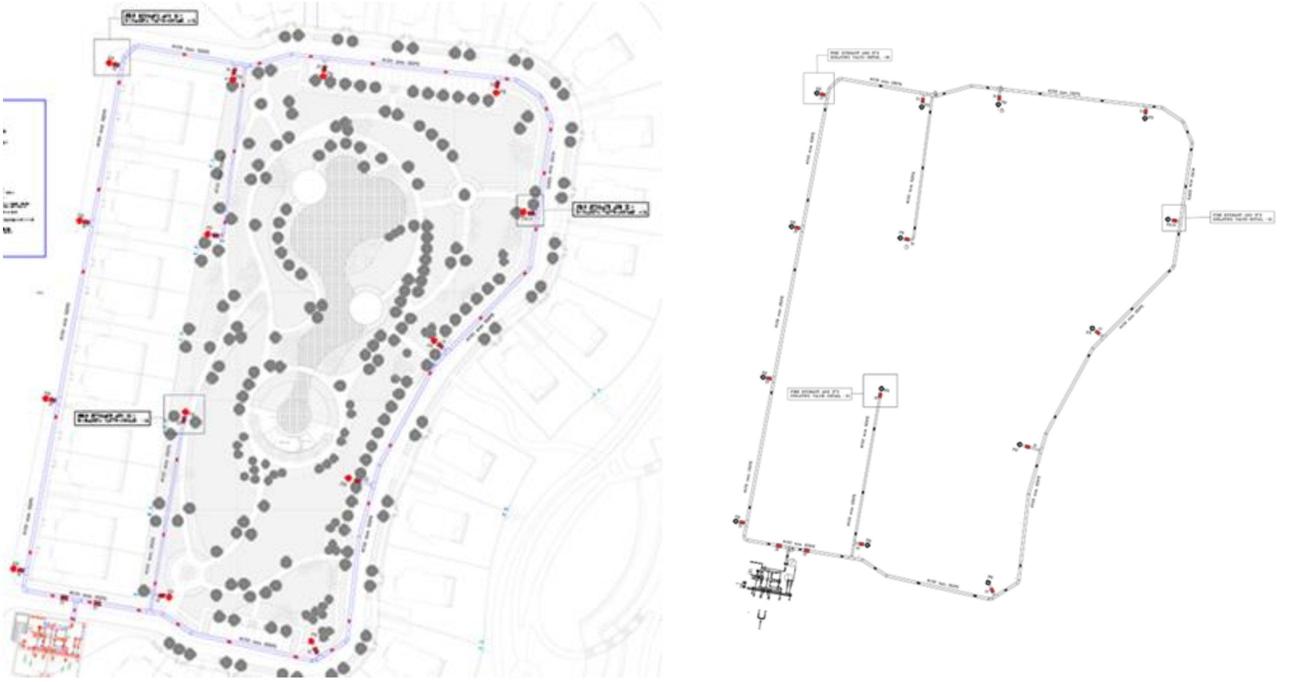
$$f(q) = Kq^n - H \quad (5)$$

Where $f(q)$ is the function that relates flow rate q to head loss, K is a constant based on pipe properties, n is the exponent in the Hazen-Williams equation, H is the head loss in the pipe.

The Hardy-Cross method is appropriate for the iterative adjustment of flow rates in a closed loop until the head losses are balanced. It relies on a series of iterative steps to converge on a solution rather than explicit equations, The choice between these methods is determined by the characteristics of the pipe network and the computational resources available. The Newton-Raphson method yields more precise results for larger and more complex networks than the Hardy-Cross method does for simpler systems. [27]

Hydrant System

The first proposed design is the Hydrant System, which serves as the default reference design in accordance with the Egyptian fire code. This design focused on established restrictions and standards, reflecting a comprehensive approach to fire safety measures. Fire hydrants are crucial for fire safety, and extinguishing fires in residential areas. A hydrant system involves a suction pump drawing water from a ground reservoir, directed through pipes to strategically placed outdoor hydrants. This research aims to design a hydrant piping system for residential complexes, aligning with industry standards and regulations. It involves determining optimal water flow rates, selecting appropriate pipe thickness, and establishing the required number of installations [28].



a) First fire suppression system on the landscape layout **b) Arrangement of hydrant system piping**

Figure 4:Firefighting hydrant system design using AutoCAD.

The study introduces an efficient fire hydrant system to mitigate fire hazards in regions of flammable dry grass covering 18,500 square meters. This system aims to overcome challenges associated with manual firefighting methods and delays in civil defense response that will take a minimum of 30 minutes to arrive, close examination of the Egyptian Fire Code, the approach strategically places fire hydrants, ensuring a spacing of up to 100 meters and a minimum of 60 meters between them, as shown in Figure 4. Utilizing advanced firefighting pumps and sophisticated software, the system optimizes water distribution and pressure, resulting in enhanced firefighting efficiency. This proposed solution has the potential to significantly enhance fire safety measures in such environments. By activating two hydrants simultaneously and discharging 500 gallons per minute per hydrant, this strategy aims to address the challenges posed by the rapid spread of the fire and minimize property loss.

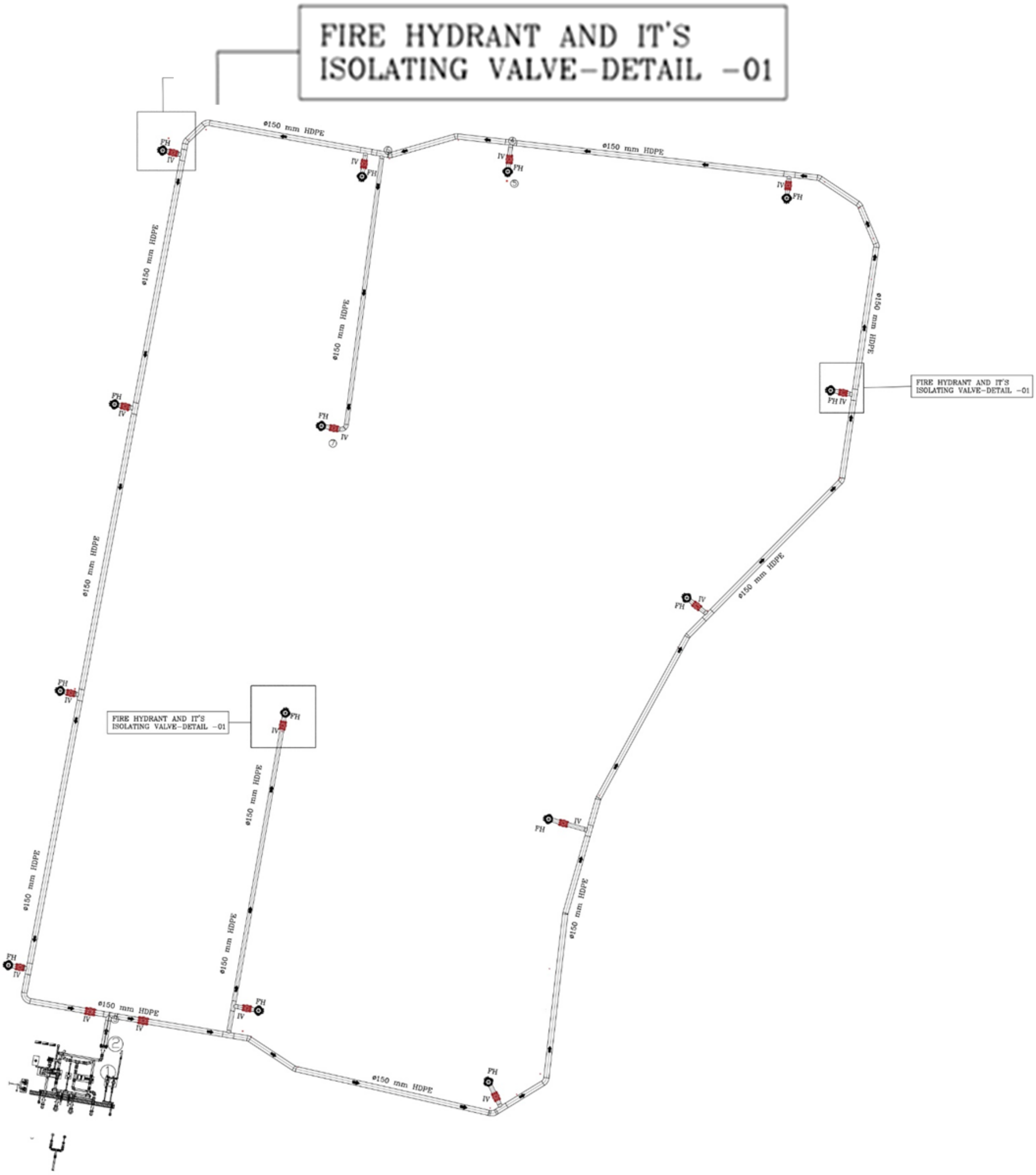


Figure 5 The detailed piping design with the location of hydrants

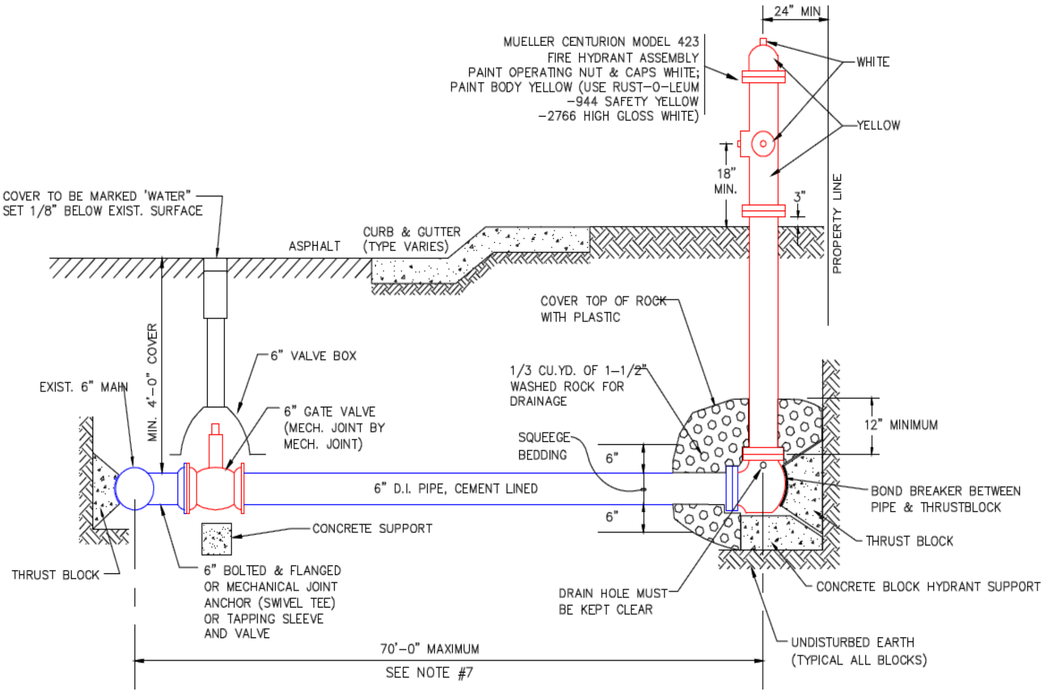


Figure 6: Fire hydrant installation instructions

Table 2 provides essential project data for fire protection system evaluation. It begins by categorizing the type of hazard under consideration, identified as "Ex. Haz. Gp. 2," indicating a specific fire risk category. The table also specifies the hose system type as "Wet," indicating a system where water is continuously present in the pipes, a critical aspect of fire suppression. Further details encompass the designated area for water application, the maximum coverage per hose, and the K-Factor associated with the hoses, which plays a critical aspect in flow rate calculations. Additionally, it records the material composition of the pipes within the system, identified as "AQUATHERM PP-R."

Table 2:Input data for hydrant system

Input Data	Value	Unit	Input Data	Value	Unit
Description Of Hazard:	Ex. Haz. Gp. 2		Hose System Type:	Wet	
Design Area Of Water Application:	600	ft²	Maximum Area Per Hose:	130	ft²
Default Hose K-Factor:	50	K	Default Pipe Material:	AQUATHERM	PP-R
Inside Hose Stream Allowance:	0	gpm	Outside Hose Stream Allowance:	0.00	Gpm
In Rack Sprinkler Allowance:	0	gpm	null	null	Null
Hose SpecificationsMake:	null	null	Model:	null	Null
Size:	4	null	Temperature Rating:	155	F
Test Hydrant ID:			Date Of Test:		
Hydrant Elevation:	0	ft	Static Pressure:	0	Psi
Test Flow Rate:	0	gpm	Test Residual Pressure:	0	Psi
Calculated System Flow Rate:	1004.72	gpm	Calculated Inflow Residual Pressure:	123.58	Psi
Calculation Mode:	Demand				
HMD Minimum Residual Pressure:	100.08	psi	Minimum Desired Flow Density:	0.4	gpm/ft²
Number Of Active Nodes:	7	null	null	null	
Number Of Active Pipes:	7	null	Number Of Inactive Pipes:	0	
Number Of Active Hoses:	2	null	Number Of Inactive Hoses:	0	

Various allowances for inside and outside hose streams are accounted for, ensuring comprehensive fire protection. The table extends to provide specifications for hoses, including make, model, size, and temperature rating, although some entries appear as "null" due to potential data gaps. The table concludes with essential information about calculation mode, minimum residual pressure according to the Hazen-Williams method, desired flow density, and counts of active nodes, pipes, and hoses, offering a holistic overview of the fire protection system's parameters and scope.

Hydrant System with Deluge System (Mixed System)

By integrating a deluge system, the system objective is to rapidly suppress and control fires until the fire civil defense team arrives. While there exists no precedent within NFPA codes specifically catering to landscape areas, we draw inspiration from analogous cases, such as dry material storage, to inform our design strategies. according to NFPA 15 regulations, we ascertain that the design density for ordinary combustible solids falls within the range of 0.15 to 0.50 gallons per minute per square foot (GPM/ft2), This meticulous approach to fire suppression holds the potential to significantly enhance safety measures and minimize the impact of fire outbreaks in outdoor spaces.

The choice of open nozzles is recommended over sprinklers due to the higher flow rate of nozzles compared to sprinklers. Open nozzles extinguish fires and cool materials, preventing flashover (fire re-ignition). In contrast, sprinklers are primarily utilized for fire control purposes as shown in NFPA 15 at 7.2.1.1 design objective. That mentioned “systems shall be designed so that extinguishment shall be accomplished, and all protected surfaces shall be cooled to prevent flashback occurring after the system Is shut off "[29]

As per NFPA guidelines, the design density for most ordinary combustible solids is recommended to be within the range of 0.15 to 0.50 gallons per minute per square foot (GPM/ft^2). For this study, the median value of 0.25 GPM/ft^2 is chosen. Based on the density area curve outlined in NFPA 13, this flow rate corresponds to area coverage of 3800 square feet (ft^2). as shown in **Figure.**

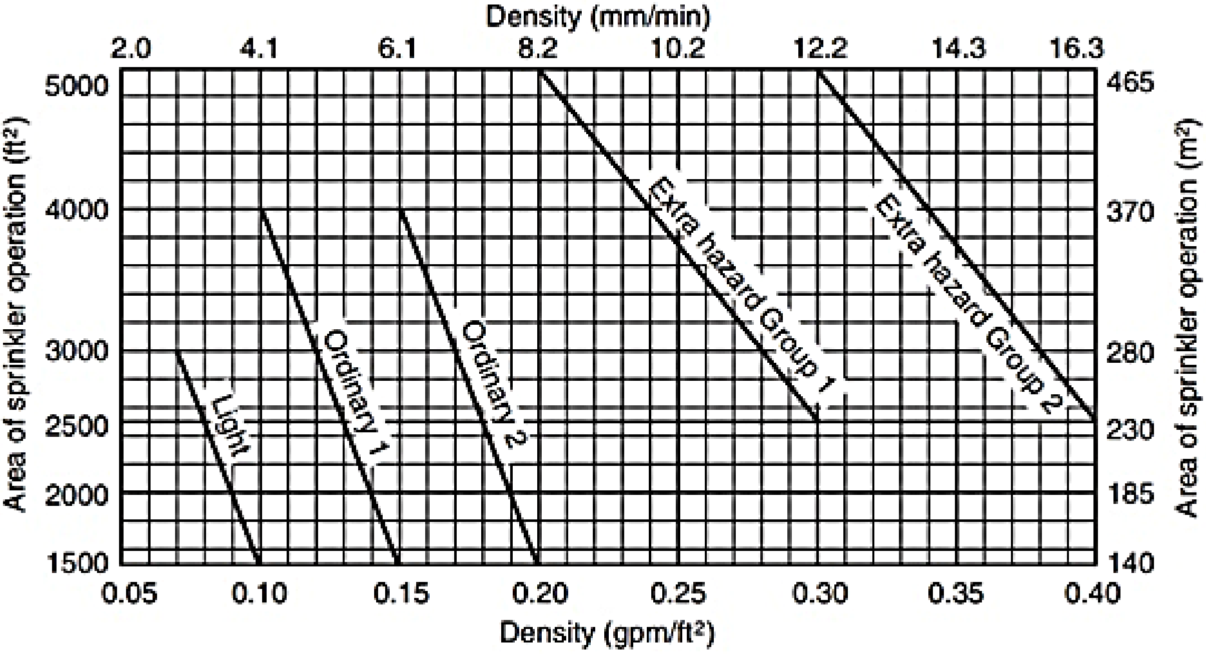
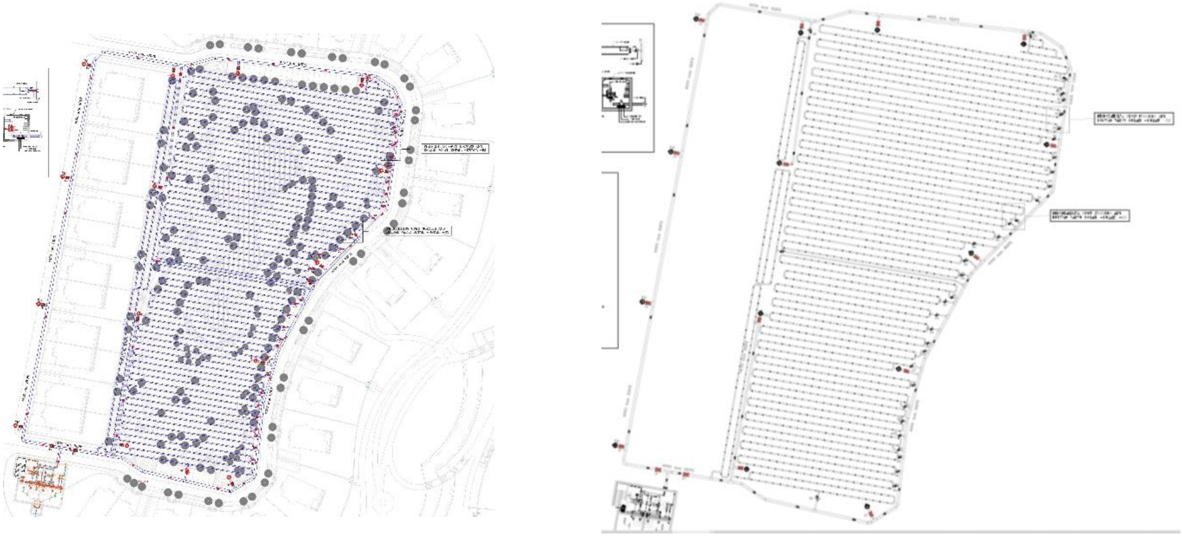


Figure 7: Density / area curves from NFPA 13

An additional fire hydrant is essential in this scenario to assist firefighters in extinguishing the fire, with a discharge rate of 500 gallons per minute (GPM). The required nozzle flow rate, calculated as 0.25 (GPM/ft^2) * 3800 ft^2, amounts to 950 GPM. The cumulative pump flow, combining the hydrant and nozzle requirements, equals 1450 GPM. Consequently, a pump with a capacity of 1500 GPM was selected to meet these demands. According to NFPA 15 the distance between nozzles is 3m as shown in the 7.1.8 nozzle design. That mentioned " nozzle spacing (vertically or horizontally) shall not exceed 10 ft (3m) "[30]



(a) The second fire suppression system on the landscape layout **(b) Arrangement of hydrant system piping with deluge system**

Figure 8: Firefighting deluge system with hydrant system design using AutoCAD.

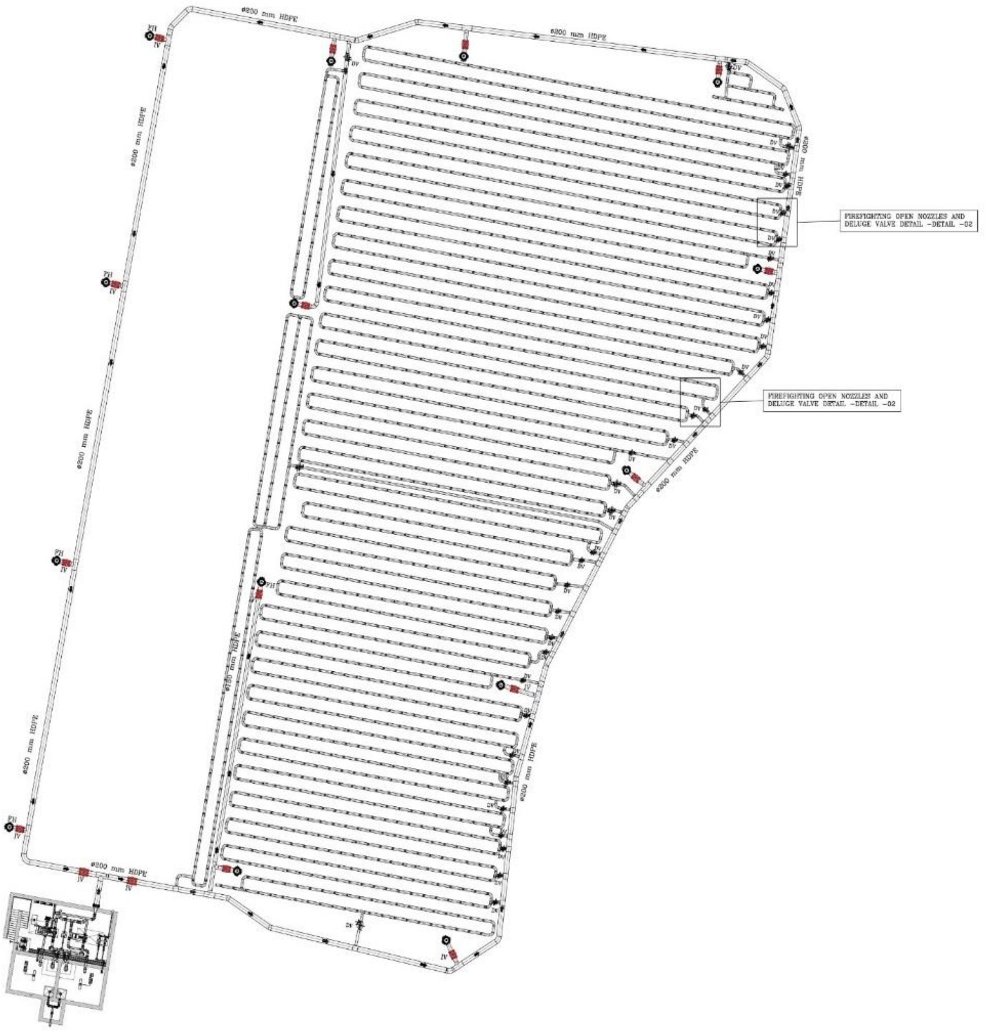


Figure 9: The detailed piping system with location of nozzles and hydrants

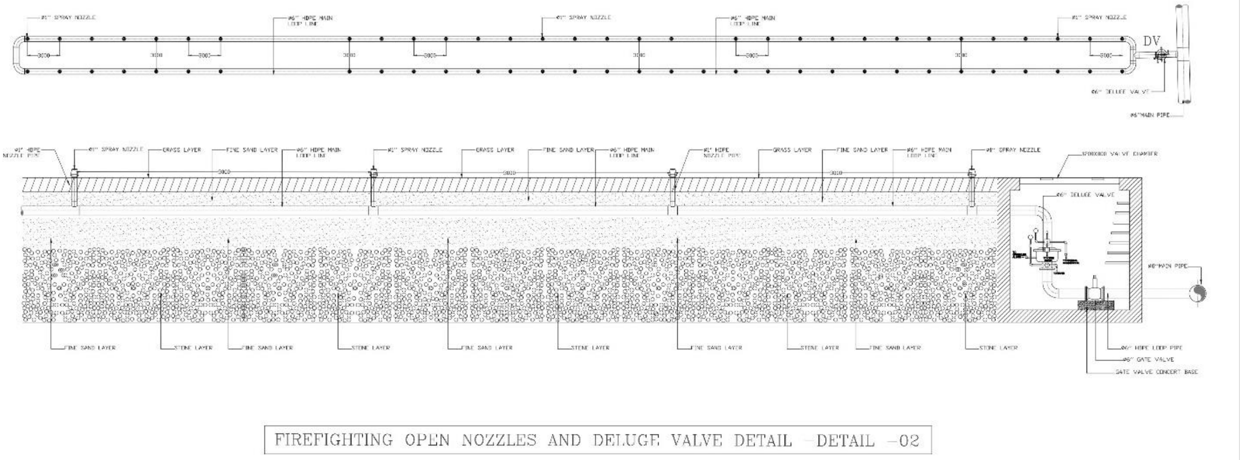


Figure 10: The detailed cross-section and installation of the nozzles

Input Data for Mixed System Analysis

Table 3 provides essential project data for fire protection system evaluation. It starts with a hazard description denoted as "Ex. Haz. Gp. 1," indicating the hazard group classification. The chosen sprinkler system type is "Dry," signifying the presence of air in the pipes until activation during a fire event. The designated area for water application within the project covers 3800 ft², with a maximum coverage area of 100 ft² per sprinkler, ensuring effective distribution. The default sprinkler K-Factor, a vital parameter impacting flow rate calculations, was recorded as 5.80 K. Moving to sprinkler specifications, specific details regarding the make, model, size (Size 1), and temperature rating (155°F) provided, emphasizing the precision and suitability of the chosen sprinkler system.

Table 3: Input data for a mixed system

Project Data					
Description Of Hazard:	Ex. Haz. Gp. 1		Sprinkler System Type:	Dry	
Design Area Of Water Application:	3800	ft²	Maximum Area Per Sprinkler:	100	ft²
Default Sprinkler K-Factor:	5.80	K	Default Pipe Material:		
Inside Hose Stream Allowance:	0.00	gpm	Outside Hose Stream Allowance:	0.00	Gpm
In Rack Sprinkler Allowance:	0.00	gpm			
Sprinkler Specifications Make:			Model:		
Size:	1		Temperature Rating:	155	F
Water Supply Test Data Source Of Information:					
Test Hydrant ID:			Date Of Test:		
Hydrant Elevation:	0	ft	Static Pressure:	0.00	Psi
Test Flow Rate:	0.00	gpm	Test Residual Pressure:	0.00	Psi
Calculated System Flow Rate:	1440.80	gpm	Calculated Inflow Residual Pressure:	45.97	Psi
Calculation Project Data					
Calculation Mode:	Demand				
HMD Minimum Residual Pressure:	21.00	psi	Minimum Desired Flow Density:	0.25	gpm/ft²
Number Of Active Nodes:	44				
Number Of Active Pipes:	45		Number Of Inactive Pipes:	0	
Number Of Active Sprinklers:	35		Number Of Inactive Sprinklers:	0	

The subsequent section outlines calculation project data, specifying the calculation mode as "Demand." Minimum residual pressure requirements are defined at 21.00 psi, with a corresponding minimum desired flow density of 0.25 gpm/ft², underscoring the importance of efficient water distribution to meet fire safety standards.

Table 3concludes by providing numerical counts of active components within the system, including 44 active nodes, 45 active pipes, and 35 active sprinklers. Notably, there are no inactive pipes or sprinklers,

Table 4 presents a detailed bill of quantities for the two-system design, offering a clear overview of the quantities and units of various components in both the first and second proposals. This table is crucial for project planning and cost estimation, allowing for a comprehensive assessment of the required materials and equipment. Additionally, the inclusion of notes regarding changes in pressure and flow rate in the pump room provides valuable context for understanding the design specifications. Overall, this well-organized table serves as a valuable reference for project stakeholders and facilitates informed decision-making during the design and implementation phases.

Table 4: Bill of quantities for the complete two-system design

Description	Unit	First Proposal	Second Proposal	Notes
		Quantity	Quantity	
6" FIRE HYDRANT	NO	14	14	
6" ISOLATING VALVE	NO	16	16	
6" HDPE PIPE	m	1100	1100	
1" OPEN NOZZLES	NO	-	1850	
3.5" DELUGE VALVE	NO	-	37	
3.5" ISOLATING VALVE	NO	-	37	
3.5" HDPE PIPE	m	-	9200	
Pump room				
8" Alarm check valve	NO	1	1	The pump room is still the same No change in pressure but a change in the flow rate
8" Non return valve	NO	2	2	
8" O.S & Y valve	NO	7	7	
8" RELIEF VALVE	NO	1	1	
3" GATE VALVE	NO	2	2	
3" Non return valve	NO	1	1	
8" BLACK STEEL PIPE	m	30	30	
3" BLACK STEEL PIPE	m	10	10	
Electric Pump	NO	1 (1000 GPM & 9BAR)	1(1500 GPM & 9BAR	
Diesel Pump	NO	1 (1000 GPM & 9BAR)	1(1500 GPM & 9BAR)	
Jockey Pump	NO	1 (100 GPM & 10BAR)	1(100 GPM & 10 BAR)	

Results

Hydrant System

as shown in **Table 5**.HMD Hose Node Number 7 refers to the identification number of the hose node in the system, HMD Actual Residual Pressure 100.08 psi represents the actual remaining pressure at the hose node after accounting for any pressure losses or friction in the system, HMD Actual GPM 500.2 GPM indicates the actual flow rate of water at the hose node in gallons per minute.

Table 5:Hydraulically most demanding hose node

Description	Quantity	Unit
HMD Hose Node Number:	7	
HMD Actual Residual Pressure:	100.08	psi
HMD Actual GPM:	500.2	GPM

The specified area of application is 600 ft^2, which indicates the area where the firefighting system is intended to be applied. The minimum desired density is 0.4 GPM/ft^2, which represents the minimum amount of water flow per square foot required for effective firefighting. The application average density of 1.675 GPM/ft^2 indicates the actual average water flow per square foot achieved in the application area. The application average area per hose is 300 ft^2, which represents the average coverage area per hose used in the firefighting system. The hose flow of 1005.02 GPM represents the total flow rate of water through all the hoses in the system. The average hose flow of 502.51 GPM indicates the average flow rate per hose in the system as shown in **Table 6.**

Table 6:Hose summary

Description	Quantity	Unit
Specified Area of Application:	600	ft^2
Minimum Desired Density:	0.4	GPM/ft^2
Application Average Density:	1.675	GPM/ft^2
Application Average Area Per Hose:	300	ft^2
Hose Flow:	1005.02	GPM
Average Hose Flow:	502.51	GPM

As shown in table 7 Maximum flow velocity in pipes 2-3 indicates the highest speed, measured in feet per second, Allowable maximum nodal pressure imbalance is the acceptable difference between connected nodes, with a limit of 0.01 psi. and maximum velocity pressure represents pressure exerted in that section. The actual average nodal pressure imbalance is 0.0042 psi, while the actual maximum flow imbalance is 0.1002 GPM, representing the average difference in pressure and flow between nodes, the data presented in **Table 8** provides insights into the fire suppression system's characteristics, including capacity, efficiency, and prerequisites. The system comprises 7 distinct pipe segments and 2 hoses, with a water volume totaling 3770.23 gallons and a minimum residual pressure of 123.58 psi at the inflow node.

Table 7:Flow velocity and imbalance summary

Description	Quantity	Unit
Maximum Flow Velocity (In Pipe 2 - 3)	11.16	ft/sec
Maximum Velocity Pressure (In Pipe 2 - 3)	0.84	psi
Allowable Maximum Nodal Pressure Imbalance	0.01	psi
Actual Maximum Nodal Pressure Imbalance	0.01	psi
Actual Average Nodal Pressure Imbalance	0.0042	psi
Actual Maximum Nodal Flow Imbalance	0.2531	GPM
Actual Average Nodal Flow Imbalance	0.1002	GPM

Table 8: Overall network summary

Description	Quantity	Unit
The Number of Unique Pipe Sections:	7	
A number Of Flowing Hoses:	2	
Pipe System Water Volume:	3770.23	gal
Hose Flow:	1005.02	GPM
Fixed Flow:	0	GPM
Minimum Required Residual Pressure At System Inflow Node:	123.58	psi
Demand Flow At System Inflow Node:	1004.72	GPM

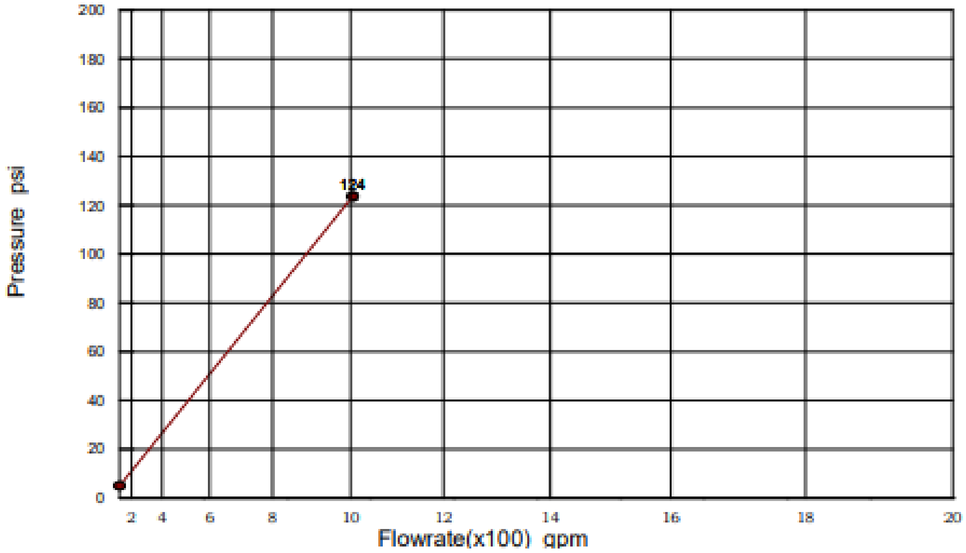


Figure 11: Hydraulic supply/demand graph

As shown in **Figure** , the calculated residual pressure of 123.58 psi represents the pressure remaining in the system after accounting for losses due to friction and elevation changes, and the calculated flow rate of 1004.72 GPM represents the rate at which water flows through the system. The pressure required for the first sprinkler downstream from the inflow node to flow is 4.97 psi, which is the minimum pressure needed to activate and maintain proper water flow through the sprinkler.

Mixed System

Table 9 displays detailed information about a particular sprinkler node identified as number 17 within a fire protection system. The "HMD Actual Residual Pressure" entry indicates that the residual pressure at this specific sprinkler node is 21 psi (pounds per square inch). This pressure level is crucial for ensuring effective water delivery to the sprinkler heads. The "HMD Actual GPM" entry represents the actual water flow rate at this sprinkler node, which is measured at 26.58 gallons per minute (GPM). This flow rate determines the volume of water that the sprinkler system can deliver to suppress or control a fire. These values offer insights into the performance and capabilities of the sprinkler system at the specified node, which are essential factors for evaluating the system's effectiveness in fire protection scenarios.

Table 9:Hydraulically most demanding sprinkler node

Description	Quantity	Unit
HMD Sprinkler Node Number:	17	NO.
HMD Actual Residual Pressure:	21	psi
HMD Actual GPM:	26.58	GPM

Table 10 includes the following details, the specified area of application for the sprinkler system is 3800 square feet (ft²), and this area is adjusted to 4940 ft². The minimum desired density of water distribution is 0.25 gallons per minute per square foot (GPM/ft²), while the application's average density is 0.248 GPM/ft². Additionally, the application's adjusted density, which is not required by NFPA 13 standards, is 0.191 GPM/ft². The table also indicates that the average area covered by each sprinkler is 108.57 ft², and this value is adjusted to 141.14 ft², which is not required by NFPA 13. The sprinkler flow rate is measured at 943.58 gallons per minute (GPM), while the average sprinkler flow is 26.96 GPM. These metrics collectively provide insights into the effectiveness and efficiency of the sprinkler system in delivering water for fire protection purposes.

The values presented in Table 11 reveal key insights about the flow dynamics in pipe sections 37 and 38 of the fire suppression system. The maximum flow velocity of 10.45 feet per second indicates the highest water flow rate through these sections, while the maximum velocity pressure of 0.73 psi signifies the pressure generated by this velocity. Also, parameters related to nodal pressure and flow imbalances are detailed.

Table 10:Sprinkler summary

Description	Quantity	Unit
Specified Area Of Application:	3800	ft²
Adjusted Area Of Application:	4940	ft²
Minimum Desired Density:	0.25	GPM/ft²
Application Average Density:	0.248	GPM/ft²
Application Adjusted Density (not required by NFPA 13):	0.191	GPM/ft²
Application Average Area Per Sprinkler:	108.57	ft²
Adjusted Area Per Sprinkler (not required by NFPA 13):	141.14	ft²
Sprinkler Flow:	943.58	GPM
Average Sprinkler Flow:	26.96	GPM

The allowable maximum nodal pressure imbalance of 0.1 psi denotes the acceptable pressure difference between adjacent nodal points, with the actual maximum nodal pressure imbalance recorded at 0.0865 psi. The average nodal pressure imbalance is 0.0137 psi. Furthermore, the actual maximum nodal flow imbalance of 5.0268 GPM represents the largest flow rate difference between adjacent nodal points, and the average nodal flow imbalance is 0.394 GPM. These values collectively provide a comprehensive understanding of pressure and flow distribution, aiding in evaluating the system's hydraulic performance and balance.

Table 11:Flow Velocity and Imbalance Summary

Description	Quantity	Unit
Maximum Flow Velocity (In Pipe 37 - 38)	10.45	ft/sec
Maximum Velocity Pressure (In Pipe 37 - 38)	0.73	psi
Allowable Maximum Nodal Pressure Imbalance:	0.1	psi
Actual Maximum Nodal Pressure Imbalance:	0.0865	psi
Actual Average Nodal Pressure Imbalance:	0.0137	psi
Actual Maximum Nodal Flow Imbalance:	5.0268	GPM
Actual Average Nodal Flow Imbalance:	0.394	GPM

Table 12 provides an overview of essential parameters in the fire suppression system analysis. The table encompasses key quantities and measurements in distinct units, allowing for a comprehensive assessment of the system's characteristics. It outlines the number of unique pipe sections, which totals 45, and the count of flowing sprinklers, which amounts to 35. Additionally, the table provides vital measurements, including the pipe system's water volume at 6428.13 gallons. The sprinkler flow, essential for fire suppression, is recorded at 943.58 gallons per minute (GPM), while the non-sprinkler flow is 500 GPM. The minimum required residual pressure at the system's inflow node stands at 45.97 pounds per square inch (psi). Finally, the demand flow at the system's inflow node is quantified at 1440.8 GPM. These parameters collectively offer a comprehensive insight into the system's hydraulic behavior and performance.

These results collectively offer valuable information about the system's performance and its ability to meet the demands of fire suppression scenarios. The demand curve data as shown in figure 12 provides valuable insights into the hydraulic behavior of the fire suppression system. The calculated residual pressure of 45.97 psi indicates the pressure remaining within the system after accounting for various pressure losses. This residual pressure is a critical parameter to ensure effective water delivery throughout the system. The calculated flow rate of 1440.80 gpm represents the rate at which water is flowing through the system, highlighting the system's capacity to supply water to the sprinklers. The pressure required for the first sprinkler downstream from the inflow node to flow is 4.26 psi, signifying the minimum pressure needed to activate and maintain proper water flow through the sprinkler

Table 12 :Overall Network Summary

Description	Quantity	Unit
A number Of Unique Pipe Sections:	45	
A number Of Flowing Sprinklers:	35	
Pipe System Water Volume:	6428.13	gal
Sprinkler Flow:	943.58	GPM
Non-Sprinkler Flow:	500	GPM
Minimum Required Residual Pressure At System Inflow Node:	45.97	psi
Demand Flow At System Inflow Node:	1440.8	GPM

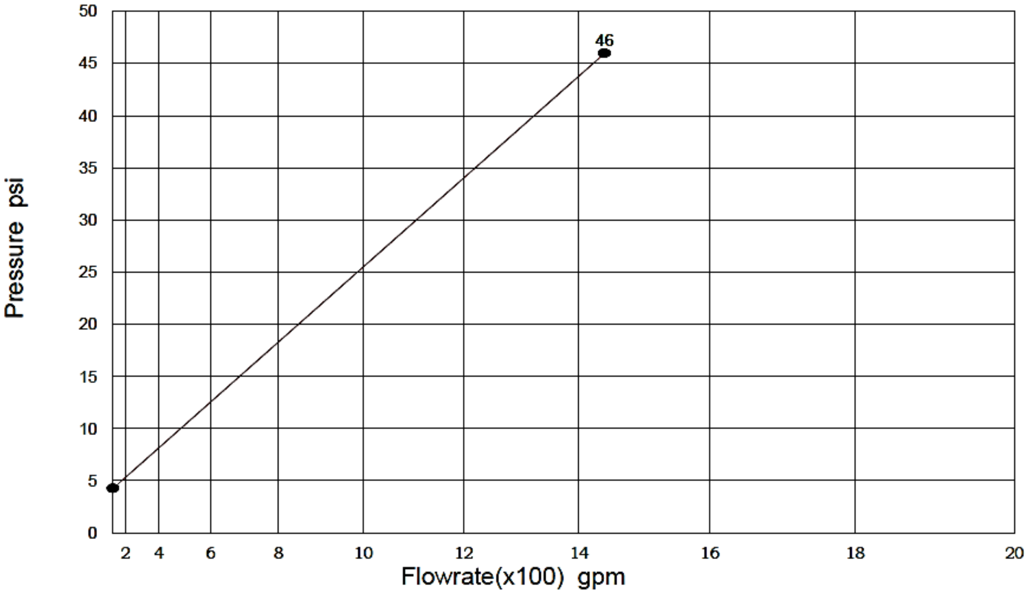


Figure 5: Hydraulic supply/demand graph

Discussion:

In evaluating the performance of the deluge system in conjunction with hydrants against the standalone hydrant system, Multiple important aspects come into consideration. Firstly, time efficiency is a key consideration. The deluge system, with its automated activation, demonstrates a remarkable advantage by responding to fires within 5 to 10 seconds. In contrast, the hydrant system relies on manual hose connections, potentially resulting in significantly slower response times, with a minimum activation time of about 30 minutes as mandated by the Egyptian Fire code.

Secondly, cost considerations play a pivotal role. As depicted in Table 4, implementing a deluge system with hydrants incurs higher upfront plays an increasingly important role in installation costs due to the inclusion of specialized components and the need for ongoing maintenance. Conversely, the hydrant system alone boasts lower installation and maintenance costs, primarily due to its simplicity and lack of complex components.

Finally, when it comes to flow rates and fire suppression capabilities, highlights a critical distinction. The deluge system excels in providing high-flow rates, enabling the effective suppression of fires over large areas, thus preventing their rapid spread. In contrast, the hydrant-controlled flow rates are more suited for localized fire suppression within the residential area.

Conclusions

The comparison between the two fire safety design approaches, involving fire hydrant systems in the first design and fire hydrant and nozzle systems in the second design, reveals distinct strategies for addressing fire hazards in landscape areas. In the first design, a fire hydrant system is proposed to efficiently combat potential fires in flammable dry grass regions. This approach involves strategically placing fire hydrants with specific spacing guidelines, as prescribed by the Egyptian Fire Code. The system incorporates advanced firefighting pumps guided by software to optimize water distribution and pressure, enhancing firefighting efficacy. The comparison illustrates significant differences between the two designed hydrant systems. The first system, with a calculated residual pressure of 123.58 psi and a flow rate of 1004.72 GPM, seems to offer higher pressure and adequate water flow for the first downstream sprinkler's activation at 4.97 psi. On the other hand, the second system, with a residual pressure of 45.97 psi and a flow rate of 1440.80 gpm, also meets pressure requirements for the first downstream sprinkler at 4.26 psi, indicating its capacity to deliver water effectively.

In summary, the choice between the deluge system with hydrants and the standalone hydrant system should be based on specific fire safety needs, budget constraints, and the desired response times. The deluge system offers rapid response and broad coverage, making it suitable for larger areas but at a higher cost. On the other hand, the hydrant system provides cost-effective fire suppression for smaller, localized incidents, albeit with longer response times. Careful consideration of these factors is essential in selecting the optimal fire safety infrastructure.

The limitation inherent to this study lies in its contextual specificity, as it primarily addresses fire safety design within a particular landscape area of a residential project located in New Cairo, Egypt. Consequently, the findings and comparisons presented herein may not be directly transferable to diverse geographical locations or alternate project types with distinct fire safety requisites. Furthermore, this study operates under the assumption of certain parameters, such as fire hydrant spacing and adherence to specific design guidelines, based on the Egyptian Fire Code, variables that might exhibit variations in other regions or under dissimilar regulatory frameworks. Consequently, future research endeavors should consider adapting these design approaches to a broader array of settings and account for alternative fire safety standards as appropriate.

The future trajectory of research in this domain could encompass the conduct of analogous comparative investigations across diverse geographic contexts. Such efforts would serve to gauge the effectiveness and feasibility of varying fire safety design approaches while elucidating region-specific best practices and guidelines for landscape fire safety. Furthermore, forthcoming research could delve into the integration of innovative technologies, including remote monitoring and automated fire suppression systems, to augment the efficiency and responsiveness of fire safety infrastructure. In parallel, there exists an imperative to evaluate the environmental and sustainability facets of fire safety systems, given their long-term implications for ecosystems and resource conservation.

Abbreviation list

NFPA - National Fire Protection Association

GPM - Gallons Per Minute

ELITE - Elite Software Fire Program

HDPE - High-Density Polyethylene

PRV - Pressure-Reducing Valve

HMD - Hydraulically Most Demanding

CAD - Computer-Aided Design

HMD Actual Residual Pressure

Declarations

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' Contributions

SH, MA, M.M, O.E contributed to the design and implementation of the research, the analysis of the results, and the writing of the manuscript.

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