DESIGN OF AUTOMATIC FIRE SPRINKLER AND PRESSRIZATION SYSTEMS IN STAIRWELL FOR HIGH-RISE BUILDING IN JORDAN

By

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DEDICATION

To My Parents

To My Wife

To My Children (Ahmad and Slma)

To the General Directorate of Civil Defence

ACKNOWLEDGMENT

I would like to address my sincere appreciation to my thesis supervisor, Prof. Mohammad A. Alsaad for his guidance, advice, and invaluable assistance in achieving the successful end of this thesis. I would like to thank Sigma Consultant Engineering office for their cooperation to support me with architectural drawings for the case study of high-rise building that is conducted in this research.

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LIST OF SYMOBLS

Ad	Design area, m^2
A_E	The effective leakage areas, m^2
A_R	Area of pressure relief, m^2
A_S	Coverage area per sprinkler, m^2
A_V	Area of air/smoke release vents, m^2
Cw_1	Pressure coefficient for windward wall
Cw_2	Pressure coefficient leeward wall
D	Actual internal diameter, mm
D_d	Design water density , mm/min
EC	Extended coverage
K-factor	Sprinkler discharge characteristics, $L/min\sqrt{kPa}$
L	Maximum distance between branches, m
L_{min}	Minimum length of rectangular area, m
L_1	Length of the pipe segment 1, m
L_2	Length of the pipe segment 2, m
N	Wind exponent
N_s	The number of sprinklers along the length of the design area
P_{high}	Higher pressure associated with the demand, kPa
P_{low}	Low Pressure associated with the demand, kPa
P_n	Normal pressure, kPa
P v	Velocity pressure, kPa
P_f	Friction loss of pipe, kPa/m
P_i	Internal pipe pressure,Psi
P_t	Total pressure, kPa
S	Maximum distance between sprinklers, m
S_t	Allowable stress in the pipe,Psi
T_f	Absolute temperature of the gas inside fire, K
T_s	Absolute temperature of the inside air, K
T_o	Absolute temperature of outside air, K
V	Velocity of water in the pipe, m/s
V_o	velocity at reference elevation, m/s
Y	Average roof height, m

$\dot{q}$	Flow rate releasing from any sprinkler, L/min
$\dot{Q}$	Flow rate passing through the segment of pipe, L/min
$\dot{Q}_1$	Flow rate in pipe segment1, L/min
$\dot{Q}_{\min}$	Minimum flow rate, L/min
L_{eq}	Equivalent length of pipe, m
$L_{fitting}$	Equivalent length of fitting, m
$P_{\min}$	Minimum pressure at any sprinkler head, kPa
P_{Loss}	Pressure loss, kPa
P_{start}	Starting pressure for sprinkler, kPa
$\dot{Q}_{adj}$	Adjusted flow rate required to adjust pressure difference, L/min
$\dot{Q}_c$	Air flow rate to the pressurized space, m^3/s
$\dot{Q}_{low}$	Flow rate associated with the lower demand, L/min
$\dot{Q}_p$	Air flow rate through open door, m^3/s
$\dot{q}_{start}$	Starting flow rate for sprinkler head, L/min
$\dot{Q}_t$	Total flow rate in the loop, L/min
$\dot{Q}_w$	Wasted air flow rate, m^3/s
Δp	Pressure difference from the shaft to the outside, Pa
Δp_w	Wind pressure across a building, Pa

LIST OF ABBREVIATION

AWDD	Actual water delivered density, mm/min
ACV	Alarm check valve
ANSI	American National Standards Institute
ASTM	American Society for Testing and Material
AHJ	Authority having jurisdiction
BHP	Brake horse power
BS	British Standard
BFV	Butterfly valve
CPVC	Chlorinated poly vinyl chloride pipes
ESFR	Early suppression fast-response
EC	Extended coverage
FM	Factory Mutual
FDC	Fire department connection
HVAC	Heating ventilation and air conditioning
HRBs	High-rise buildings
LPCB	Loss Prevention Council British
NFPA	National Fire Protection Association
NPT	National pipe threads, mm
NPSH	Net positive suction head
OSYV	Outside stem and yoke valves
PB	Polybutylene pipes
PSS	Pressurization stairwell system
QR	Quick Response
RWDD	Required water delivery density, mm/min
SCH	Schedule
S.N	Schedule number
SSP	Standard spray pendent
SSS	Standard spray sidewall
SSU	Standard spray upright
UL	Underwriter Laboratory
ZCV	Zone control valves

LIST OF APPENDICES

DESIGN OF AUTOMATIC FIRE SPRINKLER AND PRESSRIZATION SYSTEMS IN STAIRWELL FOR HIGH-RISE BUILDING IN JORDAN

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ABSTRACT

This study aims to design automatic sprinkler system, standpipe system, and pressurization system in high rise buildings in Jordan, since there is no specification for designing such systems in the country. In this study the American specification (NFPA) and the British specification (BS) were adopted for designing such systems.

A model for the sprinkler system and landing valve system was made to satisfy the requirements of high –rise buildings according to Jordanian building code, taking into consideration that it does not contradict with the international specifications.

This model has been applied on one of the proposed high- rise buildings in Jordan. The manual method for the hydraulic calculations specialized in automatic sprinklers systems was employed. The validity of the result was checked by using the Elite computer software. Comparison of the results has shown great accuracy in design.

The pressurization systems in stairwells were designed according to the British specifications. All factors concerning designing these systems and their effect on the results have been studied in detail.

`CHAPTER ONE

INTRODUCTION

This chapter presents a background on high-rise buildings, the importance of fire safety in high-rise buildings, historical developments of high–rise buildings, and the objectives of the study.

1.1 Background

Prior to 2004 there were few high-rise buildings in Jordan. Two years ago, high-rise buildings (HRBs) and towers started in Jordan with Al-Abdali area which is considered the first integrated high rise building area in Amman. One of the dangers that threaten these types of buildings is fire. The public sector represented by Ministry of Public Works and Housing , Civil Defence, and the private sector cooperated to limit its effect.

The National Jordanian Building Code Council developed the Fire Prevention Code (The Ministry of Public Works and Housing, 2004) and its modifications (The Ministry of Public Works and Housing, 2007) that were issued in 1990 (The Ministry of Public Works and Housing, 1990) to govern high-rise building regulations. Since then, the automatic sprinkler and pressurization systems became obligatory from the design drawing stage. The building code defines a high –rise as a building measuring more than 23 m from the lowest level of Civil Defence vehicles access to the highest occupiable floor. The regulations of high- rises basically depend on the American National Fire Protection Association (NFPA), (Life Safety Code NFPA 101, 2006), and the British Standard (BS) with some slight modifications.

Automatic sprinkler and pressurization systems are two of the important fire regulations to improve high-rise fire safety which will be discussed in this thesis from the design point of view.

There are many benefits of installing sprinklers and pressurization systems such as: sprinklers protect human life, and protect property. According to the NFPA statistics, the sprinkler system reduces property damage in HRBs by one–half to two-thirds. Pressurization stairwells protect stairs from smoke which is the refuge area for fire fighters and people in the building to escape.

There is not yet a fire engineering code specialized in HRBs in Jordan. So there is difficulty for the design fire system in this type of building. Particularly there are no standards for design of fire system in this type of building (HRBs). The responsibility of determination of regulations and approvals for fire safety design drawings is held by Civil Defence.

Automatic sprinkler system means an integrated system of underground and overhead piping designed in accordance with fire protection engineering standards. The portion of the sprinkler system above the ground is a network of specially sized or hydraulically designed piping installed in a building. The valve controlling each system riser is located in the system riser or its supply piping. Each sprinkler system riser includes a device for actuating an alarm when the system is in operation. The system is usually activated by heat from the fire and discharges water over the fire area (NFPA 13, 2006).

A sprinkler head will operate when the set temperature value is reached for the specific sprinkler head (from manufacture) or through bursting glass bulb which releases water into the fire. Usually the hot gases from a fire are enough to make it operate. Only sprinklers located over the fire will operate and the others remain closed.

Pressurization stairwell systems (PSS) are defined as a form of smoke control system used to keep escape routes such as stairwells and lobbies clear of smoke during a fire. This is satisfied through generating a positive pressure difference between inside of stairwell and outside the accommodation area. The major items of the PSS system are fan, duct and control system.

1.2 Fire Safety Importance in High-Rises

Fire in HRBs generally requires more complicated operational approaches than other buildings. First, it is difficult for firemen to reach the upper floors, because the highest truck ladder in Jordan extends to the seventeenth floor only. In order to extinguish blazes and fires above the seventeenth floor, firemen must climb dozens of stairs, dragging fire hoses and other heavy equipment with them. Second, it is not easy to evacuate rapidly and safely a large number of people knowing that the regulations of fire safety prevent using elevators as a mean of escape during the fire. Too many people may be obligated to descend crowded stairs. The dangers are intensified in the noise, smoke, darkness and confusion of the fire. Third, chimney effect through vertical openings such as stairwells allows smoke to pass through the upper floors .Smoke contains large amount of toxic gases such as carbon mono-oxide which is the major cause of death. Fourth, building materials in HRBs will generate poisonous smoke resulting from wires, plastics, furniture and carpeting.

Technical reports in Chicago showed that the death rate in high –rise fires is approximately 3.5 times greater than the national average. Approximately 91% of those fires occurred in non-sprinklered high-rise buildings (The Chicago High-Rise Safety Commission, 1999). According to NFPA statistics, sprinklers reduce the average of fire deaths per 1,000 fires by one-half to two-thirds. Also sprinkler reduces death rate in high-rise buildings by 71% of the rate of death per 1,000 fires (Hall, 1996).

1.3 History and Development of High-Rise Buildings

The first high-rise building appeared around the year of 1870. Since then, there has been a development in their design and construction. There have been three stages of high-rises since 1880 (Hagan, 1977) and (Tharmarajan, 2007). These stages can be simplified as follow: The first stage extended from 1870 to 1920 where the exterior walls of these buildings consisted of stone or brick and sometimes cast iron was added for decorative aims. The column and beams of this stage were constructed from cast iron and steel respectively, while the floors were made of wood. There were no standards for protection of steel. The second stage extended from 1920 to 1940 where non-combustible construction materials were used to reduce the probability of collapse of building structure during the fire. The most important characteristic of this stage is the use of fire resistance material in the construction of HRBs. These materials were included in the construction of the barriers that separate areas and provided good degree of fire resistance determined by the specific fire resistance rating of the assembly itself (Craighead, 1995). In addition, the vertical openings were enclosed with protective compartments which prevent spread of smoke and fire. The third stage extends from 1940 up to now. The majority of high rise buildings were constructed from steel frame and reinforced concrete or from steel and concrete.

1.4 Study Objectives

This study aims to investigate and discuss the following systems for high-rise building in Amman, Jordan.

First: Designing of automatic fire sprinkler system:

In this part the following items will be considered:

1. Determining the fire hazard level in this type of building: Every building should be classified for fire risk under the following categories; light hazard, ordinary hazard (group1), ordinary hazard (group 2), extra hazard (group 1), and extra hazard (group 2). These categories will be studied and discussed.
2. Determining the design criterion of optimum design area and optimum design density: The design area is a theoretical space within the building that is designated as the worst possible place where a fire can break out. The design density is the optimum amount of water per square meter that would be needed to put out a fire in the design area.
3. Determining the optimum sprinkler spacing or sprinkler coverage area.
4. Selection of the methods of networks connection: Three connection methods of sprinkler heads that are used in high-rise buildings will be studied. These are tree, loop and grid connections.
5. Selection of the types of modern sprinkler heads: Many modern types of sprinkler heads are used in high-rise buildings such as upright, pendent, sidewall, and extended coverage heads. The suitable sprinkler head for the present study will be selected in the present work.

6. Selection of the types of sprinkler systems: Four common types of sprinkler systems will be investigated such as wet, dry, pre-action, and deluge sprinkler types. One of these sprinkler types will be selected and used in the present study.
7. Studying the components of the sprinkler systems: The main components of the systems will be studied and analyzed such as gate valves, check valves, pipes, hangers, and pumps.
8. Performing computer and manual hydraulic calculations: This study will discuss in detail the computer and manual hydraulic calculations of automatic fire sprinkler systems. There are many computer software approved for fire fighting calculations, such as Elite software, which will be used to test the manual calculations. The manual hydraulic calculation will be based on Hazen–Williams formula in accordance with the area density method used in NFPA.

   The above calculations will include hose stream demand system as requirements of Jordanian codes (Fire Prevention Code, 2004) and (Fire Protection Code, 2004). Hose stream is of two types which are outside stream such as hydrant and inside stream such as hose reel and landing valve.

9. Selection of fire pumps from the rating and specification curves of fire pumps.

Second: Designing the pressurization stairwell system

The present study will focus on the following items:

1) Analysis of pressurization system: Single and multiple injection types will be analyzed and studied in order to select the suitable system for this study.
2) Analysis of stairwell and its calculations.

Third: Case study

The above systems will be applied on a selected high-rise building in Amman, Jordan. Technical engineering design drawing in accordance with the international standards will be developed. National Fire Protection Association and British standard will be used as a guide for the design.

1.5 Study Approach and Thesis Organization

The study consists of the following steps:

1. Chapter one introduces an introduction of safety in high-rise building.
2. Chapter two presents a literature review of the previous researches of the automatic sprinkler systems and pressurization systems.
3. Chapter three discusses the importance items that related to the sprinkler systems.
4. Chapter four develops the installation of sprinkler model and mathematical calculations.
5. Chapter five performs the pressurization models and calculations.
6. Chapter six introduces the conclusions and recommendations of the present study.

CHAPTER TWO

LITERATURE SURVEY

Engineers started to design new types of complex buildings such as high- rise buildings of many types of occupancy. Researchers in the field of safety systems began to develop fire safety systems, especially sprinkler and pressurization systems. However, sprinklers were used before 100 years, but the important thing here is the development and new technology in this system. Researches indicated that 99% of the fires were controlled by sprinkler alone in buildings fully protected by sprinkler system while 60% of the fires were controlled by the spray from no more than four sprinklers (Gough,2004).

2.1 Fire and Smoke Development

A fire is a chemical reaction between fuel, oxygen and adequate heat. The main component of the fuel is carbon which is contained mostly in wood, plastics, paper, fabric and combustible liquids. When the fuel is heated to a point where flammable vapors are produced, and comes in contact with an ignition source, the combustion process starts, and the flammable vapors will spread. An accidental fire begins at slow growth, then smoldering process starts which may last from a few minutes to several hours. Smoldering duration is dependent on fuel type and available oxygen. Then heat generation will increase producing light to moderate smoke. Usually, the smoke is the first indication of fire (Atrim, 1994).

Smoke, which consists of airborne solid and liquid particulates and gases, evolves when a material undergoes pyrolysis or combustion, together with the quantity of air that is mixed into the mass (NFPA 92A, 2000). The products of combustion include particulates, unburned fuel, water vapor, carbon dioxide, carbon monoxide, and some other toxic gases. When the smoke moves through the building, air mixes with the smoke mass.

Many methods are used to extinguish the fire before automatic sprinkler systems operate. Manual extinguisher, hose reel system, hydrant connections, and landing valve system are manual tools used at the first stage of fire and smoke. These tools may be used by occupant and firefighters. When the manual system failes to control fire and smoke, the temperature of fire and smoke reaches the burst temperature of sprinkler head. The automatic sprinklers releases water to extinguish fire and control the smoke.

2.2 Previous Studies

AL-Falaneh, (2000) discussed the performance and reliability of automatic sprinkler systems in Jordan. He used fault tree analysis to predict sprinkler system and components reliability of known equipment. Multiple linear regression analysis to specify system components that have the main effect was used. Sprinkler head, water reservoir, outside screw and yoke valves, check valves and jockey pump with controller were highly correlated to system reliability.

Sheppard, (2002) experimented the characteristics of fire sprinklers. The sprinkler spray characteristics required as input for computational sprinkler spray models were measured. The approach followed was to experimentally measure the spray characteristics of real fire sprinklers using state of art diagnostic techniques. The experimental results were studied to find relationships of the spray characteristics that could be used to simplify later modeling and analysis. It was found that there is a variation in the water flux from sprinkler to sprinkler, and for a given sprinkler, the water flux depends on the location and the pressure. The velocity profile was found to vary widely with no difference between upright and pendent sprinklers. The radial spray velocity has a maximum value that ranges between 4.1 to 5.8 m/s.

Madrzykowski, (1993) analyzed and tested the effect of recessed sprinkler installation on activation time. He evaluated the ability of sprinkler activation models to predict the activation time. Full scale fire test compartment was used to obtain activation times for four different types of sprinklers. The test was conducted in a compartment size of 18.9m by 9.1m by 2.35m high. Floor based fire with constant heat release rate of 115, 155, 215, 290 and 520 kW were used.

Wild and Mech, (1998) discussed the BS 5588 Part 4:1998 specifications to determine the requirements for the fan of pressurization systems. They studied the role of the important parameter of velocity and pressure on the control of pressurization. His work compared various international codes of practice about the limitation on pressurization system.

Fazi and Paks, (2004) investigated the effectiveness of stairwell pressurization systems and the factors that affect the performance of the system. They selected two buildings as a case study. One of the buildings was built in 1985 while the other was built in 1990. They found that pressurization systems without variable speed can be difficult to commission. This is due to a number of factors such as unexpected leakage within the stair shaft which may develop over time.

McGrattan, (1999) experimented the effect of vents and draft curtains on sprinkler activation time. Major findings based on this study were as follows: When the fire was not ignited directly under a roof vent, venting had no significant effect on the sprinkler activation time. While, when the fire was ignited directly under a roof vent, automatic vent activation occurred at about the same time as the first sprinkler activation. The number of sprinkler activations decreased by as much as 56% as compared with closed vents. When the draft curtain was installed, up to twice as many sprinklers were activated compared to performance without curtain.

Chowdhury, (1999) discussed the important data that help the heating ventilation and air conditioning (HVAC) system designers to design stairwell pressurization. He discussed the main factors that cause smoke to spread to areas outside compartments. The factors are stack effect, temperature effect and weather conditions. He also concluded that during the design stage it is practically impossible to estimate all the leakage paths correctly.

Richard and Beasley, (2008) studied the elevator and stairwell shafts pressurization systems as means of smoke migration prevention through the stack effect in tall buildings. They found that stairwell pressurization is feasible in the absence of elevator shaft pressurization. Elevator shaft pressurization required larger fan flow rates to achieve the required minimum pressure difference. Fan location, vents and louvers were ineffective as means of controlling the shaft pressures. Little effect of the ambient temperature was observed on the final elevator door pressure difference.

1.3 Current Study

At this time, there are no standards in Jordan that determine designing and installing of automatic fire sprinklers and pressurization systems in stairwells of high- rise buildings. This study will discuss in detail the automatic sprinklers and pressurization systems and introduce a technical design based on international standard to be used as a guide for engineers in Jordan. The present study is also a contribution to improve and update the design of sprinkler and pressurization systems. The sprinkler design will be applied to high-rise building in Amman, Jordan based on the international standards and experience of other countries.

CHAPTER THREE

AUTOMATIC SPRINKLER SYSTEMS

In this chapter types of automatic sprinkler systems, pipes connection configuration, sprinkler component, fire pump specifications, hazard occupancy, water supply, and arrangement of sprinkler networks will be discussed and studied.

3.1 Types of Automatic Sprinkler System

Standards specify the types of automatic sprinklers in four main types. These types are wet pipe system, dry pipe system, pre-action system, and deluge system.

3.1.1 Wet Pipe Sprinkler System

This sprinkler system is filled with water at all times. The water is discharged immediately from a sprinkler when the sprinkler is activated. The reliability of this system is high because it has relatively few components in contrast with other types. This system is installed in area maintained above $4^{o}C$ and below $70^{o}C$. The alarm device for this system is called alarm check valve (ACV). There are many requirements of this type of system such as: pressure gauges must be installed above and below each ACV or system riser check valve, and relief valves are used to control the pressure of system not to exceed 12.1 bar.

3.1.2 Dry Pipe Sprinkler System

This sprinkler system is filled with compressed air or nitrogen at all times. Drop in pressure can be caused by activation of a single sprinkler or by damage to the sprinkler system piping. This drop in pressure causes the main valve (dry pipe valve) of the system to open and allows water to flow in the system out of the opened sprinkler. This system is installed in areas maintained below 4°C and above 70°C such as drying ovens, cold stores…etc. There are many limitations of using this system. The most important limitations are that grid connection pipe cannot be installed and specific types of sprinkler head can not be used.

3.1.3 Pre-action Sprinkler System

This sprinkler system is attached to a piping system that contains air that might or might not be under pressure, with a supplemental detection system installed in the same area as sprinkler. Upright and listed dry sprinklers are only used in this type of system. Single interlock, non-interlock, and double interlock are mode of operation of this system.

A single interlock mode admits water to sprinkler piping system upon operation of detection devices. Sprinkler is not a main function for activation.

A non-interlock mode admits water to sprinkler piping system upon operation of detection devices or automatic sprinkler.

A double interlock mode admits water to sprinkler piping system upon operation of both detection devices and automatic sprinklers. This mode requires two events to occur before water is admitted to the system. One event consists of the activation of a device installed on the supplemental detection system; the other event includes the operation of a sprinkler that causes the maintained air pressure in the system to fall to a predetermined level. When one of these events occurs, the main valve (pre-action valve) is activated and the water enters the system.

3.1.4 Deluge Sprinkler System

This sprinkler system uses open type sprinkler, attaches piping system and connects to water supply through main valve (deluge valve) which is opened by operation of a detection system installed in the same areas of sprinklers. When this valve opens, the water flows into the piping system and discharges from all sprinklers in the network. The operation of the system is similar to pre-action system. The difference between them is that operation system uses automatic sprinkler that responds to heat, while deluge system uses open type sprinkler that has no fusible element. Also, for a deluge system when detection system operates, water flows from all sprinklers. This system is used for high- hazard areas such as aircraft hangar.

3.2 Pipes Connection Configuration

Different types of pipe configuration are used to connect piping system. Tree configuration, looped configuration and grid configuration are the most common of these types. The pipes that connect sprinkler heads are called branch lines or range pipes while the pipes that connect branch pipes is called cross main pipe or distribution pipe. All cross main pipes are connected with main distribution pipe which is connected to the main riser of the system.

3.2.1 Tree Pipe Configuration (Dead-End Pipe Configuration)

Figure (3.1) shows different types of configuration such as end-side with central feed, end-side with end feed, end-centre with central feed, and end-centre with end feed.

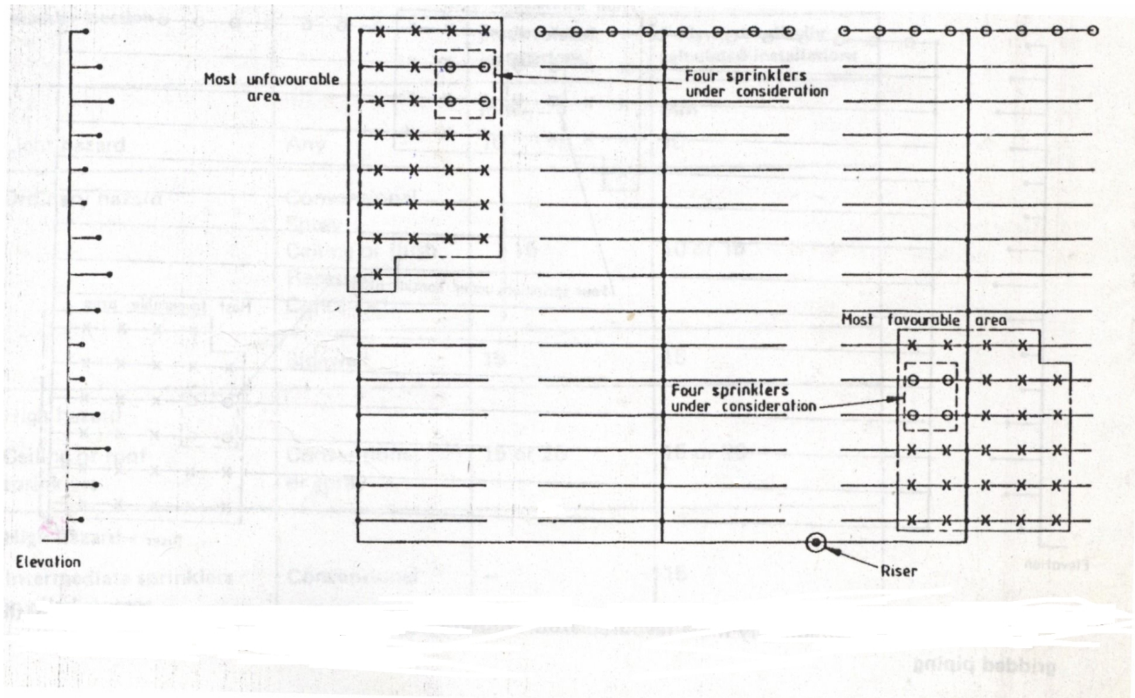


Figure 3.1. Tree Configuration, (BS 5306: part 2, 2006).

3.2.2 Looped Pipe Configuration

In this configuration, there are multiple cross main pipes that are connected together with the main distribution pipe. All branch lines are not connected with each other. More than one path of water is used to feed the branch line. Hydraulic characteristic in this system is better than tree configuration. There are no limitations in network and design consideration compared with grid configuration. Figure (3.2) shows different types of looped configuration possible.

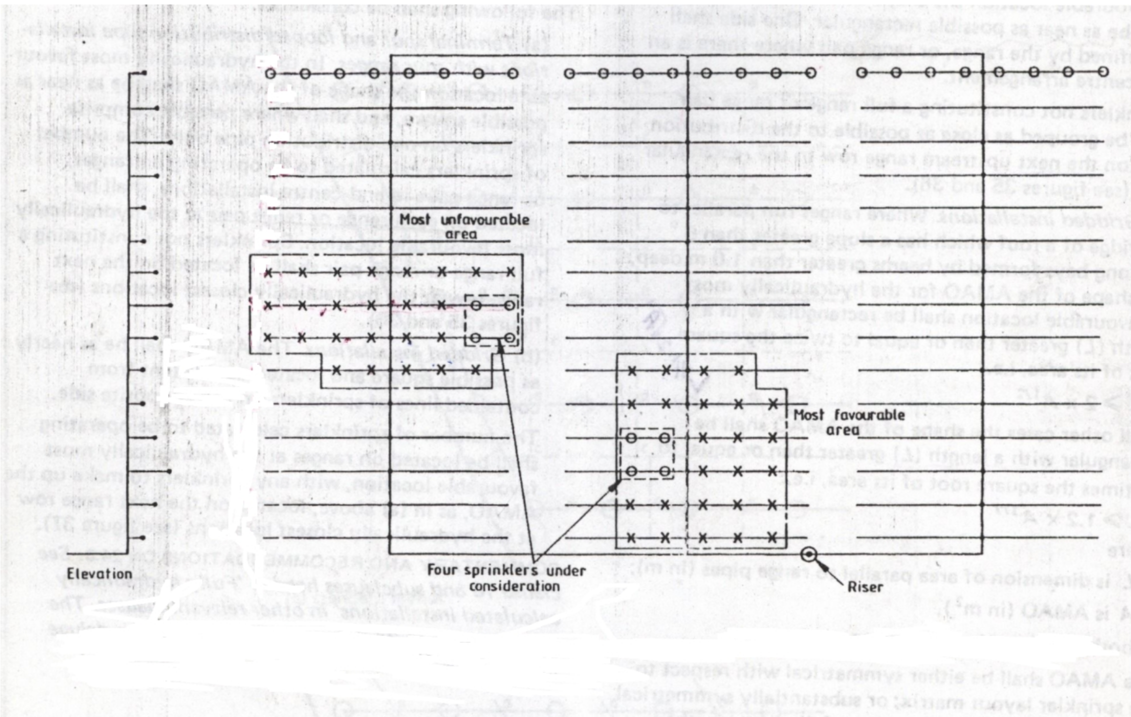


Figure 3.2. Looped Pipe Configurations, (BS 5306: part 2, 2006).

3.2.3 Gridded Pipe Configuration

In this configuration, as shown in figure (3.3), the cross main pipes are located parallel to each other. The connections between cross main pipes are multiple branch lines. The sprinkler heads when it is operated receives water from both ends of its branch line. Hydraulic characteristic in this system is better than looped configuration. Certain limitations and design conditions are existed in the grid configuration. For example it is not permitted to install in this configuration dry pipe system, and design area is not easy to determine.

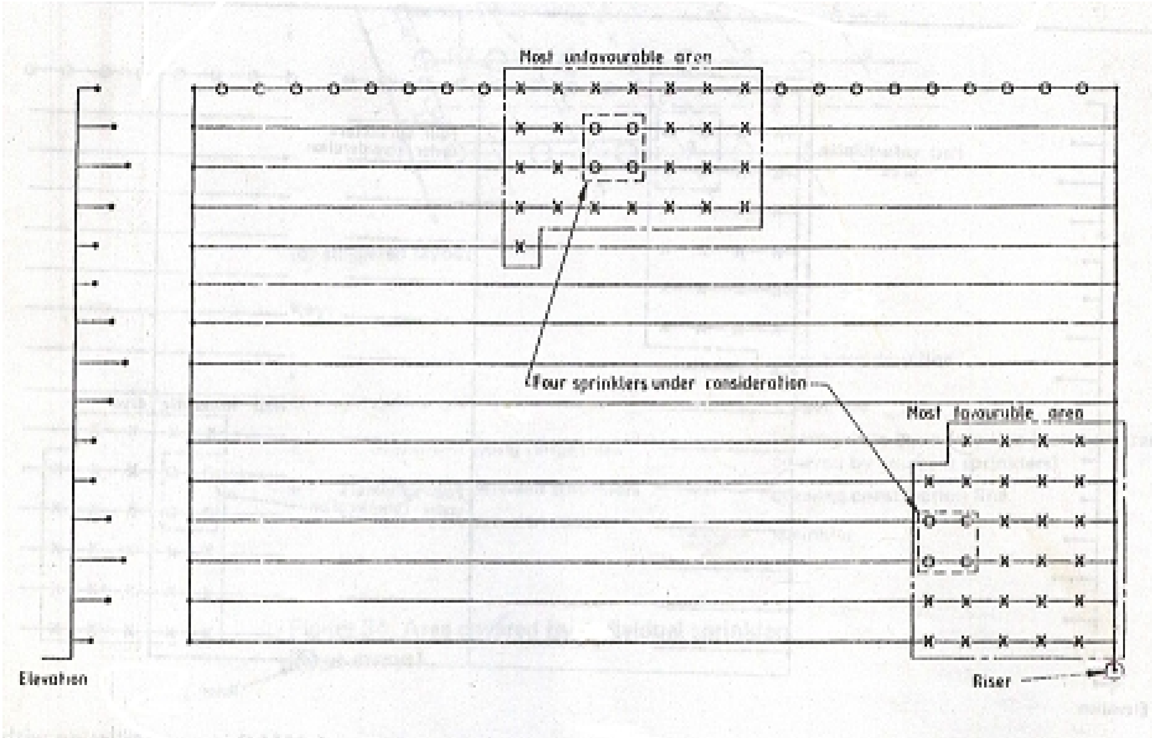


Figure 3.3. Gridded Pipe Configurations, (NFPA 13, 2006).

3.3 Sprinkler System Components

The components and materials that are used on an automatic sprinkler system must be listed and approved. The Authority Having Jurisdiction (AHJ) gives the approval on listed components and materials that are published by the organization. Examples of these organizations are Underwriter Laboratories (UL), Factory Mutual (FM) and Loss Prevention Council British (LPCB). The rated pressure of all system components that are installed above the ground is not less than 12.1 bar while that for the underground installation is not less than 10.4 bar. When the system pressure exceeds these values, the system components and material manufactured must be listed for high pressure (NFPA 13, 2006). Automatic sprinkler heads, valves, fittings, hangers and supports, siames connection, water supply and pumps are the main components of the system. Figure (3.4) illustrates the main components of the sprinkler system.

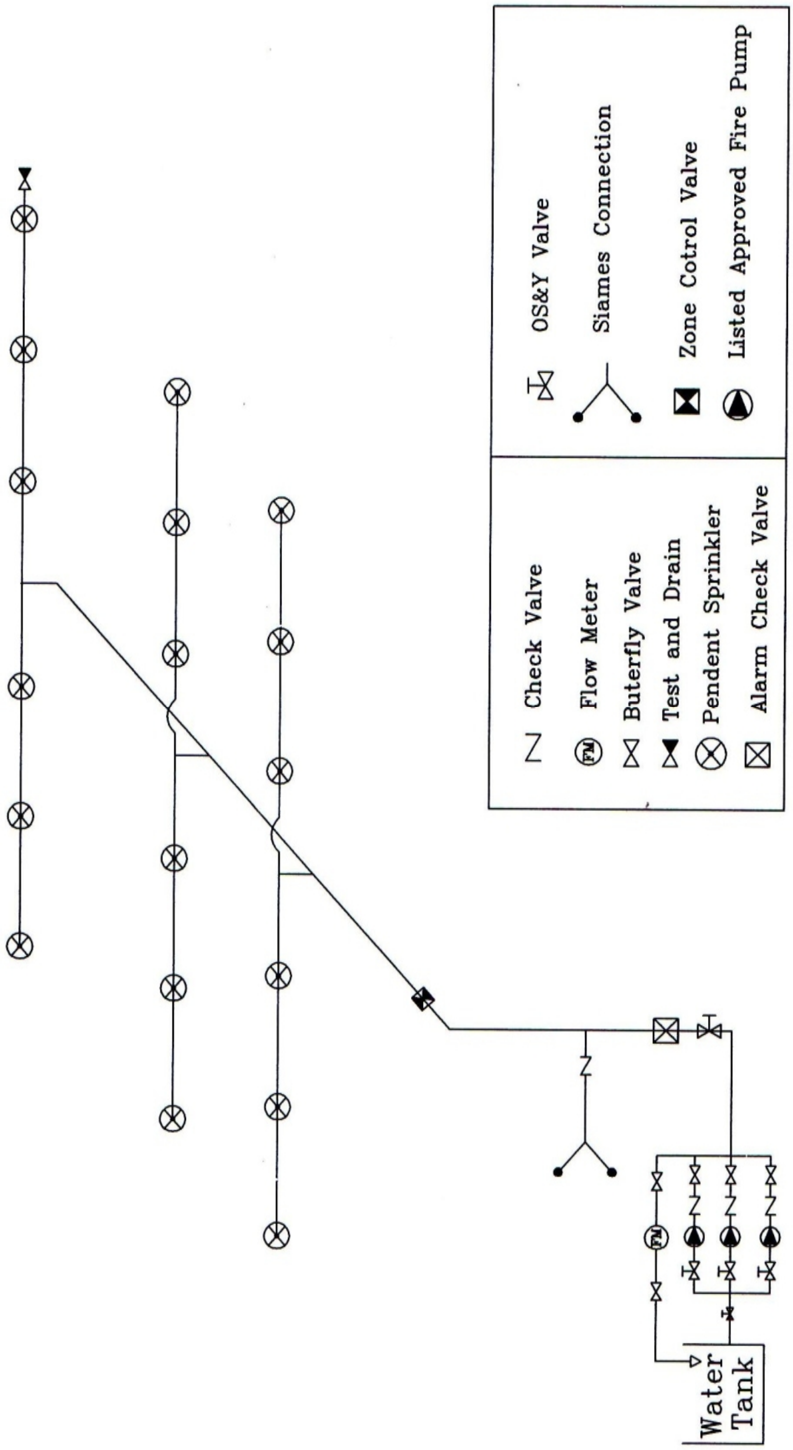


Figure 3.4. Schematic Diagram of Sprinkler System Network.

3.3.1 Automatic Sprinkler Head

Automatic sprinkler head is a fire suppression or control device. It is operated automatically when its heat-activated element is heated to its thermal rating and it discharges water over a specified area.

Year of manufacture, temperature rating, listing mark of laboratory, model number, and manufacturer must be written on its body. Advanced sprinkler technology classified sprinkler heads according to their characteristics. These characteristics are thermal sensitivity, temperature rating, orifice size, installation orientation and water distribution pattern.

Sprinkler discharge characteristics (K-factor) must be used to determine the discharge of sprinkler head at a particular pressure. Table (3.1) specifies the ranges of K-factor, national pipe threads type (NPT), nominal K-factor, and nominal orifice size of sprinkler (NFPA 13, 2006).

The fire suppression or control is dependent on the temperature rating of a sprinkler head. The selection of temperature rating depends on the occupancy classification, and the ambient ceiling temperature expected. The sprinkler rating of a sprinkler head must be greater than the highest expected ambient temperature by 30^{o}C. Sprinkler with same temperature rating must be used in the same location to minimize the chance of a non-fire sprinkler operation (BS 5306:Part2, 2006) and (Dubay, 2002). Table (3.2) specifies the permitted temperature rating of a sprinkler head, color coding, and glass bulb colors (NFPA 13, 2006) and (BS 5306:Part2, 2006).

Table 3.1. Sprinkler Discharge Characteristics Identification Factor (NFPA 13, 2006)

Nominal K-factor $L/min\sqrt{kPa}$	K-factor Range $L/min\sqrt{kPa}$	Percent of Nominal K-8.1 Discharge	Thread Type
2.0	1.9-2.2	25	12.7mm.NPT
2.7	2.6-2.9	33.3	12.7mm.NPT
4.0	3.8-4.2	50	12.7mm.NPT
6.1	5.9-6.4	75	12.7mm.NPT
8.1	7.6-8.4	100	12.7mm.NPT
11.5	10.7-11.8	140	19.0mm.NPT or 12.7mm.NPT
16.2	15.9-16.6	200	19.0mm.NPT or 12.7mm.NPT
20.2	19.5-20.9	250	19.0mm.NPT
24.2	23.1-25.4	300	19.0mm.NPT
28.3	27.2-30.1	350	25mm.NPT
32.3	31.1-34.3	400	25mm.NPT
36.3	34.9-38.7	450	25mm.NPT
40.4	38.9-43.0	500	25mm.NPT

Table 3.2 .Temperature Rating, Classification, and Color Coding

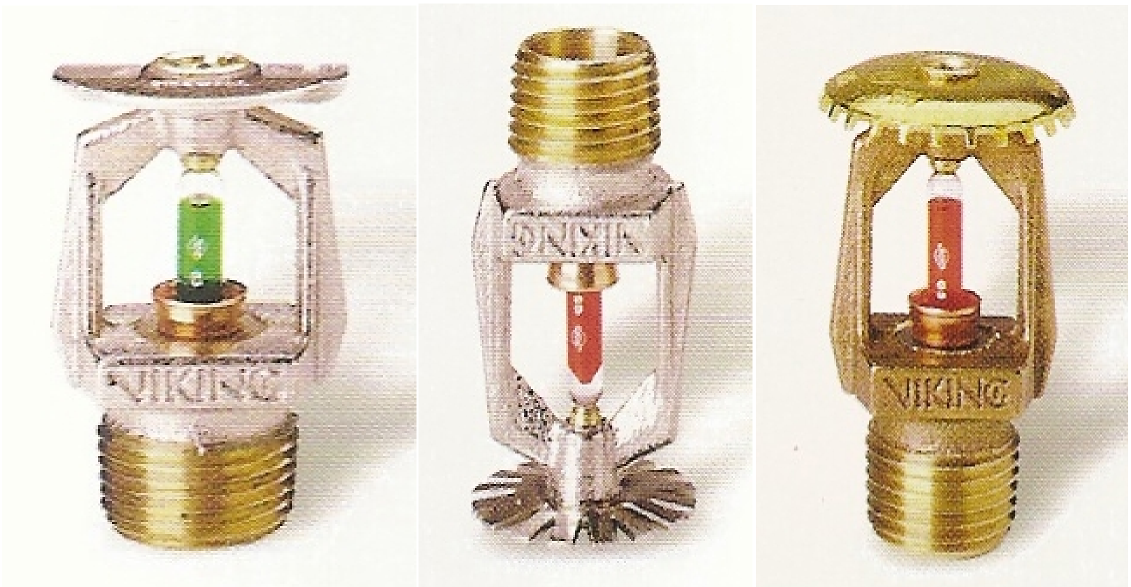
(NFPA 13, 2006) and (BS 5306: Part 2, 2006)

Maximum ceiling temperature(°C)	Temperature rating(°C)	Temperature classification	Color code	Glass bulb colors
38	55-77	Ordinary	Uncolored or black	Orange or red
66	79-107	Intermediate	White	Yellow or green
107	121-149	High	Blue	Blue
149	163-191	Extra high	Red	Purple
191	204-246	Very extra high	Green	Black
246	260-302	Ultra high	Orange	Black

The types of sprinkler heads are defined according to the design and performance characteristics, sprinkler coverage area and orientation installations. The most common types are the conventional sprinkler (old style), standard spray sprinkler, extended coverage sprinkler, quick-response sprinklers, early suppression fast-response, and large-drop sprinkler.

The conventional (old style) sprinkler is designed to direct from 40 to 60 percent of the total water initially in a downward direction and it can be installed either upright or pendent (NFPA 13, 2006).

The standard spray sprinkler as shown in figure (3.5) is designed to provide fire control for a wide range of fire hazard. It is manufactured in three basics styles. These styles are: standard spray upright (SSU) sprinkler, standard spray pendent (SSP) sprinkler, standard spray sidewall (SSS) sprinkler.



Sidewall Pendent Upright

Figure 3.5. Standard Spray Sprinklers Head.

A SSU Sprinkler is designed to be installed when the water spray is directed upward against the deflector. It is mounted upright above the branch line of the sprinkler. Its deflector consists of a metal plate whose edges are designed to deflect water downward from sprinkler. A SSP sprinkler is designed to be installed when the water is directed downward against the deflector. Its deflector is designed to be flat. A sidewall sprinkler is designed to discharge most of the water away from the nearby wall in a pattern one-quarter of sphere, while the small portion discharged is directed at the wall behind the sprinkler. Figure (3.6) shows the shape of the discharge flow pattern of SSU.

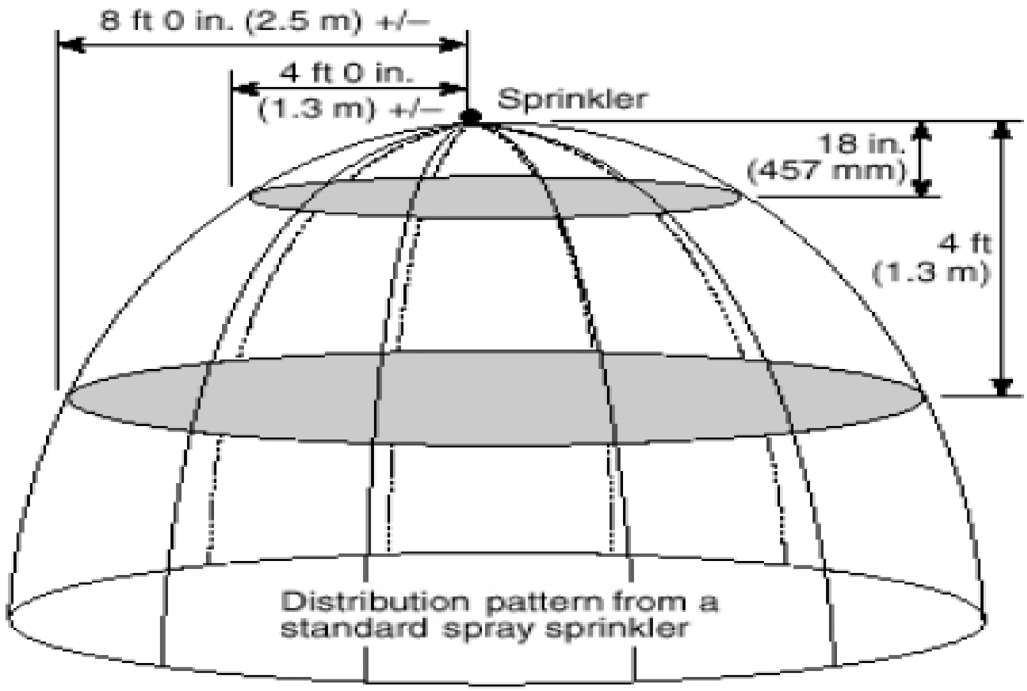


Figure 3.6. Sprinkler Discharge Pattern Development for Standard Spray Sprinkler, (Dubay, 2002).

The extended coverage (EC) sprinkler is a type of spray sprinkler with listed maximum area. It is available in the pendent, upright and sidewall configurations. Coverage area is greater than in the other types of standard spray sprinklers. Its orifice sizes are designed to discharge water over an area having the maximum dimensions indicated in the individual listings. The designer must know the limitation of using it such as installations and hazard occupancy.

The early suppression fast-response (ESFR) sprinkler is designed to provide fire suppression of specific high-challenge fire hazards such as storage occupancies. The effectiveness of ESFR is determined through the measured actual water delivered density (AWDD), required water delivery density (RWDD), and RTI. The designer must know all characteristics of this type of sprinkler such as characteristic factor (K-factor) of the orifice, coverage area, and minimum pressure for operation, and place where it can be installed.

The quick response (QR) sprinkler is designed to reduce operating time by providing increased surface-to-mass area for operating elements, or a reduction in mass area. These sprinklers are designed to be used in hotels, motels, health care centers, high-rise office buildings, and apartment buildings.

The large-drop sprinkler is a type of sprinkler that is capable of producing large characteristics of water droplets. It is characterized for its capability to provide fire control of specific high challenge fire hazards (NFPA 13, 2006). It is designed to deliver water flow greater than the standard sprinkler with approximately 100 percent at high velocity. Water discharged from sprinkler is performed to penetrate the fire plume, cool the radially spread in hot gases under the ceiling, and wet immediately surrounding combustibles. Its normal operating pressure reached two bars.

The recessed sprinkler is designed in a way that all parts of the body are mounted within a recessed housing.

The concealed sprinkler is designed like recessed sprinkler but with cover plate. The cover plate drops when exposed to a certain amount of heat. The fusible element holding the cover plate is designed to operate prior to the activation of the sprinkler thermal element.

The characteristic curves of standard spray sprinkler can not apply to ESFR, QR, and large drop sprinklers.

3.3.2 Aboveground Pipes, Fittings and Joining of Pipe

Steel pipes, copper tubes, some of nonmetallic pipes and associated fittings are permitted to use in sprinkler systems. All of them must meet the standards established by the American Society for Testing and Material (ASTM), the American National Standards Institute (ANSI), and British Standard. Steel pipes were classified with respect to their schedule (SCH) such as SCH5, SCH10, SCH30, SCH40, SCH 80. Copper tubes were classified with respect to their types such as type K, L and M. The nonmetallic pipes that are listed to use in sprinkler system application were determined for Chlorinated Poly Vinyl Chloride pipes (CPVC) and Polybutylene pipes (PB). Many restrictions on installation of nonmetallic pipe existed such as maximum and minimum temperature limit, use only for wet pipe systems, hazard classification, and the need of a special type of fittings (Bryan, 1997). Each type or schedule has standardization dimensions which contains inside and outside diameter, wall thickness, and nominal pipe size (NFPA13, 2006) and (BS 5306:Part2, 2006).

The selection of a particular pipe material, schedule pipes or pipes type are subjected to the environmental conditions of the space in which the pipe is installed. All pipes must be marked with manufacture name, model designation or schedule.

The designer is the one who decides which type, schedule, and material must be used in designing drawing. This decision depends on many factors. These factors are ease of handling and installation, cost-effectiveness, reduction of friction losses, improved corrosion resistance, hanger strength, resistance to failure when exposed to elevated temperature, movement during sprinkler operation, unsupported vertical stability, pressure rating, methods of joining, physical characteristics related to integrity during earthquakes and pipe bending (Duby, 2002).

The fittings are manufactured in many varieties. Cast iron, malleable iron and CPVC are examples of fitting materials. The fittings must be compatible with pipes that are listed. The designer must know the limitations of fitting and joining. For examples, screwed unions can not be used on a pipe larger than 2 inches because it has a tendency to develop leaks. One-piece of bushing fitting can be used to reduce the size of pipe. There are different methods for sprinkler fittings such as threaded fore cast iron and malleable iron, welded, flanged, cut or roll-grooved, soldered for copper tubes and pipe bending (Dubay, 2002).

3.3.3 Hangers

The hanger must be designed to support five times the weight of the water-filled pipe plus 114 kg at each point of piping support. The material of support component must be ferrous. There are different types of hangers such as U-hook, eye rods, pipe clamp, riser clamp, fasteners, etc. The purpose of support is to prevent lateral and horizontal movement of pipes in static and dynamic cases (NFPA 13, 2006) and (BS 5306: Part 2, 2006).

The British Standard and National Fire Protection Association Standard specify general rules for the installation of pipe support as follows. There is at least one support between the adjacent sprinkler located on branch pipe (ranges pipe) and between the branch pipes on the cross main pipe (distribution pipe). The maximum distance between the first support on the branch pipe and the cross main pipe is not more than 2.0m. Also the maximum distance between the last support on the branch pipe and the end of pipe is not more than 1.5m. The maximum distance between the first support on the cross main pipe and the main distribution pipe is not more than 2.0m. Also the maximum distance between the last support on the cross main pipe and the end of the pipe is not more than 450mm. The minimum distance between the center line of sprinkler head and any support is not less than 150mm. The maximum distance between supports is illustrated in table (3.3). Other specifications of supports such as materials, types and design are determined in the American and British standards (NFPA13, 2006) and (BS5306:part2, 2006).

Table 3.3. Maximum Distance between Supports (BS 5306: Part 2, 2006)

Maximum distance between supports		
Pipe nominal diameter (mm)		Maximum support spacing (m)
Over	Not greater than	
Up to 65	65	4.0
65	100	6.1
100	250	6.5

3.3.4 Valves

The valves used in sprinkler system are controlling valves, check valve, and test and drain valves. The controlling fire protection valves are outside stem and yoke valves (OSYV) as shown in figure (3.7), vertical indicator post valve, wall indicator post valve, and butterfly valve. All valves controlling fire protection system are designed to close in no less than five second when operated at maximum possible speed from the fully open position to minimize water hammer. Water hammer increases the pressure of the system above the design pressure value. The results of water hammer are either damage of components or leakage. The controlling valve except test and drain valves must be listed and must be visually identified as opened or closed. The OSYV, BFV, and the post indicator valve must be monitored electrically with tamper switches. Tamper switches will send signals if the valves are not fully open. Each type of the valve has a specific location in sprinkler network. The drain and test valve must be only approved, because they are not essential for operation sprinkler system. Non indicating valves such as an underground gate valve with approved roadway box, complete with T-wrench and accepted from authority having jurisdiction (AHJ) must be permitted.

Figure 3.7. Outside Stem and Yoke Valve

3.3.5 Fire Department Connection (Siamese Connection)

A fire department connection (FDC) may be designed as an auxiliary water supply to the system. It increases the overall system reliability. FDC must be equipped with listed plugs or caps. The reliability of FDC depends on its relative ease of use which means removing caps without special tools. Figure (3.8) illustrates the FDC arrangement.

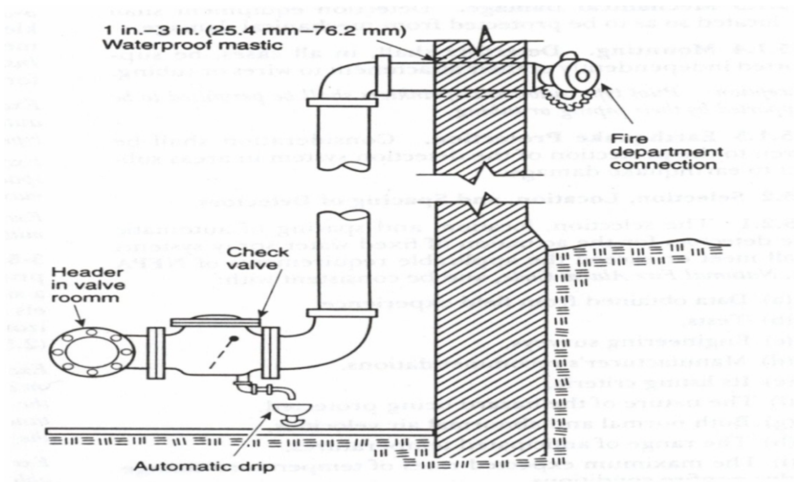


Figure 3.8. Fire Department Connection Arrangement, (NFPA 13, 2006).

3.4 Classification of Hazard Occupancies

Many factors have played a critical role in classifying the hazard of occupancy. These factors are quantity and combustibility of the contents, the expected heat release and the potential energy of heat release, the presence of flammable and combustible liquids, and the height of storage materials. The American standard classified the hazard occupancy for the design of automatic sprinkler purposes as light hazards, ordinary hazards group one and two, and extra hazard group one and two.

Light hazard occupancies are occupancies or portion of occupancies where the quantity and/or combustibility of contents are low and fires with relatively low rates of heat release are expected. Examples of light hazard occupancies are churches, clubs, Educational institutions, Hospitals, Libraries, except large stock rooms, museums, offices, restaurant seating area, and any occupancies having uses and conditional similar to the above (NFPA 13,2006).

Ordinary hazard occupancies group one are occupancies or portion of other occupancies where combustibility is low, quantity of combustibles is moderate, stockpiles of combustibles do not exceed 2.4m, and fires with moderate rates of heat release are expected. Examples of ordinary hazard occupancies group one are automobile parking and showrooms, bakeries, beverage manufacturing, canneries, dairy products manufacturing and processing, electronic plants, glass and glass products manufacturing, laundries, restaurant service areas, and any occupancies having uses and conditional similar to the above (NFPA 13,2006).

Ordinary hazard occupancies group two are occupancies or portion of other occupancies where the quantity and combustibility of contents are moderate to high. Stockpiles do not exceed 3.7m, and fires with moderate to high rates of heat release are expected. Examples of ordinary hazard occupancies group two are machine shops, metal working, mercantile, paper and process plants, post offices, printing and publishing, repair garages, stages, textile manufacturing, tire manufacturing, tobacco products manufacturing, wood machining, wood product assembly, and any occupancies having uses and conditional similar to the above (NFPA 13,2006).

Extra hazard occupancies group one are occupancies or portion of other occupancies where the quantity and combustibility of contents are very high and dust, lint, or other materials are present, introducing the probability of rapidly developing fires with high rates of heat release but with little or no combustible or flammable liquids. Examples of extra hazard occupancies group one are aircraft hangers (except as governed by NFPA 409, standard on aircraft hangers), combustible hydraulic fluid use areas, die casting, metal extruding, saw mills, plywood and particle board manufacturing, printing using inks having flash points below 38°C, upholstering with plastic foams, and any occupancies having uses and conditional similar to the above (NFPA 13, 2006).

Extra hazard occupancies group two are occupancies or portion of other occupancies with moderate to substantial amounts of flammable or combustible liquids or occupancies where shielding of combustible is extensive. Examples of extra hazard occupancies group two are asphalt saturating, flammable liquids spraying, flow coating, open oil quenching, plastics processing, solvent cleaning, varnish and paint dipping, and any occupancies having uses and conditional similar to the above (NFPA 13,2006).

3.5 Water Supplies

The effectiveness of sprinkler system mainly depends on the reliability, adequacy and continuity of the water supply, so the designer should take this consideration in design. For each sprinkler system, at least one automatic water supply is needed. There are different types of water supplies such as gravity tanks, pressure tanks, rivers or lakes and fire pumps.

The gravity tanks are acceptable for water supply source. They must be installed according to NFPA 22 or BS 5306: part 2. If the gravity tanks are used, they must satisfy the system discharge requirement. They may be used in high rise buildings if the requirement of the system is satisfied.

Water supply connection must be installed in a way that mud and sediment must be avoided. Therefore, approved strainers and approved double removable screen muse be installed in a corrected manner. The reliability and ability to meet the system demands must be satisfied at all times. Because of seasonal fluctuations, the authorities may limit the use of this water supply.

The pressure tanks contain both water and air under pressure. A sufficient pressurized air must be available to discharge water to the system. The pressure tanks must be installed according to the NFPA 22 or BS 5306: part 2. The disadvantage of this water supply is not used for manual systems such as hose reel system. Public water supplies always fluctuate widely from season to season and sometimes within a day, so the reliability of this water supply is low. The possibility of damaged pipes either by natural reasons or human reasons also affect on the reliability.

3.6 Specifications of Fire Pumps

A fire pump is a device used to take water from any supply source such as public mains, private mains, tanks, ponds, or reservoirs, and increase the pressure of water to force it to any fire protection system such as sprinklers, standpipes, water spray or foam system. The fire pumps are used, when other sources of water supply are insufficient to satisfy the demands of the fire protection system. Figure (3.9) shows a typical fire pump installation. The suction pipe of a fire pump which is the side connected to the water supply must be galvanized to minimize corrosion. The type of gate valve that must be existed on the suction pipe is OSYV. The reducer connected directly to the pump must be designed to eliminate air pockets that cause cavitations.

Three factors are taken to evaluate water supply. These factors are flow rate, pressure, and duration time. The flow rate represents the volume of water needed for the fire system over a period of time and it is measured by liter per minute (L/min). The duration time is the amount of time that the water supply can provide the flow, and it is measured in minutes. So, the total quantity of water available is then determined by multiplication flow by time. Water supply system can not be expressed without these factors together.

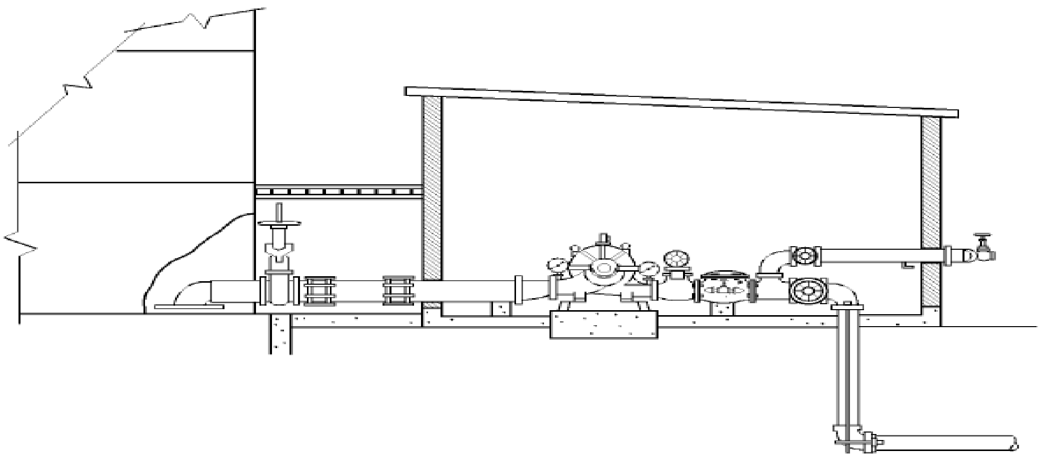


Figure 3.9. Typical Fire Pump Installations, (Puchovsky and Isman, 1998).

The maximum net pressure in the fire pumps is called churn or no-load condition. It occurs when there is no water flowing through the pumps into the fire system. This means the pump does not have to work very hard. As water is flowing through the pump into the fire system, the pump has to work harder. Fire pump manufacturers have given each pump a rated flow rate and pressure at a certain rotation speed. Pump manufacturers parameters are determined by NFPA 20. These parameters are: at the churn pressure, the pump must not create a net pressure greater than 140 percent of a rated net pressure. Pump manufacturers are allowed to design pumps to create any net pressure at churn greater than the rated net pressure, but it does not exceed the 140 percent. At the maximum load condition which is equal 150 percent of the rated flow rate, the pump must produce at least 65 percent of the rated pressure.

Pump manufacturers are allowed to design pumps to create any net pressure at maximum load greater than 65 percent of the rated pressure. Fire pump manufacturers can achieve different performance from their pumps by changing the radius of the impeller, the distance between the shrouds, the number of vanes, the angle of curvature of the vanes, and the speed of the rotation. Figure (3.10) shows a flow curve for a pump, the end points given NFPA 20, 140 percent of the rated net pressure at churn and 65 percent of the rated net pressure at maximum load, and the acceptable flow curves for the pump.

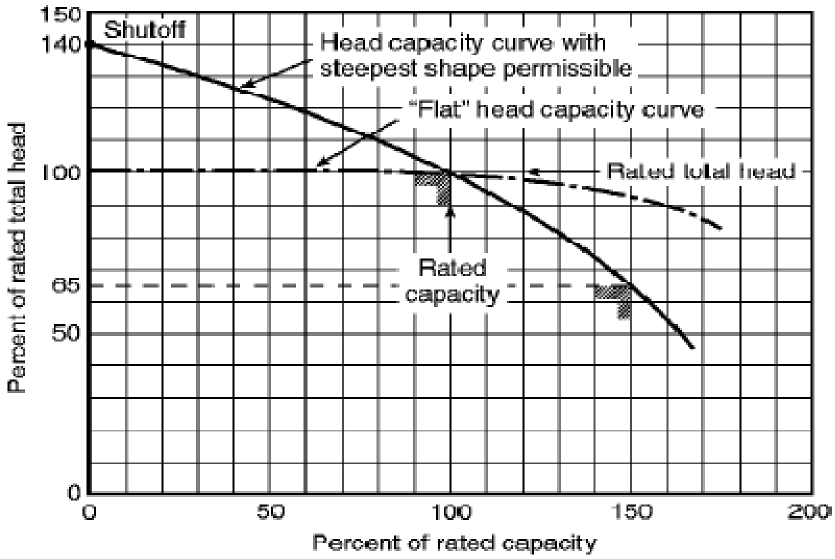


Figure 3.10. Pump Characteristics Flow Curve, (Puchovsky and Isman, 1998).

Other important parameters are brake horse power (BHP) and net positive suction head (NPSH). The maximum BHP requires driving the pump at rated speed. The maximum BHP can be obtained from the horse power curves supplied by the pump manufacturer. The net positive suction head is the total suction head in meter of liquid absolute, determined at the suction nozzle, and corrected to datum (pump center line) less than the vapor pressure of the liquid in meter absolute (Puchovsky and Kenneth, 1998). There are two types of NPSH. These are NPSH available, and NPSH required. The NPSH available is the excess of the pressure of the liquid over its vapor pressure at the exact condition of the liquid as it arrives at the pump suction flange, while the NPSH required is made up of the suction velocity head ($V_s^2/2g$) plus the increase in velocity head between the pump suction flange and the impeller vanes plus the friction and turbulence loss between suction flange and the inlet vane of the impeller. The difference between NPSH available and NPSH required is the safety margin available. This positive margin is important to avoid pumps from vibration, noise, and cavitations. The manufacturer provides three types of curves for each fire pump as illustrated in figure (3.11). These curves are total head (m) or pressure (bar) versus discharge rate (L/min), brake horsepower versus discharge, and efficiency versus discharge rate. These curves represent pump performance when pump is operating at a constant speed equal to its rated speed.

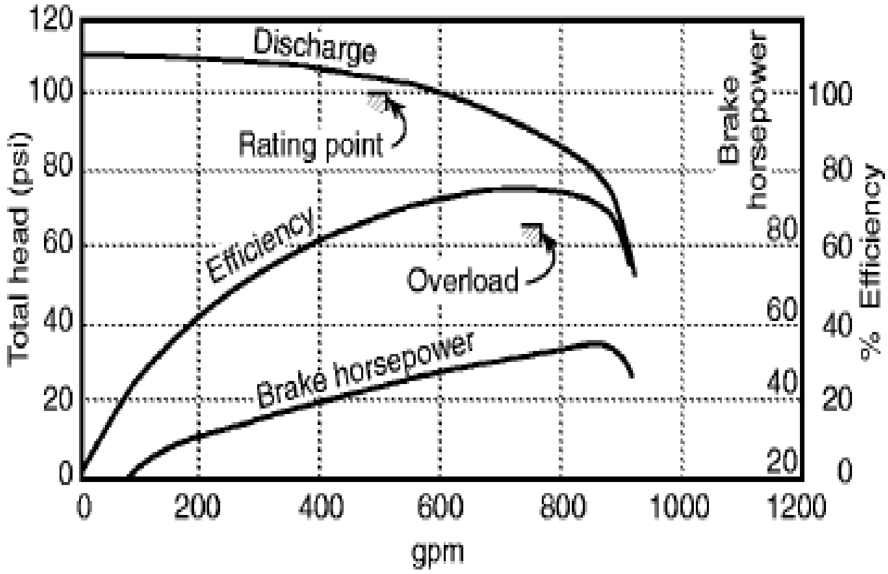


Figure 3.11. Performance Pump Curve, (Puchovsky and Isman, 1998).

3.7 Sprinkler Spacing, Location and Arrangement

The appropriate location of sprinkler head plays a critical role in covering the area of sprinkler head because there are many obstructions in the buildings either vertical obstructions or horizontal obstructions. Also, the spacing between sprinklers must not exceed the permitted distances according to the standard or the coverage area listed for sprinkler head.

3.7.1 Sprinkler Spacing

The distance between sprinklers heads on the branch line or between branch lines is measured between the centerline of sprinklers and is measured along the slope of the roof as shown in figure (3.12).

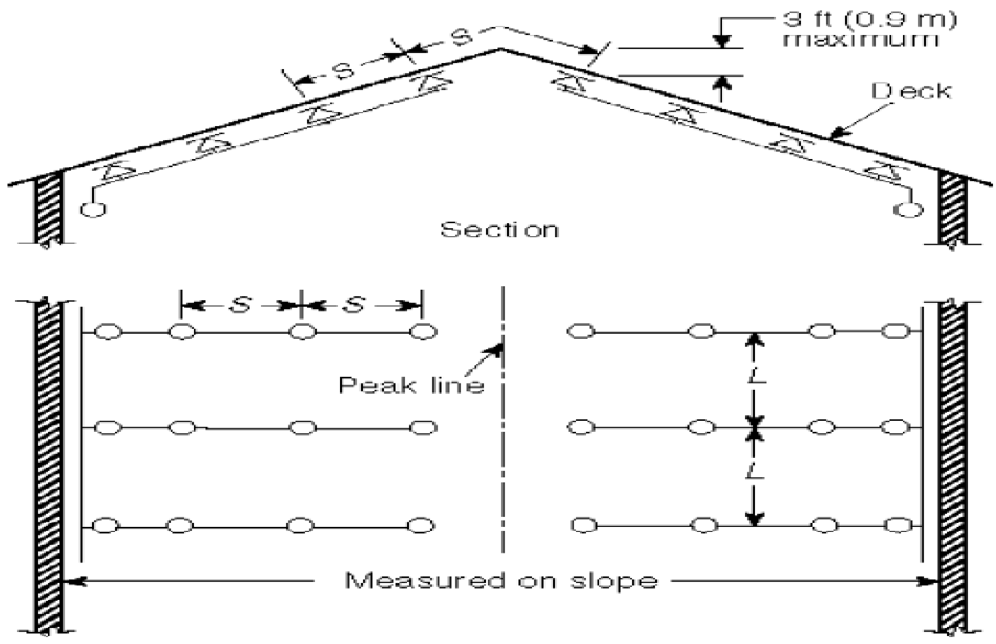


Figure 3.12. Branch Lines Parallel to the Slope of Ceiling, (NFPA 13, 2006).

The allowable maximum and minimum distances between sprinklers, the maximum coverage area per sprinkler, obstruction in the building, and the type of sprinkler heads are the main factors that affect the spacing of sprinkler head. There are the maximum and minimum distances between sprinklers specified in the national standards. The purpose of minimum distance is to prevent operating sprinklers from wetting adjacent sprinkler and to prevent skipping of sprinklers. The distance from the wall to the centerline of sprinkler must be measured perpendicular to the wall, and also there are maximum and minimum specified distances in national standards. The distance from the wall to the centerline of sprinkler must not exceed one-half of the allowable maximum distance between sprinklers and not less than 102mm. Also, the distance from the corner of the wall to the centerline of sprinkler must not exceed two-third of the allowable maximum distance between sprinklers. The minimum distance between sprinklers and wall must not be less than 102mm to ensure that sprinkler will operate properly.

3.7.2 Coverage Area of Sprinklers

The coverage area per sprinkler (A_S) must be determined as follows:

1- Measure the maximum distance between sprinklers on the branch line, and twice the maximum distance between the sprinkler and the wall or obstruction, then choose the maximum value of them (S).

2- Measure the maximum distance between the branch lines, and twice the maximum distance between the sprinkler and the wall or obstruction along the distribution pipe, then choose the maximum value of them (L).

3- The coverage area of sprinkler (A_S) can be calculated by multiplication of the values of S and L.

The maximum value of A_S must not exceed the permitted values that are determined in the national standard. This value depends on the type of sprinkler, construction features, and the occupancy hazard of the space. The maximum value of A_S must not exceed $36m^2$ for any type of sprinkler. Table (3.4) gives the maximum spacing of standard spray sprinklers either upright or pendent, and the maximum coverage area of standard spray sprinklers.

Table 3.4. Maximum Coverage, Maximum and Minimum Spacing between Standard Spray Sprinkler (BS 5306: Part 2, 2006)

Hazard class	Maximum coverage area per sprinkler(A_S) m^2	Maximum distance between sprinkler(m)		Minimum distance between sprinkler(m)	
		S	S	0.5 S	0.5 L
Light	21	4.6	4.6	2.3	2.3
Ordinary	12	4.0	4.0	2.0	2.0
Extra	9	3.7	3.7	2.0	2.0

3.7.3 Deflector Position

The deflectors of sprinkler head must be parallel to the ceiling, roofs or the inclined stairs to prevent the discharge from hitting a sloped ceiling which affect the effective discharge. Types of sprinkler, and the obstruction shape and its dimension are main factors to determine the distance between the deflector of sprinkler and the ceiling. The ranges of distances between the deflectors of sprinkler head and the unobstructed construction ceiling are 25.4 to 30.5 mm (NFPA 13, 2006). The maximum distance between the deflector of sprinkler head and the obstructed ceiling must be not more than 559mm. The sprinklers location must be located and take any obstruction in consideration as in NFPA 13 limitation. Figure (3.13) illustrated example of ceiling obstruction, and the effect of ceiling sprinkler on the spacing distance between the sprinkler head.

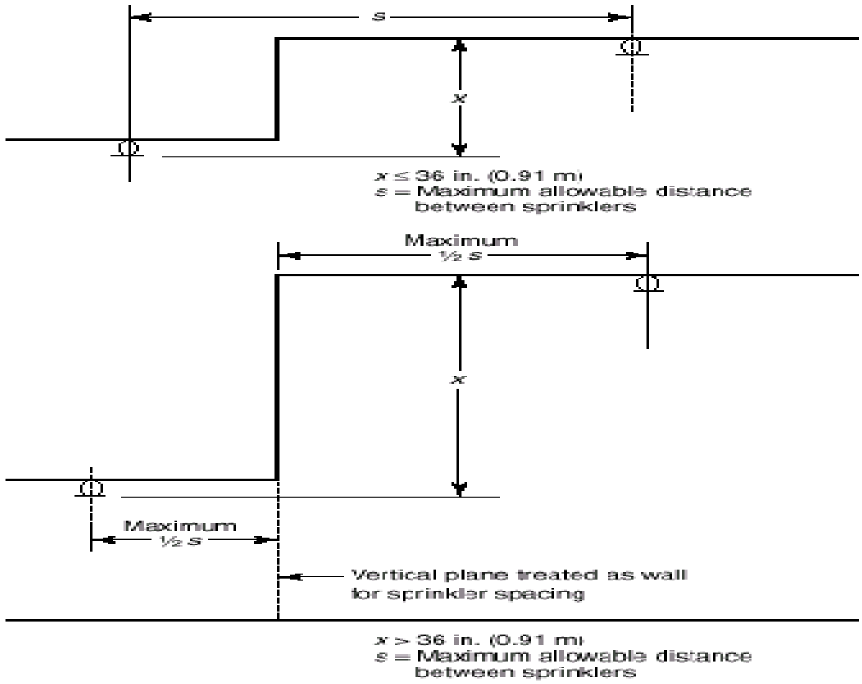


Figure 3.13. Vertical Changes in Ceiling Elevations, (NFPA 13, 2006).

3.8 System Protection Area Limitation

System protection area limitation means the maximum coverage area, floor area, per system on any one floor in a building. The maximum coverage areas are not to be extended to another building that has its own sprinkler system. NFPA 13 deals with each floor as a separate fire area, so there are not limitations on the number of floors that may be connected to a riser. If the floor area exceeded the values specified in the table (3.5), more than one riser system would be needed. Floor control valves, zone control valves (ZCV), must be provided on each floor of a high-rise building to determine which sprinkler operation occurred. For each maximum area there is ZCV. Manifold riser is used when there is more than one riser. Mezzanines floor are not included in the maximum area limitation per floor (NFPA 13, 2006).

Table 3.5. Maximum Floor Area per Zone Control Valve (NFPA 13, 2006)

Hazard occupancy	Maximum floor area(m^2)
Light hazard	4831
Ordinary hazard	4831
Extra hazard hydraulically calculated	3716

3.9 Water Demand Requirement Based on Area/Density Method

One of the most common methods that are used in hydraulic method for determining the water demand is Area/Density method which is cleared in chapter four. The water supply for standard spray sprinkler is determined by using Density/ Area Curves. Density of the water can be determined from the figure if the hazard occupancy is specified.

CHAPTER FOUR

MATHMATICAL AUTOMATIC SPRINKLER MODEL

This chapter will discuss the mathematical formulas that are used in sprinkler calculations. In addition, it will discuss the model installed according to NFPA and BS. In this chapter the predicted model will be discussed also.

4.1 Mathematical Formula

The Hazen- Williams formula is the most popular friction loss formula. This formula is not derived but it is an empirical formula. Allen Hazen (a Civil Engineer) and Gardner S. Williams (professor of civil engineering at the University of Michigan) developed it at the beginning of the 20^{th} century. It is recognized by NFPA 13 and BS 5306 for calculating the pressure loss in a pipe due to friction. It is expressed as (BS 5306: Part 2, 2006).

$$P_f = 6.05 \times \left(\frac{\dot{Q}^{1.85}}{C^{1.85} \times D^{4.87}} \right) \times 10^7 \qquad (4.1)$$

Where P_f is friction loss of pipe (kPa/m), $\dot{Q}$ is flow rate (L/min), D is actual internal diameter (mm), and C is Hazen-Williams roughness coefficient. The Hazen-Williams roughness coefficient is a dimensionless measure of the relative roughness or smoothness of the internal surface of a pipe. Table (4.1) shows the different values of C–factor for different pipe materials.

Table 4.1. Hazen-Williams Roughness Coefficient, (BS 5306: Part 2, 2006)

Pipe material	Cast iron	Ductile iron	Mild steel	Galvanized Steel	Spun cement	Copper	Asbestos cement
C- factor	100	110	120	120	130	140	140

The split flow rate formula can be used in loop and grid network to determine how flow splits in two pipe segments if the total flow of the loop is known. The split flow rate formula is expressed as (Gagnon, 1996).

$$\dot{Q}_1 = \frac{\dot{Q}_t}{\left(1+\left(\frac{L_1}{L_2}\right)\right)^{0.54}} \tag{4.2}$$

Where $\dot{Q}_1$ is the flow rate in pipe segment1, $\dot{Q}_t$ is the total flow rate in the loop, and L_1 and L_2 are the length of the pipe in the pipe segment 1 and segment2.

The pressure difference from two different demands must be adjusted according to the following balance formula (Gagnon, 1996).

$$\dot{Q}_{adj} = \dot{Q}_{low}\sqrt{\frac{P_h}{P_l}} \tag{4.3}$$

Where $\dot{Q}_{low}$ and P_l are the flow rate and pressure associated with the lower demand, P_h is the higher pressure associated with the demand, and $\dot{Q}_{adj}$ is adjusted flow rate required to adjust pressure difference.

The velocity pressure must be determined by using the following formula (Gagnon, 1996).

$$P_v = 221.5 \times \frac{\dot{Q}^2}{D^4} \qquad (4.4)$$

Where P_v is the velocity pressure (kPa), $\dot{Q}$ is the flow rate (L/min), and D is the inside diameter (mm). The velocity pressure can also be expressed as follows (Harold, 1983)

$$P_v = 1.42 \times \frac{V^2}{2 \times g} \qquad (4.5)$$

Where V is the fluid velocity of water in the pipe (m/s) and g is the earth gravitational constant (9.81m/s^2). The fluid velocity of water in the pipe can be expressed based on the following formula (Gagnon, 1996).

$$V = 21.22 \times \frac{\dot{Q}}{D^2} \qquad (4.6)$$

Where $\dot{Q}$ is the flow rate (L/min), and D is the inside diameter (mm).

Normal or static pressure must be determined depending on the following formula (NFPA13, 2006).

$$P_n = P_t - P_v \qquad (4.7)$$

Where P_n is the normal pressure (kPa) and P_t is the total pressure (kPa). The normal pressure is the pressure acting perpendicular to the pipe wall and perpendicular to the velocity pressure.

The discharge from sprinkler heads can be calculated by the following using the sprinkler head flow equation (Dubay, 2002).

$$\dot{Q} = \frac{K \times \sqrt{P}}{10} \tag{4.8}$$

Where $\dot{Q}$ is the flow rate from sprinkler head (L/min), K is the discharge coefficient depends on the sprinkler head, and P is the pressure of discharged water (kPa).

The steel pipe schedule number can be evaluated by the following formula (Mark's Handbook, 1967)

$$S.N = \frac{1000 \times Pi}{St} \tag{4.9}$$

Where S.N is the schedule number for steel, P_i is the internal pipe pressure (Psi), and S_t is the allowable stress in the pipe for steel (Psi). For fabricated steel pipe the allowable stress for ASTM A53 equals 15000 Psi (Mark's Handbook, 1967).

4.2 Equivalent Length of Valves and Fittings

The equivalent lengths of valves for C-factor equal 120 are given in table (4.2). If the fittings or valves that are used in a sprinkler system do not exist in the table (4.2), the equivalent length must be taken from the manufacturer.

4.3 Methodology of Hydraulic Calculation for Sprinkler Systems

Hydraulic calculation of sprinkler systems is a critical one because it depends on the accuracy of determination of the input data for calculation, which depends on the designer. The designer must know how to select proper hazard occupancy and hydraulic water density, how to determine the suitable location of the design area, how to determine the appropriate shape of the design area and its length, and how to calculate the friction loss in each pipe segment.

Table 4.2. Equivalent Length of Fitting and Valves, (BS 5306 Part 2, 2006)

Fitting and valves	Equivalent length of medium grade steel straight pipe (in m) accordance to BS 1387 (C-factor=120)										
	Nominal diameter (mm)										
	20	25	32	40	50	65	80	100	150	200	250
90° screwed elbow	0.63	0.77	1.04	1.22	1.46	1.89	2.37	3.04	4.30	5.67	7.42
90° Welded elbow(r/d=1.5)	0.30	0.36	0.49	0.56	0.69	0.88	1.10	1.43	2.00	2.64	3.35
45° screwed elbow	0.34	0.40	0.55	0.66	0.75	1.02	1.27	1.61	2.30	3.05	3.89
Standard screwed tee or cross(flow through branch)	1.25	1.54	2.13	2.44	2.91	3.81	4.75	6.10	8.61	11.34	14.85
Gate valve-straightway(flanged fitting	-	-	-	-	0.38	0.51	0.63	0.81	1.13	1.50	1.97
Alarm or non return valve(swinging) flanged fitting	-	-	-	-	2.42	3.18	3.94	5.07	7.17	9.40	12.30
Alarm or non return valve(mushroom) flanged fitting	-	-	-	-	12.08	18.91	19.7	25.36	35.8	47.27	61.85
Butterfly valve(flanged fitting)	-	-	-	-	2.19	2.86	3.55	4.56	6.38	8.62	9.90
Glob valve - straightway(flanged fitting	-	-	-	-	16.43	21.64	26.8	34.48	48.7	64.29	84.11

4.3.1 Determination of Hazard Level in the Building and Hydraulic Water Density

Based on the determination of the correct building hazard occupancy or portion of hazard building, the design density of water and the total design area are chosen from the area/ density curve illustrated in figure (4.1).

The selection of the occupancy is considered the most critical decision that a fire protection system designer makes during the hydraulic calculation because the reliability and meaningful hydraulic calculation depend on the correct selection of occupancy hazard.

Figure (4.1) is the function of a design density (flow rate per unit area) and the total design area of sprinkler operation for wet pipe systems only. For dry pipe systems the design area is 30% larger than wet systems and the density is not modified as required in NFPA 13. It is only valid for only standard spray sprinkler head. The design density is the quantity of water flow per square mm of a design area. The design area is the area that demands more water for fire suppression than any other area on the system. Also, it may depend on the geographical most remote area. The correct way to determine the correct design area is to perform at least one hydraulic calculation for different occupancies in the building.

4.3.2 Specification of Hydraulic Design Area

The most hydraulic design area represents the highest risk rectangular area in the building where a fire can break out. When the design area is selected, the area risk level is applied to the entire building.

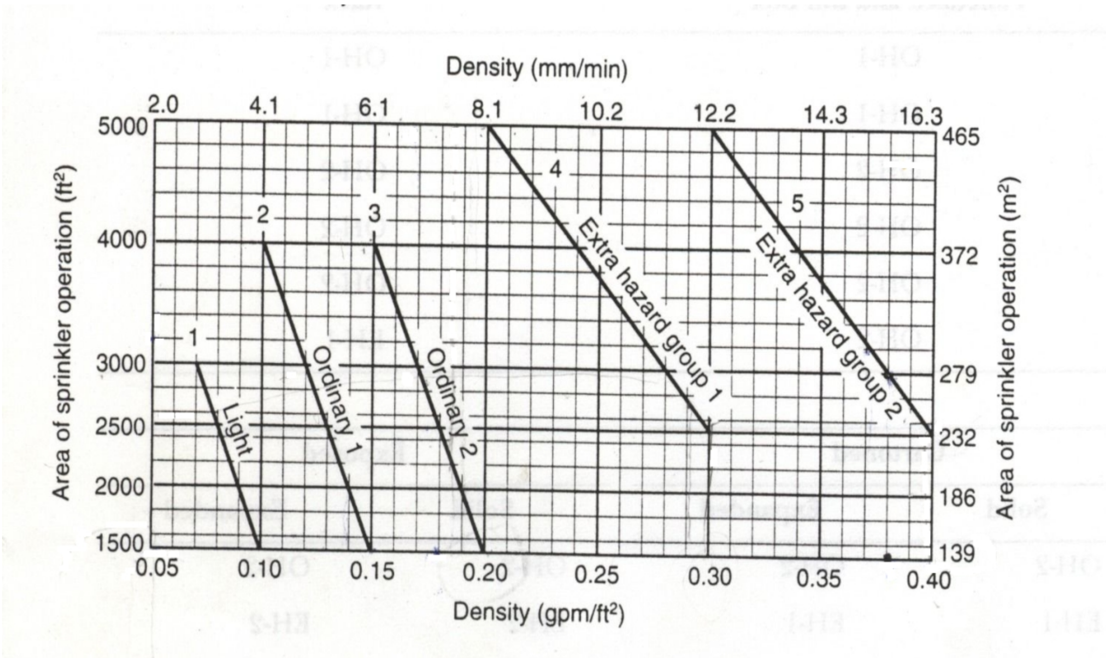


Figure 4.1. Area/ Density Curves, (NFPA 13, 2006).

The minimum length of rectangular design area (L_{min}) that is parallel to the branch line is equal or greater than 1.2 times the square root of the design area (Ad). For gridded system the designer must perform calculation at least for two design areas (NFPA 13, 2006).

The number of sprinklers along the length of the design area (N_s) is determined by dividing L_{min} by the distance between sprinklers (S) (NFPA 13, 2006). Sometimes the rectangular shape cannot be satisfied because of the obstruction existing in the building. In this case the designer anticipates the risk area depending on the experience and hydraulic calculation.

Examples how to select the most unfavorable area in gridded system is cleared in figure (4.2). The British Standard shows other cases for tree and loop configuration.

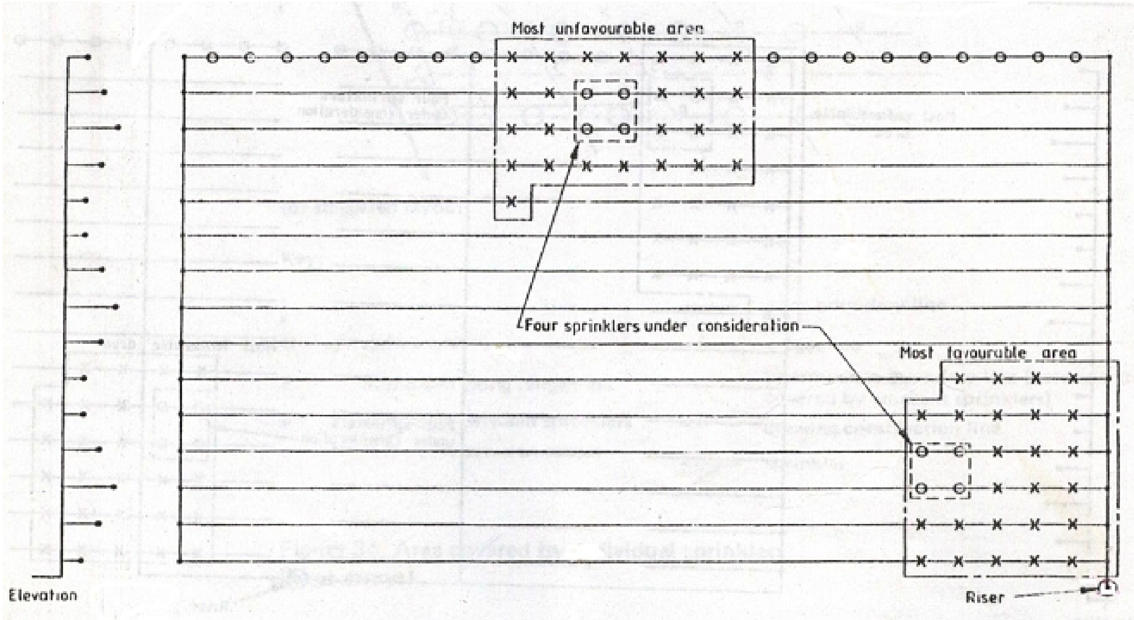


Figure 4.2. Selection of Design Area in Grid Pipe Configuration, (BS 5306: Part 2, 2006).

4.3.3 Minimum Flow and Pressure at the Most Demanding Sprinkler

The minimum flow rate ($\dot{Q}$) and minimum pressure (P_{min}) of the most demanding sprinkler head is the function of the design density (D_d), the coverage area of sprinkler head (A_s) and the sprinkler discharge characteristic (K) (NFPA 13,2006).

$$\dot{Q}_{min} = D_d \times A_s \tag{4.10}$$

$$P_{min} = \left(\frac{\dot{Q}_{min}}{k}\right)^2 \tag{4.11}$$

NFPA 13 specifies that the minimum pressure at any sprinkler must not be less than 0.5 bars. The largest coverage area of any sprinkler head in the design area must be taken in calculation when the area coverage is not uniform.

4.3.4 Friction Loss Specifications

Friction loss in piping network must be calculated by using Hazen-Williams formula. The tee fitting at the top of a riser nipple must be included in the branch line, while the tee fitting at the base of the riser nipple must be included in the riser nipple. The tee fitting or cross at the cross main pipe must be included in the cross main. The equivalent length of the reduced elbow must be taken based on the smaller diameter. The friction losses of the fittings that are directly connected to sprinkler heads are not taken in calculation. The only tee fitting and elbow that must be taken in calculation are caused by changing direction of flow (NFPA 13, 2006).

4.4 Installation of Automatic Sprinkler System

Automatic sprinkler system and standpipes system are examples of the requirements of high-rise building according to the Jordanian Fire Prevention Code. The most common methods for the installation of these systems are multi-zone installation and high-rise sprinkler system installation. Multi-zone installation is used according to the NFPA14 as shown in Figure (4.3). Many approved and listed fire pumps will be used at least in multi-zone installation because two pumps will be used for each zone in addition to the jokey pumps. The two pumps are driven by different power sources. In multi-zone installation, pumps capacity is high because it operates automatic sprinkler system and standpipe systems at the same time. High-rise sprinkler system installation is used according to the BS 5306. In the high-rise sprinkler system installation the automatic sprinkler system is completely separated with standpipe systems as shown in figure (4.4). For each zone, at least two approved and listed fire pumps will be used with different power source.

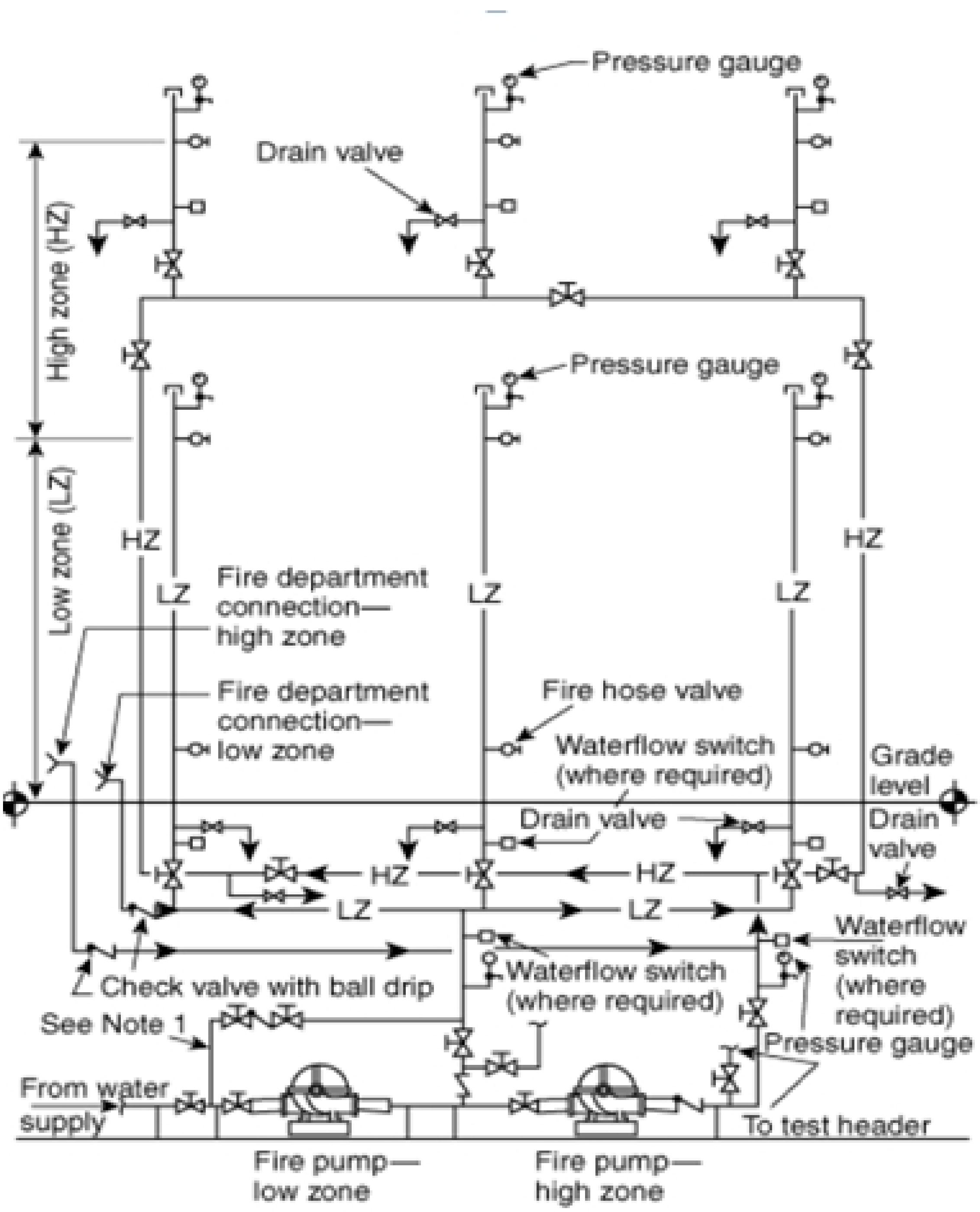


Figure 4.3. Sprinkler Floor Assembly for High-Rise Building, (NFPA 14, 2006).

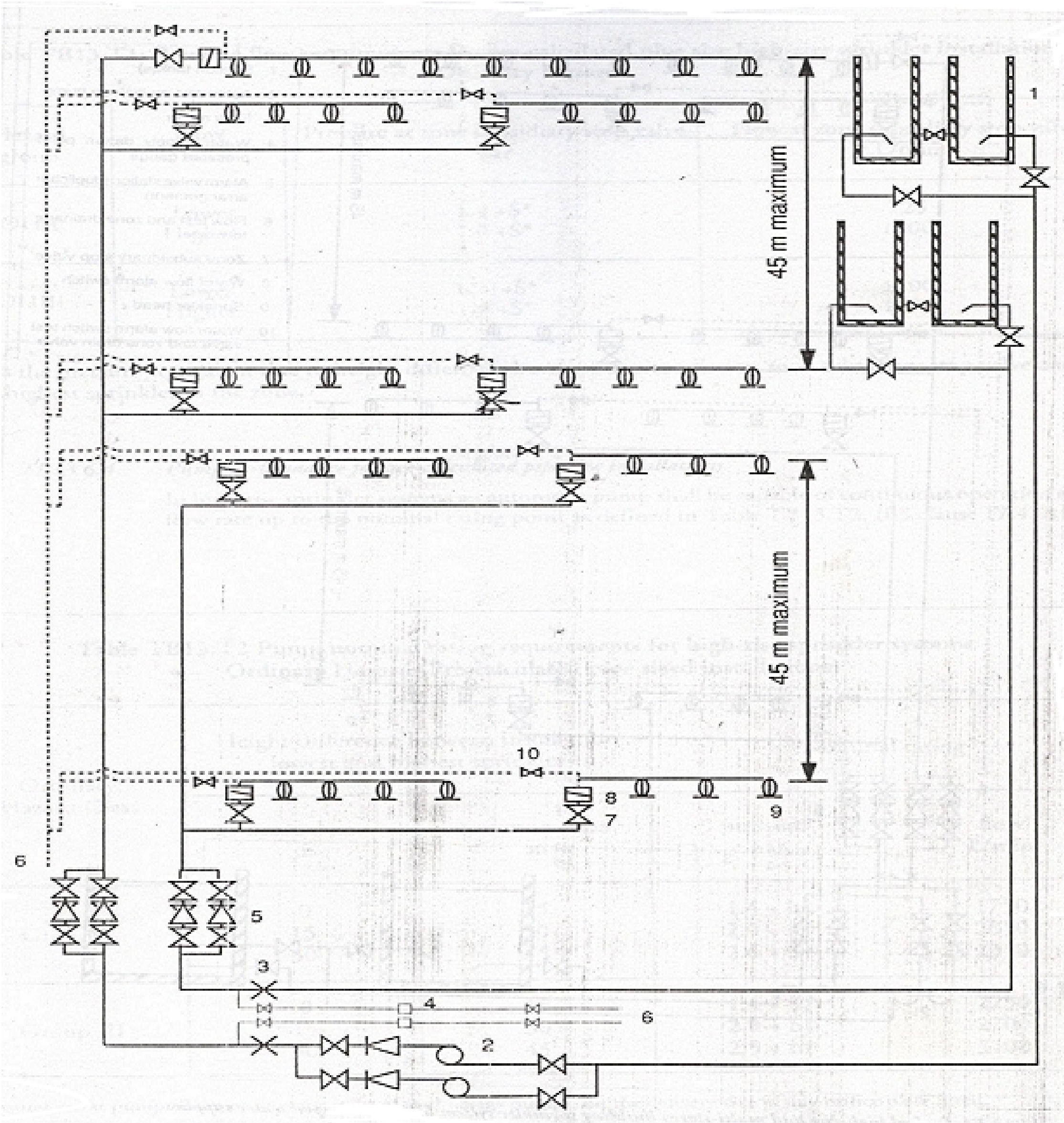


Figure 4.4. Typical High-Rise and Multi-Story Building Sprinkler Layout, (BS 5306:Part4, 2006).

The suggested installation system method is based on the separation of the automatic sprinkler and the standpipe systems. This separation involves water storage, pumps and network. The only connection between these systems is the fire department connection pipe. The suggested installation system is installed according to the NFPA 13 standard and NFPA 14 standard. One set of approved and listed fire pumps is used for automatic sprinkler system and another set of fire pumps is used for standpipe system. Landing valve and hose reel systems are fed by a fire pump or by a bypass connection according to NFPA 20 connection as shown in figure (4.5) and appendix (B). Fire Hydrants are fed by a bypass connection. The Automatic Sprinkler System is fed by a set of listed fire pumps. The fire department connection pipe used is fed by the water storage for standpipe system and from an external source like water tanks.

4.5 Installation of Standpipe Systems

The local codes in Jordan determine the different types of standpipe systems that are used in high rise building in Jordan. Standpipe Systems are arrangements of pipes, valves, hose connection, hoses with nozzle, pumps, and water supply that are installed to give appropriate amount of discharge water and pressure. It is considered to be the first attack line that is used by the occupant or Civil Defence at the beginning of the fire. The hose connection must be accessible and located near to the exits roots in the building. Standpipe Systems used according to the local codes are wet landing valves system and hose reel system in addition to the hydrant system. NFPA 14 and local fire protection code determine the minimum residual flow and pressure that must be satisfied at the exit of the nozzles. For the hose reel system the minimum residual flow and pressure are 30 L/min and 1.5 bars, respectively. For the hydrant and landing valves, these values must not be less than 946 L/min and 4.5 bars, respectively (Fire Protection Code, 2004). Pipe sizing must be determined according to the hydraulic calculation. At least two landing valves and two hose reels must be taken in the hydraulic calculation. The number of hose reel cabinets depends on the hazard of occupancy and the floor area. Each exit stairway must be provided with separate standpipes according to the NFPA 14 rules.

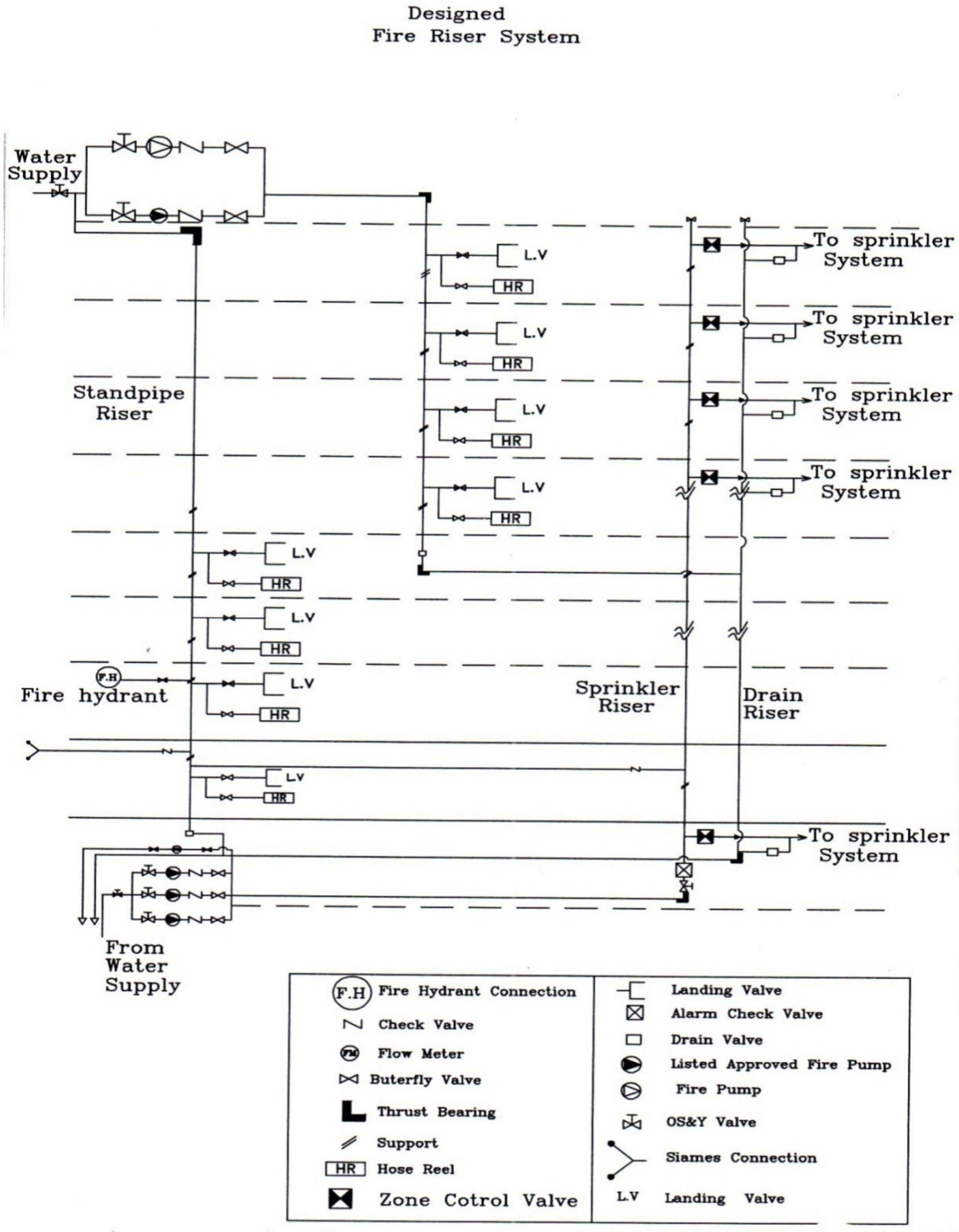


Figure 4.5. Designed Model for Sprinkler Floor Assembly of High-Rise Building.

4.6 Modeling Approach

One of the suggested high-rise building projects in Amman is called K-Tower. The K-Tower is taken as a case study in the present research. The tower is located in AL-Abdali region which is one of the areas that are considered to be a tower area in Amman. The K-Tower is a mixed-use building consisting of fourty four stories with variable floor heights, and floor areas. The occupancy type, the floor area, the number of main staircase, and the number of main elevators are shown in the table (4.3). AutoCAD software 2009 is used to draw piping network for the automatic sprinkler system and standpipe systems for this study.

Table 4.3. Specifications of K-Tower Building, (Architectural drawing from Segma Consultant Engineering Office).

Name of floor	Occupancy type	Floor area m^2	Number of main staircase	Number of main elevator
Basement seven	Water storage and storage room	1500	2	-
Basement six up to one	Car park	16952	4	2
Ground up to podium one	Mercantile shops	3563	5	11
podium two up to podium six	Offices	8074	4	9
T_1 up to T_{30}	Offices	20833	3	6

4.7 Manual Hydraulic Calculation

There is more than one hazard area in the suggested building, so two designed areas will be selected. Each design area will be calculated hydraulically and separately to determine which of them is the critical case.

4.7.1 Design Area Number One

The first design area is located at the floor number (29) as shown in figure (4.6). The hatched area in figure (4.6) is the critical design area in the floor (29) which is shown in figure (4.7). After the determination of the predicted design area, there are input data before doing the calculations. The following are the input data.

1. The offices occupancy is classified as a light hazard based on the classification of hazard in chapter three.
2. The design density and design area for the light hazard occupancy are 4.1 mm/min, and 139 m^2 respectively based on figure (4.1).
3. The maximum allowable coverage area per sprinkler head for the light hazard is 21 m^2 bases on table (3.3), but the maximum coverage area used in the case study is 16 m^2.
4. Black steel pipe schedule 40 will be selected with C-factor equal 120.
5. The following type of sprinkler head will be adopted for this study as shown in table (4.4).

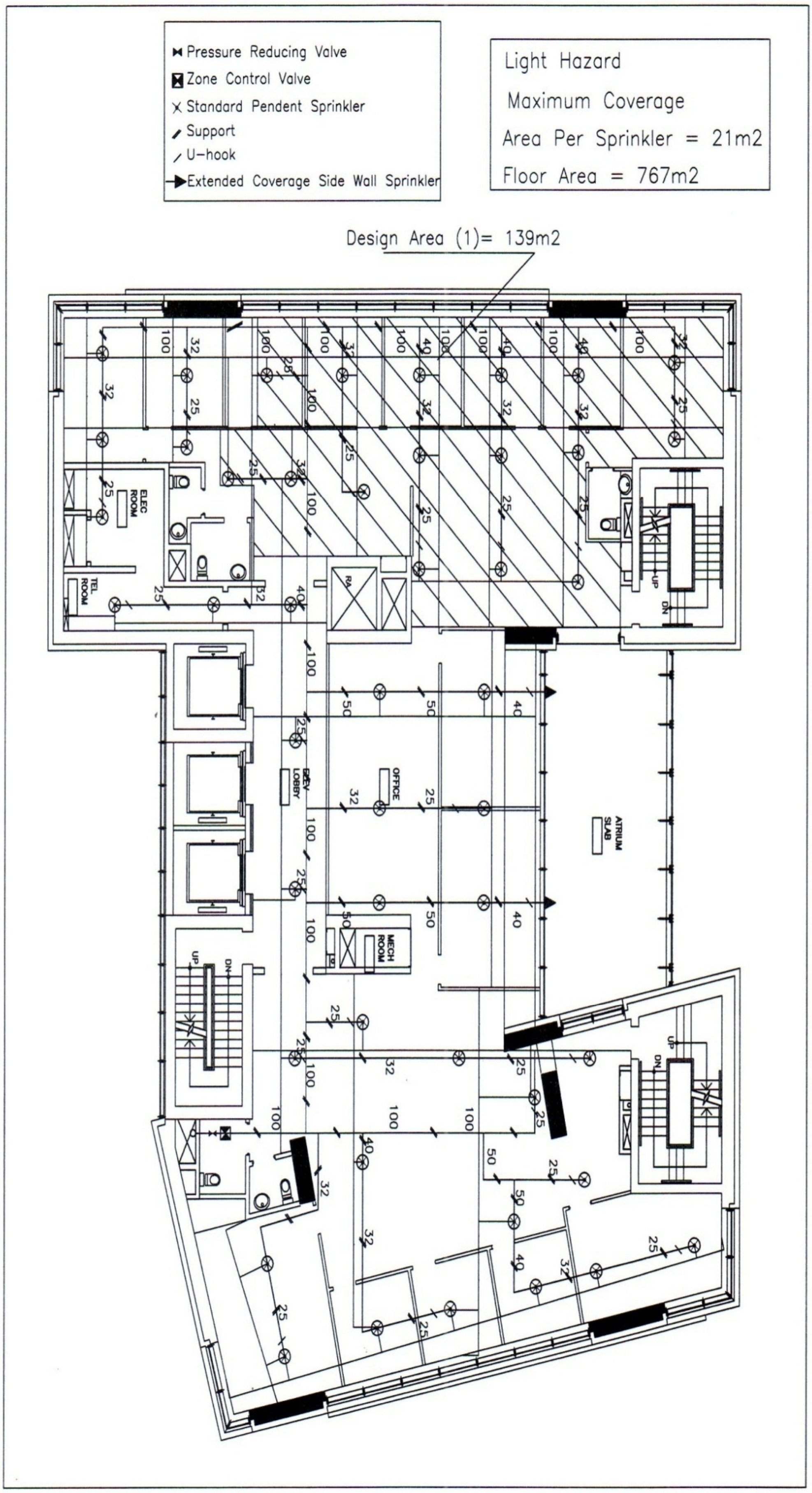


Figure 4.6. The Determined Critical Design Floor Area Number One at the Floor (T29) of the K-Tower.

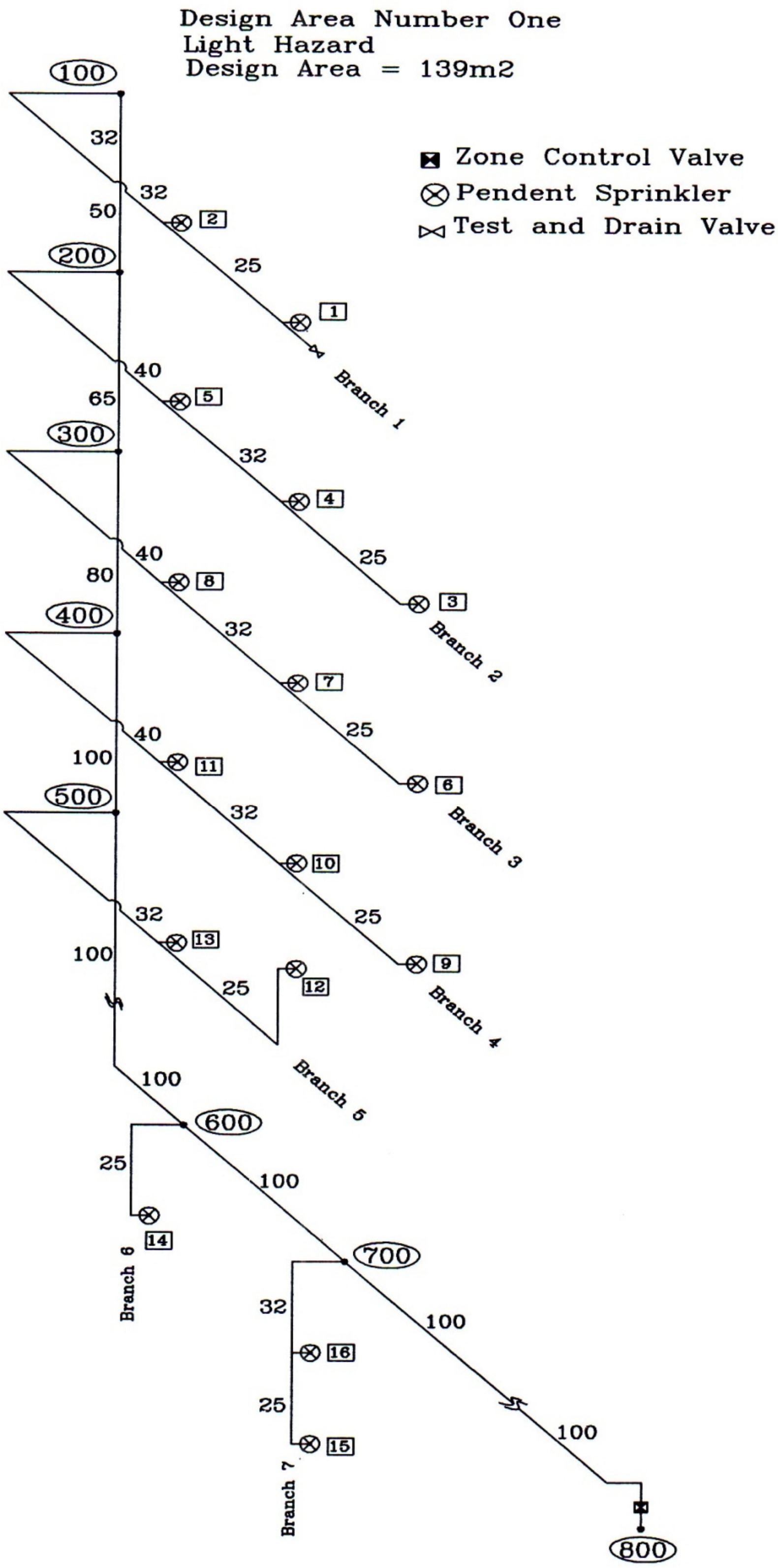


Figure 4.7. The Determined Hatched Critical Design Area Number One at the Foor(T29) OF the K-Tower.

Table 4.4. Specifications of Sprinkler Head Selected for Modeling Approach, (Tyco-Fire Protection Catalogue, 2003)

Sprinkler Head Type	Model	Nominal K-Factor $L/min\sqrt{kPa}$	Temperature Rating °C	Thread Size NPT mm	Sprinkler Height mm	Identification Number
Standard coverage pendent	TY-B	80	57-79	0.5	55.6	SIN TY 3251
Standard coverage pendent	TY-L	80	74	0.5	66.7	SIN TY 3111
Extended coverage side wall	TY-FRL	80	74	0.5	71.4	SIN TY 3251

Elementary calculation will be carried out to calculate the starting flow rate and starting pressure($\dot{q}_{start}$, P_{start}), respectively.

$$\dot{q}_{start} = A_s \times D_d$$

Then: $\dot{q}_{start} = 16 \times 4.1 = 65.6\ L/min$

From equation 4.8 and solving for P_{start}:

$$P_{start} = \left(\frac{65.6 \times 10}{80}\right)^2 = 67.24\ kPa$$

Minimum number of sprinkler in the design area (MSDA) = D_A/A_S

Therefore, MSDA =139/16= 8.7 sprinkler (at least 9 sprinkler will be taken).

The next step is to calculate the flow rate and pressure at each node in the design area, where $\dot{q}_{start}$ and P_{start} represent the flow rate and pressure at node 1 of figure (4.7).

To calculate the flow rate and pressure at node 2 or at each node of figure (4.7), Hazen-William formula for friction loss and elevation loss equation will be used.

Consider segment1-2 of branch line 1 of figure (4.7).

But $\dot{q}_{start} = \dot{q}_1$ flow rate of sprinkler 1 and $P_{start} = P_1$ = pressure of sprinkler 1

For $\dot{q}_1 = 65.6\ L/min$, D = 25 mm, C =120.

Substitute the above values in equation 4.7 to find the velocity through the segment1-2.

$$V = 21.22 \times \frac{65.6}{25^2} = 2.23\ m/s$$

Also, apply equation 4.6 to find the velocity pressure.

$$P_v = 221.5 \times \frac{65.6^2}{25^4} = 2.44 kPa$$

Then, equation 4.8 gives the normal pressure:

$$P_n = 67.24 - 2.44 = 64.8\ kPa$$

To calculate the friction loss pressure, $P_{Loss} = L_{eq} P_f$ where: $L_{eq} = L_{pipe} + P_f$

Therefore, using table (4.2) to find equivalent length of fitting.

Then: $L_{eq} = 2.2 + 0 = 2.2m$

Apply equation 4.1 then: $P_f = 3.08\ kPa/m$

$P_{Loss} = 3.08 \times 2.2 = 6.78\ kPa$

Now, $P_2 = P_1 + P_f$ then $P_2 = 67.24 + 6.78 = 74.02\ kPa$

Apply equation 4.8 to compute the resulted flow rate from sprinkler 2.

$$\dot{q}_2 = \frac{80}{10} \times \sqrt{74.02} = 68.83\ L/min$$

Now, the flow rate passes through the segment 2-100 is:

$$\dot{Q}_2 = \dot{q}_1 + \dot{q}_2 = 65.6 + 68.83 = 134.43\ L/min$$

Similarly, for segment 2-100 of figure (4.7)

For $\dot{Q}_2 = 134.43 L/min$, D = 32 mm, C =120.

From equation 4.7 then:

$$V = 21.22 \times \frac{134.43}{32^2} = 2.78\ m/s$$

Next, the velocity pressure is:

$$P_v = 221.5 \times \frac{134.43^2}{32^4} = 3.81 kPa$$

Then, equation 4.8 applies:

$$P_n = 67.24 - 2.44 = 64.8\ kPa$$

To calculate the friction loss pressure, $P_{Loss} = L_{eq}\, P_f$

Where: $L_{eq} = L_{\text{pipe}} = L_{fitting(2E)}$. Therefore, using table (4.2) to find equivalent length of fitting.

$L_{eq} = 1.3 + 2.08 = 3.38m$

Equation 4.1 applies. Then: $P_f = 3.49kPa/m$

$P_{Loss} = 3.49 \times 3.38 = 11.80\ kPa$= 3.49

The static pressure Pe is:

$$Pe = 0.3 \times \frac{100}{10} = 3 \text{ kPa}$$

Now the pressure at node 100, P_{100} is:

$$P_{100} = P_2 + P_{loss} + P_e$$

Therefore, P_{100}= 74.02+11.8+3 = 88.82 kPa

Similar calculations are carried out for all other nodes and branch lines of figure (4.7).

Branch line 3 and branch line 4 is similar to branch line 2, thus typical branch lines treats as one big sprinkler with an orifice factor, K_{branch} as follow:

$K_{branch} = 10 \times \frac{\dot{Q}_{branch}}{\sqrt{P_{branch}}}$, where K_{branch} is an equivalent factor for branch line, $\dot{Q}_{branch}$ and P_{branch} are the resultant flow rate and pressure for the branch line respectively.

The resultant flow rate and pressure from branch line 2 as shown in table (4.5) are:

$\dot{Q}_{branch} = 211.48\ L/min$, $P_{branch} = 103.83\ kPa$

Therefore, $K_{branch} = 10 \times \frac{211.48}{\sqrt{103.83}} = 207.54\ L/min\sqrt{kPa}$

Thus, equation 4.8 applies for branch 3. The value of flow rate that results from branch line 3 of figure (4.7) is:

$\dot{Q}_{branch3} = \frac{207.54}{10} \times \sqrt{115.84} = 224 \text{ L/ min}$, Where P_{300} = 115.84 kPa

Similar procedure applies with an orifice factor equal to $207.54 \frac{L}{min\sqrt{kPa}}$ to find the flow rate of branch line 4. Finally, the results of all nodes and branch lines of figure (4.7) are shown in table (4.5).

The total flow rate and pressure of design area number one as shown in table (4.5) are:

$\dot{Q}$ =1168 L/min and PT = 1736 kPa, respectively.

Equation 4.9 applies to verify the steel schedule 40 is appropriate for the design calculation.

$$S.N = \frac{255 \times 1000}{15000} = 17$$

So, schedule 40 is appropriate for the calculation.

Table 4.5. Summary of Manual Detailed Calculation for the Design Area Number One

Sprinkler Indent.& Location	Flow rate In L/min	Node Elevation M	Pipe Size mm	Pipe Fitting& Device	Equivalent Pipe Length m	Friction Loss kPa/m	Velocity m/s	Pressure Summary kPa
1-2 1	q = 65.6 Q = 65.6	156→156	25	-	Length = 2.2 Fitting =0 Total =2.2	3.08	2.23	PT =67.24 PE=0 PF=6.78
2-100 2	q = 68.83 Q = 134.43	156→155.7	32	2 E	Length = 1.3 Fitting = 2.08 Total = 3.38	3.49	2.78	PT = 74.02 PE= 3 PF= 11.80
100-200	q = 0 Q = 134.83	155.7→155.7	32	T+E	Length = 3.6 Fitting = 2.13 Total = 5.73	3.49	2.78	PT = 88.82 PE=0 PF= 20.0
3-4 3	q = 65.6 Q = 65.6	156→156	25	-	Length = 4 Fitting =0 Total = 4	3.08	2.83	PT = 67.24 PE= 0 PF= 12.23
4-5 4	q = 71.36 Q = 136.96	156→156	32	-	Length = 2 Fitting =0 Total = 2	3.61	2.8	PT = 74.56 PE= 0 PF= 7.22
5-200 5	q = 74.52 Q = 211.48	156→155.7	40	E+T	Length = 1.5 Fitting= 3.66 Total= 5.16	2.723	2.8	PT= 86.78 PE = 3 PF = 14.05
200-300	q = 216.6 Q = 531	155.7	50	-	Length = 3 Fitting= 0 Total= 3	2.34	1.76	PT = 103.83 PE = 0 PF = 7.02
300-400	q = 224 Q = 575	155.7	65	-	Length = 2.2 Fitting= 0 Total = 2.2	3.56	1.91	PT = 115.84 PE = 0 PF = 3.56
400-500	q = 226.78 Q = 801.81	155.7	80		Length = 2.24 Fitting =0 Total = 2.24	1.1	1.7	PT = 119.4 PE=0 PF= 2.66
12-13 12	q = 65.6 Q = 65.6	156	25	E	Length = 4.2 Fitting= 0.77 Total= 4.77	3.08	2.23	PT = 67.24 PE= 0 PF = 14.75
13-500 13	q = 72.43 Q = 139.67	156-→155.7	32	E+T	Length = 2.1 Fitting= 3.17 Total= 5.27	3.75	2.89	PT = 82 PE= 3 PF = 19.76
500-600	q = 150.76 Q = 952.57	155.7	100	E	Length = 3 Fitting= 6.1 Total= 9.1	0.51	2.02	PT = 104.76 PE= 0 PF = 4.56

Sprinkler Indent.& Location	Flow rate In L/min	Node Elevation M	Pipe Size mm	Pipe Fitting& Device	Equivalent Pipe Length m	Friction Loss Pa/m	velocity m/s	Pressure Summary Pa
14-600 14	$\dot{q}$ = 65.6 $\dot{Q}$ = 65.6	156→155.7	25	E+T	Length =2.3 Fitting = 2.31 Total = 4.61	3.08	2.23	PT = 67.24 PE= 3 PF=14.2
600-700	$\dot{q}$ = 73.64 $\dot{Q}$ = 1026.21	155.7	100		Length = 3.2 Fitting =0 Total = 3.2	0.59	2.18	PT =104.41 PE=0 PF= 1.89
15-16 15	$\dot{q}$ = 65.6 $\dot{Q}$ = 65.6	156	25	E	Length = 2.6 Fitting =0.77 Total = 3.37	3.08	2.23	PT =67.24 PE=0 PF= 10.38
16-700	$\dot{q}$ = 70.48 $\dot{Q}$ = 137.72	156→155.7	32	E+T	Length = 1.3 Fitting = 3.17 Total = 4.47	3.63	2.85	PT =77.62 PE= 3 PF= 20
700-800	$\dot{q}$ = 141.55 $\dot{Q}$ = 1167.7	155.7→155.4	100	6E+T+GV	Length = 24 Fitting = 19.24 Total = 43.24	0.746	2.48	PT = 100.62 PE= 3 PF= 32.26
800-900	$\dot{q}$ = 1168 $\dot{Q}$ = 1168	155.4	150		Length = 109.6 Fitting=0 Total= 109.6	0.106	11.62	PT= 1135.88 PE = 1096 PF = 11.62
900-1000	$\dot{q}$ = 1168 $\dot{Q}$ = 1168	155.4→0	150	6E+T+GV+CH	Length = 233 Fitting= 35.21 Total= 268.21	28.43	1.11	PT = 1243.5 PE = 464 PF = 28.43
1000	**$\dot{Q}$ =1168**							PT = **1736**

E=Elbow, T=Tee, GV=Gate Valve, CH=Check Valve, PT=Total Pressure, PE=Static Pressure, PF=Friction Loss, $\dot{q}$ = Flow Rate Released from Sprinkler, $\dot{Q}$ = Flow Rate through the Segment.

4.7.2 Design Area Number Two

The second design area which is located at the podium floor number (P1) as shown in figure (4.8). The hatched area in the figure (4.9) is the critical design area in the podium floor number (1) which is shown in figure (4.8). After the determination of the design area predicted, there are input data before doing the calculations. The following are the input data.

1. The mercantile occupancy is classified as an ordinary hazard group two based on the classification of hazard in chapter three.
2. The design density and the design area for the ordinary hazard group two are 8.1 mm/min, and 139 m^2, respectively based on the figure (4.1).
3. The maximum allowable coverage area per sprinkler head for the ordinary hazard is 12 m^2 bases on the table (3.3).
4. Black steel pipe schedule 40 will be used with C-factor equal 120.
5. The types of sprinkler head adopted for this study are as shown in table (4.5).

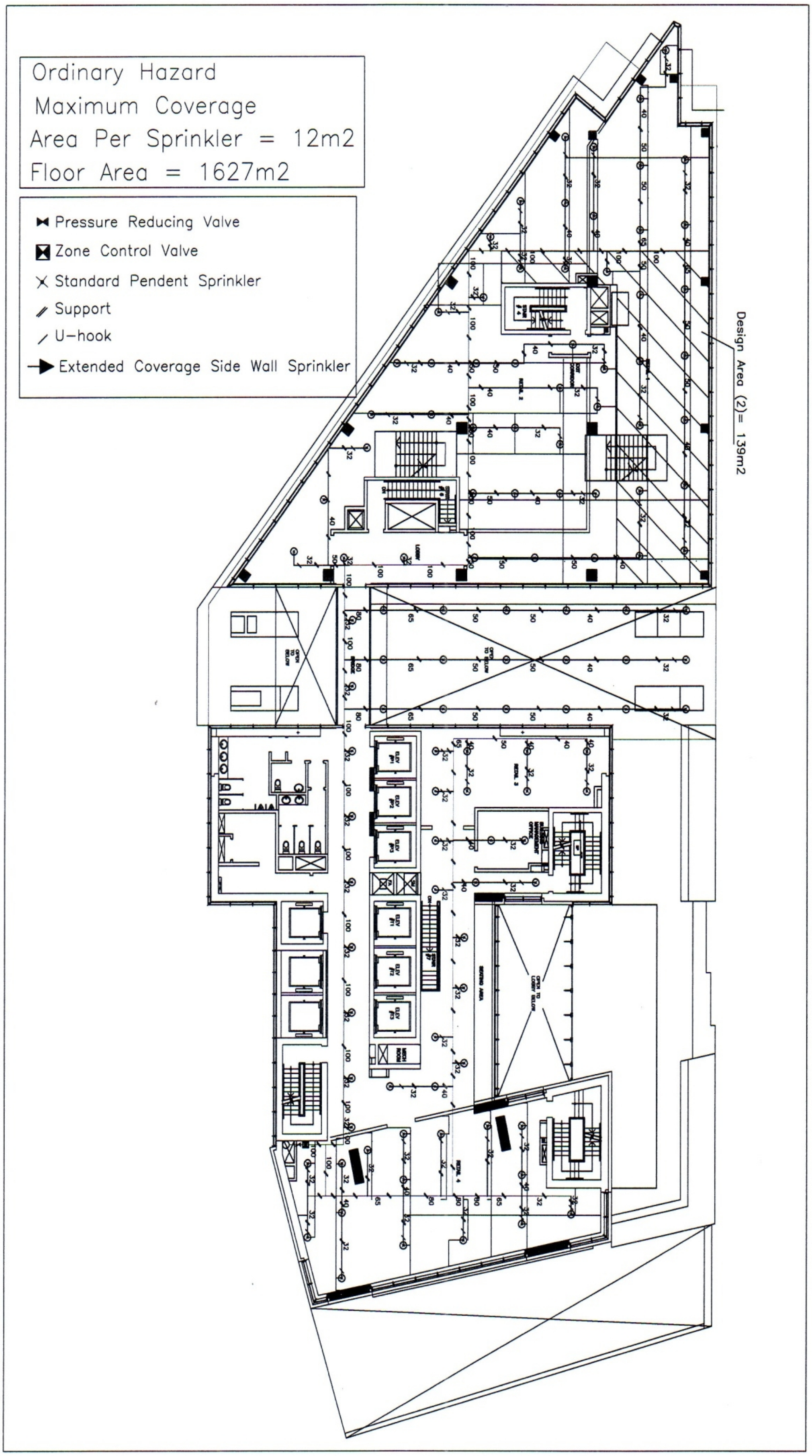


Figure 4.8. The determined Critical Design Floor Area Number Two at the Podium Floor (P1) of the K-Tower.

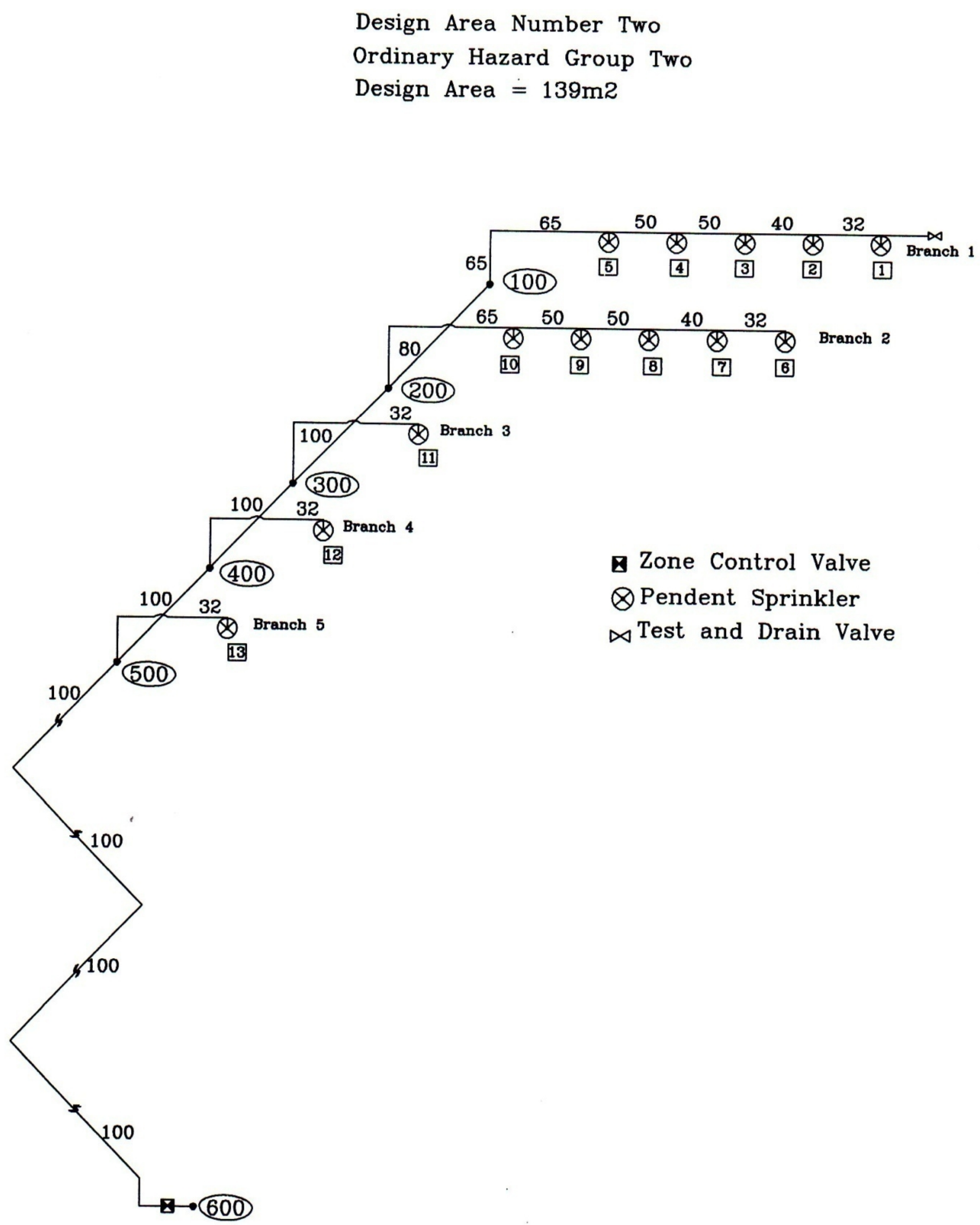


Figure 4.9. The determined Critical Design Area Number Two at the Podium Floor (P1) of the K-Tower.

Elementary calculation will be carried out to calculate the starting flow rate and starting pressure ($\dot{q}_{start}$, P_{start}), respectively.

$$\dot{q}_{start} = A_s \times D_d$$

Then: $\dot{q}_{start} = 12 \times 8.1 = 97.2\ L/min$

From equation 4.8 and solving for P_{start}:

$$P_{start} = \left(\frac{97.2 \times 10}{80}\right)^2 = 147.62\ kPa$$

Minimum number of sprinkler in the design area (MSDA) = D_A/A_S

Therefore, MSDA =139/12= 11.58 sprinkler (at least 12 sprinkler will be taken).

The next step is to calculate the flow rate and pressure at each node in the design area, where $\dot{q}_{start}$ and P_{start} represent the flow rate and pressure at node 1 of figure (4.9).

To calculate the flow rate and pressure at node 2 or at each node of figure (4.9), Hazen-William formula for friction loss and elevation loss equation will be used.

Consider segment1-2 of branch line 1 of figure (4.9).

But $\dot{q}_{start} = \dot{q}_1$ = flow rate of sprinkler 1 and $P_{start} = P_1$ = pressure of sprinkler 1

For $\dot{q}_1 = 97.2\ L/min$, D = 32 mm, C =120.

Substitute the above values in equation 4.7 to find the velocity through the segment1-2.

$$V = 21.22 \times \frac{97.2}{32^2} = 2.01\ m/s$$

Also, apply equation 4.6 to find the velocity pressure.

$$P_v = 221.5 \times \frac{97.2^2}{32^4} = 2.0\ kPa$$

Then, equation 4.8 gives the normal pressure:

$$P_n = 147.62 - 2.0 = 145.62\ kPa$$

To calculate the friction loss pressure, $P_{Loss} = L_{eq} P_f$ where: $L_{eq} = L_{pipe} + L_{fitting}$

Therefore, using table (4.2) to find equivalent length of fitting.

Then: $L_{eq} = 4 + 0 = 4m$

Apply equation 4.1 then: $P_f = 1.916\ kPa/m$

$$P_{Loss} = 1.916 \times 4 = 7.664\ kPa$$

Now, $P_2 = P_1 + P_f$ then $P_2 = 62 + 7.664 = 155.284\ kPa$

Apply equation 4.8 to compute the resulted flow rate from sprinkler 2.

$$\dot{q}_2 = \frac{80}{10} \times \sqrt{155.284} = 99.69\ L/min$$

Now, the flow rate passes through the segment 2-3 is:

$$\dot{Q}_2 = \dot{q}_1 + \dot{q}_2 = 97.2 + 99.69 = 196.89\ L/min$$

Similarly, for segment 2-3 of figure (4.9).

For $\dot{Q}_2 = 196.89\ 3L/min$, D = 40 mm, C =120.

From equation 4.7 then:

$$V = 21.22 \times \frac{196.89}{40^2} = 2.61\ m/s$$

Next, the velocity pressure is:

$$P_v = 221.5 \times \frac{196.89}{40^4} = 3.35\ kPa$$

Then, equation 4.8 applies:

$$P_{\ n} = 155.284 - 3.35 = 151.934\ kPa$$

To calculate the friction loss pressure, $P_{\ Loss} = L_{eq}P_f$ where: $L_{eq} = L_{pipe} + L_{fitting}$

Therefore, $L_{eq} = 4 + 0 = 4m$

Equation 4.1 applies. Then: $P_f = 1.916\ kPa/m$

$$P_{\ Loss} = 2.167 \times 4 = 8.668 \text{ kPa}$$

Now, the pressure at node 3 is:

$$P_3 = P_2 + P_{loss}$$

Therefore, $P_3 = 155.284 + 8.668 = 163.952\ kPa$

Similar calculations are carried out for all other nodes and branch lines of figure (4.9). The result is shown in table (4.6).

The total flow rate and pressure of design area number two as shown in table (4.6) are:

$\dot{Q}$ =1362 L/min and PT = 622 kPa.

Table 4.6. Summary of Manual Detailed Calculation for the Design Area Number Two

Sprinkler Indent.& Location	Flow rate In L/min	Node Elevation m	Pipe Size mm	Pipe Fitting& Device	Equivalent Pipe Length m	Friction Loss Pa/m	Velocity m/s	Pressure Summary Pa
1-2 1	q = 97.2 Q = 97.2	31.8	32		Length = 4 Fitting =0 Total = 4	1.916	2.01	PT = 147.62 PE=0 PF= 7.664
2-3 2	q = 99.69 Q = 196.89	31.8	40		Length = 4 Fitting =0 Total = 4	2.167	2.61	PT = 155.284 PE=0 PF= 8.668
3-4 3	q = 102.435 Q = 299.325	31.8	50		Length = 4 Fitting =0 Total = 4	1.746	2.54	PT = 163.952 PE=0 PF= 6.984
4-5 4	q = 104.594 Q = 403.919	31.8	50		Length = 4 Fitting =0 Total = 4	3.04	3.43	PT = 170.936 PE=0 PF= 12.161
5-100 5	q = 108.251 Q = 512.17	31.8→31.5	65	2E	Length = 3.3 Fitting = 5.7 Total = 9	1.315	2.57	PT = 183.097 PE= 3 PF= 11.835
100-200	q = Q = 512.17	31.5	65		Length = 3 Fitting=0 Total= 3	1.315	2.57	PT= 197.9 PE =0 PF = 3.945
200-300	q = 517.249 Q = 1029.42	31.5	80		Length = 2.2 Fitting= 0 Total= 2.2	1.739	3.41	PT = 201.845 PE = 0 PF = 3.826
11-300 11	q = 97.2 Q = 97.2	31.8→31.5	32	2E	Length = 2 Fitting= 2.1 Total = 4.1	1.916	2.01	PT = 147.62 PE = 3 PF = 7.85
300-400	q = 110.73 Q = 1140.149	31.5	100		Length = 2.6 Fitting =0 Total = 2.6	0.71	2.42	PT = 205.671 PE=0 PF= 1.846
12-400 12	q = 97.2 Q = 97.2	31.8→31.5	32	2E	Length = 2 Fitting= 2.1 Total= 4.1	1.916	2.01	PT = 147.62 PE= 3 PF = 7.85
400-500	q = 111.23 Q = 1251	31.5	100		Length = 3 Fitting=0 Total= 3	0.139	2.65	PT = 207.52 PE=0 PF = 0.417
13-500 13	q = 97.2 Q = 97.2	31.8→31.5	32	2E	Length = 2 Fitting= 2.1 Total= 4.1	1.916	2.01	PT = 147.62 PE= 3 PF = 7.85

Sprinkler Indent.& Location	Flow rate In L/min	Node Elevation m	Pipe Size mm	Pipe Fitting& Device	Equivalent Pipe Length m	Friction Loss Pa/m	Velocity m/s	Pressure Summary Pa
500-600	$\dot{q}$ = 110.93 $\dot{Q}$ = 1362	31.5	100	4E+GV	Length = 71 Fitting = 6.53 Total = 77.53	0.985	2.89	PT = 206.417 PE= 3 PF= 76.987
600-700	$\dot{q}$ = 0 $\dot{Q}$ = 1362	31.5→0	150	6E+T+CH+ GV	Length = 112 Fitting = 35.21 Total = 147.21	0.136	1.284	PT = 290 PE=312 PF= 20.13
700	$\dot{Q}$ = **1362**							**PT = 622**

E=Elbow, T=Tee, GV=Gate Valve, CH=Check Valve, PT=Total Pressure, PE=Static Pressure, PF=Friction Loss, $\dot{q}$ = Flow Rate Released from Sprinkler, $\dot{Q}$ = Flow Rate through the Segment.

4.8 Computer Simulation for the Hydraulic Calculation

Elite software is one of the most common software used in the hydraulic calculation of automatic sprinkler systems. Elite software is used in the research to check the manual hydraulic calculation for the case study. To perform Elite software the following data must be determined:

1- Hazard classification
2- Design density and design area
3- Specification of sprinkler head and pipe material
4- Coverage area per sprinkler
5- Nodes, distance between nodes, fitting type, and elevation nodes
6- Imbalance at the connection points and damping factor

Appendix (A) shows the simulation of the design area number one and number two for the case study.

4.9 Comparing between Manual and Hydraulic Calculations

Table (4.7) shows the accuracy of manual hydraulic calculations results of table (4.5) and table (4.6). The accuracy of the results is due to the accuracy of the procedure which is adopted by the designer. The small difference between the results can be ignored because the selections of the fire pump capacity depend on the listed rated flow and listed pressure ranges.

Table 4.7. **Comparing between the Results of Manual and Computer Calculation**.

Design Area Number	Manual Result		Computer Result		% error		Critical Demand	
	$\dot{Q}$ L/min	P kPa	$\dot{Q}$ L/min	P kPa	flow	pressure	$\dot{Q}$ L/min	P kPa
One	1168	1736	1148	1699	1.74	2.2	1168	1736
Two	1362	622	1362	596	0	4.36		

4.10 Selection of Fire Pump

The calculation results show the critical design area in the design area which located at the floor (T_{29}). This critical design area represents the capacity of the fire pump. The main data of the listed fire pump are model designation, rated capacity (L/min), speed (RPM), pressure ranges (kPa), discharge size (mm), and maximum allowable pressure (kPa). Each fire pump is provided with performance curves by the manufactures.

In this research, Fairbanks Morse Pump Corporation catalogues used. Table 4.8 and figure 4.10 shows the selected fire pump and their performance curves.

Using data in table 4.8 then:

$$Water\ tanks\ storage = \frac{500 \times 3.785 \times 60}{1000} = 114\ m^3$$

Water pump capacity of the automatic fire sprinkler system is calculated based on the rated flow of pumps. The durability of water supply depends on the hazard. For light hazard, the time will be 30 minutes while for ordinary hazard it will be 60 minutes (Jordan Fire Code).

Table 4.8. Specification of the Selected Fire pump, (Fairbanks morse, 1997)

Rated capacity (GPM)	Discharge size(Inches)	Model designation	Speed RPM	Pressure ranges(psi)	Maximum allowed pressure(psi)
500	4	1924F	3000	188-330	367

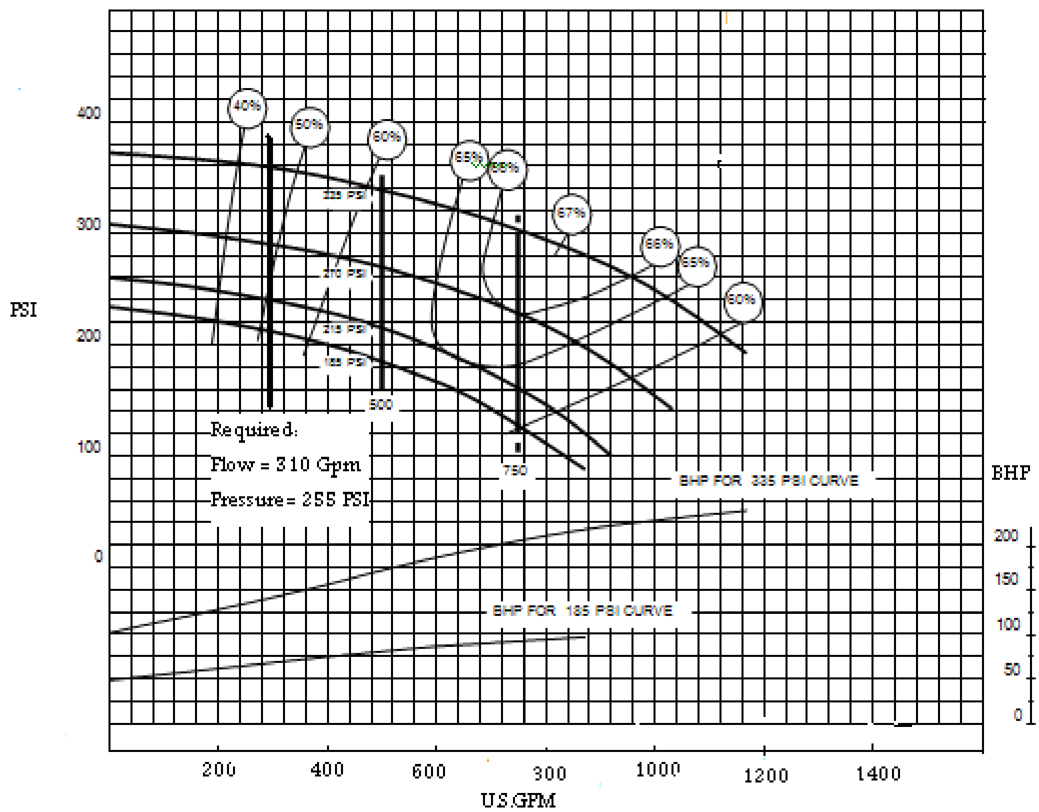


Figure 4.10. The Fire Pumps Performance Curve, (Fairbanks Morse, 2006).

4.11 Discussion

The operation of the automatic fire sprinkler system depends on the accuracy of the input data for the calculations. The hazard occupancy is the first step of the design. In this step, the size of the area of sprinkler operation, coverage area per sprinkler heads, and design water density are determined. The second step is to determine the critical floor in the tower and the critical design area in that floor. The critical area means the most demanding area with respect to flow rate and pressure. The minimum number of sprinkler heads must be satisfied in the design area, but there is no limitation on the maximum number of sprinkler head on the design area. This depends on the nature of the obstruction whether vertical or horizontal. Thus, one of the important parameters that play important roles in determining the design area is the number of sprinkler heads.

The manual results of the critical demand as indicated in table (4.7) shows that the water flow rate and pressure are1168 L/min and 1736 kPa, respectively. These values are close that obtain by Elite software. Minimum pipe schedule number for the calculation is 17. Pipe schedule number 17 is not ordinarily made. Pipe schedule 40 is selected in the design calculations. The minimum pipe diameter selected for the branches line equals 25mm which is the minimum permitted diameter used in the fire fighting networks as required in the NFPA standard.

The values of the velocity pressure resulted in the calculation can be ignored in the manual hydraulic calculations because its value is very small. So, the friction loss and the elevation loss are necessary in the manual calculations. The friction loss depends on the flow rate, diameter, types of pipes, and the equivalent length of the pipe selected. While the elevation losses depend on the static elevations of nodes.

The developed system separates the system into two sets of fire pumps. The first set of the pumps is located on the top of the tower which is supplied to the standpipe system. The upper floors are supplied from the fire pump and the lower floor is supplied by bypass connection. The start point of the bypass connection depends on satisfying the minimum pressure of the standpipe system which is 4.5 bar. The second set of approved and listed fire pump is located on the lowest floor. This set of pumps is supplied to the automatic sprinkler system alone. The main connection between these two sets is the fire department connection pipe. This pipe is connected by the standpipe riser and sprinkler system riser which mean that there is always an availability of water in the sprinkler system riser. Also, this pipe is connecting to the outside of the building to feed the system from external sources. These arrangements of pipes are according to the international standard. The local requirement of fire system does not require a listed and approved fire pumps for the standpipe system. So, the proposed model will decrease the cost of the fire system because the listed and approved fire pump is expensive. The proposed system needs pressure reducing valves at the points where the pressure is more than 12.1 bar for sprinkler system and 5 bar fore hose reel system. This device is also installed in the previous system. Also the locations of the sites of fire pumps depend on the mount of water because the amount of water for standpipe system is always less than for sprinkler system.

The electrical rooms, computer rooms and generator room are occupancies existed in the K-tower building. Automatic sprinkler system is not appropriate to control the fire in these occupancies. Clean agent systems is suitable to extinguish and control the fire in these occupancies.

CHAPTER FIVE

STAIRWELL PRESSURIZATION

In this chapter design considerations for stairwell pressurization will be developed. These considerations of design will be applied on a case study which was taken in the chapter four.

5.1 Introduction

Statistical analysis of mortality that resulted from the fire incidents in the high rise buildings indicated that smoke and toxic gases are the major killer in the building rather than direct burning. NFPA 92 defined that smoke which consists of the airborne solid and liquid particulates and gases. These are evolved when a material undergoes pyrolysis or combustion together with the quantity of air that is entrained or otherwise mixed into the mass smoke hazards due to toxicity, temperature, and light obscuration. Vertical openings such as stairwell shafts, ducts, and elevator shafts lead to spreading the smoke and toxic gases through the buildings.

Fire safety systems are one of the important factors that takes into consideration the stage of the design of the high rise building. Preventing fire initiation and managing fire impact are two basic approaches for fire protection systems as defined in the ASHRAE Standard 2000. It must be taken into consideration at the stage of design. Eliminating ignition sources and keeping fuel away from ignition sources are examples of preventing fire initiation (Klote and Milke, 1992). Managing threat and managing exposure are the ways of the manage impact. Managing threat includes sprinklers, fire walls, fire dampers, and fire doors, while managing exposure includes exit systems and smoke management systems.

In this chapter, managing fire impact will be outlined, particularly smoke management systems. Smoke management is a critical parameter especially when the time needed for evacuation at the emergency stage is greater than the time for the development of untenable smoke conditions on the building. Pressurization stairwells are one of the types of smoke management systems that are used to control the smoke movement in the building. The local fire authorities represented by the Civil Defence require that escape stairwells connected to the outdoors at ground level must be maintained free from smoke and toxic gases to enable mass evacuation.

The main objectives of the smoke management systems are to reduce the injuries and deaths that result from the movement of smoke by keeping the escape route smoke free, to enable firefighting operations to proceed efficiently, and to prevent spread of smoke into sensitive areas such as an escape stairwell, elevator, and corridor. This action will reduce the property loss from smoke. The aims of pressurization system used in stairwell are to provide a refuge area from smoke and fire for the firefighters and occupants.

Pressurization systems consist of approved and listed mechanical fan driven by power supply, distribution ductwork system, and actuation system to separate the flow rate through the shaft. The higher pressure side is the refuge area or stairwell, while the lower pressure is exposed to smoke. Pressurization can be satisfied by both air pressure differences across the doors and airflow rate movement which depends on average air velocity. Pressurization system can be activated through alarm detection systems or connected to sprinkler flow switches. Also, it can be activated manually.

5.2 Factors of Spreading Smoke in the Building

The main driving forces for the spread of smoke through the building are stack effect, temperature effect of fire, and weather conditions.

5.2.1 Stack Effect

When the temperature of the inside building is different from that of the outside building, pressure differential will occur. In this case, when there are vertical openings such as a shafts, stake effect, and chimney effect will promote a natural airflow rate through the building. Normal stack, and upwards direction effect will occur if the temperature of the air of the building is higher than of the outside. Reverse stake effect will occur if the temperature of the air of the building is lower than the outside.

For standard atmospheric pressure of air, the pressure differential due to stack effect is evaluated by the following equation (Klote and Milke, 2002).

$$\Delta P = 3460\left(\frac{1}{T_o} - \frac{1}{T_s}\right) H \qquad (5.1)$$

Where ΔP is the pressure difference from the shaft to the outside (Pa), T_o is absolute temperature of outside air (K), T_s is the absolute temperature of the inside air (K), H is the distance above neutral plane (m). Natural plane is a horizontal plane where the pressure inside the fire compartment equals to that outside.

5.2 Temperature Effect of Fire

High temperature smoke has a bouncy force due to it is reduced density. For standard atmospheric pressure of air, the pressure differential due to bouncy force is evaluated by the following equation (Klote and Milke, 2002).

$$\Delta P_b = 3460\left(\frac{1}{T_o} - \frac{1}{T_f}\right) H \qquad (5.2)$$

Where ΔP_b is the pressure difference from the fire compartment to surrounding due to the outside (Pa), T_o is absolute temperature of outside air (K), T_f is the absolute temperature of the gas inside fire (K), and H is the distance above neutral plane (m).

5.2.3 Wind Effect

The pressure effect and wind velocity due to wind effect are expressed in the following equations respectively (Klote and Milke, 2002).

$$\Delta P_w = 0.6\ (Cw_1 - Cw_2)\ V^2 \qquad (5.3)$$

Where ΔP_w is the wind pressure across a building (Pa), Cw_1 and Cw_2 are pressure coefficients for windward and leeward wall respectively (dimensionless),V is the wind velocity (m/s) expressed as follows:

$$V = V_o\left(\frac{z-y}{z_o}\right)^n \qquad (5.4)$$

Where V_o is the velocity at reference elevation (m/s), z and z_o are the elevations at velocity V and $V_{o,}$ respectively (m), y is the average roof height (m), and n is the wind exponent.

5.3 System Classification

For design consideration, British Standard classified the buildings for smoke control as shown in table (5.1). For each class there are recommended values for velocity, pressure difference, and the number of open doors during the emergency case.

Table 5.1. Classification of Buildings for Smoke Control Using Pressure Difference, (BS 5588-4, 1998)

System Class	Examples
A	Residential, Sheltered Housing and Buildings designed for three doors protection.
B	Protection of Firefighting Shafts.
C	Commercials Premises.
D	Hotels, Hostels and Institution-type Buildings ,Excluding Building Designed to meet class A.
E	Phased Evacuation.

5.4 System Classes Requirements

The pressure difference, critical velocity, and number of open doors are determined in BS 5588-4. The pressure difference for all classes is within the range of (50 to 60) Pa ± 10% when all doors are closed. The pressure difference when final exit door is open for classes (C, D, E) is not less than 10 Pa. The air flow rate velocity through open fire floor door is not less than 0.75 m/s for classes (A, C, D, E), and at least 2 m/s for class B. Three open doors must be taken in a calculation for class B, one of them is located at the fire floor, and the other open door is located at different locations. But two open doors with different location must be taken for other classes. One of the open doors for all classes is located at the ground floor. BS Standard states that the maximum value of the force that applied at the door handle is 130 N .The maximum forces depend mainly on the person's strength, and the location of the door knob (BS 5588-4, 1998).

5.5 Methods of Pressurizing the Spaces

The different methods of pressurization are pressurizing stairwells only, pressurizing stairwell and part of the horizontal route, and pressurizing lobbies or corridors only.

Pressurization of stairwell only is appropriate in the building where the stairwell is approached directly from accommodation area or through a simple lobby which has no access to lift or other rooms such as toilets.

Pressurization stairwell and parts of the horizontal routes are appropriate when there is a connection between stairwells and distributed lobby or corridor. In such cases, all these areas must be pressurized as stairwell with the same magnitude pressure which is no more than 5 Pa.

5.6 Air Distribution Systems

A single injection and multiple injection systems are the methods used to supply pressurized air to the stairwell.

5.6.1 Single Injection System

In this system a pressurized air is supplied to the stairwell at one location. This location is usually located at the building top as shown in figure (5.1). This system has failed for high rise building, when a few doors near the air supply injection are open. The pressurized air will be lost through these open doors. So the system can not maintain a positive pressure across the doors further from the injection point. ASHARE recommended using this system up to eight floors while BS5588 recommended that a single supply entry point is not to be used unless the building has three floors or less.

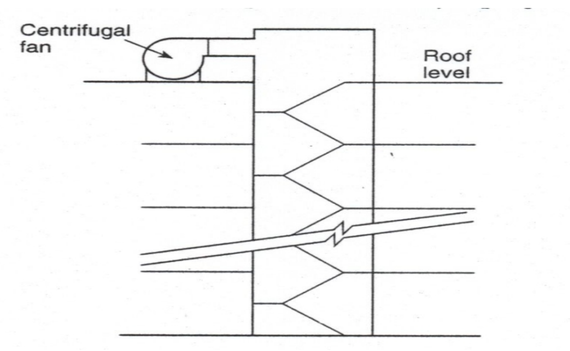


Figure 5.1. Stairwell Pressurization by Top Injection, (Klote and Milke, 2002).

5.6.2 Multiple Injections Systems

Multiple injections systems come to overcome the limitations of the single injection systems. There is no limitation around the location of the fan as shown in figure (5.2). The supply duct should be distributed through the whole height of the stairwell. The most standard recommended for each three stories will be air outlet grilles.

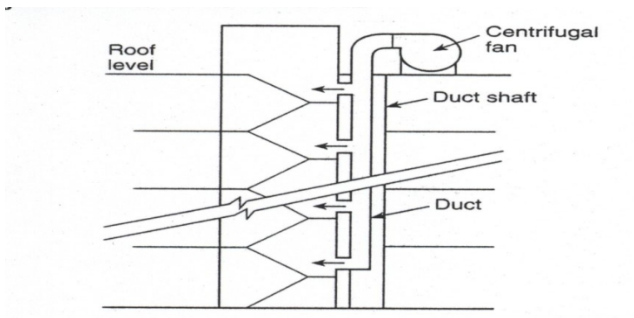


Figure 5.2. Stairwell Pressurization by Multiple Injection with Roof Mounted Fan, (Klote and Milke, 2002).

5.6.3 Supply Air Intakes

The location of supply air intake must be separated from exhausts, outlets of smoke shafts and roof smoke and heat vents. The separation should be as great as possible. There are many approaches for this separation. One of them recommends that all the supply air intakes are near the bottom of the building and smoke outlets above roof level, or supply air intake on one side of the building, and the smoke outlet on the other side, and on the roof.

5.7 Methodology of the Design

The purpose of the pressurization stairwell is either for means of escape or firefighting shaft. The flow paths in a system may be in series, in parallel, or in a combination of series and parallel paths. The sources of the flow paths, and leakage flow are open doors, gaps around doors, lift doors, window. The effective area of flow areas is the area which leads to the same flow as the system when the system undergoes to the same pressure difference over the total system flow paths.

The effective leakage areas, A_E of parallel paths can be evaluated by applying the following formula (BS 5588-4, 1998).

$$A_E = A_1 + A_2 + A_3 + \ldots\ldots + A_n \qquad (5.4)$$

Also the effective leakage areas, A_E of series paths can be evaluated by applying the following formula (BS 5588-4, 1998).

$$A_E = (1/A_1^2 + 1/A_2^2 + 1/A_3^2 + \ldots\ldots 1/A_m^2)^{-1/2} \qquad (5.5)$$

Where A_1, A_2, A_3, …. are leakage areas for various types of doors, windows, and for walls and floors are evaluated in BS-5588 Part-4 and ASHARE HANDBOOK 2000.

The leakage area for different types of doors is shown in table (5.2). The distributed lobbies that separate the stairwells from the accommodation area must be separately pressurized with a separate duct as stairwell with the same magnitude or not below 5 Pa.

When all the stairwell doors are closed, the system maintains satisfactory pressurization. While when some doors are open, the pressure difference across the closed doors drops to low level which is not sufficient to prevent smoke infiltration into stairwell. The leakage flow through the exterior doorway is greater than other doors and may be reached up to three to ten times. Thus the main cause for pressure fluctuation is due to opening the exterior doors.

The relationship between the air supply, the leakage area, and the pressure differential is given as follows (Hutcheon and Handegord ,1983).

$$\dot{Q}_C = 0.827 \times A \times (P)^{\frac{1}{N}} \qquad (5.6)$$

Where $\dot{Q}_C$ is the air flow rate to the pressurized space in m^3/s, A is the total effective leakage area in m^2, P is the pressure differential in Pa, N is an index whose value ranges between 1 and 2. For a wide crack around doors and large opening the value of N is 2, while for narrow leakage paths around window the value of N is 1.6.

The air flow rate to the pressurized space which maintains the air velocities within the ranges specified can be determined by the following formula (Wild and Mech, 2000):

$$\dot{Q}_P = A \times V \qquad (5.7)$$

Where $\dot{Q}_P$ is the flow rate through open door in m^3/s, A is the area of open door in m^2, and V is the specified velocity according to the standard in m/s.

The area of air/smoke release vents from fire floor can be evaluated by applying the following formula (Wild and Mech, 2000).

$$A_V = \frac{\dot{Q}}{2.5} \qquad (5.8)$$

Where A_V is air/smoke release vent in m^2 and $\dot{Q}$ is the flow rate in m^3/s.

Table 5.2. Leakage Areas, (BS 5588-4, 1998)

Air Leakage Data for Doors			
Types of Doors	Leakage Area m^2	Pressure Differential Pa	Air Leakage m3/s
Single Leaf Opening into a Pressurized Space with size(2m×800mm)	0.01	15	0.03
		20	0.04
		25	0.04
		50	0.06
Single Leaf Opening Outwards from a Pressurized Space with size(2m×800mm)	0.02	15	0.06
		20	0.07
		25	0.08
		50	0.012
Double Leaf with size(2m×1.6m)	0.03	15	0.1
		20	0.11
		25	0.12
		50	0.18

5.8 Modeling Approach for Pressurization System

The K-Tower building is considered to apply the rules of pressurization system according to the BS 5588: Part 4:1998. The specification of stairwell in the K-Tower building is summarizes in table (5.3). The stairwells are connected directly to the accommodation area, so the stairwell is only pressurized as shown in figure (5.3), which is similar to the case for the design drawing in the K-Tower (BS 5588: Part 4, 1998).

Table (5.3). Specification of Stairwell in the K-Tower Building, (Architectural drawing from Segma Consultant Engineering Office).

Stairwell Number	The number of connected floors	The purpose of stairwell
One	38	Firefighting
Two	45	Firefighting
Three	45	Firefighting
Four	8	Means of escape

Any stairwell provided by firefighting equipment such as standpipes system is called firefighting stairwell and it is classified as Class B System according to BS standard. These stairwells are used by firefighters to deal with the fire. The firefighting stairwell must be connected with the accommodation area through a firefighting lobby to limit the spread of smoke into the stairwell. In this case there is no firefighting lobby in the design drawing.

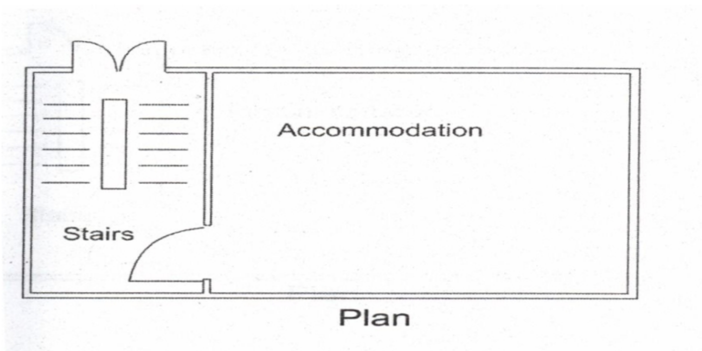


Figure 5.3. Case of Pressurization Stairwell only, (BS 5588: Part 4, 1998)

To calculate the flow rate capacity of a fan for the pressurization system, three modes will be used. Mode one proposed that all the doors are closed in the stairwell. Mode two proposed that fire floor door is open as a purpose of means of escape. Mode three proposed that fire floor door is open as a purpose of fire fighting case.

5.9 Calculation of Stairwells

The calculations of stairwell are either for firefighting purposes or for means of escape. Each of these purposes has a limitation of air flow velocity.

5.9.1 Calculation Modes for Firefighting Purposes

Calculations of stairwell number two and three which are classified to be the fire fighting stairwell will be outlined. Mode one and mode three will be used for these calculations.

Fan capacity, air release vent, and pressure relief vent must be calculated for each stairwell.

Mode one: All doors are proposed to be closed as shown in figure (5.4), where the number of single leaf doors equal 45 and that for double leaf doors is one. The leakage area for single and double doors is shown in table (5.2).

A_L =Number of doors × Leakage area for each single leaf doors + Number of doors × leakage area for each double leaf doors

$= 45 \times 0.02 + 1\times 0.03 = 0.93$ m^2

Apply equation 5.6 for N=2 then:

$$\dot{Q}_c = 0.827 \times 0.93 \times \sqrt{50} = 5.43\ m^3$$

British Standard recommends adding 50% for mode one.

Thus: $\dot{Q}_c = \dot{Q}_c + 0.5 \times \dot{Q}_c$ then $\dot{Q}_c = 5.43 + 0.5 \times 5.43 = 8.15\ m^3/s$

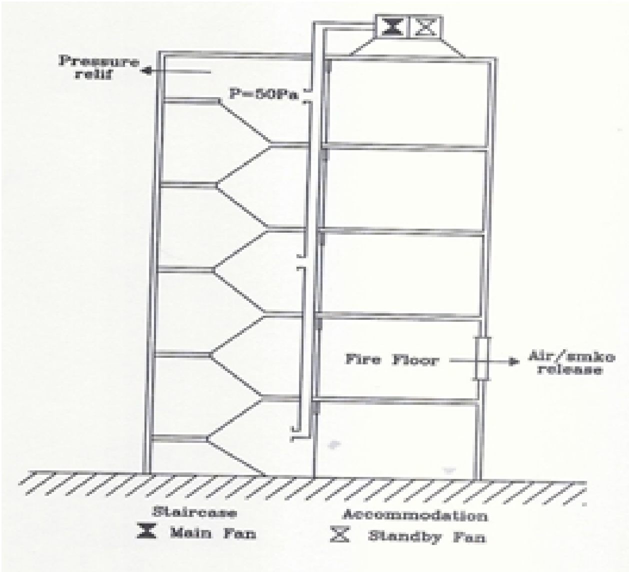


Figure 5.4. Schematic diagram for Closed Doors

Mode three: Two doors are proposed to be opened. One of them is located at the fire floor and the other is located at the exit floor.

Equation 5.7 will be applied to calculate the air flow rate through open fire floor to maintain velocity criterion, $\dot{Q}_P$ as shown in figure (5.5) where:

A = Area of a single leaf door located at the fire door. (See table 5.2)

$A = 2.0 \times 0.8 = 1.6\ m^2$

Velocity through open fire door is proposed to be 2 m/s, therefore,

$\dot{Q}_P = 1.6 \times 2 = 3.2\, m^3/s$

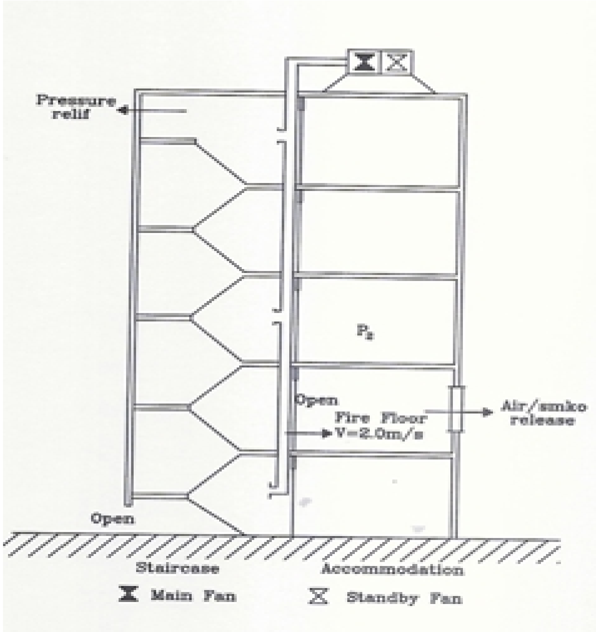


Figure 5.5. Schematic diagram for Class B System (Velocity Criterion)

Equation 5.8 will be applied to calculate the area of exhaust vent that must be located at the fire floor.

$$A_V = \frac{3.2}{2.5} = 1.28\, m^2$$

Effective area through the fire floor will be calculated by applying equation 5.5.

$$A_E = \left(\frac{1}{1.6^2} + \frac{1}{1.28^2}\right)^{-1/2} = 1.0\, m^2$$

The pressure through open fire floor will be evaluated by applying equation 5.6.

$$P = \left(\frac{3.2}{0.827 \times 1.0}\right)^2 = 14.8\, Pa$$

Substitute in equation 5.6 to calculate the air flow rate through open fire floor to maintain pressure criterion, $\dot{Q}_P$ as shown in figure (5.6).

$\dot{Q}_P = 0.827 \times 1.0 \times 14.8^{1/2} = 3.18\ m^3/s$

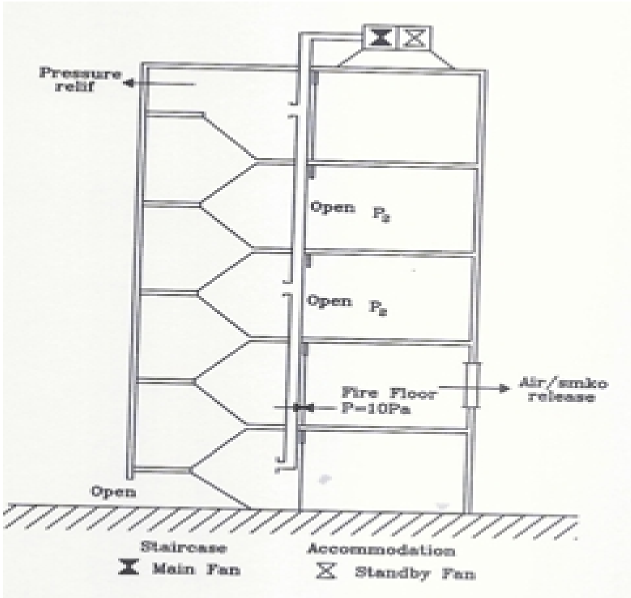


Figure 5.6. Schematic diagram for Class B System (Pressure Criterion)

So, the total volume of air flow rate, Q_{total} required to maintain the air velocity through open door on the fire floor is the sum of mode one and mode three.

$\dot{Q}_{total} = 8.158 + 3.180 + 3.20 = 14.548\ m^3/s$

Fan capacity required is 14.548 m^3/sec at 50Pa +system losses

Area of pressure relief (A_R) must be evaluated by using equation 5.6

Where $\dot{Q}_W = \dot{Q}_{total} - \dot{Q}_C$

Therefore, $\dot{Q}_W = 14.548 - 8.158 = 6.30\ m^3/s.$

Using equation 5.6 and solving for the area:

$A = \frac{6.30}{0.827 \times 50^{1/2}} = 1.09\ m^2$

Calculations of stairwell number one which is classified to be the fire fighting stairwell will be outlined. Mode one and mode three will be used for these calculations. Fan capacity, air release vent, and pressure relief vent must be calculated for each stairwell.

Similar calculations for stairwell number one will be carried out. The specification of stairwell number one is 38 single leaf doors and one double leaf door. The result is shown in table (5.4).

5.9.2 Calculation Modes for Means of Escape Purposes

Calculations of stairwell number four which are classified to be the mean of escape stairwell will be outlined. Mode one and mode two will be used for these calculations.

Fan capacity, air release vent, and pressure relief vent must be calculated for each stairwell.

Mode one: All doors are proposed to be closed, where the number of single leaf doors equal 8 and that for double leaf doors is one. The leakage area for single and double doors is shown in table (5.2).

A_L =Number of doors × Leakage area for each single leaf doors + Number of doors × leakage area for each double leaf doors

$= 8 \times 0.02 + 1\times 0.03 = 0.19\ m^2$

Apply equation 5.6 for N=2 then:

$$\dot{Q}_c = 0.827 \times 0.19 \times \sqrt{50} = 1.11\ m^3/s$$

British Standard recommends adding 50% for mode one.

Thus: $\dot{Q}_{c} = \dot{Q}_{c} + 0.5 \times \dot{Q}_{c}$

$$\dot{Q}_{c} = 1.11 + 0.5 \times 1.11 = 1.65\, m^3/s$$

Mode two: Two doors are proposed to be opened. One of them is located at the fire floor and the other is located at the exit floor.

Equation 5.7 will be applied to calculate the air flow rate through open fire floor to maintain velocity criterion, $\dot{Q}_{P}$ as shown in figure (5.7) where:

A = Area of a single leaf door located at the fire door. (See table 5.2)

$$A = 2.0 \times 0.8 = 1.6\, m^2$$

Velocity through open fire door is proposed to be 0.75 m/s, therefore,

$$\dot{Q}_{P} = 1.6 \times 0.75 = 1.2\, m^3/s$$

Equation 5.8 will be applied to calculate the area of exhaust vent that must be located at the fire floor.

$$A_v = \frac{3.2}{2.5} = 0.48\, m^2$$

Effective area through the fire floor will be calculated by applying equation 5.5.

$$A_E = \left(\frac{1}{1.6^2} + \frac{1}{0.48^2}\right)^{-1/2} = 0.46\, m^2$$

The pressure through open fire floor will be evaluated by applying equation 5.6.

$$P = \left(\frac{3.2}{0.827 \times 1.0}\right)^2 = 10\, Pa$$

Substitute in equation 5.6 to calculate the air flow rate through open fire floor to maintain pressure criterion, $\dot{Q}_P$.

$$\dot{Q}_P = 0.827 \times 1.0 \times 14.8^{1/2} = 3.18\, m^3/s$$

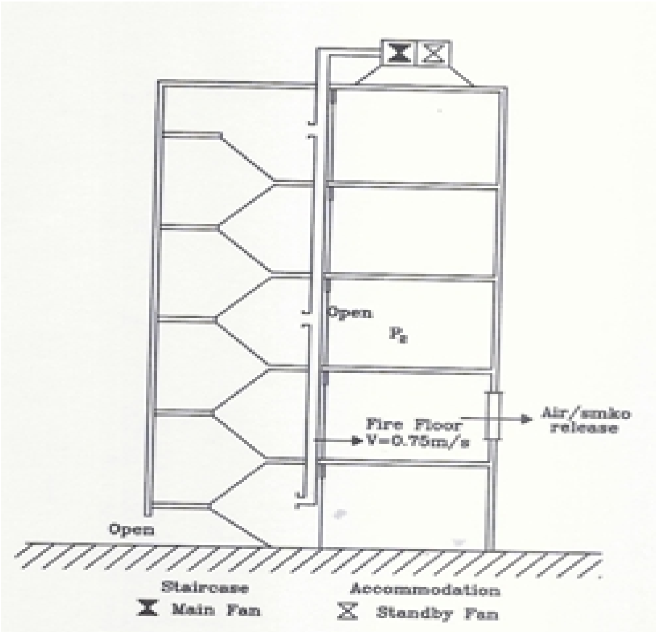


Figure 5.7. Schematic diagram for means of Escape

So, the total volume of air flow rate, $\dot{Q}_{total}$ required to maintain the air velocity through open door on the fire floor is the sum of mode one and mode three.

$$\dot{Q}_{total} = 1.65 + 1.2 + 1.6 = 4.45\, m^3/s$$

Fan capacity required is 4.45 m^3/sec at 50Pa + system losses

Area of pressure relief (A_R) must be evaluated by using equation 5.6

Where $\dot{Q}_W = \dot{Q}_{total} - \dot{Q}_C$

Therefore, $\dot{Q}_W = 4.45 - 1.65 = 2.80\ m^3/s$

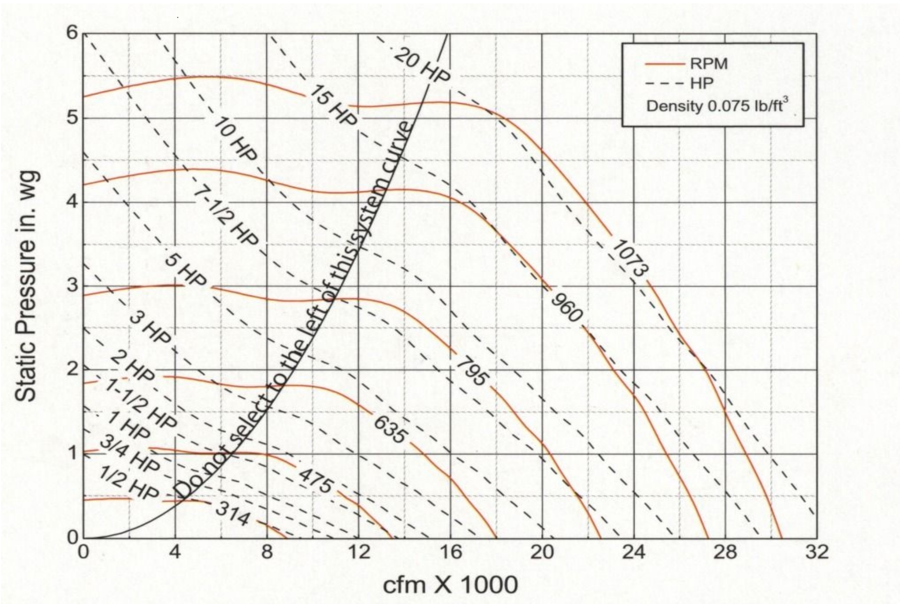
Using equation 5.6 and solving for the area:

$$A = \frac{2.8}{0.827 \times 50^{1/2}} = 0.48\ m^2$$

5.9.3 Fan Selection

The selected fan which is used in pressurization systems must be listed and approved for smoke control systems. The performance curves are taken from Greenheck Company which is specialized for producing smoke control fans. There are other companies which specialize in the smoke control fans. The performance curve for smoke control fan is illustrated in the figures (5.8).

Figure 5.8. Performance curve for smoke control fan size ,(Greenheck catalogue, 2000)



The specification of the pressurization fans for the stairwell K- Tower is tabulated in table (5.4).

Table 5.4 .Specification of the Fan Selected,(Greenheck Cataloge,2007)

Stairwell Number	Air Flow Rate m^3/s	Static pressure Pa	Model	Maximum BHP	Speed RPM	Outlet Area cm^2
1	12.68	125	SWB-236-Belt Drive-Series 200	15.3	960	600
2	14.55	63	SWB-236-Belt Drive-Series 200	21.3	1073	600
3	14.55	63	SWB-236-Belt Drive-Series 200	21.3	1073	600
4	4.45	250	SWB-236-Belt Drive-Series 200	1.84	475	600

5.10 Discussion

The resulting data showed that the most effective important parameters used in the calculation of the pressurization stairwell are leakage area, number of open doors, and the type of application of stairwell. The designer must be accurate when the purpose of stairwell is determined. For example, when the purpose of stairwell is for firefighting, the required air flow is greater than approximately four times for means of escape. This result proved clearly the importance of the stairwell purpose on the air flow rate required so the designers must study stairwells in the tower and decide correctly which of them is used for means of escape or for firefighting purposes. These purposes must be cleared and known for the occupants and for firefighter men. Especially in the emergency case, the only exit permitted to be used for evacuation of people is stairwells according to the Jordanian Fire Prevention Code. The other important factor is the leakage area. The designer at the stage of design depends on the approximation to estimate the leakage area. Thus, international standards recommend using fifty percent as a factor of safety added to the first mode of calculation. This may compensate for any error of calculation of the leakage area. The number of opening doors which is taken in the calculation depends on the Authorization Having Jurisdiction (AHJ). Every international standard determines the number of opening doors that must be included in the calculation and their location in the stairwell. In this study, BS standard is adopted for the number of open doors that must be included in the design because the AHJ requires that one door is selected on the proposed fire floor, and the other open door is located at the ground door.

The manual calculations for firefighting and occupant escape purpose shows that the air flow rate for all stairwell firefighting purpose are about three times larger than for occupant escape purpose. This due to the required air speed considers for each of these cases.

The fire safety engineers must work together with the civil engineer, electrical engineer and the heating ventilation air conditioning engineers. The requirements of the pressurization systems which are important for the civil and architectural engineers is the shaft for the main duct , pressure relief damper, fan opening at the top of the stairwell, specification of the fire doors for stairwell , and supply air opening for each three floors as recommended in the BS Standard. Satisfying a high degree of tenable environment in the stairwell to enable rapid evacuation as recommended in the NFPA 92A.Thus, a fire safety engineer must be cooperative to maintain this target. Also, the power source needed to drive the fan in the emergency case which is very important for the operation of the system must by analyzed by electrical engineers.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the conclusions of the current study, and introduces some recommendations for relevant future research.

Based on this work, the following conclusions are made:

1. The proposed installation model for automatic fire sprinkler system is developed. Manual hydraulic calculation for the proposed model is applied on the case study that introduced in chapter four. Computer software is used to check the manual calculations. Also, pressurization of stairwell procedure is developed in this study. This procedure is applied on the case study selected.
2. The accuracy of determining the shape and the location of design area is another important factor effective on the calculations.
3. The calculations showed the effectiveness of the proposed installation model in the high-rise building.
4. The proposed model satisfies the requirement of the local codes in Jordan.
5. The critical parameters for the pressurization stairwell are the effective leakage area, and the purpose of stairwell either for firefighting or means of escape. The results of the fan are approximated because the actual number of the occupants is unknown and the effective leakage area is approximate.
6. Any modification on the stairwell arrangements means a new calculation will be done. So, the cooperation between fire safety engineer and archictural engineer is necessary in the design and shop drawing stage.

7. The previous model is either sprinkler system or combined system. The local requirement of high-rise building is automatic sprinkler and standpipe systems. The designed model is developed in these systems.

Based on this study, the following recommendations for future work may be stated:

1- Study the cost analysis of the proposed installation compared with other installations of sprinkler system.

2- Study the reliability of the proposed model on the constructed high-rise building.

3- Study the reliability of pressurization stairwell system on the constructed high-rise building.

4- The location of fire pumps must be determined accurately with cooperation with architectural engineers. The entrance of the fire pump must be safe and as close as possible to the pressurized stairwell. The location of the fire room increases the reliability of the automatic systems

5- The British Standard recommended that it is necessary for stairwells in tower building to be a lobby existing in front of it to maintain high reliability of the pressurization system and to limit of propagation of smoke into the stairwell

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APPENDIX A

Appendix A.1: Elite Software for the Design Area Number One for the K-Tower

DESIGN AREA NUMBER ONE
Fire Sprinkler Reports

for

K-Tower Building (Case Study)

Al-Abdali Region, Amman, Jordan

Prepared By:

Student Name : Abdulla Olimat
Faculty of Engineering
Amman - Jordan

2009

FIRE - Fire Sprinkler Hydraulics Calculation Program
pReJkEr Class nr 666

Elite Software Development, Inc.
Design Area Number One

General Project Data Report

General Data

Project Title:	Design Area Number One	Project File Name:	ABDULLA THESIS DA1.fiw
Designed By:	Student Name : Abdulla Olimat	Date:	2009
Code Reference:	NFPA 13 ,NFPA 14 , Jordan Code	Approving Agency:	Discussion Comittee
	The Design Area Number One is Located at the Floor Number (29)		
Client Name:	K-Tower Building (Case Study)	Phone:	
Address:	Al-Abdali Region, Amman, Jordan	City, State Zip Code:	
	One of suggested high-rise buiding in Amman-Jordan .It is height reached up to 156 m approximately		
Company Name:	Faculity of Engineering	Representative:	The University of Jordan
Company Address:	Amman - Jordan	City And State:	
Phone:			
	This work is done by the student to verify the manual hydraulic calculation		
Building Name:	K-Tower	Building Owner:	K-Tower
Contact at Building:		Phone at Building:	
	The K-Tower is selected to be the case study which is introduced by the student for master thesis under the title Design of Automaic Sprinkler System in Jordan		

Project Data

Description Of Hazard:	Light Hazard	Sprinkler System Type:	Wet
Design Area Of Water Application:	139 m²	Maximum Area Per Sprinkler:	16 m²
Default Sprinkler K-Factor:	80.00 Km	Default Pipe Material:	SCHED 40 WET STEEL
Inside Hose Stream Allowance:	0.00 Lpm	Outside Hose Stream Allowance:	0.00 Lpm
In Rack Sprinkler Allowance:	0.00 Lpm		

Sprinkler Specifications

Make:	TYCO	Model:	TY-B
Size:	12.7	Temperature Rating:	57.23 C

Water Supply Test Data

Source Of Information:			
Test Hydrant ID:		Date Of Test:	
Hydrant Elevation:	0 m	Static Pressure:	0.00 kPa
Test Flow Rate:	0.00 Lpm	Test Residual Pressure:	0.00 kPa
Calculated System Flow Rate:	1148.60 Lpm	Calculated Inflow Residual Pressure:	1698.94 kPa
Available Inflow Residual Pressure:	0 kPa		

Calculation Project Data

Calculation Mode:	Demand		
HMD Minimum Residual Pressure:	48.00 kPa	Minimum Desired Flow Density:	4.09 Lpm/m²
Number Of Active Nodes:	26		
Number Of Active Pipes:	25	Number Of Inactive Pipes:	0
Number Of Active Sprinklers:	16	Number Of Inactive Sprinklers:	0

Active Version 6.0.189 | 1000 Pipe Capacity | Friday, October 02, 2009

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Design Area Number One

Fire Sprinkler Input Data

Node Input Data

Node No.	Node Description	Area Group	Sprinkler KFactor (Km)	Pressure Estimate (kPa)	Node Elevation (m)	Non-Sprinkler Discharge (Lpm)
1	Sprinkler		80.00	67.53	156.00	0.00
2	Sprinkler		80.00	72.55	156.00	0.00
3	Sprinkler		80.00	67.00	156.00	0.00
4	Sprinkler		80.00	75.99	156.00	0.00
5	Sprinkler		80.00	80.52	156.00	0.00
6	Sprinkler		80.00	70.88	156.00	0.00
7	Sprinkler		80.00	80.36	156.00	0.00
8	Sprinkler		80.00	85.16	156.00	0.00
9	Sprinkler		80.00	73.82	156.00	0.00
10	Sprinkler		80.00	83.66	156.00	0.00
11	Sprinkler		80.00	88.61	156.00	0.00
12	Sprinkler		80.00	78.31	156.00	0.00
13	Sprinkler		80.00	90.53	156.00	0.00
14	Sprinkler		80.00	94.20	156.00	0.00
15	Sprinkler		80.00	87.31	156.00	0.00
16	Sprinkler		80.00	97.08	156.00	0.00
100	No Discharge		N/A	83.01	155.70	0.00
200	No Discharge		N/A	95.67	155.70	0.00
300	No Discharge		N/A	81.34	157.70	0.00
400	No Discharge		N/A	104.90	155.70	0.00
500	No Discharge		N/A	107.45	155.70	0.00
600	No Discharge		N/A	111.32	155.70	0.00
700	No Discharge		N/A	112.91	155.70	0.00
800	No Discharge		N/A	143.71	155.40	0.00
900	No Discharge		N/A	1226.82	45.80	0.00
1000	No Discharge		N/A	1698.94	0.00	0.00

Active Version 6.0.189 1000 Pipe Capacity Friday, October 02, 2009

Fire Sprinkler Input Data

Pipe Input Data

Beg. Node	End. Node	Pipe Description	Nominal Diameter (mm)	Type Group	Fitting Data	Nominal Length (m)	Fitting Length (m)	Total Length (m)	CFactor (gpm/inch-psi)
1	2	SCHED 40 WET STEEL	25.400	0		2.20	0.00	2.20	120
2	100	SCHED 40 WET STEEL	31.750	0		1.30	2.10	3.40	120
3	4	SCHED 40 WET STEEL	25.400	0		4.00	0.00	4.00	120
4	5	SCHED 40 WET STEEL	31.750	0		2.00	0.00	2.00	120
5	200	SCHED 40 WET STEEL	38.100	0		1.50	3.70	5.20	120
6	7	SCHED 40 WET STEEL	25.400	0		4.00	0.00	4.00	120
7	8	SCHED 40 WET STEEL	31.750	0		2.00	0.00	2.00	120
8	300	SCHED 40 WET STEEL	38.100	0		1.50	3.70	5.20	120
9	10	SCHED 40 WET STEEL	25.400	0		4.00	0.00	4.00	120
10	11	SCHED 40 WET STEEL	31.750	0		2.00	0.00	2.00	120
11	400	SCHED 40 WET STEEL	38.100	0		1.50	3.70	5.20	120
12	13	SCHED 40 WET STEEL	25.400	0		4.00	0.70	4.70	120
13	500	SCHED 40 WET STEEL	31.750	0		2.10	3.20	5.30	120
14	600	SCHED 40 WET STEEL	25.400	0		2.30	2.30	4.60	120
15	16	SCHED 40 WET STEEL	25.400	0		2.60	0.80	3.40	120
16	700	SCHED 40 WET STEEL	31.750	0		1.30	3.20	4.50	120
100	200	SCHED 40 WET STEEL	31.750	0		3.60	2.10	5.70	120
200	300	SCHED 40 WET STEEL	50.800	0		3.00	0.00	3.00	120
300	400	SCHED 40 WET STEEL	63.500	0		2.20	0.00	2.20	120
400	500	SCHED 40 WET STEEL	76.200	0		2.20	0.00	2.20	120
500	600	SCHED 40 WET STEEL	101.600	0		3.00	6.10	9.10	120
600	700	SCHED 40 WET STEEL	101.600	0		3.20	0.00	3.20	120
700	800	SCHED 40 WET STEEL	101.600	0		24.00	19.20	43.20	120
800	900	SCHED 40 WET STEEL	152.400	0		109.60	0.00	109.60	120
900	1000	SCHED 40 WET STEEL	152.400	0		233.00	35.20	268.20	120

Fire Sprinkler Output Data

Overall Node Groupings Output Data

Pipe Segment Beg. Node	Pipe Segment End. Node	Pipe Type Group	Pipe Flow Rate (Lpm)	Sprinkler Flow At Beg. Node (Lpm)	Non-Sprinkler Flow Out (+) (Lpm)	Non-Sprinkler Flow In (-) (Lpm)	Beg. Node Residual Pressure (kPa)	Imbalance Flow At Beg. Node (Lpm)
1	2	0	-65.71	65.71	0.00	0.00	67.53	
2	1	0	65.71	68.11	0.00	0.00	72.55	0.00233
2	100	0	-133.82					
3	4	0	-65.45	65.45	0.00	0.00	67.00	0.00218
4	3	0	65.45	69.71	0.00	0.00	75.99	0.00113
4	5	0	-135.16					
5	4	0	135.16	71.76	0.00	0.00	80.52	0.00296
5	200	0	-206.91					
6	7	0	-67.32	67.32	0.00	0.00	70.88	0.00164
7	6	0	67.32	71.68	0.00	0.00	80.36	0.00239
7	8	0	-139.00					
8	7	0	139.00	73.79	0.00	0.00	85.16	0.00368
8	300	0	-212.79					
9	10	0	-68.70	68.71	0.00	0.00	73.82	0.00182
10	9	0	68.70	73.14	0.00	0.00	83.66	0.00256
10	11	0	-141.84					
11	10	0	141.84	75.28	0.00	0.00	88.61	0.00393
11	400	0	-217.12					
12	13	0	-70.76	70.77	0.00	0.00	78.31	0.00212
13	12	0	70.76	76.08	0.00	0.00	90.53	0.00370
13	500	0	-146.84					
14	600	0	-77.61	77.61	0.00	0.00	94.20	0.00373
15	16	0	-74.72	74.72	0.00	0.00	87.31	0.00282
16	15	0	74.72	78.79	0.00	0.00	97.08	0.00413
16	700	0	-153.50					
100	2	0	133.82	0.00	0.00	0.00	83.01	-0.00009
100	200	0	-133.82					
200	5	0	206.91	0.00	0.00	0.00	95.67	-0.00105
200	100	0	133.82					
200	300	0	-340.73					
300	8	0	212.79	0.00	0.00	0.00	81.34	-0.00112
300	200	0	340.73					
300	400	0	-553.52					

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Elite Software Development, Inc.
Design Area Number One

Fire Sprinkler Output Data

Overall Node Groupings Output Data (cont'd)

Pipe Segment Beg. Node	End. Node	Pipe Type Group	Pipe Flow Rate (Lpm)	Sprinkler Flow At Beg. Node (Lpm)	Non-Sprinkler Flow Out (+) (Lpm)	In (-) (Lpm)	Beg. Node Residual Pressure (kPa)	Imbalance Flow At Beg. Node (Lpm)
400	11	0	217.12	0.00	0.00	0.00	104.90	-0.00099
400	300	0	553.52					
400	500	0	-770.64					
500	13	0	146.84	0.00	0.00	0.00	107.45	-0.00064
500	400	0	770.64					
500	600	0	-917.48					
600	14	0	77.61	0.00	0.00	0.00	111.32	-0.00045
600	500	0	917.48					
600	700	0	-995.09					
700	16	0	153.50	0.00	0.00	0.00	112.91	-0.00053
700	600	0	995.09					
700	800	0	-1148.60					
800	700	0	1148.60	0.00	0.00	0.00	143.71	-0.00005
800	900	0	-1148.60					
900	800	0	1148.60	0.00	0.00	0.00	1226.82	0.00004
900	1000	0	-1148.60					
1000	900	0	1148.60	0.00	0.00	-1148.5950553033	1698.94	

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Fire Sprinkler Output Data

Overall Pipe Output Data

Beg. End. Node	Nodal KFactor (Km)	Elevation (m)	Spk/Hose Discharge (Lpm)	Residual Pressure (kPa)	Nom. Dia. Inside Dia. C-Value	Q (Lpm) Velocity (m/s)	F. L./m (kPa/m) Fittings Type-Grp	Pipe-Len. Fit-Len. Tot-Len. (m)	PF-(kPa) PE-(kPa) PV-(kPa)
1	80.00	156.00	65.71	67.53	25.40	65.71	0.10018	2.20	4.986
2	80.00	156.00	68.11	72.55	26.645	1.96	-----	0.00	0.033
	SCHED 40 WET STEEL				120		0	2.20	1.927
3	80.00	156.00	65.45	67.00	25.40	65.45	0.09945	4.00	8.998
4	80.00	156.00	69.71	75.99	26.645	1.96	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	4.00	1.912
4	80.00	156.00	69.71	75.99	31.75	135.16	0.10005	2.00	4.527
5	80.00	156.00	71.76	80.52	35.052	2.33	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	2.00	2.722
6	80.00	156.00	67.32	70.88	25.40	67.32	0.10477	4.00	9.479
7	80.00	156.00	71.68	80.36	26.645	2.01	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	4.00	2.022
7	80.00	156.00	71.68	80.36	31.75	139.00	0.10538	2.00	4.768
8	80.00	156.00	73.79	85.16	35.052	2.40	-----	0.00	0.033
	SCHED 40 WET STEEL				120		0	2.00	2.879
9	80.00	156.00	68.71	73.82	25.40	68.70	0.10879	4.00	9.843
10	80.00	156.00	73.14	83.66	26.645	2.05	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	4.00	2.106
10	80.00	156.00	73.14	83.66	31.75	141.84	0.10940	2.00	4.950
11	80.00	156.00	75.28	88.61	35.052	2.45	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	2.00	2.998
12	80.00	156.00	70.77	78.31	25.40	70.76	0.11490	4.00	12.215
13	80.00	156.00	76.08	90.53	26.645	2.12	-----	0.70	0.000
	SCHED 40 WET STEEL				120		0	4.70	2.235
15	80.00	156.00	74.72	87.31	25.40	74.72	0.12705	2.60	9.772
16	80.00	156.00	78.79	97.08	26.645	2.23	-----	0.80	0.000
	SCHED 40 WET STEEL				120		0	3.40	2.491
2	80.00	156.00	68.11	72.55	31.75	133.82	0.09823	1.30	7.555
100	0.00	155.70	0.00	83.01	35.052	2.31	-----	2.10	2.905
	SCHED 40 WET STEEL				120		0	3.40	2.668
5	80.00	156.00	71.76	80.52	38.10	206.91	0.10384	1.50	12.214
200	0.00	155.70	0.00	95.67	40.894	2.63	-----	3.70	2.938
	SCHED 40 WET STEEL				120		0	5.20	3.443
100	0.00	155.70	0.00	83.01	31.75	133.82	0.09823	3.60	12.665
200	0.00	155.70	0.00	95.67	35.052	2.31	-----	2.10	0.000
	SCHED 40 WET STEEL				120		0	5.70	2.668
8	80.00	156.00	73.79	85.16	38.10	212.79	0.10936	1.50	12.864
300	0.00	157.70	0.00	81.34	40.894	2.70	-----	3.70	-16.684

FIRE - Fire Sprinkler Hydraulics Calculation Program
pReJkEr Class nr 666

Elite Software Development, Inc.
Design Area Number One

Fire Sprinkler Output Data

Overall Pipe Output Data (cont'd)

Beg. End. Node	Nodal KFactor (Km)	Elevation (m)	Spk/Hose Discharge (Lpm)	Residual Pressure (kPa)	Nom. Dia. Inside Dia. C-Value	Q (Lpm) Velocity (m/s)	F. L./m (kPa/m) Fittings Type-Grp	Pipe-Len. Fit-Len. Tot-Len. (m)	PF-(kPa) PE-(kPa) PV-(kPa)
	SCHED 40 WET STEEL				120		0	5.20	3.642
200	0.00	155.70	0.00	95.67	50.80	340.73	0.07739	3.00	5.252
300	0.00	157.70	0.00	81.34	52.502	2.62	-----	0.00	-19.589
	SCHED 40 WET STEEL				120		0	3.00	3.437
11	80.00	156.00	75.28	88.61	38.10	217.12	0.11351	1.50	13.352
400	0.00	155.70	0.00	104.90	40.894	2.76	-----	3.70	2.938
	SCHED 40 WET STEEL				120		0	5.20	3.791
300	0.00	157.70	0.00	81.34	63.50	553.52	0.07993	2.20	3.978
400	0.00	155.70	0.00	104.90	62.713	2.99	-----	0.00	19.589
	SCHED 40 WET STEEL				120		0	2.20	4.455
13	80.00	156.00	76.08	90.53	31.75	146.84	0.11664	2.10	13.984
500	0.00	155.70	0.00	107.45	35.052	2.54	-----	3.20	2.938
	SCHED 40 WET STEEL				120		0	5.30	3.213
400	0.00	155.70	0.00	104.90	76.20	770.64	0.05119	2.20	2.547
500	0.00	155.70	0.00	107.45	77.927	2.69	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	2.20	3.622
14	80.00	156.00	77.61	94.20	25.40	77.61	0.13630	2.30	14.183
600	0.00	155.70	0.00	111.32	26.645	2.32	-----	2.30	2.938
	SCHED 40 WET STEEL				120		0	4.60	2.688
500	0.00	155.70	0.00	107.45	101.60	917.48	0.01882	3.00	3.874
600	0.00	155.70	0.00	111.32	102.260	1.86	-----	6.10	0.000
	SCHED 40 WET STEEL				120		0	9.10	1.731
16	80.00	156.00	78.79	97.08	31.75	153.50	0.12661	1.30	12.889
700	0.00	155.70	0.00	112.91	35.052	2.65	-----	3.20	2.938
	SCHED 40 WET STEEL				120		0	4.50	3.511
600	0.00	155.70	0.00	111.32	101.60	995.09	0.02187	3.20	1.583
700	0.00	155.70	0.00	112.91	102.260	2.02	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	3.20	2.037
700	0.00	155.70	0.00	112.91	101.60	1148.60	0.02852	24.00	27.865
800	0.00	155.40	0.00	143.71	102.260	2.33	-----	19.20	2.938
	SCHED 40 WET STEEL				120		0	43.20	2.713
800	0.00	155.40	0.00	143.71	152.40	1148.60	0.00388	109.60	9.610
900	0.00	45.80	0.00	1226.82	154.051	1.03	-----	0.00	1073.501
	SCHED 40 WET STEEL				120		0	109.60	0.527
900	0.00	45.80	0.00	1226.82	152.40	1148.60	0.00388	233.00	23.517
1000	0.00	0.00	0.00	1698.94	154.051	1.03	-----	35.20	448.598
	SCHED 40 WET STEEL				120		0	268.20	0.527

Fire Sprinkler Output Data

Overall Sprinkler Output Data

Flowing Sprinkler Node No.	Area Group Code	Sprinkler KFactor (Km)	Sprinkler Elevation (m)	Residual Pressure (kPa)	Flowing Area (m²)	Flowing Density (Lpm/m²)	Sprinkler Discharge (Lpm)
1		5.55	156.00	67.53	16.00	0.101	65.71
Sub Totals For Non-Group					16.00	4.107	65.71
2		5.55	156.00	72.55	16.00	0.104	68.11
Sub Totals For Non-Group					16.00	4.257	68.11
3		5.55	156.00	67.00	16.00	0.100	65.45
Sub Totals For Non-Group					16.00	4.091	65.45
4		5.55	156.00	75.99	16.00	0.107	69.71
Sub Totals For Non-Group					16.00	4.357	69.71
5		5.55	156.00	80.52	16.00	0.110	71.76
Sub Totals For Non-Group					16.00	4.485	71.76
6		5.55	156.00	70.88	16.00	0.103	67.32
Sub Totals For Non-Group					16.00	4.208	67.32
7		5.55	156.00	80.36	16.00	0.110	71.68
Sub Totals For Non-Group					16.00	4.480	71.68
8		5.55	156.00	85.16	16.00	0.113	73.79
Sub Totals For Non-Group					16.00	4.612	73.79
9		5.55	156.00	73.82	16.00	0.105	68.71
Sub Totals For Non-Group					16.00	4.294	68.71
10		5.55	156.00	83.66	16.00	0.112	73.14
Sub Totals For Non-Group					16.00	4.571	73.14
11		5.55	156.00	88.61	16.00	0.115	75.28
Sub Totals For Non-Group					16.00	4.705	75.28
12		5.55	156.00	78.31	16.00	0.109	70.77
Sub Totals For Non-Group					16.00	4.423	70.77
13		5.55	156.00	90.53	16.00	0.117	76.08
Sub Totals For Non-Group					16.00	4.755	76.08
14		5.55	156.00	94.20	16.00	0.119	77.61
Sub Totals For Non-Group					16.00	4.851	77.61
15		5.55	156.00	87.31	16.00	0.115	74.72
Sub Totals For Non-Group					16.00	4.670	74.72
16		5.55	156.00	97.08	16.00	0.121	78.79
Sub Totals For Non-Group					16.00	4.924	78.79
Totals For All Groups					256.00	4.487	1148.63

FIRE - Fire Sprinkler Hydraulics Calculation Program
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Elite Software Development, Inc.
Design Area Number One

Fire Sprinkler Output Summary

Hydraulically Most Demanding Sprinkler Node

HMD Sprinkler Node Number:	3	
HMD Actual Residual Pressure:	67.00	kPa
HMD Actual GPM:	65.45	Lpm

Sprinkler Summary

Sprinkler System Type:	Wet	
Specified Area Of Application:	139.00	m²
Minimum Desired Density:	4.091	Lpm/m²
Application Average Density:	8.264	Lpm/m²
Application Average Area Per Sprinkler:	8.69	m²
Sprinkler Flow:	1148.63	Lpm
Average Sprinkler Flow:	71.79	Lpm

Flow Velocity And Imbalance Summary

Maximum Flow Velocity (In Pipe 300 - 400)	2.99	m/sec
Maximum Velocity Pressure (In Pipe 300 - 400)	4.46	kPa
Allowable Maximum Nodal Pressure Imbalance:	0.0103	kPa
Actual Maximum Nodal Pressure Imbalance:	0.0061	kPa
Actual Average Nodal Pressure Imbalance:	0.0014	kPa
Actual Maximum Nodal Flow Imbalance:	0.0041	Lpm
Actual Average Nodal Flow Imbalance:	0.0018	Lpm

Overall Network Summary

Number Of Unique Pipe Sections:	25	
Number Of Flowing Sprinklers:	16	
Pipe System Water Volume:	6690.05	L
Sprinkler Flow:	1148.63	Lpm
Non-Sprinkler Flow:	0.00	Lpm
Total System Demand Flow:	1148.63	Lpm
Minimum Required Residual Pressure At System Inflow Node:	1698.94	kPa
Demand Flow At System Inflow Node:	1148.60	Lpm

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FIRE - Fire Sprinkler Hydraulics Calculation Program
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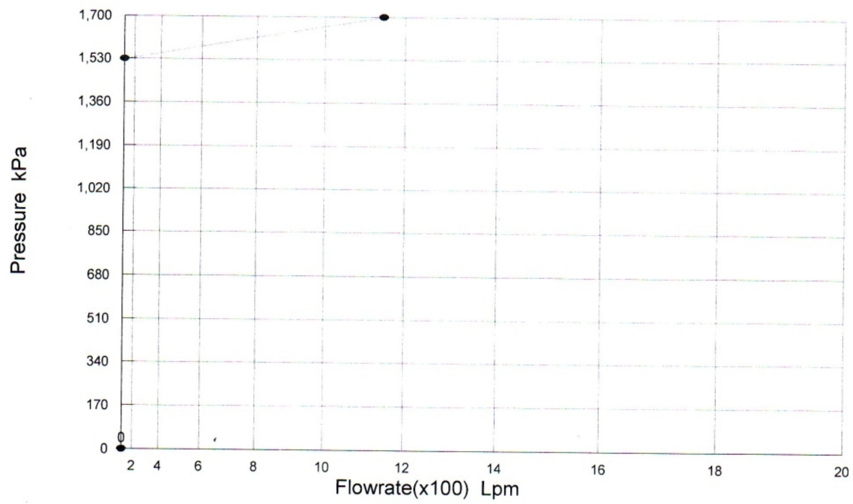
Elite Software Development, Inc.
Design Area Number One

Fire Sprinkler Output Data

Hydraulic Supply/Demand Graph



Adjusted Hydrant Data

Static Pressure: 0 kPa
Test Residual Pressure: 0 kPa
Test Flow Rate: 0 Lpm

Demand Point Data

Calculated Residual Pressure: 1698.94 kPa
Calculated Flow Rate: 1148.60 Lpm
Excess Available Inflow Residual Pressure: -1698.94 kPa

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Appendix A.2: Elite Software for the Design Area Number Two for the K-Tower Building.

DESIGN AREA NUMBER TWO
Fire Sprinkler Reports

for

K-Tower Building (Case Study)

Al-Abdali Region, Amman, Jordan

Prepared By:

Student Name : Abdulla Olimat
Faculity of Engineering
Amman - Jordan

2009

General Project Data Report

General Data

Project Title: DESIGN AREA NUMBER TWO
Designed By: Student Name : Abdulla Olimat
Code Reference: NFPA 13 ,NFPA 14 , Jordan Code
Project File Name: ABDULLA THESIS DA2.fiw
Date: 2009
Approving Agency: Discussion Comittee
The Design Area Number Two is Located at the podium Floor Number (1)

Client Name: K-Tower Building (Case Study)
Address: Al-Abdali Region, Amman, Jordan
Phone:
City, State Zip Code:
One of suggested high-rise building in Amman-Jordan . It is height reached up to 156 m approximately

Company Name: Faculty of Engineering
Company Address: Amman - Jordan
Phone:
Representative: The University of Jordan
City And State:
This work is done by the student to verify the manual hydraulic calculation

Building Name: K-Tower
Contact at Building:
Building Owner: K-Tower
Phone at Building:
The K-Tower is selected to be the case study which is introduced by the student for master thesis under the title Design of Automaic Sprinkler System in Jordan

Project Data

Description Of Hazard:	Ordinary 2	Sprinkler System Type:	Wet
Design Area Of Water Application:	139 m²	Maximum Area Per Sprinkler:	12 m²
Default Sprinkler K-Factor:	80.00 Km	Default Pipe Material:	SCHED 40 WET STEEL
Inside Hose Stream Allowance:	0.00 Lpm	Outside Hose Stream Allowance:	0.00 Lpm
In Rack Sprinkler Allowance:	0.00 Lpm		

Sprinkler Specifications

Make:	TYCO	Model:	TY-B
Size:	12.7	Temperature Rating:	57.23 C

Water Supply Test Data

Source Of Information:			
Test Hydrant ID:		Date Of Test:	
Hydrant Elevation:	0 m	Static Pressure:	0.00 kPa
Test Flow Rate:	0.00 Lpm	Test Residual Pressure:	0.00 kPa
Calculated System Flow Rate:	1362.50 Lpm	Calculated Inflow Residual Pressure:	597.05 kPa
Available Inflow Residual Pressure:	0 kPa		

Calculation Project Data

Calculation Mode:	Demand		
HMD Minimum Residual Pressure:	48.00 kPa	Minimum Desired Flow Density:	8.15 Lpm/m²
Number Of Active Nodes:	20		
Number Of Active Pipes:	19	Number Of Inactive Pipes:	0
Number Of Active Sprinklers:	13	Number Of Inactive Sprinklers:	0

Fire Sprinkler Input Data

Node Input Data

Node No.	Node Description	Area Group	Sprinkler KFactor (Km)	Pressure Estimate (kPa)	Node Elevation (m)	Non-Sprinkler Discharge (Lpm)
1	Sprinkler		80.00	149.54	31.80	0.00
2	Sprinkler		80.00	154.52	31.80	0.00
3	Sprinkler		80.00	163.11	31.80	0.00
4	Sprinkler		80.00	168.71	31.79	0.00
5	Sprinkler		80.00	178.18	31.80	0.00
6	Sprinkler		80.00	153.24	31.80	0.00
7	Sprinkler		80.00	158.32	31.80	0.00
8	Sprinkler		80.00	167.12	31.80	0.00
9	Sprinkler		80.00	172.75	31.80	0.00
10	Sprinkler		80.00	182.53	31.80	0.00
11	Sprinkler		80.00	195.59	31.70	0.00
12	Sprinkler		80.00	196.24	31.80	0.00
13	Sprinkler		80.00	198.43	31.80	0.00
100	No Discharge		N/A	195.10	31.50	0.00
200	No Discharge		N/A	199.90	31.49	0.00
300	No Discharge		N/A	204.09	31.50	0.00
400	No Discharge		N/A	205.87	31.49	0.00
500	No Discharge		N/A	208.13	31.49	0.00
600	No Discharge		N/A	273.64	31.21	0.00
700	No Discharge		N/A	597.05	0.00	0.00

FIRE - Fire Sprinkler Hydraulics Calculation Program
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Elite Software Development, Inc.
DESIGN AREA NUMBER TWO

Fire Sprinkler Input Data

Pipe Input Data

Beg. Node	End. Node	Pipe Description	Nominal Diameter (mm)	Type Group	Fitting Data	Nominal Length (m)	Fitting Length (m)	Total Length (m)	CFactor (gpm/inch-psi)
1	2	SCHED 40 WET STEEL	31.750	0		4.00	0.00	4.00	120
2	3	SCHED 40 WET STEEL	38.100	0		4.00	0.00	4.00	120
3	4	SCHED 40 WET STEEL	50.800	0		4.00	0.00	4.00	120
4	5	SCHED 40 WET STEEL	50.800	0		4.00	0.00	4.00	120
5	100	SCHED 40 WET STEEL	63.500	0		3.30	5.70	9.00	120
6	7	SCHED 40 WET STEEL	31.750	0		4.00	0.00	4.00	120
7	8	SCHED 40 WET STEEL	38.100	0		4.00	0.00	4.00	120
8	9	SCHED 40 WET STEEL	50.800	0		4.00	0.00	4.00	120
9	10	SCHED 40 WET STEEL	50.800	0		4.00	0.00	4.00	120
10	200	SCHED 40 WET STEEL	63.500	0		3.30	5.70	9.00	120
11	300	SCHED 40 WET STEEL	31.750	0		2.00	2.10	4.10	120
12	400	SCHED 40 WET STEEL	31.750	0		2.00	2.10	4.10	120
13	500	SCHED 40 WET STEEL	31.750	0		2.00	2.10	4.10	120
100	200	SCHED 40 WET STEEL	63.500	0		3.00	0.00	3.00	120
200	300	SCHED 40 WET STEEL	76.200	0		2.20	0.00	2.20	120
300	400	SCHED 40 WET STEEL	101.600	0		2.60	0.00	2.60	120
400	500	SCHED 40 WET STEEL	101.600	0		3.00	0.00	3.00	120
500	600	SCHED 40 WET STEEL	101.600	0		71.00	0.00	71.00	120
600	700	SCHED 40 WET STEEL	152.400	0		112.00	35.20	147.20	120

FIRE - Fire Sprinkler Hydraulics Calculation Program
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Elite Software Development, Inc.
DESIGN AREA NUMBER TWO

Fire Sprinkler Output Data

Overall Node Groupings Output Data

Pipe Segment Beg. Node	Pipe Segment End. Node	Pipe Type Group	Pipe Flow Rate (Lpm)	Sprinkler Flow At Beg. Node (Lpm)	Non-Sprinkler Flow Out (+) (Lpm)	Non-Sprinkler Flow In (-) (Lpm)	Beg. Node Residual Pressure (kPa)	Imbalance Flow At Beg. Node (Lpm)
1	2	0	-97.79	97.79	0.00	0.00	149.54	
2	1	0	97.79	99.40	0.00	0.00	154.52	0.00391
2	3	0	-197.19					
3	2	0	197.19	102.13	0.00	0.00	163.11	0.00289
3	4	0	-299.31					
4	3	0	299.31	103.87	0.00	0.00	168.71	0.00222
4	5	0	-403.18					
5	4	0	403.18	106.74	0.00	0.00	178.18	0.00508
5	100	0	-509.91					
6	7	0	-98.99	98.99	0.00	0.00	153.24	0.00207
7	6	0	98.99	100.62	0.00	0.00	158.32	0.00072
7	8	0	-199.60					
8	7	0	199.60	103.37	0.00	0.00	167.12	0.00478
8	9	0	-302.97					
9	8	0	302.97	105.10	0.00	0.00	172.75	0.00226
9	10	0	-408.07					
10	9	0	408.07	108.04	0.00	0.00	182.53	0.00568
10	200	0	-516.10					
11	300	0	-111.83	111.83	0.00	0.00	195.59	0.00783
12	400	0	-112.01	112.02	0.00	0.00	196.24	0.00803
13	500	0	-112.64	112.64	0.00	0.00	198.43	0.00832
100	5	0	509.91	0.00	0.00	0.00	195.10	-0.00026
100	200	0	-509.91					
200	10	0	516.10	0.00	0.00	0.00	199.90	-0.00660
200	100	0	509.91					
200	300	0	-1026.02					
300	11	0	111.83	0.00	0.00	0.00	204.09	-0.00209
300	200	0	1026.02					
300	400	0	-1137.85					
400	12	0	112.01	0.00	0.00	0.00	205.87	-0.00142
400	300	0	1137.85					
400	500	0	-1249.86					
500	13	0	112.64	0.00	0.00	0.00	208.13	0.00053
500	400	0	1249.86					

FIRE - Fire Sprinkler Hydraulics Calculation Program
pReJkEr Class nr 666

Elite Software Development, Inc.
DESIGN AREA NUMBER TWO

Fire Sprinkler Output Data

Overall Node Groupings Output Data (cont'd)

Pipe Segment Beg. Node	Pipe Segment End. Node	Pipe Type Group	Pipe Flow Rate (Lpm)	Sprinkler Flow At Beg. Node (Lpm)	Non-Sprinkler Flow Out (+) (Lpm)	Non-Sprinkler Flow In (-) (Lpm)	Beg. Node Residual Pressure (kPa)	Imbalance Flow At Beg. Node (Lpm)
500	600	0	-1362.50					
600	500	0	1362.50	0.00	0.00	0.00	273.64	-0.00080
600	700	0	-1362.50					
700	600	0	1362.50	0.00	0.00	- 1362.500 95391078	597.05	

FIRE - Fire Sprinkler Hydraulics Calculation Program
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Elite Software Development, Inc.
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Fire Sprinkler Output Data

Overall Pipe Output Data

Beg. End. Node	Nodal KFactor (Km)	Elevation (m)	Spk/Hose Discharge (Lpm)	Residual Pressure (kPa)	Nom. Dia. Inside Dia. C-Value	Q (Lpm) Velocity (m/s)	F. L./m (kPa/m) Fittings Type-Grp	Pipe-Len. Fit-Len. Tot-Len. (m)	PF-(kPa) PE-(kPa) PV-(kPa)
1	80.00	31.80	97.79	149.54	31.75	97.79	0.05498	4.00	4.974
2	80.00	31.80	99.40	154.52	35.052	1.69	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	4.00	1.425
2	80.00	31.80	99.40	154.52	38.10	197.19	0.09499	4.00	8.595
3	80.00	31.80	102.13	163.11	40.894	2.50	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	4.00	3.127
3	80.00	31.80	102.13	163.11	50.80	299.31	0.06089	4.00	5.509
4	80.00	31.79	103.87	168.71	52.502	2.30	-----	0.00	0.092
	SCHED 40 WET STEEL				120		0	4.00	2.652
4	80.00	31.79	103.87	168.71	50.80	403.18	0.10566	4.00	9.560
5	80.00	31.80	106.74	178.18	52.502	3.10	-----	0.00	-0.092
	SCHED 40 WET STEEL				120		0	4.00	4.812
6	80.00	31.80	98.99	153.24	31.75	98.99	0.05623	4.00	5.088
7	80.00	31.80	100.62	158.32	35.052	1.71	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	4.00	1.460
7	80.00	31.80	100.62	158.32	38.10	199.60	0.09716	4.00	8.791
8	80.00	31.80	103.37	167.12	40.894	2.53	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	4.00	3.204
8	80.00	31.80	103.37	167.12	50.80	302.97	0.06227	4.00	5.635
9	80.00	31.80	105.10	172.75	52.502	2.33	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	4.00	2.717
9	80.00	31.80	105.10	172.75	50.80	408.07	0.10804	4.00	9.776
10	80.00	31.80	108.04	182.53	52.502	3.14	-----	0.00	0.000
	SCHED 40 WET STEEL				120		0	4.00	4.930
5	80.00	31.80	106.74	178.18	63.50	509.91	0.06867	3.30	13.980
100	0.00	31.50	0.00	195.10	62.713	2.75	-----	5.70	2.938
	SCHED 40 WET STEEL				120		0	9.00	3.781
10	80.00	31.80	108.04	182.53	63.50	516.10	0.07022	3.30	14.295
200	0.00	31.49	0.00	199.90	62.713	2.78	-----	5.70	3.077
	SCHED 40 WET STEEL				120		0	9.00	3.873
100	0.00	31.50	0.00	195.10	63.50	509.91	0.06867	3.00	4.660
200	0.00	31.49	0.00	199.90	62.713	2.75	-----	0.00	0.139
	SCHED 40 WET STEEL				120		0	3.00	3.781
11	80.00	31.70	111.83	195.59	31.75	111.83	0.07046	2.00	6.535
300	0.00	31.50	0.00	204.09	35.052	1.93	-----	2.10	1.959
	SCHED 40 WET STEEL				120		0	4.10	1.863
200	0.00	31.49	0.00	199.90	76.20	1026.02	0.08693	2.20	4.326
300	0.00	31.50	0.00	204.09	77.927	3.59	-----	0.00	-0.139

Active Version 6.0.189 | 1000 Pipe Capacity | Friday, October 02, 2009

FIRE - Fire Sprinkler Hydraulics Calculation Program
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Elite Software Development, Inc.
DESIGN AREA NUMBER TWO

Fire Sprinkler Output Data

Overall Pipe Output Data (cont'd)

Beg. End. Node	Nodal KFactor (Km)	Elevation (m)	Spk/Hose Discharge (Lpm)	Residual Pressure (kPa)	Nom. Dia. Inside Dia. C-Value	Q (Lpm) Velocity (m/s)	F. L./m (kPa/m) Fittings Type-Grp	Pipe-Len. Fit-Len. Tot-Len. (m)	PF-(kPa) PE-(kPa) PV-(kPa)
	SCHED 40 WET STEEL				120		0	2.20	6.421
12 400	80.00 0.00 SCHED 40 WET STEEL	31.80 31.49	112.02 0.00	196.24 205.87	31.75 35.052 120	112.01 1.93	0.07068 ----- 0	2.00 2.10 4.10	6.555 3.077 1.869
300 400	0.00 0.00 SCHED 40 WET STEEL	31.50 31.49	0.00 0.00	204.09 205.87	101.60 102.260 120	1137.85 2.31	0.02802 ----- 0	2.60 0.00 2.60	1.648 0.139 2.663
13 500	80.00 0.00 SCHED 40 WET STEEL	31.80 31.49	112.64 0.00	198.43 208.13	31.75 35.052 120	112.64 1.95	0.07141 ----- 0	2.00 2.10 4.10	6.623 3.077 1.890
400 500	0.00 0.00 SCHED 40 WET STEEL	31.49 31.49	0.00 0.00	205.87 208.13	101.60 102.260 120	1249.86 2.54	0.03334 ----- 0	3.00 0.00 3.00	2.263 0.000 3.213
500 600	0.00 0.00 SCHED 40 WET STEEL	31.49 31.21	0.00 0.00	208.13 273.64	101.60 102.260 120	1362.50 2.76	0.03911 ----- 0	71.00 0.00 71.00	62.815 2.687 3.818
600 700	0.00 0.00 SCHED 40 WET STEEL	31.21 0.00	0.00 0.00	273.64 597.05	152.40 154.051 120	1362.50 1.22	0.00532 ----- 0	112.00 35.20 147.20	17.704 305.708 0.741

FIRE - Fire Sprinkler Hydraulics Calculation Program
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Elite Software Development, Inc.

DESIGN AREA NUMBER TWO

Fire Sprinkler Output Data

Overall Sprinkler Output Data

Flowing Sprinkler Node No.	Area Group Code	Sprinkler KFactor (Km)	Sprinkler Elevation (m)	Residual Pressure (kPa)	Flowing Area (m²)	Flowing Density (Lpm/m²)	Sprinkler Discharge (Lpm)
1		5.55	31.80	149.54	12.00	0.200	97.79
Sub Totals For Non-Group					12.00	8.149	97.79
2		5.55	31.80	154.52	12.00	0.203	99.40
Sub Totals For Non-Group					12.00	8.283	99.40
3		5.55	31.80	163.11	12.00	0.209	102.13
Sub Totals For Non-Group					12.00	8.511	102.13
4		5.55	31.79	168.71	12.00	0.212	103.87
Sub Totals For Non-Group					12.00	8.656	103.87
5		5.55	31.80	178.18	12.00	0.218	106.74
Sub Totals For Non-Group					12.00	8.895	106.74
6		5.55	31.80	153.24	12.00	0.202	98.99
Sub Totals For Non-Group					12.00	8.249	98.99
7		5.55	31.80	158.32	12.00	0.206	100.62
Sub Totals For Non-Group					12.00	8.385	100.62
8		5.55	31.80	167.12	12.00	0.211	103.37
Sub Totals For Non-Group					12.00	8.614	103.37
9		5.55	31.80	172.75	12.00	0.215	105.10
Sub Totals For Non-Group					12.00	8.759	105.10
10		5.55	31.80	182.53	12.00	0.221	108.04
Sub Totals For Non-Group					12.00	9.003	108.04
11		5.55	31.70	195.59	12.00	0.229	111.83
Sub Totals For Non-Group					12.00	9.320	111.83
12		5.55	31.80	196.24	12.00	0.229	112.02
Sub Totals For Non-Group					12.00	9.335	112.02
13		5.55	31.80	198.43	12.00	0.230	112.64
Sub Totals For Non-Group					12.00	9.387	112.64
Totals For All Groups					156.00	8.734	1362.54

FIRE - Fire Sprinkler Hydraulics Calculation Program
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Elite Software Development, Inc.
DESIGN AREA NUMBER TWO

Fire Sprinkler Output Summary

Hydraulically Most Demanding Sprinkler Node

HMD Sprinkler Node Number:	1
HMD Actual Residual Pressure:	149.54 kPa
HMD Actual GPM:	97.79 Lpm

Sprinkler Summary

Sprinkler System Type:	Wet
Specified Area Of Application:	139.00 m²
Minimum Desired Density:	8.149 Lpm/m²
Application Average Density:	9.802 Lpm/m²
Application Average Area Per Sprinkler:	10.69 m²
Sprinkler Flow:	1362.54 Lpm
Average Sprinkler Flow:	104.81 Lpm

Flow Velocity And Imbalance Summary

Maximum Flow Velocity (In Pipe 200 - 300)	3.59 m/sec
Maximum Velocity Pressure (In Pipe 200 - 300)	6.42 kPa
Allowable Maximum Nodal Pressure Imbalance:	0.0103 kPa
Actual Maximum Nodal Pressure Imbalance:	0.0068 kPa
Actual Average Nodal Pressure Imbalance:	0.0014 kPa
Actual Maximum Nodal Flow Imbalance:	0.0083 Lpm
Actual Average Nodal Flow Imbalance:	0.0033 Lpm

Overall Network Summary

Number Of Unique Pipe Sections:	19
Number Of Flowing Sprinklers:	13
Pipe System Water Volume:	2815.46 L
Sprinkler Flow:	1362.54 Lpm
Non-Sprinkler Flow:	0.00 Lpm
Total System Demand Flow:	1362.54 Lpm
Minimum Required Residual Pressure At System Inflow Node:	597.05 kPa
Demand Flow At System Inflow Node:	1362.50 Lpm

FIRE - Fire Sprinkler Hydraulics Calculation Program
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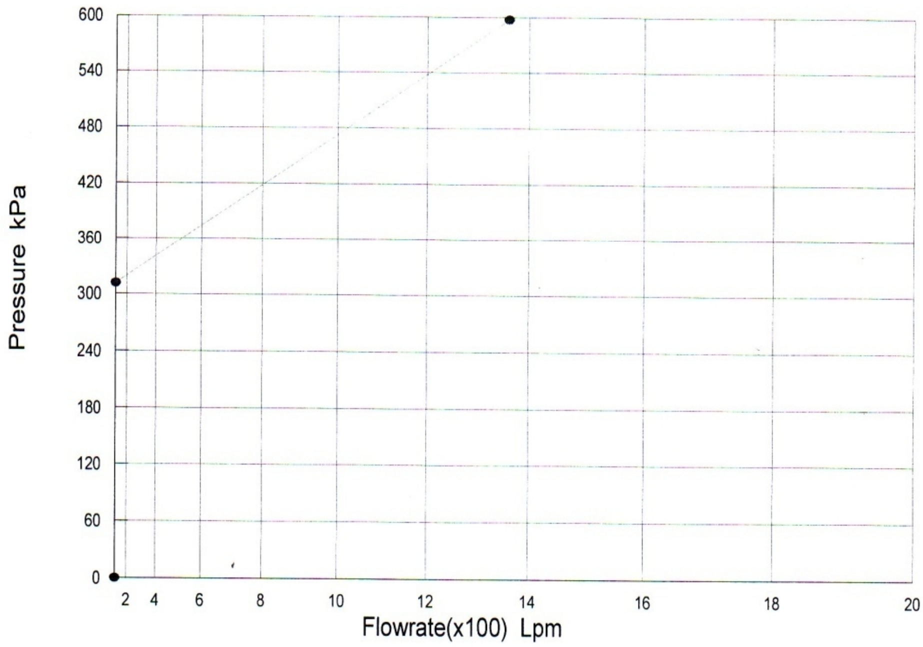
Elite Software Development, Inc.
DESIGN AREA NUMBER TWO

Fire Sprinkler Output Data

Hydraulic Supply/Demand Graph



Adjusted Hydrant Data

Static Pressure: 0 kPa
Test Residual Pressure: 0 kPa
Test Flow Rate: 0 Lpm

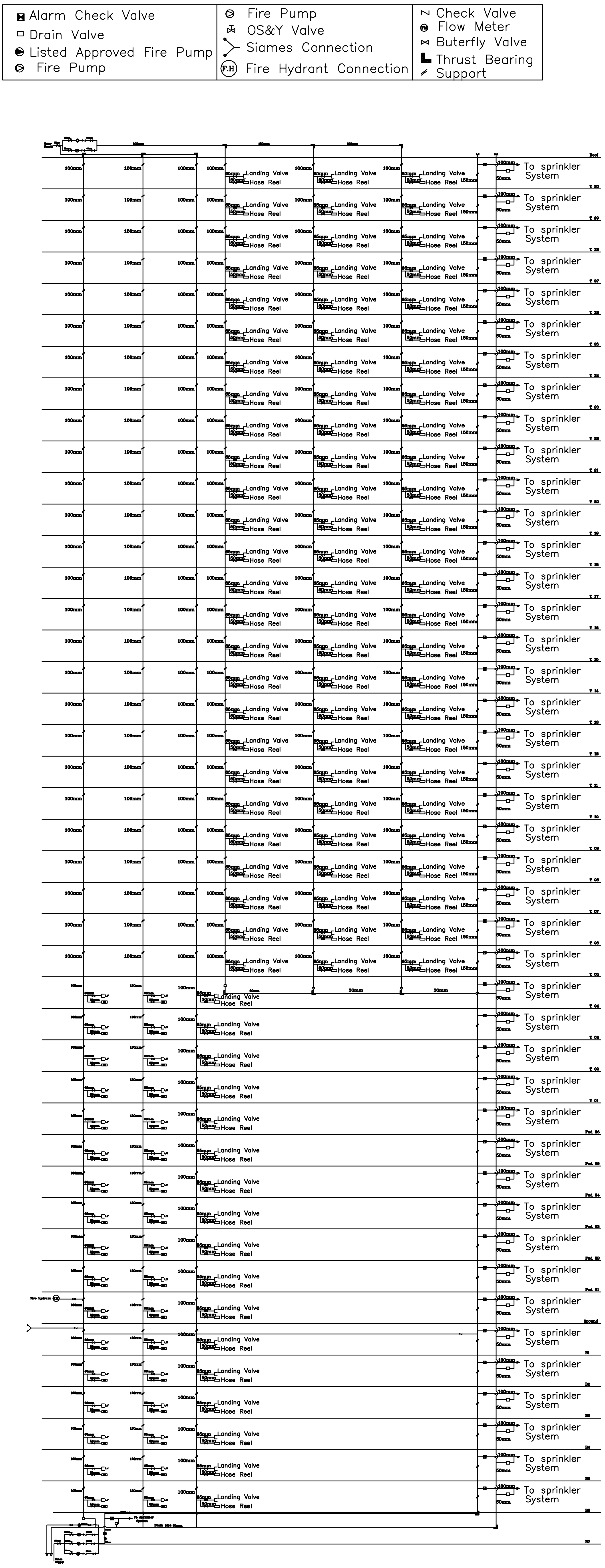
Demand Point Data

Calculated Residual Pressure: 597.05 kPa
Calculated Flow Rate: 1362.50 Lpm
Excess Available Inflow Residual Pressure: -597.05 kPa

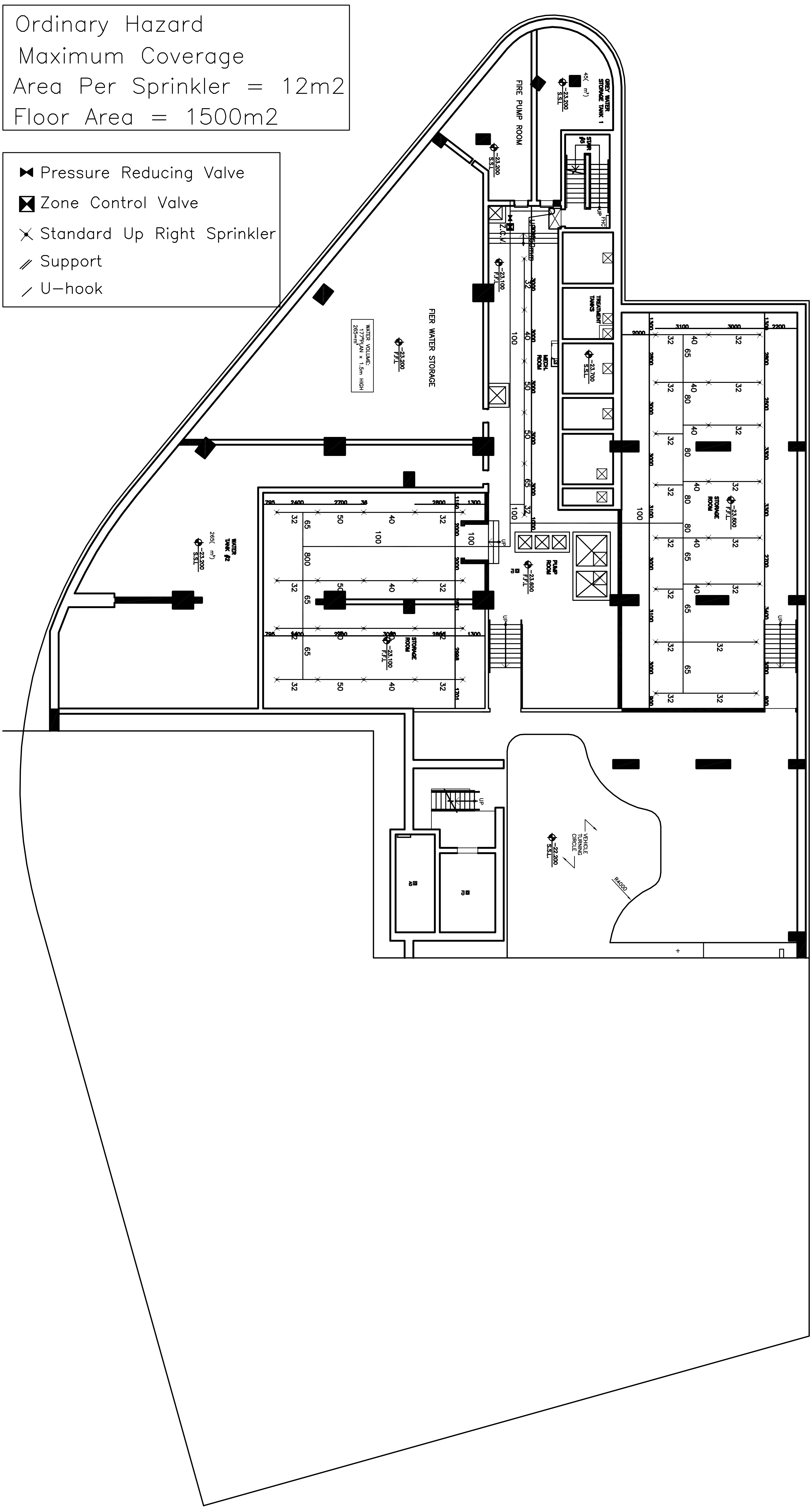
APPENDIX B

Appendix B contains the important drawings that used in the study. These are: designed riser diagram for sprinkler of the K-tower building, designed sprinkler network at the basement floor number six , seven and the roof floor of the K-tower building , determined critical floors for the sprinkler network of the K-tower building (P1, T29), and the typical floor for the landing valves and hose reel system.

Appendix B.1 Designed Riser Diagram for the Sprinkler and Standpipe Systems of the K–Tower Building



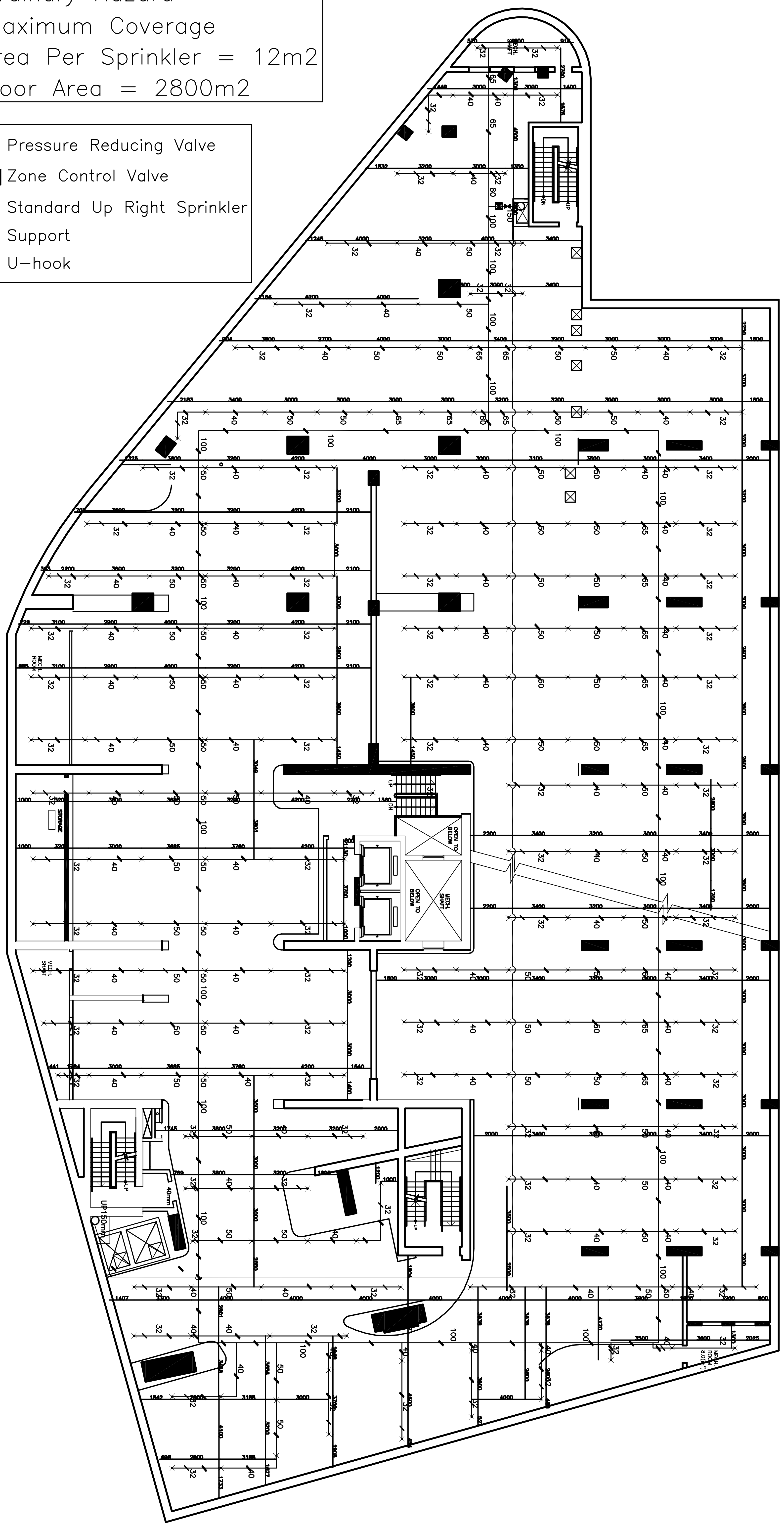
Appendix B.2 Designed Sprinkler Network for the Basement Floor Number Seven of the K–Tower Building



Appendix B.3 Designed Sprinkler Network for the Basement Floor Number Six of the K–Tower Building

Ordinary Hazard
Maximum Coverage
Area Per Sprinkler = 12m2
Floor Area = 2800m2

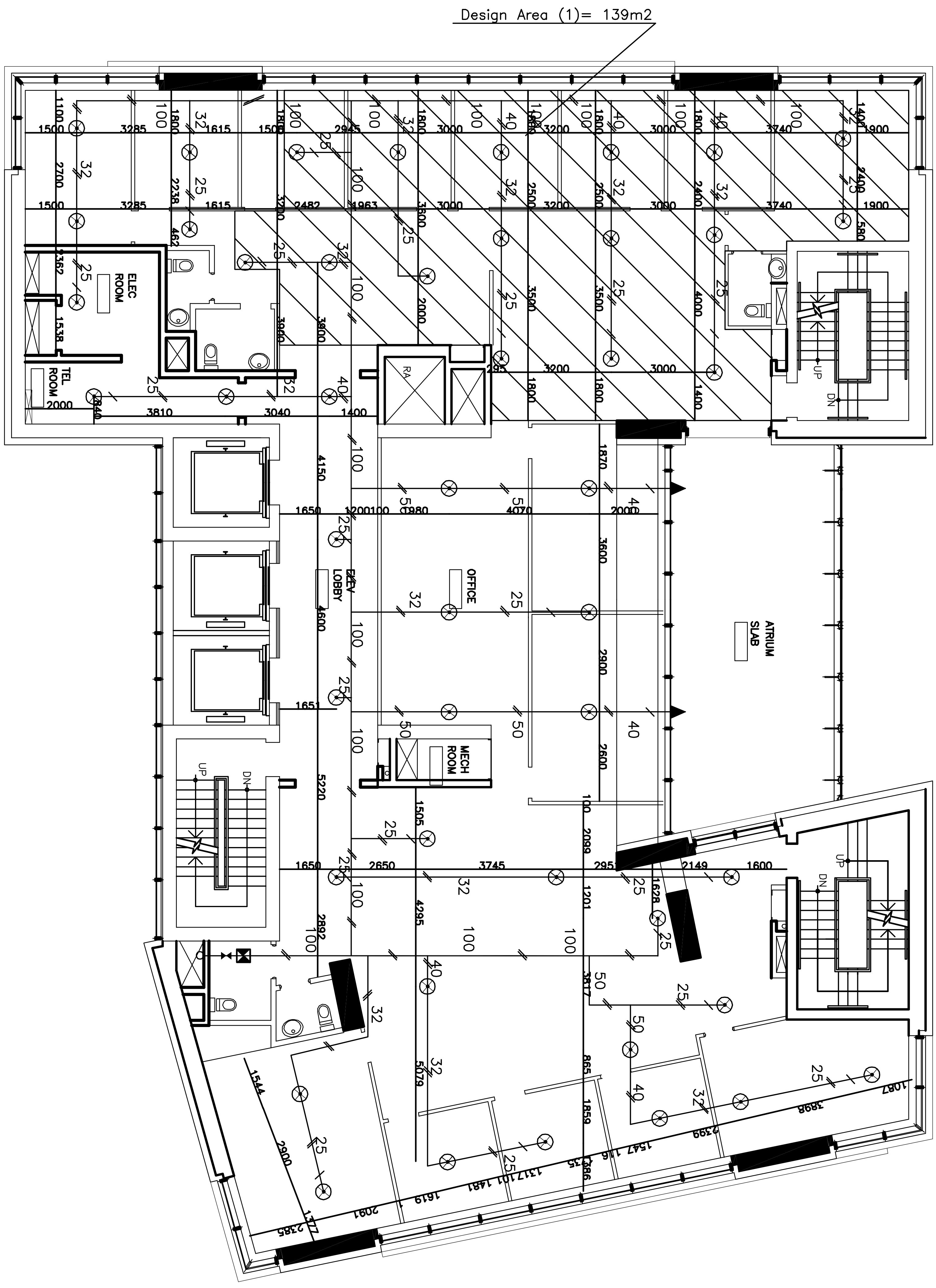
- Pressure Reducing Valve
- Zone Control Valve
- Standard Up Right Sprinkler
- Support
- U–hook



Appendix B.4 Determined Critical Floor for the Design Area Number One (T29) of the K–Tower Building

Light Hazard
Maximum Coverage
Area Per Sprinkler = 21m2
Floor Area = 767m2

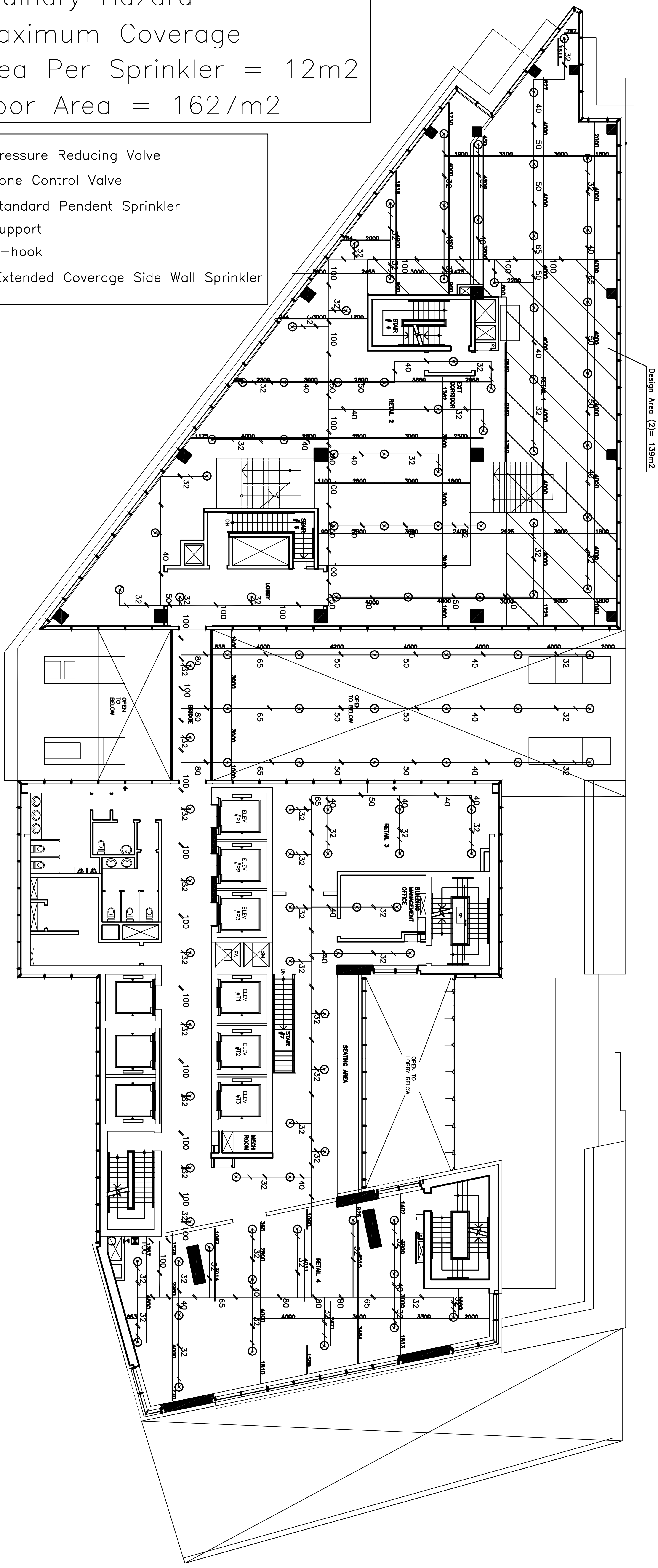
Pressure Reducing Valve
Zone Control Valve
Standard Pendent Sprinkler
Support
U–hook
Extended Coverage Side Wall Sprinkler



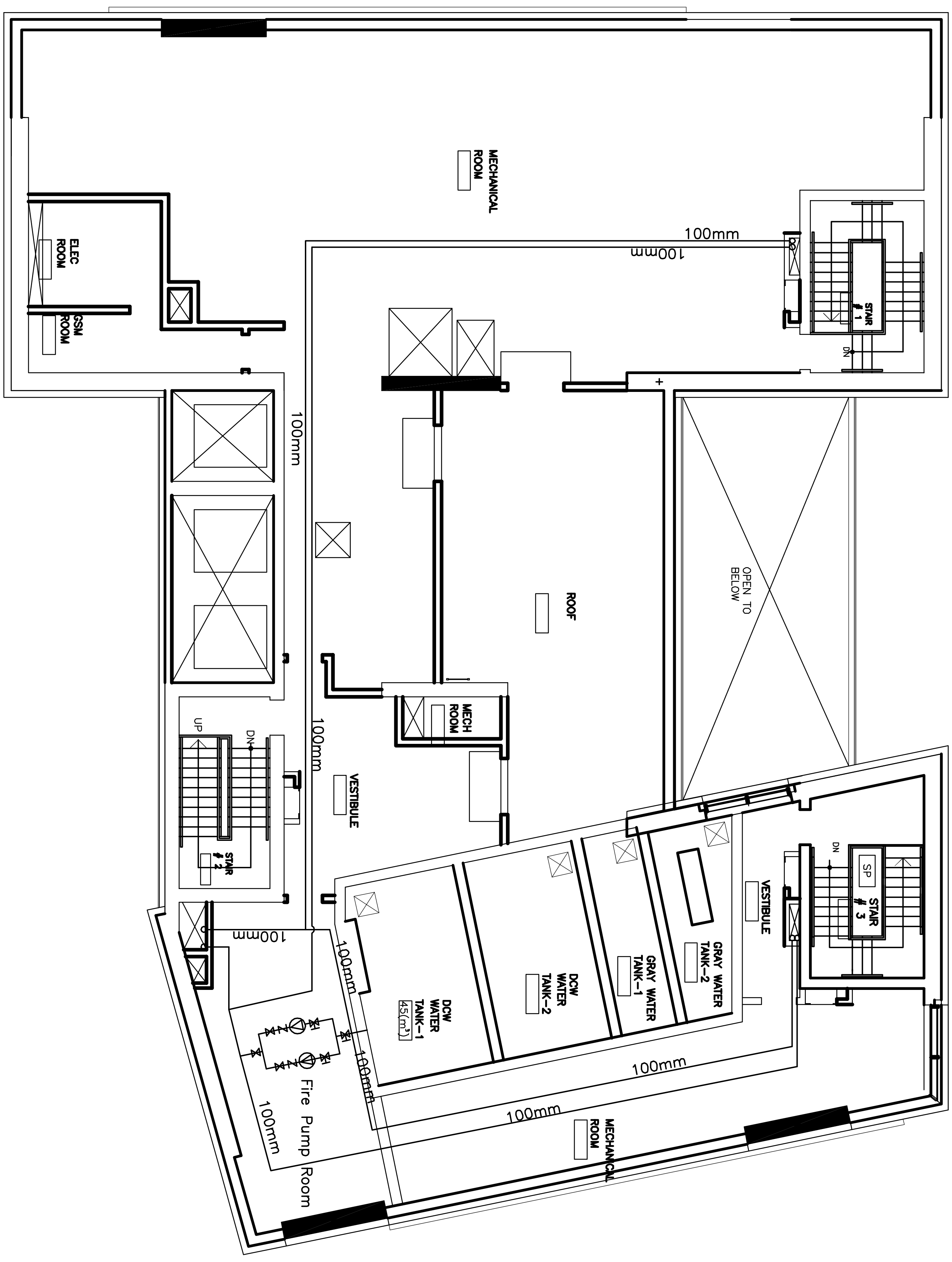
Appendix B.5 Determined Critical Floor for the Design Area Number Two (P1) of the K–Tower Building

Ordinary Hazard
Maximum Coverage
Area Per Sprinkler = 12m2
Floor Area = 1627m2

Pressure Reducing Valve
Zone Control Valve
Standard Pendent Sprinkler
Support
U–hook
Extended Coverage Side Wall Sprinkler

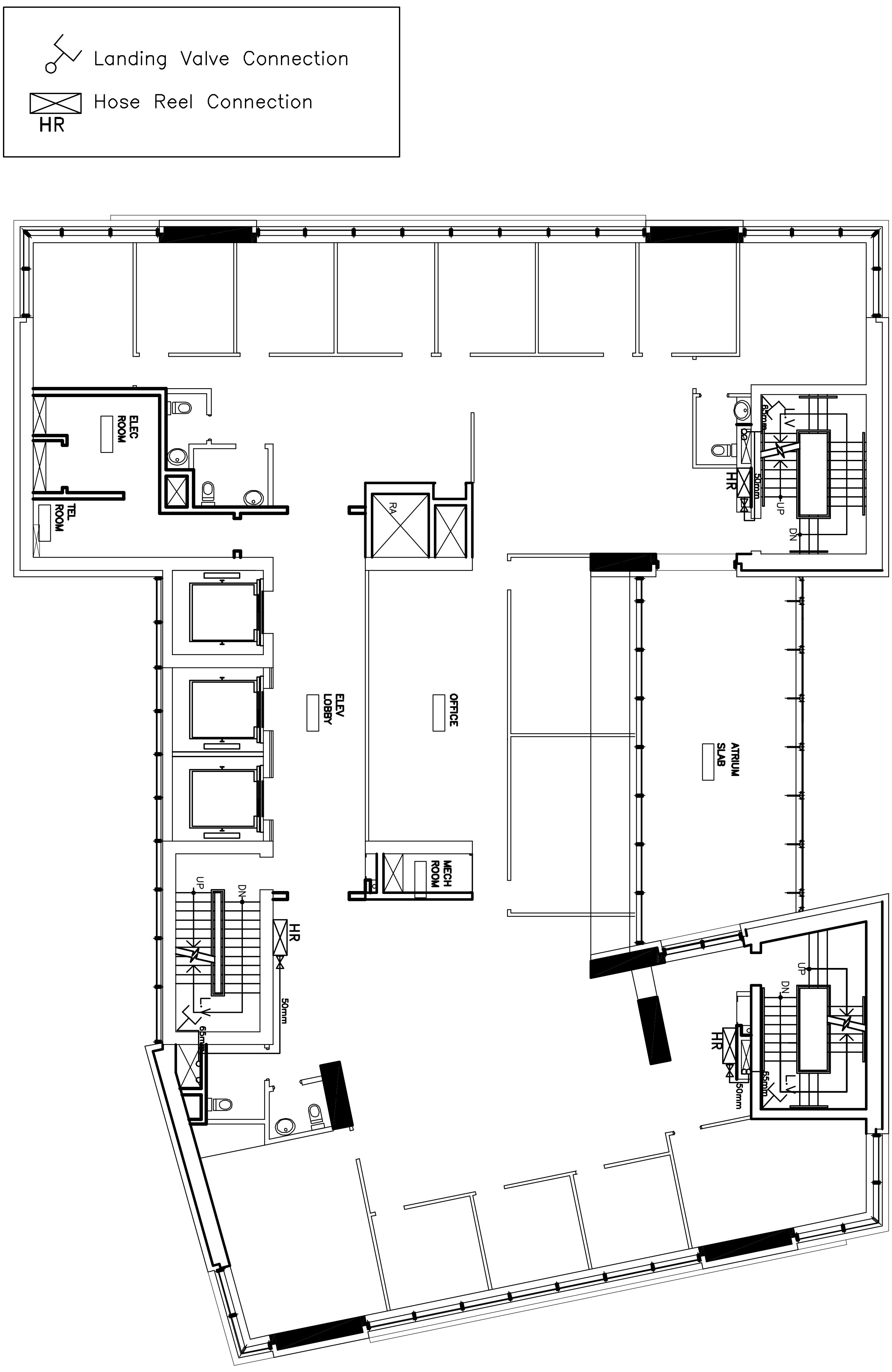


Appendix B.6 Designed Network for the Roof Floor of the K-Tower Building



Appendix B.7 Designed Standpipe Systems for the Typical Floor of the K–Tower Building

Hose Reel and Landing Valve Location
From T30 up T04
For All Floors



تصميم أنظمة مرشات الحريق التلقائيه وأنظمة الضغط في بيوت الادراج للمباني العاليه في الاردن

إعداد

عبدالله نصرالله محمد عليمات

المشرف

الأستاذ الدكتور محمد احمد السعد

ملخص

تهدف هذه الدراسه إلى تصميم نظام مرشات الحريق وانظمه الضغط في بيوت الادراج للمباني العاليه في الاردن . وحيث لا يوجد مواصفه تختص في تصميم هذة الانظمه في المباني العاليه في الاردن. فقد استندت هذه الدراسه بشكل اساسي على المواصفه الامريكيه (NFPA) والمواصفه البريطانيه (BS) في تصميم هذه الانظمه.

تم تصميم نموذج لانظمه المرشات وانظمه الصواعد بحيث يتواكب مع متطلبات المباني العاليه حسب كودات البناء الاردني مع الاخذ بعين الاعتبار عدم تعارضه مع المواصفات الدوليه.

تم تطبيق النموذج على إحدى المباني العاليه المقترحه في الاردن . وتم استخدام الطريقه اليدويه في الحسابات الهيدروليكيه الخاصه بنظام المرشات التلقائيه. وتم التأكد من صحه النتائج من خلال استخدام إحدى برامج الكميوتر(Elite Software) . اظهرت مقارنه النتائج دقه عاليه في التصميم. تم تصميم انظمه الضغط في بيوت الادراج بالاعتماد على المواصفه البريطانيه. تم دراسه كافه العوامل التي تخص تصميم هذة الانظمه بشكل تفصيلي واثرها في النتائج.