Pumping Stations Design

For Infrastructure Master Program
Engineering Faculty-IUG

Lecture 5: Design of wastewater pumping stations

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5.1 General introduction

- Main components of WWPS:

  - Bar screen
  - Grit removal
  - Wet well or wet well + dry well
  - Electricity distribution and control room (MDB + PLC)
  - Transformer room
  - Stand by generator and its fuel tank
  - Guard room and its services (kitchen + showers and toilet)
  - Pressure pipes and control valves
  - Fence and landscaping

5.2 Typical layout of WW pumping stations

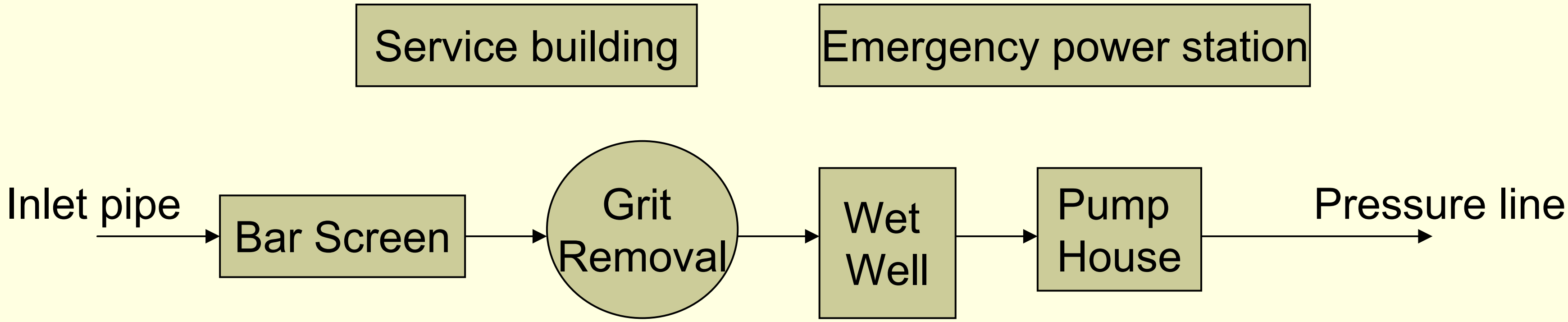


Fig 5.1 Typical Layout of Wastewater Pumping Station

5.2 Typical layout of WW pumping stations

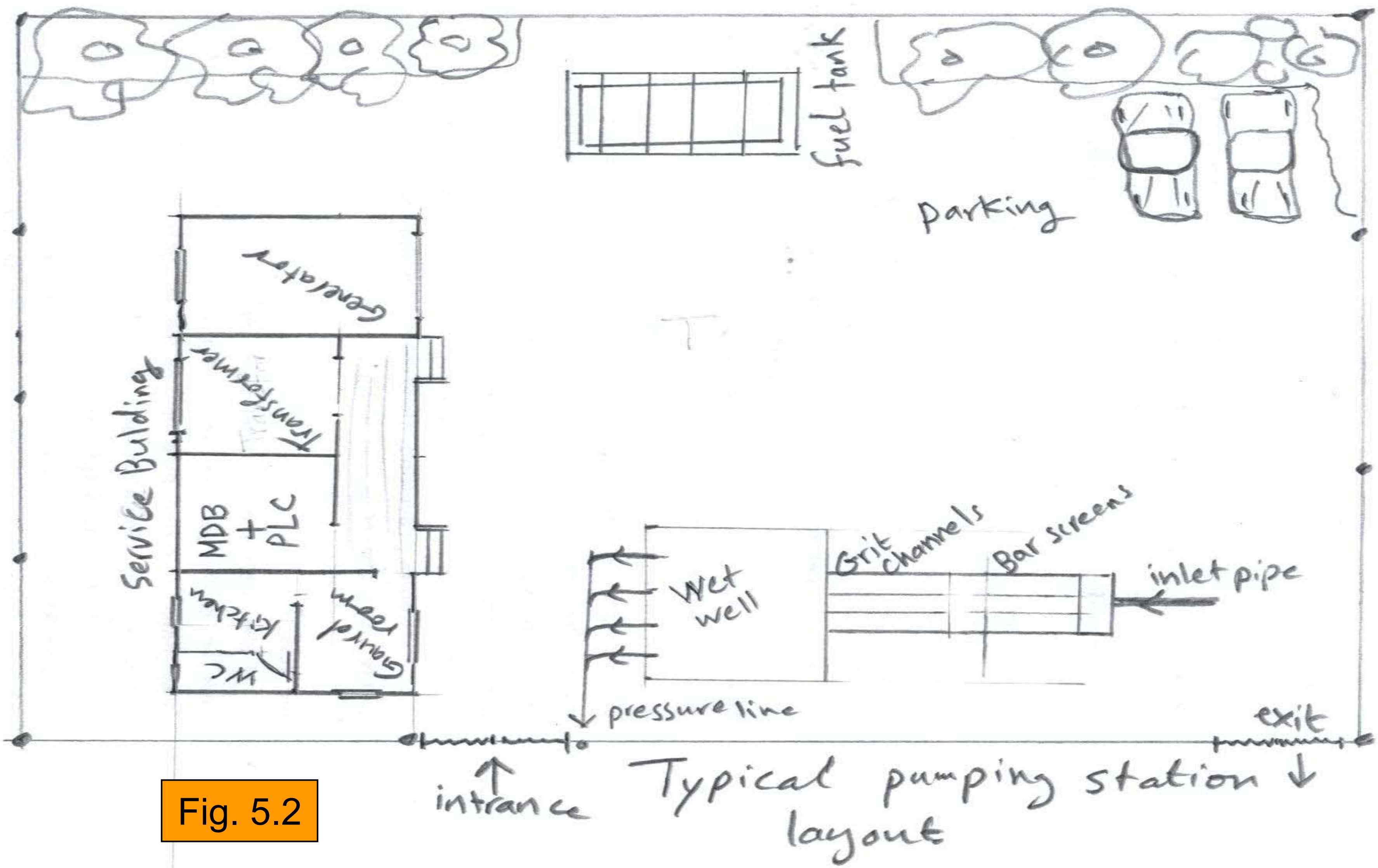


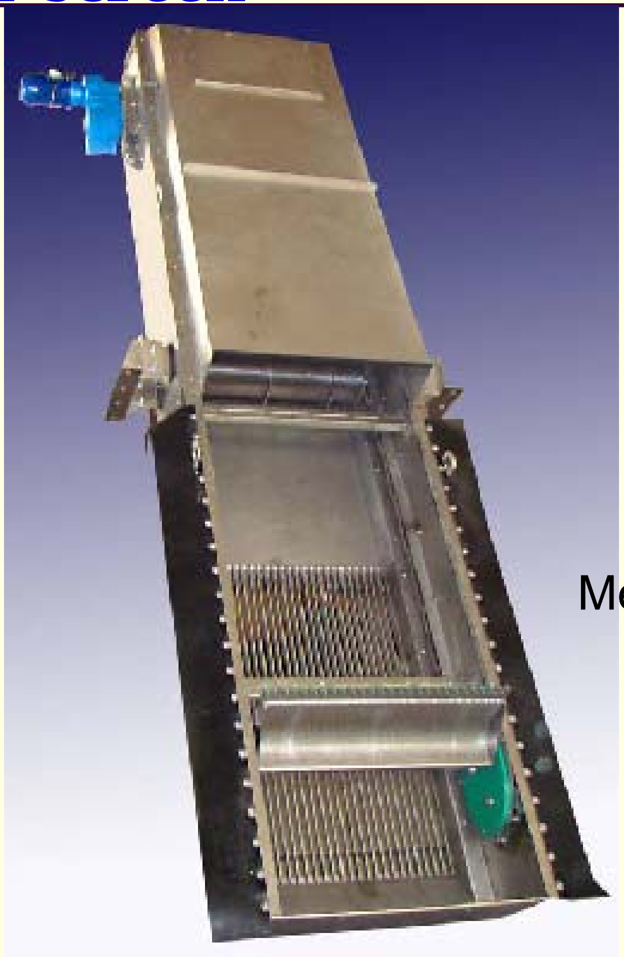
Fig. 5.2

5.3 main components of WW pumping stations

Bar screen

Fig. 5.3

Manual Bar Screen



Mechanical Bar Screen

5.3 main components of WW pumping stations

Bar screen

Fig. 5.4 Mechanical Bar Screen

5.3 main components of WW pumping station

Grit Removal

Grit Removal vortex type

Fig. 5.5

5.3 main components of WW pumping station

Wet Well

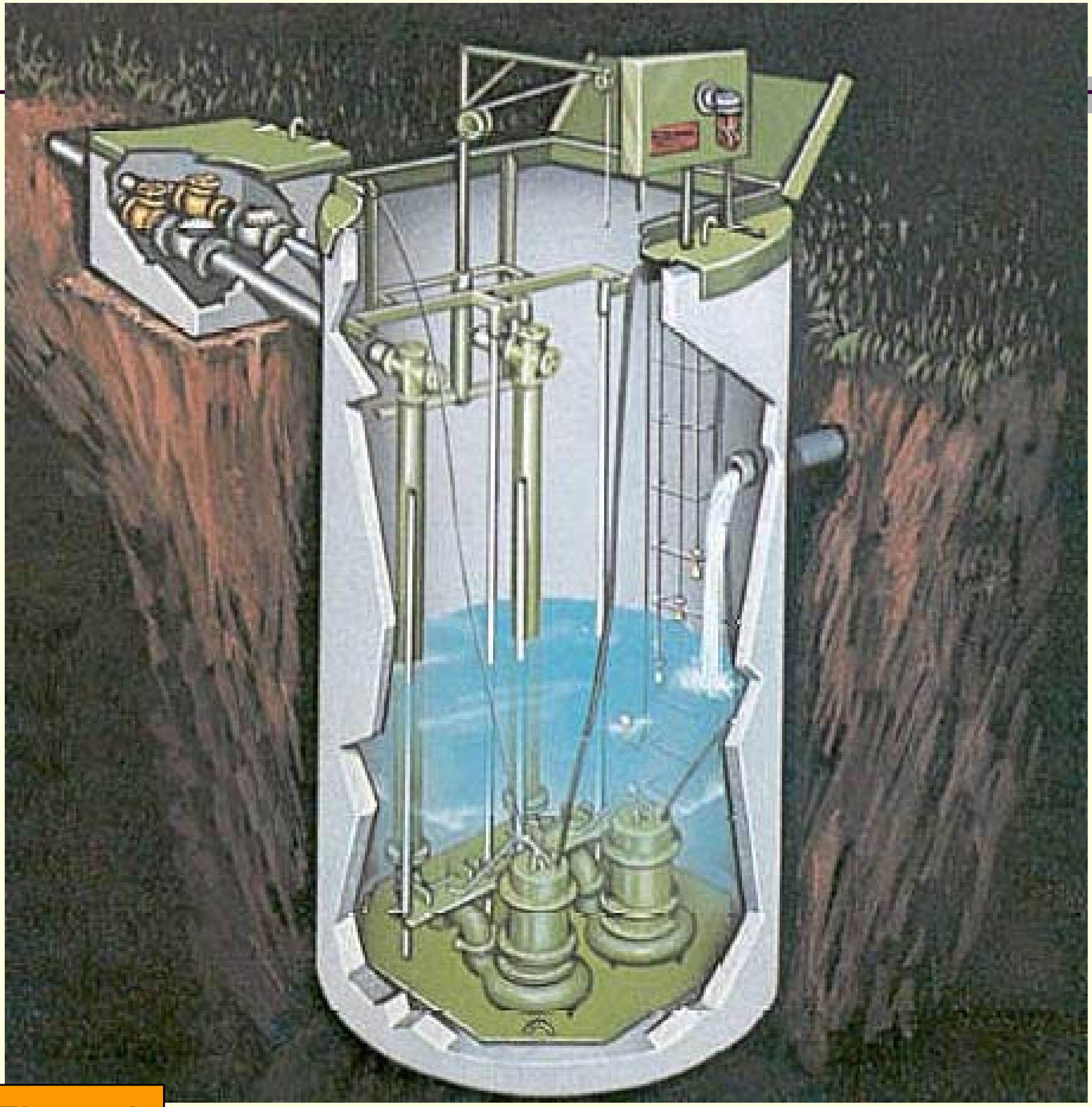


Fig. 5.6 Wet well Pump House

5.3 main components of WW pumping station

Fig. 5.7

5.3 main components of WW pumping station

Dry Well

Fig. 5.8 Dry room for dry pumps

5.3 main components of WW pumping station

Fig. 5.9 Dry room for dry pumps

5.3 main components of WW pumping station

Dry Well

Fig. 5.10 Dry room for dry pumps

5.3 main components of WW pumping station

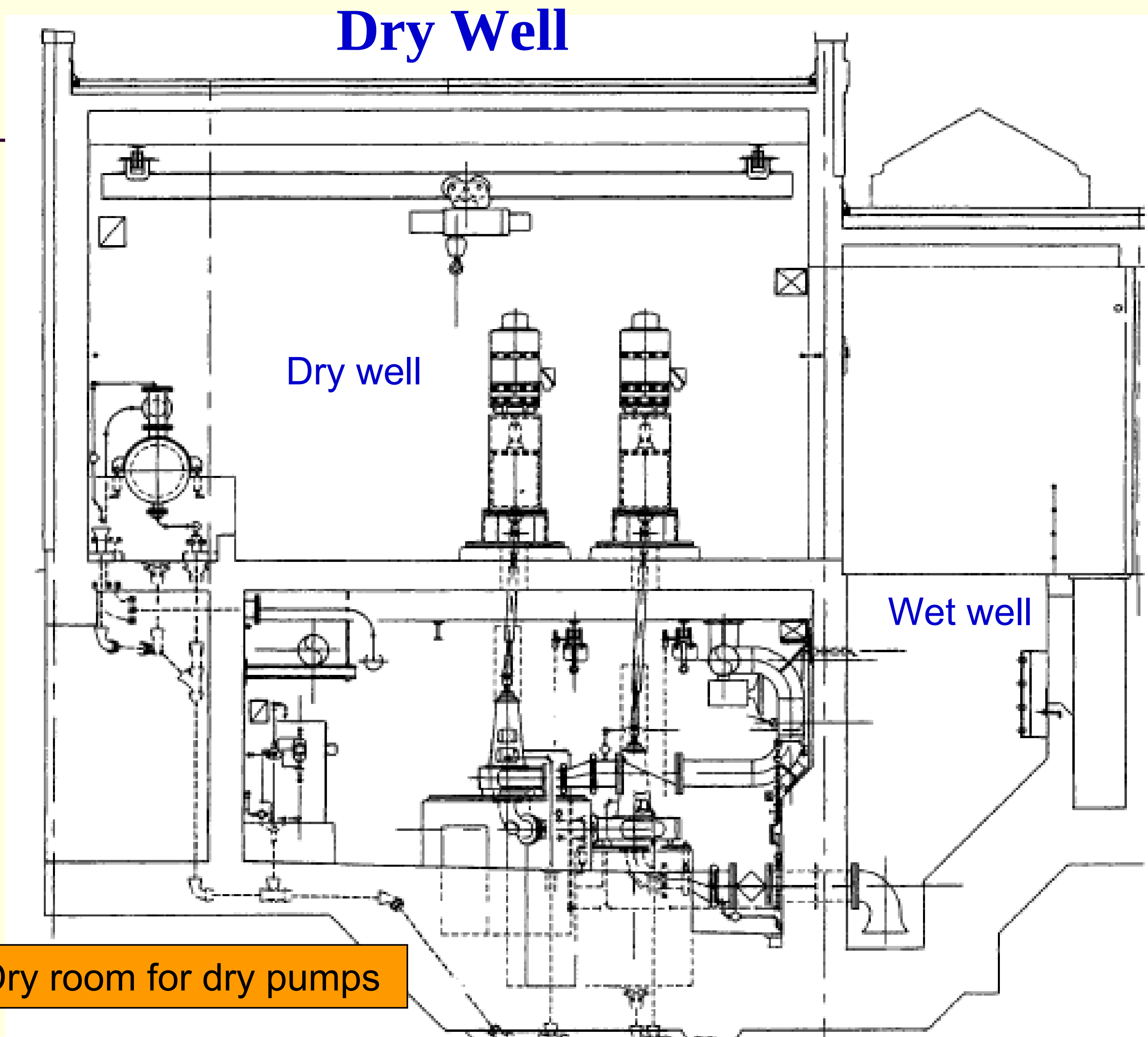


Fig. 5.11 Dry room for dry pumps

5.3 main components of WW pumping station

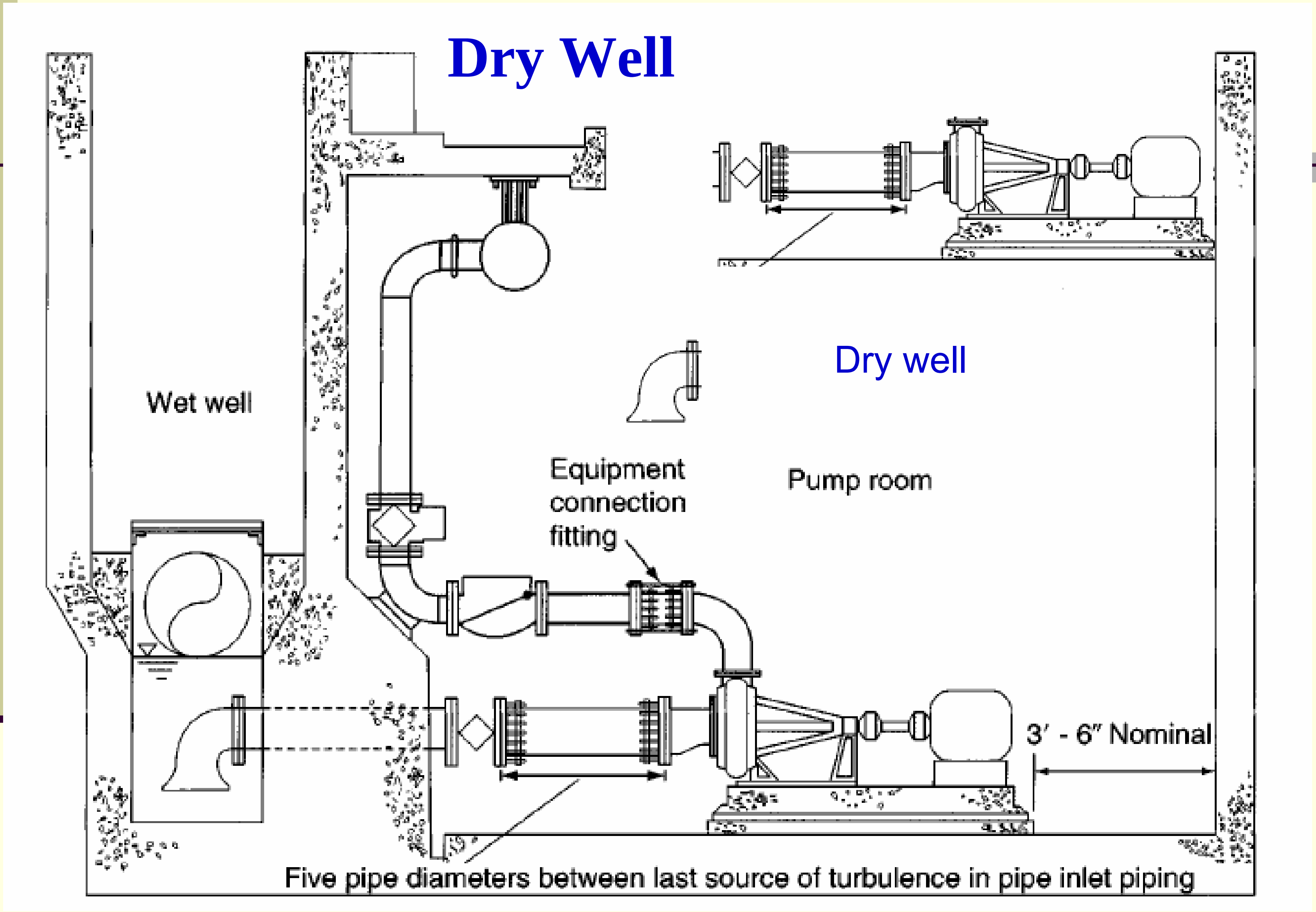


Fig. 5.12 Dry room for dry pumps

5.3 main components of WW pumping station

Dry Well

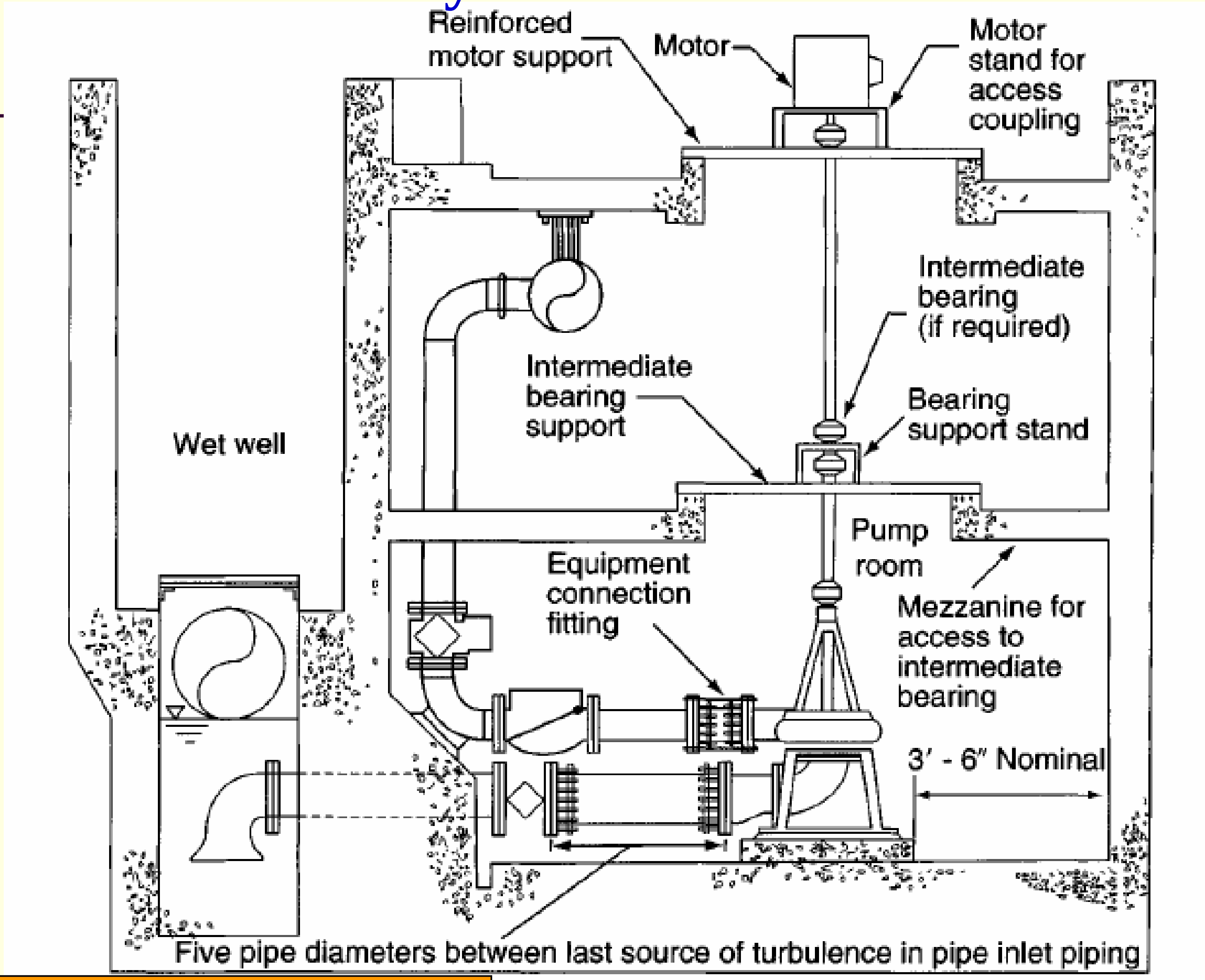


Fig. 5.13 Dry room for dry pumps

5.3 main components of WW pumping station

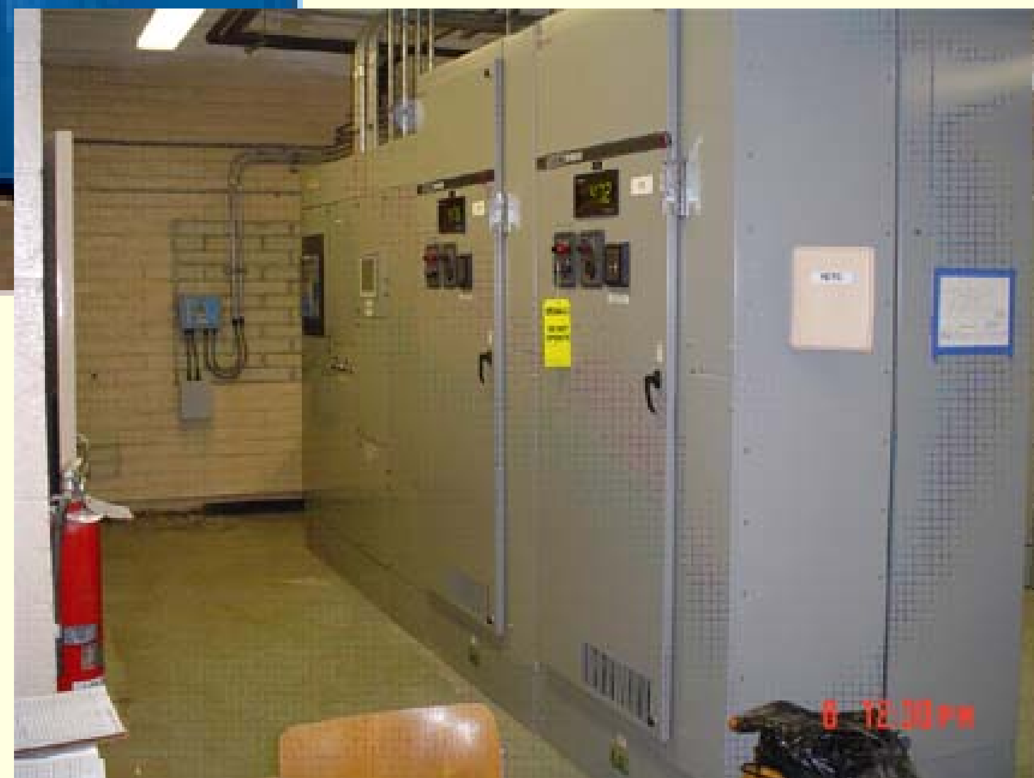


Fig. 5.14 Electricity distribution and control room (MDB + PLC)

5.3 main components of WW pumping station

Stand by Generator

Stand by generator

Fuel tank

Fig. 5.15 Standby generator and its fuel tank

5.3 main components of WW pumping station

Transformer

Transformer room

Fig. 5.15 Electricity Transformer

5.3 main components of WW pumping station

Fig. 5.16 **Service Building**

5.3 main components of WW pumping station

Pumping station fence and gate

Fig. 5.17 **Pumping station fence and gate**

5.3 main components of WW pumping station

Delivery Pipes , valves and manifold

Fig. 5.18 **Delivery Pipes , valves and manifold in WWPS**

5.4 Design of the main components of WWPS

- After the introduction to the main components of WWPS we will study the design of the following components:

  - Design of the general layout of the WWPS
  - Design of Bar screen channel
  - Design of Grit removal channels
  - Design of Wet well for submersible pumps
  - Design of Wet well and dry well for dry pumps
  - Design of the delivery pipes and the pressure line

5.4 Design of the main components of WWPS

5.4.1 Design of the general layout of the WWPS:

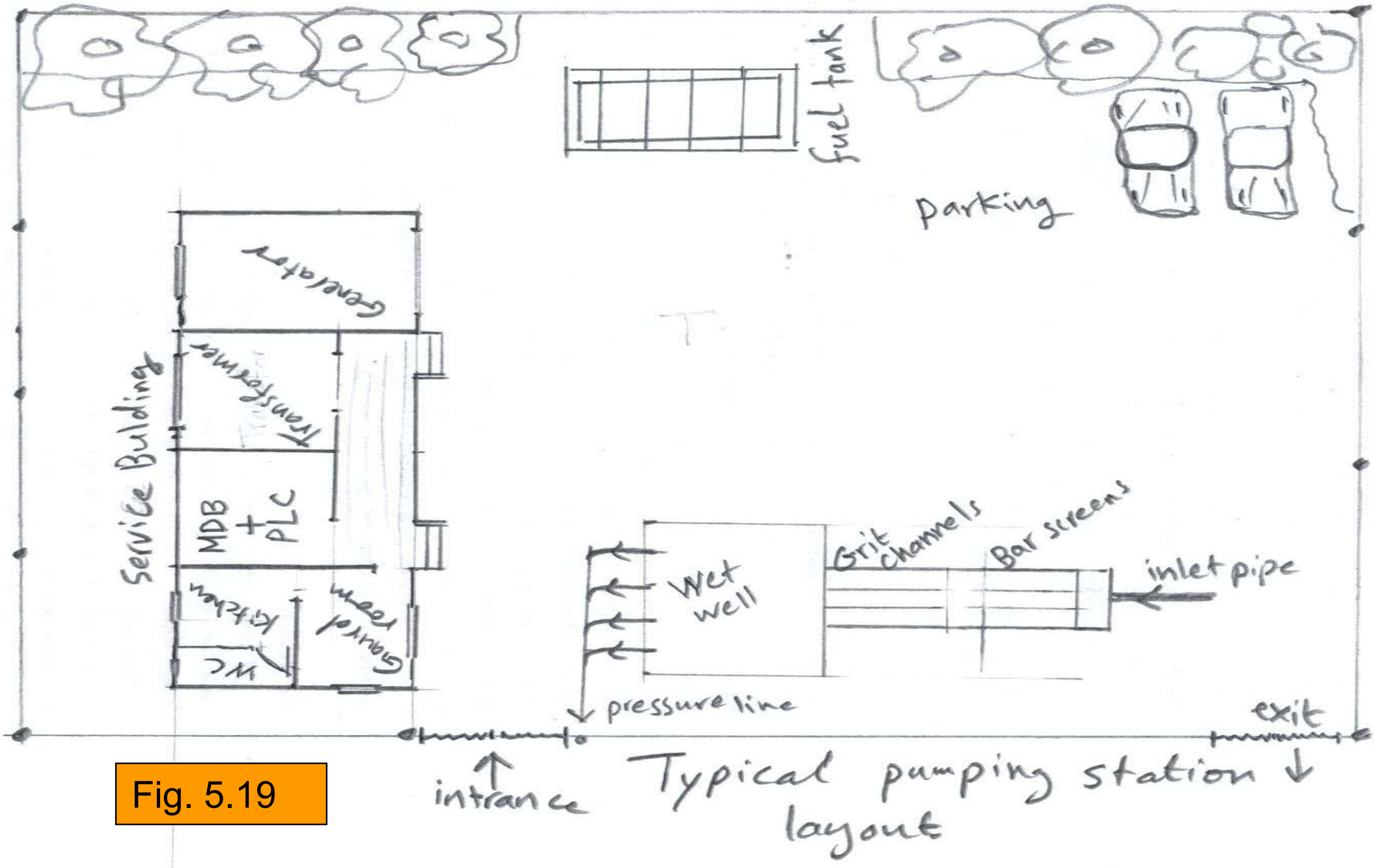


Fig. 5.19

5.4 Design of the main components of WWPS

5.4.2 Design of Bar screens

Screens are used in wastewater treatment for the removal of coarse solids. Screens are either manually or mechanical cleaned.

- **Bar spacing is in range of 2-5 cm**
- **The screen is mounted at an angle of 30-45**
- **Bars are usually 1 cm thick, 2.5 wide**
- **Minimum approach velocity in the bar screen channel is 0.45 m/s to prevent grit deposition.**
- **Maximum velocity between the bars is 0.9m/s to prevent washout of solids through the bars.**

- **Bar spacing is in range of 1.5-4 cm**
- **The screen is mounted at an angle of 30-75**
- **Bars are usually 1 cm thick, 2.5 wide**
- **Minimum approach velocity in the bar screen channel is 0.45 m/s to prevent grit deposition.**
- **Maximum velocity between the bars is 0.9 m/s to prevent washout of solids through the bars.**

5.4 Design of the main components of WWPS

5.4.2 Design of Bar screens

Design of the bar screen channel (Approach Channel)

The cross section of the bar screen channel is determined from the continuity equation:

$Q_d = A_c V_a$

$\mathbf{A_c = Q_d / V_a}$

Q_d = design flow, m^3/s

A_c = bar screen cross section, m2

V_a = Velocity in the approach channel, m/s

Usually, rectangular channels are used, and the ratio between depth and width is taken as 1.5 to give the most efficient section.

The head loss through the bar screen

$$H_l = \frac{(V_b^2 - V_a^2)}{2g} \bullet \frac{1}{0.7}$$

H_l = head loss

V_a = approach velocity, m/s

V_b = Velocity through the openings, m/s

g = acceleration due to gravity, m/s^2

Example

A manual bar screen is to be used in an approach channel with a maximum velocity of 0.64 m/s, and a design flow of 300 L/s. the bars are 10 mm thick and openings are 3 cm wide. Determine:

The cross section of the channel, and the dimension needed
The velocity between bars
The head loss in meters
The number of bars in the screen

1. $A_c = Q_d/V_a = 0.3/0.64 = 0.47$ m2

$A_c = W \times 1.5W = 1.5\, W \times W$

W = 0.56 m, Depth (d) = 1.5 W = 0.84 m

$$A_{net} = A_c \frac{S_c}{S_c + t_{bar}}$$

$= 0.84 \times 0.56\ (3/3+1) = 0.35\ m^2$

From continuity equation: $V_a A_c = V_b A_{net}$

$V_b = 0.64 \times 0.56 \times 0.84/0.35 = 0.86$ m/s < 0.9 m/s ok

3. Head loss:

$$H_l = \frac{(V^2_b - V^2_a)}{2g} \bullet \frac{1}{0.7}$$

$$H_l = \frac{(0.86^2 - 0.64^2)}{2 \bullet 9.81} \bullet \frac{1}{0.7} = 0.024 \text{ m}$$

4. $n\, t_{bar} + (n-1)S_c = W$

$n \times 1 + (n-1) \times 3 = 56$

$n = 14.75 = 15$

5.4.3 Design of rectangular Grit removal channel

Design a set of rectangular grit basins with proportional flow weir for a plant which has a peak flow of 80,000 m^3/day, an average flow of 50,000 m^3/day and a minimum flow of 20,000 m^3/day. Use three basins. Make the peak depth equal to the width. The design velocity (V_h) is 0.25 m/s, Vs = 0.021 m/s

Solution

The peak flow per channel will be 80,000/3 = 26,666 m^3/day = 0.31 m^3/s.

The average flow per channel will be 50,000/3= 16,666 m^3/day = 0.19 m^3/s.

The minimum flow per channel will be 20,000/3= 6,666 m^3/day = 0.077 m^3/s.

$A = Q/V_h$

$A_{peak} = 0.31/0.25 = 1.24\ m^2$.

The water depth D = W = 1.114

Take W = 1.10 m.

Then D = 1.13 m at peak flow

Take the channel depth = 1.50 m

This would provide a freeboard of 37 cm at peak flow.

$L = D\ (V_h/V_s)$

The length of the channel = 1.15 (0.25/0.021)

= 13.7 m

The weir must be shaped so that:

$Q = 8.18 * 10^{-6}\ wy^{1.5}$

***W* = width of the proportional weir at depth y.**

W (mm)	Y (mm)	Q (m^3/min)
120.50	280	4.62
76.70	691	11.4
66.90	909	15.0
59.90	1130	18.6

Note: $Y= Q/(V_h*\mathbf{W})$

5.4.3 Design of rectangular Grit removal channel

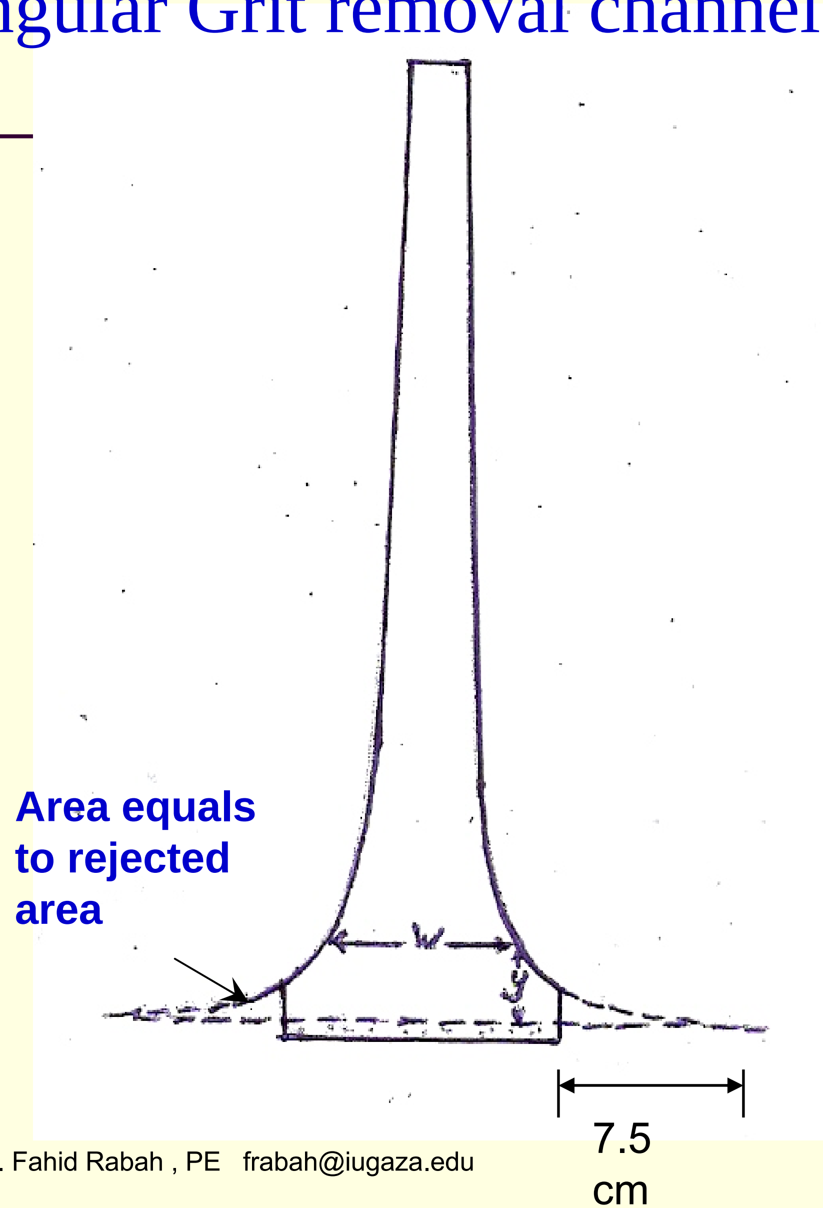


Fig 5.20 Proportional flow weir for use with rectangular grit chamber

5.4 Design of the main components of WWPS

5.4.4 Design of the wet well for submersible pumps

❑ Design of horizontal cross section of the wet well:

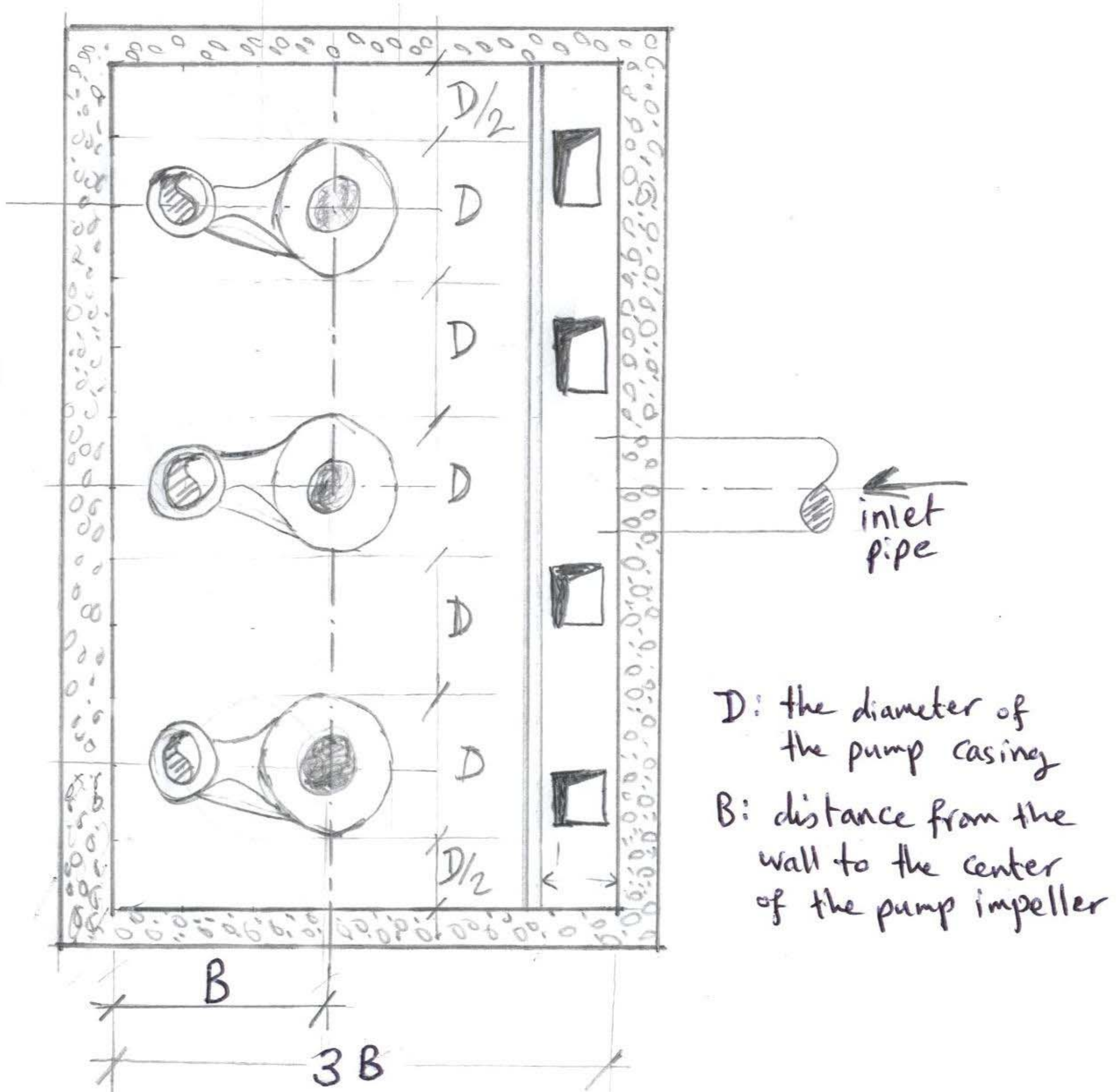
• The dimensions of the horizontal cross section of the wet well depends on the pump size and the recommended distance between the pumps.

• Figure 5.21 shows the recommended dimensions of the horizontal cross section of the wet well . Note that the diameter of the pump casing “D” is the dimension That decides the length of the wet well.

• The second needed distance is B, the distance between the wet well wall and the center of the pump. The distance B is necessary to decide the width of the wet well. The distances D and B is taken from the pump catalogs as those shown in figures 15.23 and 15.22.

• An inlet channel inside the wet well opposite to the inlet pipe is usually needed to As energy breaker to prevent turbulence in the wet well. The width of the channel is usually 50 to 70 cm and its height is equal to the inlet pipe diameter plus 30 cm.

• Figure 15.25 shows a horizontal plan of the wet well at a level above the concrete frame.



Horizontal section of the wet well Showing the typical dimenssions.

Fig. 5.21

5.4 Design of the main components of WWPS

5.4.4 Design of the wet well for submersible pumps

- Design of the vertical cross section of the wet well:
  - Figure 5.24 shows a typical vertical cross section of the wet well.
  - The LWL is taken from the manufacturer catalog of the pump. For example, the LWL for the KSB is indicated as the distance "R" in figure 15. 22.
  - The HWL is calculated from the active volume as will be indicated later. The active volume is the volume between the LWL and the HWL.
  - The HWL is taken as the level of the invert level of the inlet pipe as indicated in figure 15.22. The distance from the HWL to the top of the roof of the wet well depends on the ground level. It is usually preferred to take the level of the top of roof the of the wet well as 50 cm higher than the ground level.
  - As shown in figure 15.22, a hoist and chain should be located above the pump to left it for maintenance. For this purpose a concrete frame should be built to hang the electrical hoist on it. The capacity of the hoist is decided according to the weight of each pump. The weight of the pump is taken from the manufacturer catalog as in figure15.23.
  - A rectangular benching is needed to prevent solids from settling away from the pumps. The dimension of this triangle is shown in figure 15.24.

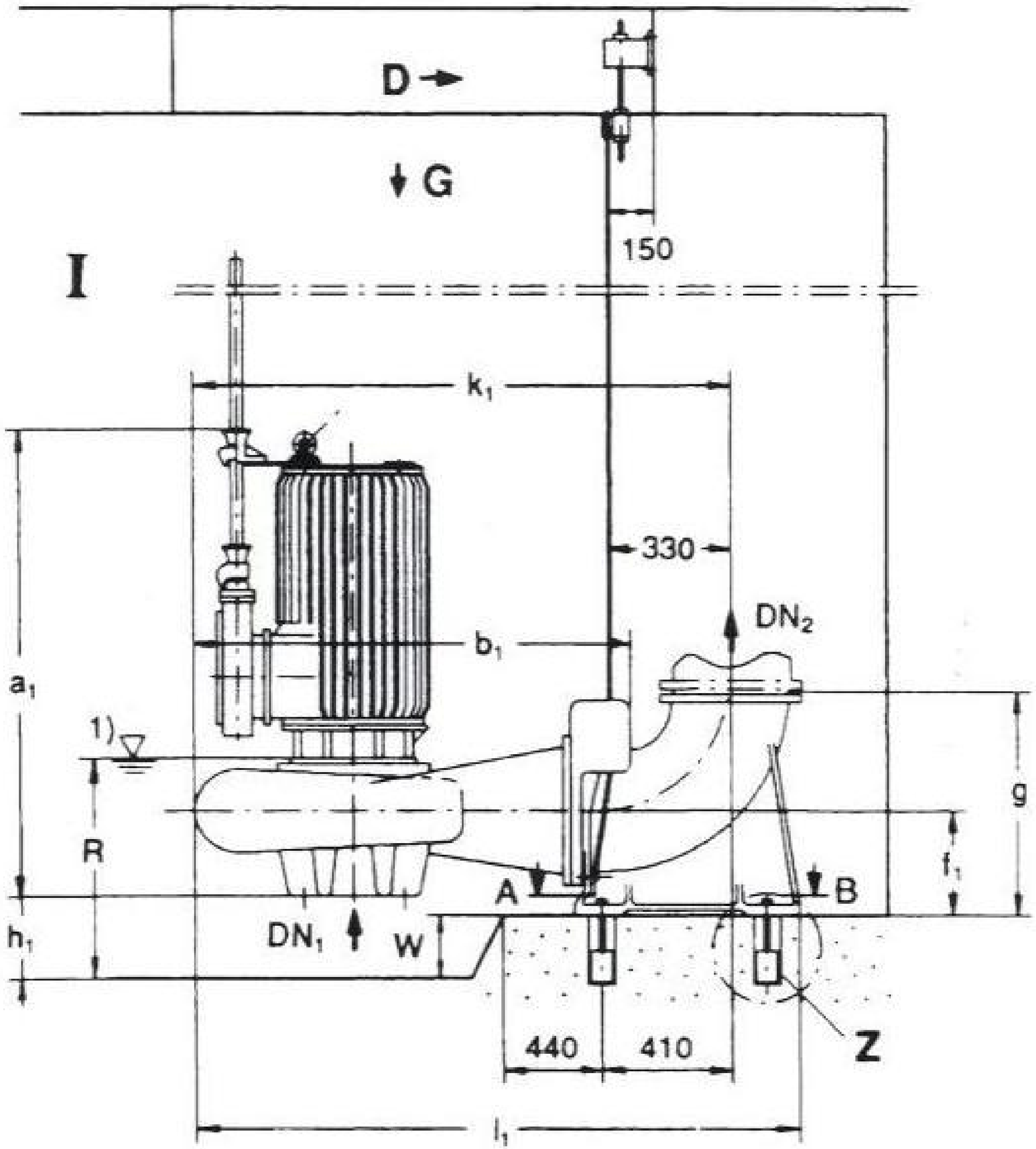
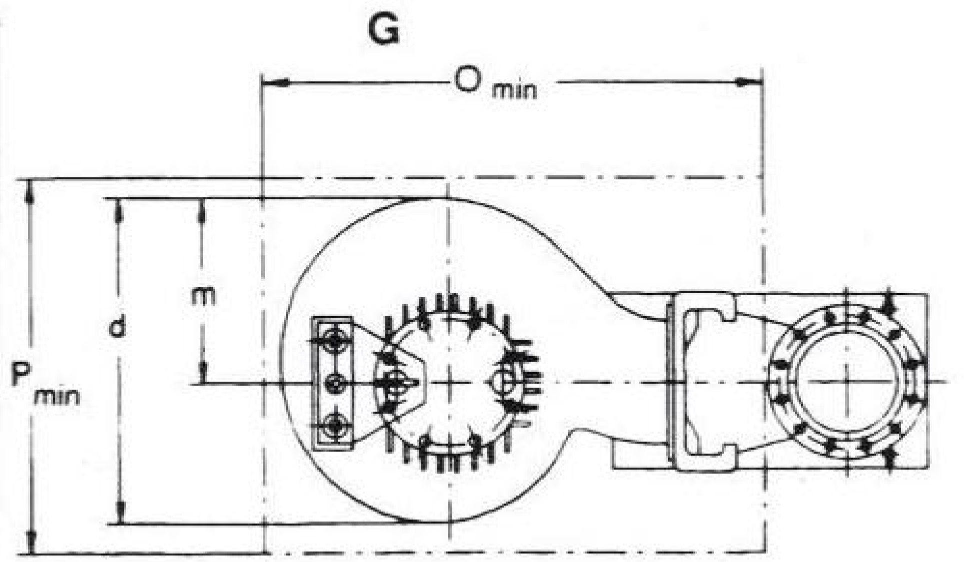


Fig. 5.22 Typical dimensions of a submersible KSB pump needed for the design of the wet well



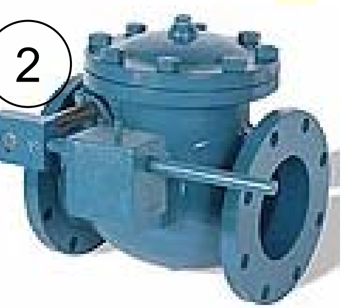
[1] tiefster Ausschaltpunkt bei Automatikbetrieb
[1] Lowest shut-off point for automatic operation
[1] Point d'arrêt le plus bas en service automatique

Flansch / Flange / Bride					
DN_2	g_f	K_f	D_f	Z_f	ø l_f
300	370	400	445	12	22

	KRT ... / ... U/X/W		Pumpe / Pump / Pompe													Fundament / Foundation / Fondation									[kg]
			DN_1	DN_2		a_1	b_1	d	f_1	g	h_1	k_1	l_1	l_2	m	L	M	N	O	P	R	S	V	W	G
K	300-400 /	1104 1	300	300		1640	1285	830	440	840	350	1535	1760	—	480	120	250	—	1500	1060	900	420	65	180	1450
		1354 1			I																				1560
		1504 1																							1600
		2104				1875	1395					1645	—	1945									45		2100
		2504			II																				2250
		2804																							2450
		376 1				1335	1230					1465	1790	—									65		1000
		456 1																							1050
		646 1			I	1440																			1150
		806 1				1430	1265					1515	1740												1350
		1026				1640	1285					1535	1760												1500
K	300-500 /	646 1	300	300		1445	1200	790	440	840	350	1450	1670	—	440	120	250	—	1600	1200	850	420	65	180	1260
		806 1			I	1430	1245					1495	1720						1700						1470
		1026				1640	1265					1515	1740												1580
		1206																							1700
		1386				1878	1375					1625	—	1920					1800				45		2000
		1656			II																				2160
		2006																							2320

0W ... / Cotes en mm

Fig. 5.23 Typical dimensions of a submersible KSB pump needed for the design of the wet well



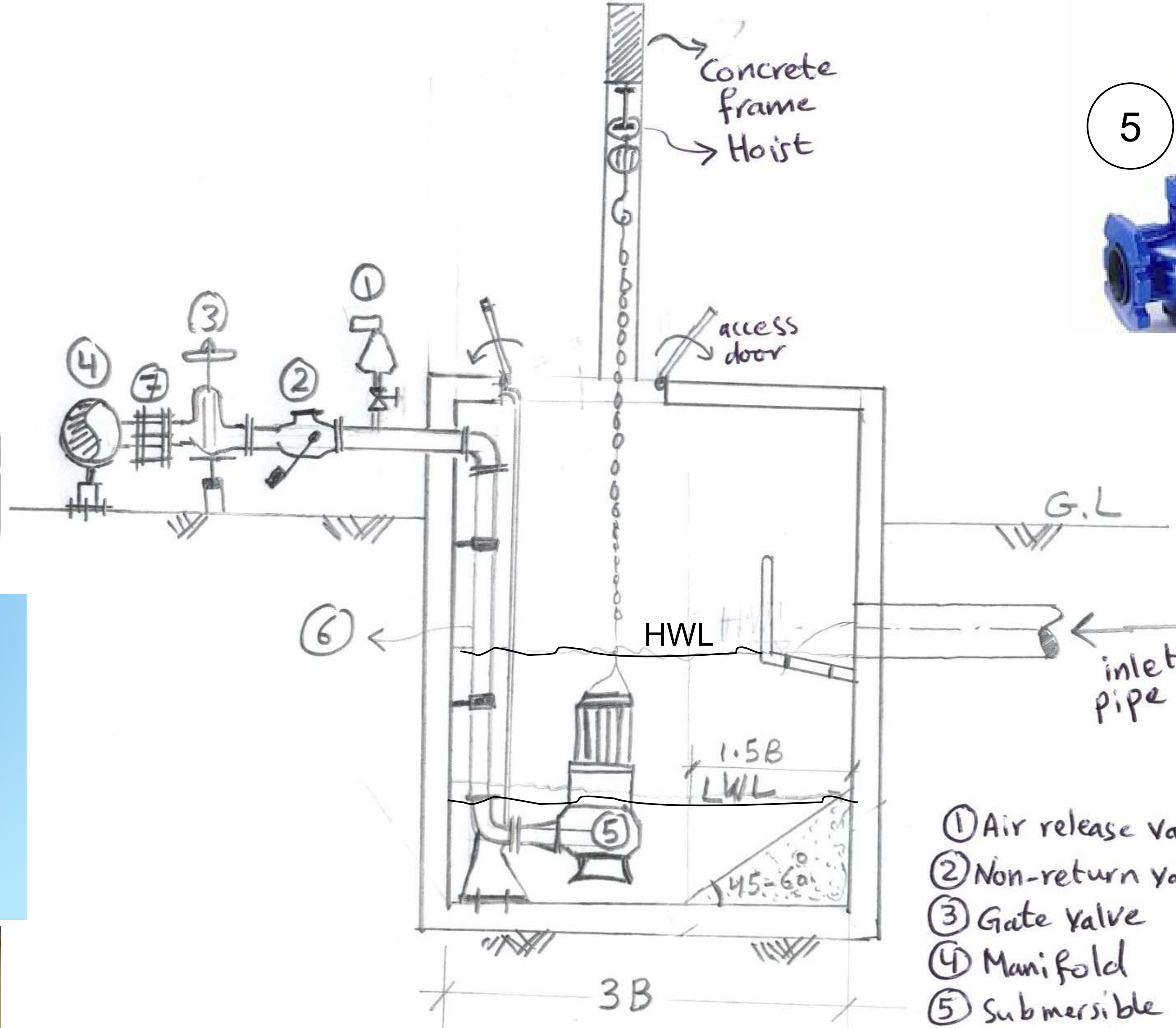
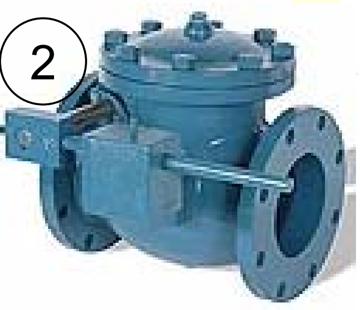
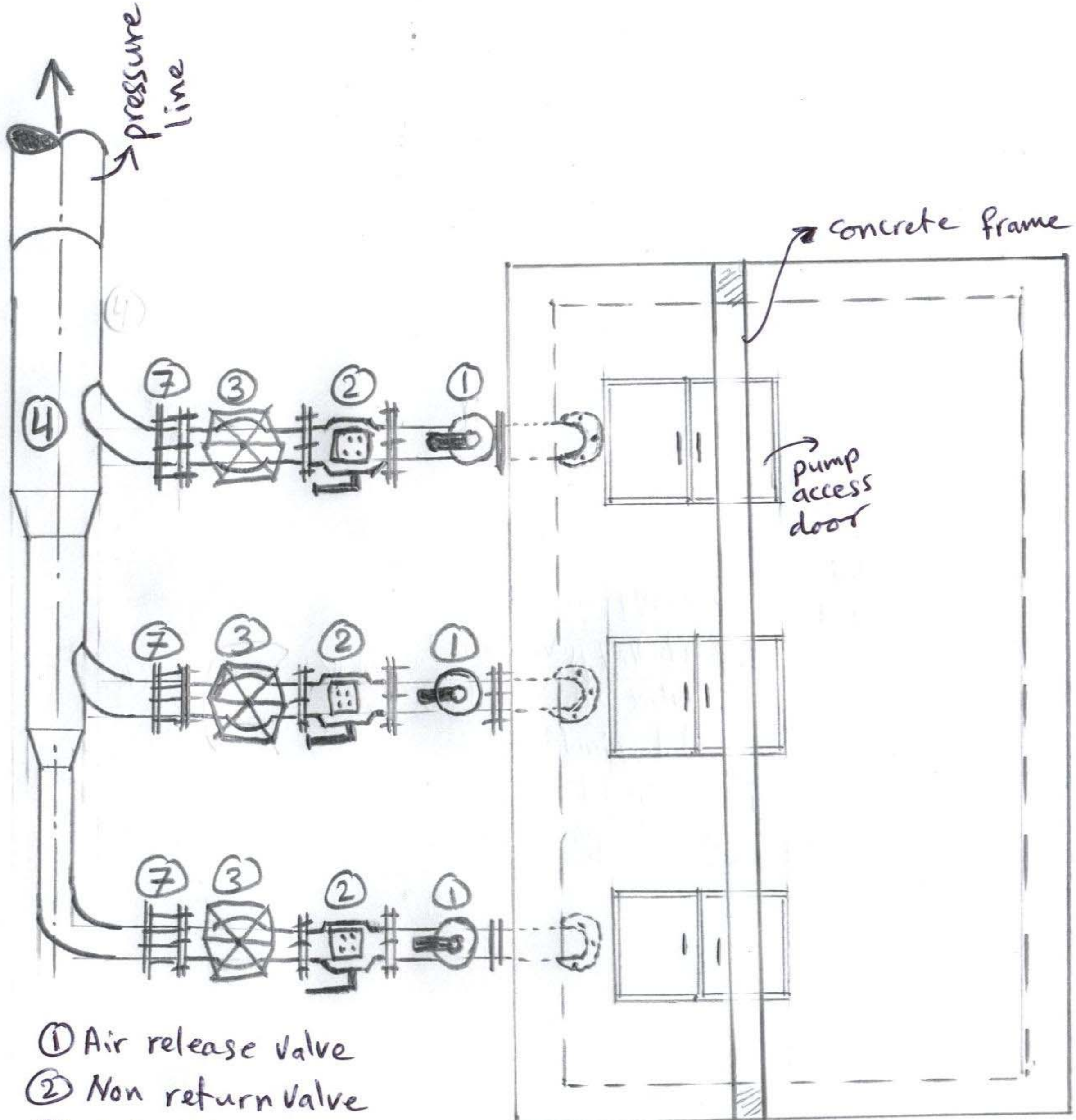


Fig. 5.24 Vertical cross section in a wet well installation

① Air release valve
② Non-return valve
③ Gate valve
④ Manifold
⑤ Submersible pump
⑥ pump delivary pipe
⑦ Dresser (flexiable) Joint





① Air release Valve
② Non return Valve
③ Gate Valve
④ Manifold
⑦ Dresser (flexiable joint)

plan of the wet well

Fig. 5.25

Fig. 5.26

An example of a submersible pump installed in the wet well

Fig. 5.27 A photo at the top of a wet well showing delivery pipes and valves

5.4 Design of the main components of WWPS

5.4.4 Design of the wet well for submersible pumps

- Determination of the wet well active volume:

• The active volume in the wet well is the volume enclosed between the LWL and the HWL.

• This volume depends on many factors such as the number of pumps, the capacity of each pump and the raw WW influent flow rate.

• The active volume (V) when one pump is in operation is calculated from the following equation:

$$V = \frac{Tq}{4}$$

Where:

T: minimum cycle time between pump starts, min.

q : the pumping rate of a single pump in operation, m^3/min

V: active volume for one pump in operation, m^3

$$\text{T} = \text{time to fill} + \text{time to empty}$$

5.4 Design of the main components of WWPS
5.4.4 Design of the wet well for submersible pumps

- Determination of the wet well active volume:

• The cycle time T depends on the pump type and the manufacturer recommendations.

• Typical value of T 6 minutes. This will lead to 10 starts of the pump in 1 hour. it is recommended to limit the number of pump starts to 12 as a maximum to protect the pump and to increase its effective life span.

•If more than a pump is used, an additional 15 cm is added to the height of the wet well for each pump other than the first.

5.4 Design of the main components of WWPS

5.4.4 Design of the wet well for submersible pumps

- Determination of the wet well active volume:

Example:
What is the active volume of a wet well that has 3 pumps working in parallel plus one standby pump. The capacity of one pump when operating alone is 14.7 m^3/min. Take T as 6 minutes. The area of the horizontal cross section of the wet well is 15 m^2 .

Solution:

V = (14.7*6)/4 = 22.05 m^3

Water height = (22.05)/15 = 1.47 m

Total height of active volume = 1.47 + 2*0.15 = 1.77 m

Total active volume = 1.77 * 15 = 26.55 m^3

5.4 Design of the main components of WWPS

5.4.4 Design of the wet well for submersible pumps

- Determination of the wet well active volume:

The pumps operation sequence can be set according to the active volume calculated in the previous example as indicated in the following figure.

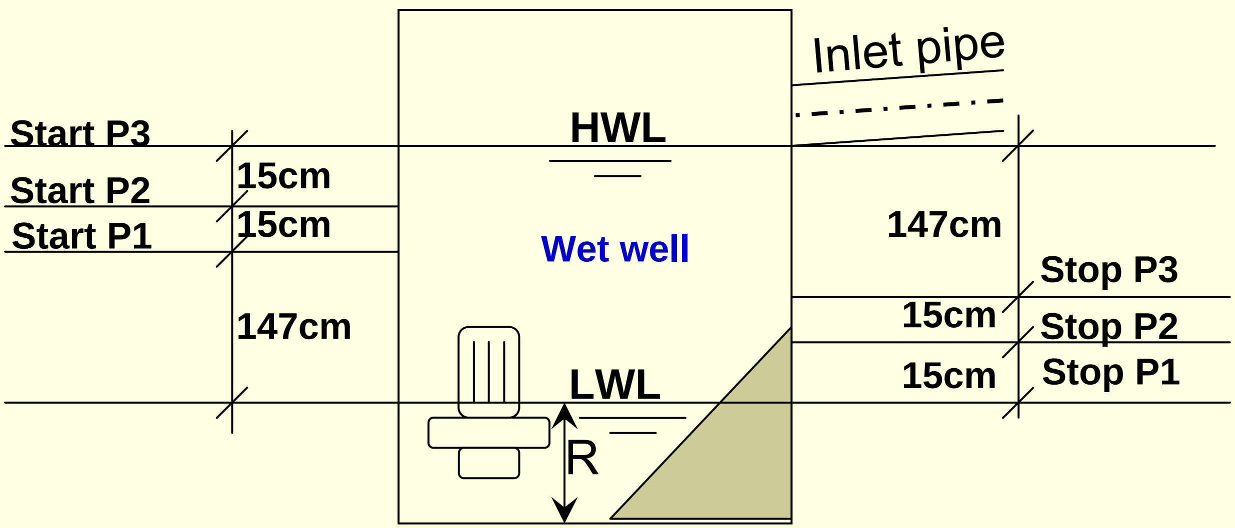


Fig. 5.28 Pumps operation sequence

5.4 Design of the main components of WWPS

Dry well installation

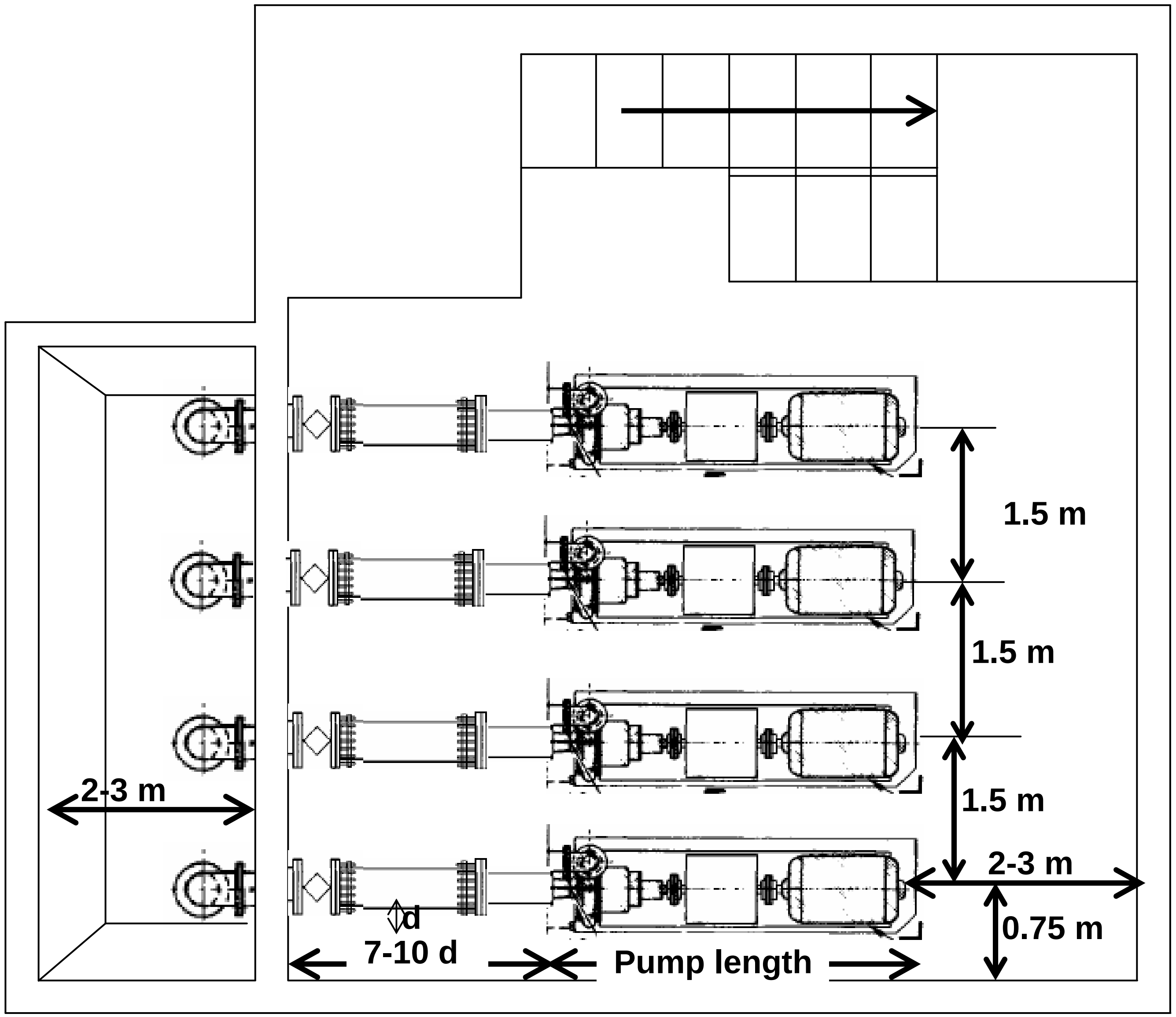


Fig. 5.29 Typical dimensions of the horizontal section of dry well installation

5.4 Design of the main components of WWPS

Dry well installation

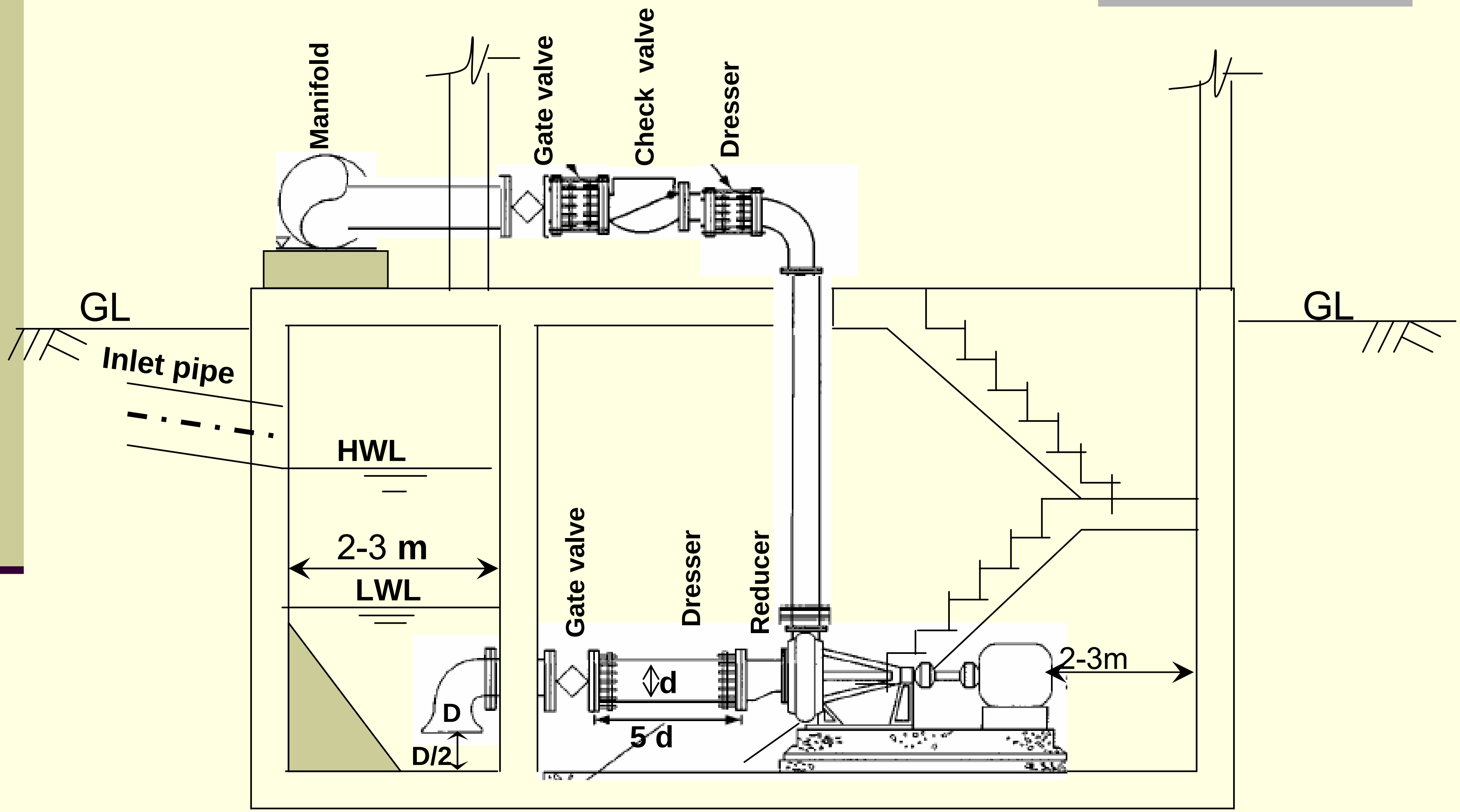


Fig. 5.30 Typical dimensions of the vertical section of dry well installation

5.4 Design of the main components of WWPS

5.4.5 Design of the wet and dry wells for dry pumps

- Figure 5.29 gives the typical dimensions of the the horizontal cross section of the dry and wet well installation.

- Figure 5.30 gives the typical dimensions of the the vertical cross section of the dry and wet well installation.

- The active volume and pump operation sequence is the same as for the wet wall installation as discussed in the previous example.

5.4 Design of the main components of WWPS

5.4.6 Design of the delivery pipes and the pressure line:

- ❑ pressure line (selecting the most economical diameter)
- ❑ delivery pipes
- ❑ Valves on the pressure line
- ❑ Thrust block

5.4 Design of the main components of WWPS

5.4.6 Design of the delivery pipes and the pressure line:

- Delivery pipes:

A delivery pipe is the pipe that connects the pump with the manifold. The diameter of this pipe is determined using the Continuity equation:

$$D = \left[\frac{4Q_{pump}}{\pi V} \right]^{\frac{1}{2}}$$

Where:

D = pipe diameter, m

Q_{pump} = discharge of one pump when operation alone, m^3/d

V = flow velocity, m/s

The velocity in delivery pipes is usually assumed in the range of 2-2.5 m/s. Q pump is the determined from the intersection between the system curve and The characteristic curve of a single pump in operation.

5.4 Design of the main components of WWPS

5.4.6 Design of the delivery pipes and the pressure line:

- The friction losses in the delivery pipe are calculated using the Hazen Williams equation :

$$h_f = \frac{10.7 * L}{D^{4.87}} \left[\frac{Q}{C} \right]^{1.852}$$

- The minor losses in the delivery pipe are calculated using the following equation :

$$h_m = k \frac{V^2}{2g}$$

- The material of the delivery pipes is usually steel, but some times UPVC pipes are used. The Thickness of the pipe wall is determined according to the pressure Exerted on the pipe, especially water hammer pressure.

- The valves and fittings installed on the delivery pipe are shown on Figures 15.24 and 15.25

5.4 Design of the main components of WWPS

5.4.6 Design of the Manifold:

- Manifold:

The manifold is the pipe that connects the delivery pipes with the main pressure line. As shown on Figure 15.25 the diameter of the manifold is variable diameter of this pipe is determined using the Continuity equation:

$$D = \left[\frac{4Q}{\pi V} \right]^{\frac{1}{2}}$$

Where:

D = pipe diameter (variable) according to the # of pumps in operation, m

Q = discharge (variable) according to the # of pumps in operation, m^3/d

V = flow velocity (variable) according to the # of pumps in operation, m/s

- The velocity in the manifold is usually assumed in the range of 1 to 2 m/s.

Q is Q_{pump} for the first segment (the smallest), and equals Q_{2pumps} for the second segment and Q_{3pumps} for the second third segment and so on.

Some designers us constant diameter of the manifold designed for Q_{3pumps} .

5.4 Design of the main components of WWPS

5.4.6 Design of the Manifold :

- The friction losses in the manifold pipe are calculated using the Hazen Williams equation :

$$h_f = \frac{10.7 * L}{D^{4.87}} \left[\frac{Q}{C} \right]^{1.852}$$

- The minor losses in the manifold pipe are calculated using the following equation :

$$h_m = k \frac{V^2}{2g}$$

- The material of the manifold pipes is usually steel, but some times UPVC pipes are used. The Thickness of the pipe wall is determined according to the pressure Exerted on the pipe, especially water hammer pressure.

5.4 Design of the main components of WWPS

5.4.6 Design of the main Pressure line (Rising main):

- Selecting the diameter:

The main pressure line is the pipe that connects the manifold with ponit of disposal. Its determined is determined using the Continuity equation:

$$D = \left[\frac{4Q_{peak}}{\pi V} \right]^{\frac{1}{2}}$$

Where:

D = pipe diameter (variable) according to the # of pumps in operation, m

Q_{peak} = discharge (variable) according to the # of pumps in operation, m^3/d

V = flow velocity at peak flow, m/s

- The velocity at peak flow in the main pressure line is usually assumed in the range of 1 to 2 m/s. However the velocity when one pump in operation should not be less than 0.60 m/s.

5.4 Design of the main components of WWPS

5.4.6 Design of the Manifold :

- The friction losses in the main pressure line are calculated using the Hazen Williams equation :

$$h_f = \frac{10.7 * L}{D^{4.87}} \left[\frac{Q}{C} \right]^{1.852}$$

- The minor losses in the main pressure line are calculated using the following equation :

$$h_m = k \frac{V^2}{2g}$$

- The material of the main pressure line is usually steel, but some times UPVC pipes are used. The Thickness of the pipe wall is determined according to the pressure Exerted on the pipe, especially water hammer pressure.

5.4 Design of the main components of WWPS

5.4.6 Design of the main Pressure line (Rising main):

- Selecting the most economical diameter for the main pressure line:

• As understood from the continuity equation, D is a function of V, so there are many combinations of D and V that satisfy the equation. Since we , as engineers, look for the most economical design we usually try to use the smallest pipe Diameter, Unfortunately, when D decreases, V increases, consequently the Power needed and the operation cost increases. So we need to select the most Optimum combination between D and V. This is done using the graph shown below (Figure 15.31).

• From figure 15.31, when we add up the capital cost and the operation cost we get the concave up curve. The point of inflection indicates the minimum total Cost. From this point draw a vertical line that will intersect the X-axis at the most Optimum diameter.

• Notice that the running cost paid along the life span of the pump station and the Pressure line so the values on figure 15.31 are the present worth value of the Running cost. The capital cost is paid in one payment at the beginning of the project.

5.4 Design of the main components of WWPS

5.4.6 Design of the main Pressure line (Rising main):

- Selecting the most economical diameter for the main pressure line:

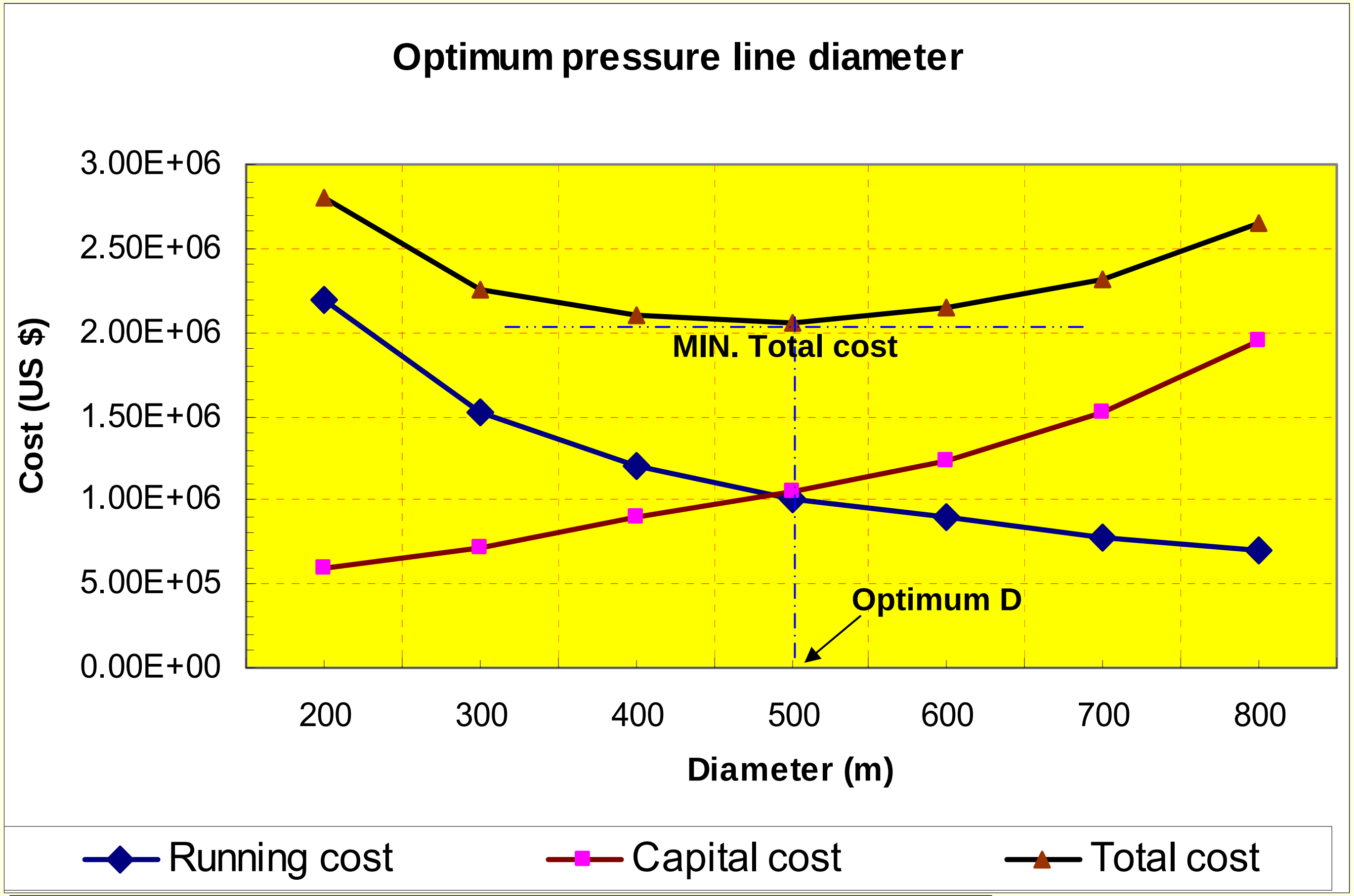


Fig. 5.31 Optimum pipe diameter

5.4 Design of the main components of WWPS

5.4.6 Design of the main Pressure line (Rising main):

- Valves and tanks installed on the main pressure line:
  - There are two main valves that are installed on the pressure lines:

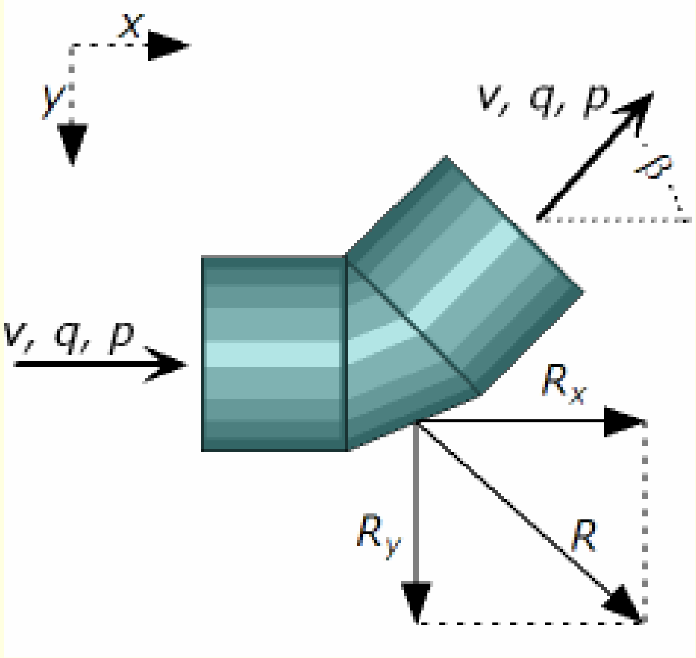
1. Air release /Vacuum valves are installed at:
   - All height points
   - long rising segments at intervals of 750 to 1000 m
   - long descending segments at intervals of 750 to 1000 m
2. Drainage valves are :
   - All low point
   - Long rising and flat pipes at intervals of 500 m
3. Pressure relief valves are installed at:
   - Low points along the pipe where high pressure is expected
   - locations related to water hammer waves such as before valves or after pumps. If other tools are used to control water hammer, these valves will be not necessary.
4. Surge tanks and Air champers are installed at:
   - Just after the pumps.
   - At high points a long the pipe to prevent column separation.

5.4 Design of the main components of WWPS

5.4.6 Design of the main Pressure line (Rising main):

- Thrust blocks installed on the main pressure line:

Thrust blocks are concrete blocks installed along the pressure lines at horizontal and bends vertical to protect the pipe from the water thrust force created due to The change in direction.



5.4 Design of the main components of WWPS

5.4.6 Design of the main Pressure line (Rising main):

- Thrust blocks installed on the main pressure line:

The resulting force due to mass flow and flow velocity can be expressed as :

$$R_x = \rho\pi\left(\frac{d}{2}\right)^2 \bullet V^2(1-\cos\beta)$$

$$R_y = \rho\pi\left(\frac{d}{2}\right)^2 \bullet V^2 \sin\beta$$

$$R = (R_x^2 + R_y^2)^{\frac{1}{2}}$$

Rx = resulting force in x-direction (N)
Ry = resulting force in y-direction (N)
R = Resultant of the x and y forces (N)
v = flow velocity , m/s
β = bend angle , degrees
ρ = fluid density, kg/m
d = internal pipe diameter , m

5.4 Design of the main components of WWPS

5.4.6 Design of the main Pressure line (Rising main):

- Thrust blocks installed on the main pressure line:

Resulting force due to Static Pressure:

$$R_x = P\pi\left(\frac{d}{2}\right)^2(1-\cos\beta)$$

$$R_{py} = P\pi\left(\frac{d}{2}\right)^2 \sin\beta$$

$$R_p = (R_{px}^2 + R_{py}^2)^{\frac{1}{2}}$$

R_{px} = resulting force due to pressure in x-direction ,N

R_{py} = resulting force due to pressure in x-direction ,N

Rp= resultant force on the bend due to pressure, N

P = gauge pressure inside pipe (Pa, N/m^2)

5.4 Design of the main components of WWPS

5.4.6 Design of the main Pressure line (Rising main):

See also chapter 4

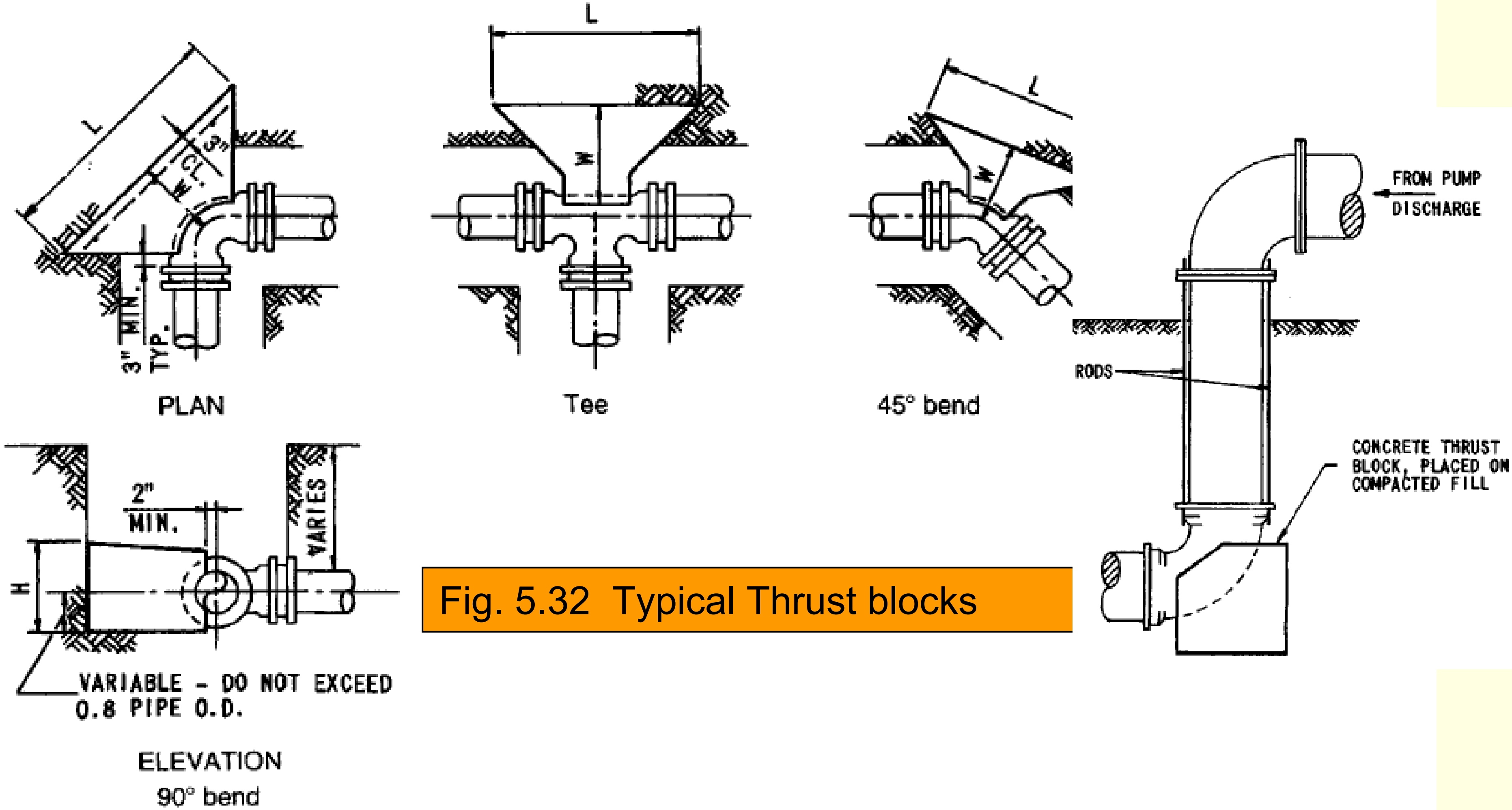


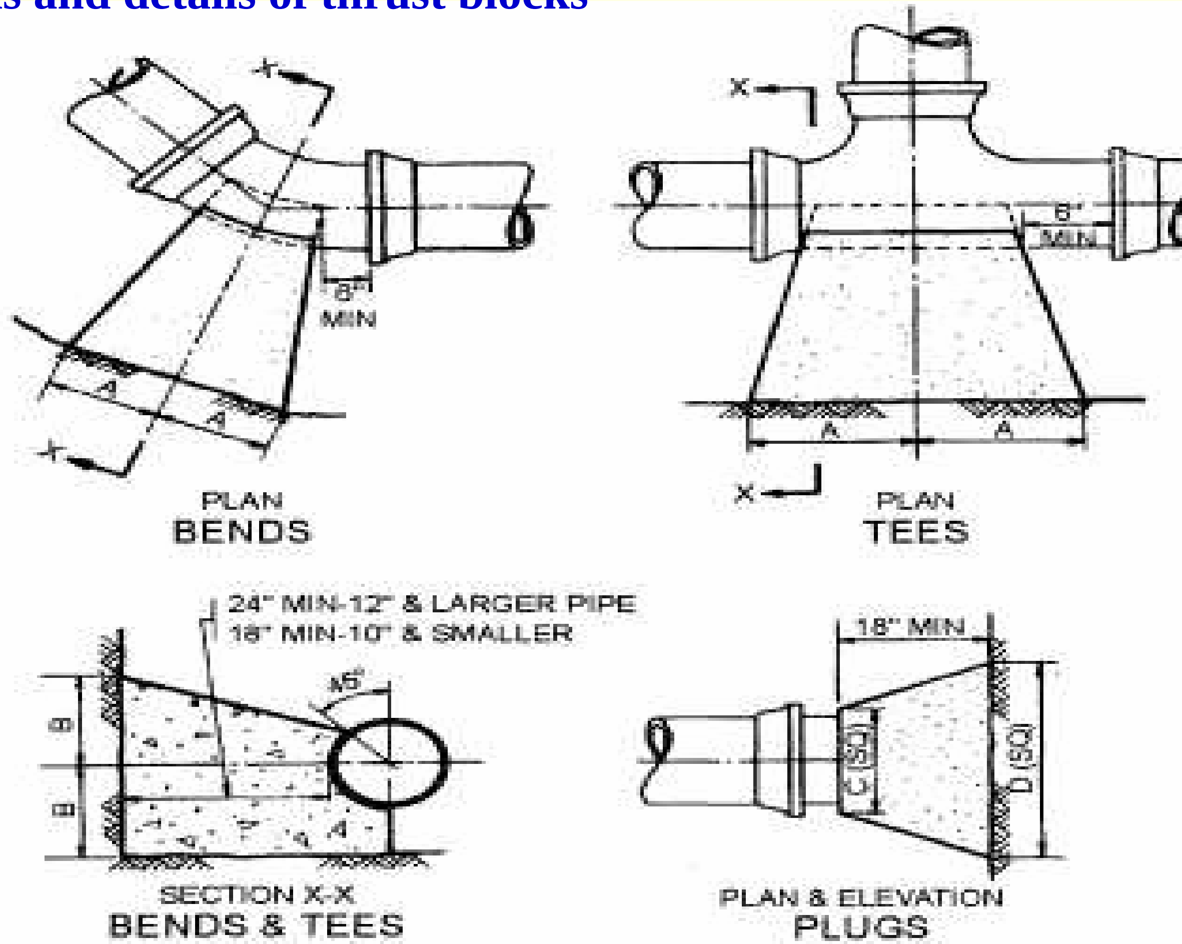
Fig. 5.32 Typical Thrust blocks

5.4 Design of the main components of WWPS

5.4.6 Design of the main Pressure line (Rising main):

Fig. 5.33 Thrust block under construction

Typical dimensions and details of thrust blocks



TYPE	SIZE	1/4 BENDS		1/8 BENDS		1/16 BENDS		TEES		PLUGS	
		A	B	A	B	A	B	A	B	C	D
TYPE I 4000 PSF SOIL	6"	8"	10"	6"	8"	3"	8"	8"	8"	10"	15"
	8"	12"	12"	8"	10"	5"	9"	9"	12"	12"	20"
	10"	16"	14"	10"	12"	6"	10"	11"	14"	14"	25"
	12"	19"	16"	12"	14"	8"	11"	14"	16"	16"	30"
	14"	23"	18"	14"	16"	10"	12"	16"	18"	18"	34"
	16"	26"	20"	16"	18"	11"	13"	18"	20"	20"	38"
TYPE II 2000 PSF SOIL	6"	16"	10"	9"	10"	6"	8"	10"	12"	10"	21"
	8"	22"	13"	12"	13"	8"	10"	13"	16"	12"	29"
	10"	26"	17"	14"	17"	10"	13"	16"	20"	14"	36"
	12"	29"	21"	16"	21"	11"	16"	18"	24"	16"	41"
	14"	35"	24"	19"	24"	12"	20"	22"	27"	18"	48"
	16"	38"	27"	21"	27"	12"	24"	24"	30"	20"	54"