CIV3264
URBAN WATER AND WASTEWATER SYSTEMS

Introduction to Wastewater System Design and Practice

Session 3 - Hydraulics of Grit Chambers

Introduction

- Grit may cause problems in:
  - Pumps
  - Sludge digestion
  - Dewatering facilities
  - In addition, it may settle out in downstream pipes and processes
- The grit removal process is carried out at an early stage of treatment because:
  - The particles cannot be broken down by biological process
  - The particles are abrasive and wear down equipment

Introduction

- Grit chambers are designed to remove inorganic solids > 2 mm
- Removal is commonly effected using:
  - Settlement
  - Separation using a vortex
  - Settlement in the presence of aeration (to keep the lighter organic particles in suspension)
- There are important hydraulic principles associated with each of these

Contents of Lecture

- In this lecture:
  - The three main types of grit chamber are described
  - The hydraulic aspects of the operation of each are described qualitatively and - where appropriate - quantitatively
  - Design aspects are discussed

Choice of Grit Removal Process

- The choice of grit removal process depends largely on the size of the STP
  - PE < 5,000
    - Horizontal flow (constant velocity) unit (utilises settling)
  - 5,000 < PE < 10,000
    - Vortex type grit chamber
  - PE > 10,000
    - Aerated grit chamber (vortex type may sometimes be used)

Choice of Grit Removal Process

- Whichever type is used, it is vital that the unit must operate over the full range of expected flows
- Other (non-hydraulic) design considerations include:
  - Grit removal from unit (manual or mechanical)
  - Handling, storage, and disposal of grit
  - Provision of standby or bypass facilities

Horizontal Constant Velocity Grit Chamber

- This is basically an open channel with a detention time sufficient to allow design particles to settle
- Additionally, the velocity must be high enough to scour organic materials
  - Organic materials should pass through the grit chamber for subsequent biological treatment

Velocity Considerations

- The Camp-Shields equation is commonly used to estimate the scour velocity required to resuspend settled organic material

$$v_s = \sqrt{\frac{8kgd}{f} \left| \frac{\rho_p - \rho}{\rho} \right|}$$

where v_s is the velocity of scour

d is particle diameter

k is an empirical constant

f is the Darcy-Weisbach friction factor

ρ_p is the particle density

ρ is the fluid density

Velocity Considerations

$$v_s = \sqrt{\frac{8kgd}{f} \left| \frac{\rho_p - \rho}{\rho} \right|}$$

- Typically, this equation yields a required horizontal flow velocity of 0.15 - 0.3 m/sec
  – Design recommendation is 0.2 m/sec
- Primary hydraulic design issue is:
  – How do we ensure that this velocity will be maintained over a range of flows?
- We discuss the problem on the next slide

Velocity Considerations

- Assume a rectangular channel with the flow passing over a rectangular weir

  The discharge relationship for the weir is

$$Q = C_d B \sqrt{2g} H^{3/2}$$

(Refer to notes from course on Design of Flow Measurement Systems)

The horizontal velovity, v_h, is related to the flow rate, Q, and channel geometry by

$$v_h = \frac{Q}{Bh} = C_d \sqrt{2g} H^{1/2}$$

Substituting for $H^{1/2}$ from the weir equation

$$v_h = C_d \sqrt{2g} \left| \frac{Q}{C_d \sqrt{2g} B} \right|^{1/3}$$

Velocity Considerations

$$v_h = C_d \sqrt{2g} \left(\frac{Q}{C_d \sqrt{2g} B} \right)^{1/3}$$

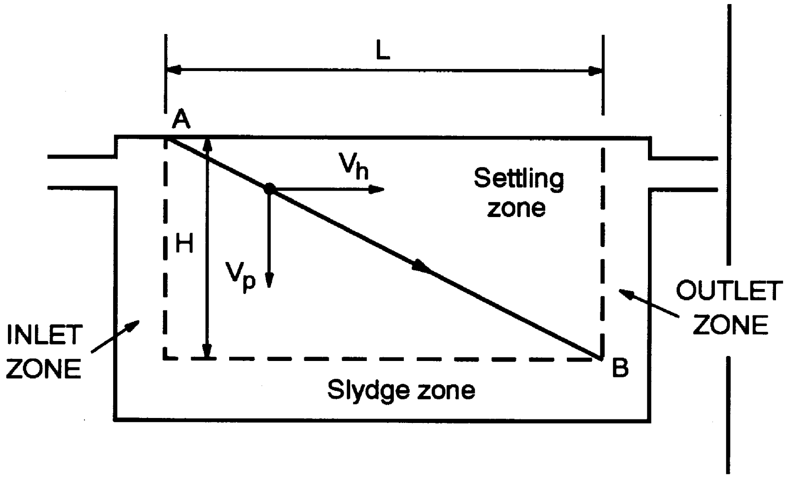
$$\therefore \frac{v_{h(\max)}}{v_{h(\min)}} = \left(\frac{Q_{\max}}{Q_{\min}} \right)^{1/3}$$

- Now, if the ratio of $\frac{Q_{\max}}{Q_{\min}}$ is 5:1 (a typical value), then the corresponding value of $\frac{v_{h(\max)}}{v_{h(\min)}}$ would be $(5)^{1/3} = 1.71$
- If 0.2 m / sec is chosen for $v_{h(\min)}$, the corresponding value of $v_{h(\max)}$ would be 0.342 m / sec
- This is too large
- We must modify either the channel or the weir to maintain a satisfactory horizontal velocity

Settling Properties

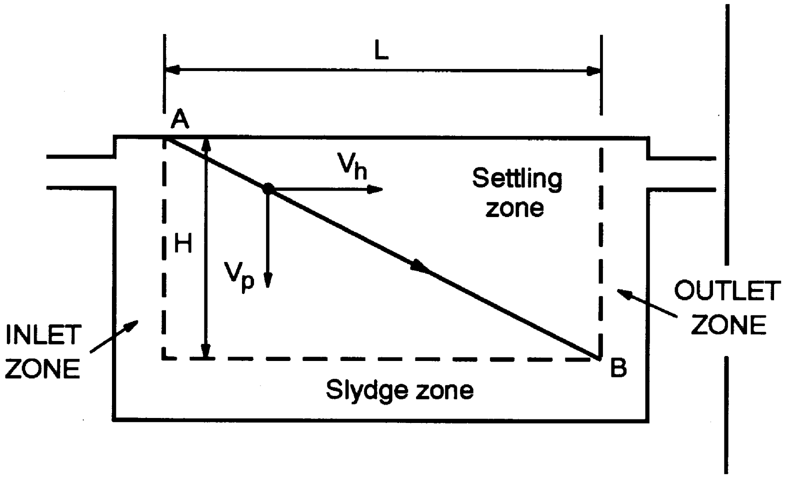
- Before examining different methods of maintaining constant velocity, we examine ideal settling properties of a tank
- For simplicity, we assume a rectangular tank cross section

Settling Properties



- The tank has four zones:
  - Inlet zone
  - Outlet zone
  - <u>Settling zone</u>
  - Sludge zone
- At this stage, we consider only the settling zone

Settling Properties



- The particle will travel vertically from A to B in the same time as it takes to travel horizontally from A to B
- This is the detention time and is given by

$$t_d = \frac{H}{v_p} = \frac{L}{v_h}$$

- Furthermore, $v_h = \dfrac{Q}{BH}$ (continuity)

Settling Properties

$$t_d = \frac{H}{v_p} = \frac{L}{v_h}$$

$$v_h = \frac{Q}{BH}$$

$$\therefore v_p = v_h \frac{H}{L} = \frac{Q}{BH}\frac{H}{L} = \frac{Q}{BL}$$

- *BL* is the surface area of the tank
- $\frac{Q}{BL}$ is termed the surface loading rate
- The equation shows that the basin design is independent of depth
- The surface area of the tank is defined in terms of the flow rate and the particle settling velocity

Settling Properties

$$v_p = \frac{Q}{BL}$$

- This equation indicates also that the sedimentation efficiency is independent of detention time in the basin
- This is not a mathematical oddity
- Consider a basin with the flow uniformly introduced over the surface area of the basin, resulting in an upflow velocity of v_0
  - Any particle with a fall velocity> v_0 will be removed (settled) after being introduced, regardless of the detention time in the basin
  - Likewise, any particle for which $v_p < v_0$ will eventually exit with the effluent overflowing from the basin

Channel Modification

- How can we modify the channel shape to keep the velocity constant for all flow rates?
- We assume that the channel discharges into a rectangular control section (eg a long-throated or Parshall flume)
  - This device is used as a water level control and/or a flow measurement device

Channel Modification

- Let w_t be the width of the rectangular throat section in the long-throated flume (w_t is constant)
- The flow through the throat is:

$$Q = \left|\frac{2}{3}\right|^{3/2} \sqrt{g} w_t y^{3/2}$$

(refer to notes on Design of Flow Measurement Systems)

$$\therefore dQ = \sqrt{\frac{2}{3} g} w_t y^{1/2} dy \qquad (1)$$

- Within the channel:

$$v_h = \frac{Q}{wy}$$

or $$Q = v_h wy$$

- Therefore the flow through an elemental horizontal strip of width w in the channel is

$$dQ = v_h wdy \qquad (2)$$

Channel Modification

$$dQ = \sqrt{\frac{2}{3}g} w_t y^{1/2} dy \qquad (1)$$

$$dQ = v_h w dy \qquad (2)$$

$$\therefore \sqrt{\frac{2}{3}g} w_t y^{1/2} dy = v_h w dy$$

- Solving this equation for *w*:

$$w = \sqrt{\frac{2}{3}g} \frac{w_t}{v_h} y^{1/2}$$

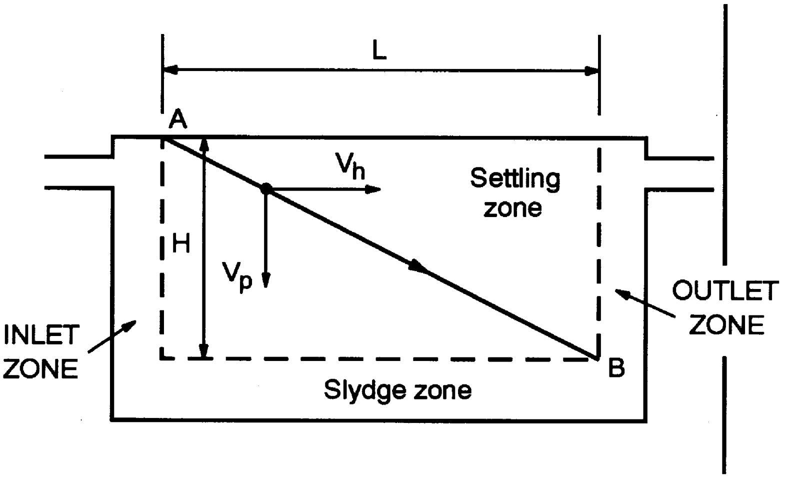
or $$w = \text{constant } y^{1/2}$$

- This describes a parabola, indicating that a parabolic shape for the channel cross section will ensure constant v_h regardless of flow rate

Channel Modification

- Practical Design Hydraulics:
  - To reduce construction costs, the parabolic shape is approximated with a trapezoid
  - One channel and a bypass or two or more channels should be installed
  - Determine design flows
    - Maximum
    - Average
    - Minimum
    - Emergency (maximum flow with one channel out of service)

Channel Modification



- Turbulence occurs in the inlet zone as the flow is established
- A similar phenomenon occurs in the outlet zone as the flow streamlines turn upwards
- Normally a 25 - 50% increase in the calculated settling length is applied to allow for these

Channel Modification Typical Design Criteria

Water Depth (m)	0.6-1.5	Dependent on channel area and flow rate
Length (m)	3 - 25	Function of channel depth & grit settling vel.
Extra for in- & outlet	25 - 50%	Based on theoretical length
Detention at peak flow	15-90 secs	Function of velocity and channel length
Horizontal vel. (m/sec)	0.15-0.4	0.2 specified in Guidelines for Developers

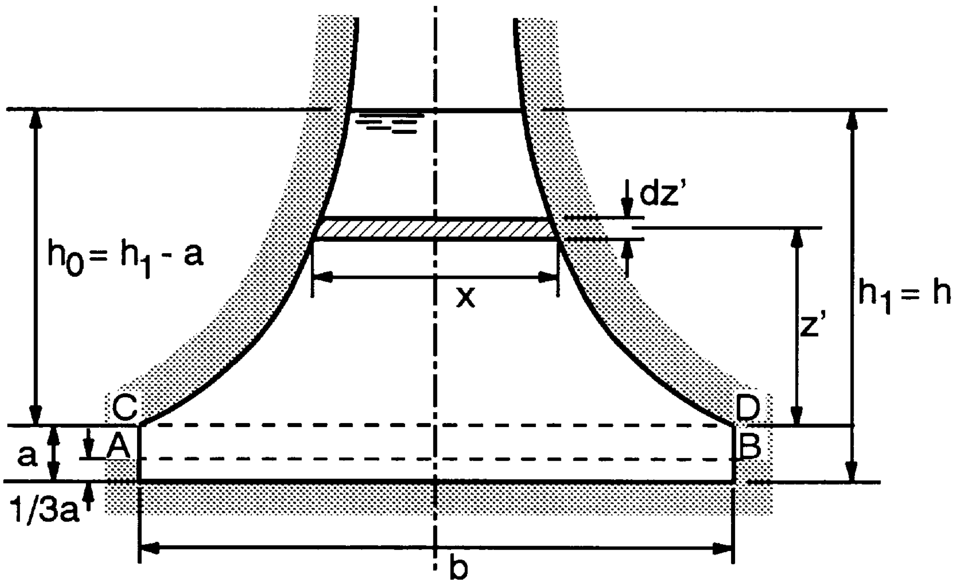
Horizontal Grit Channel

- Design procedure for parabolic channel is illustrated in the notes with an example
- Hydraulic aspects of weir modification:
  - We seek a weir which will promote a constant velocity through the grit channel, regardless of flow rate
    - ie designed to give a linear relationship between flow rate and head on crest

Weir Modification

- Such a weir is called a Sutro or proportional weir
- The weir can be used in conjunction with a rectangular grit channel to ensure a constant velocity at all flow rates

Weir Modification



Now, flow through the curved section is

$$Q = C_d \sqrt{2g} \int_0^{h_0} \left(h_0 - z'\right)^{1/2} x dz'$$

It can be shown that this is equivalent to

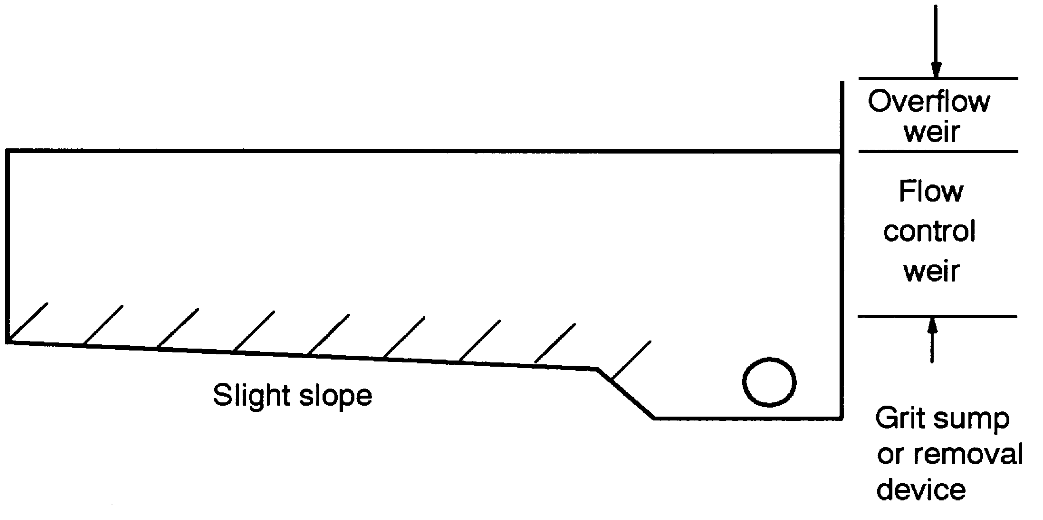
$$Q = 1.57 C_d \sqrt{2g} L h^{3/2}$$

where L is the opening width at an elevation h
It is evident that a linear $Q - h$ relationship is maintained if $Lh^{1/2}$ is kept constant

Weir Modification

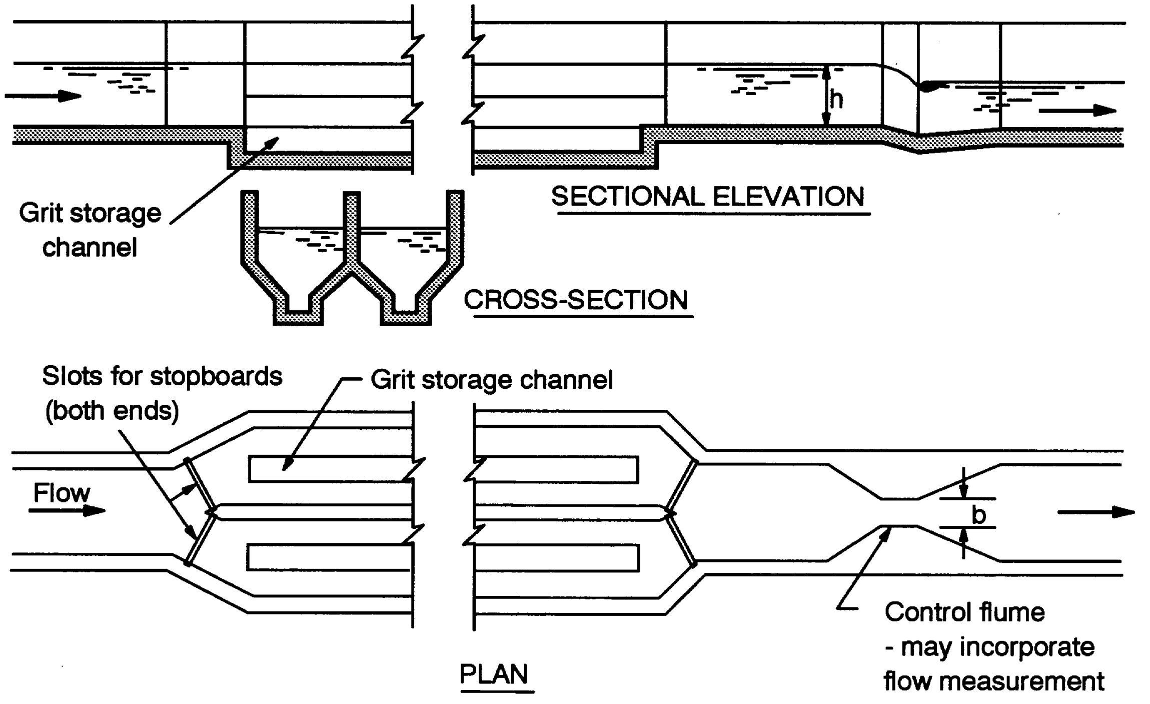
- Practical aspects:
  - C_d typically has a value of 0.6
  - The curved profile cannot be taken right to $h = 0$, because this would imply a width of infinity
    - Usual to cut off the ends of the weir with a vertical line of about 2 cm
  - Equation given will assure a close-to-linear response
    - But if high accuracy is desired, calibrate the meter
  - To allow sufficient nappe aeration TWL>0.05m below crest

Design Aspects



- Channel should slope slightly towards the grit well
- Volume provided for grit storage depends on cleaning frequency and grit quantities

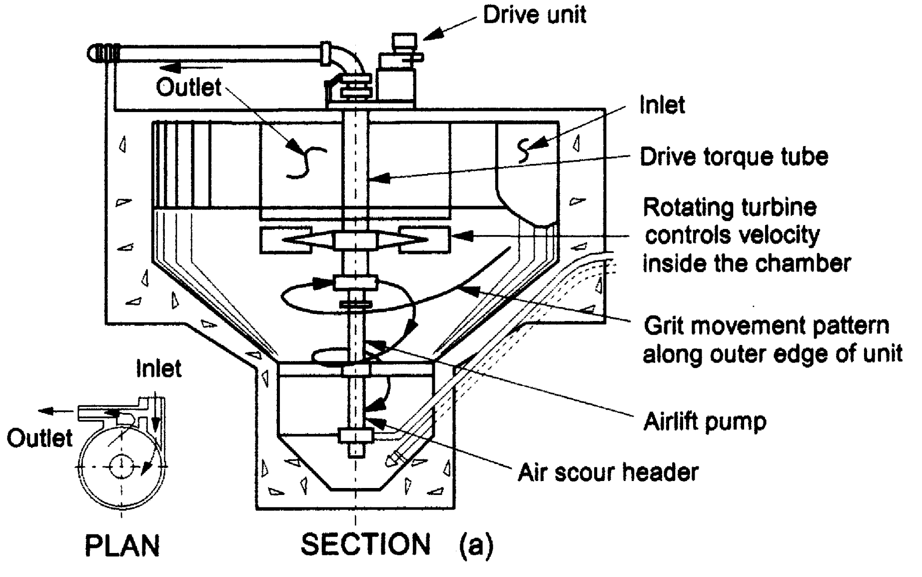
Typical Horizontal Grit Chamber

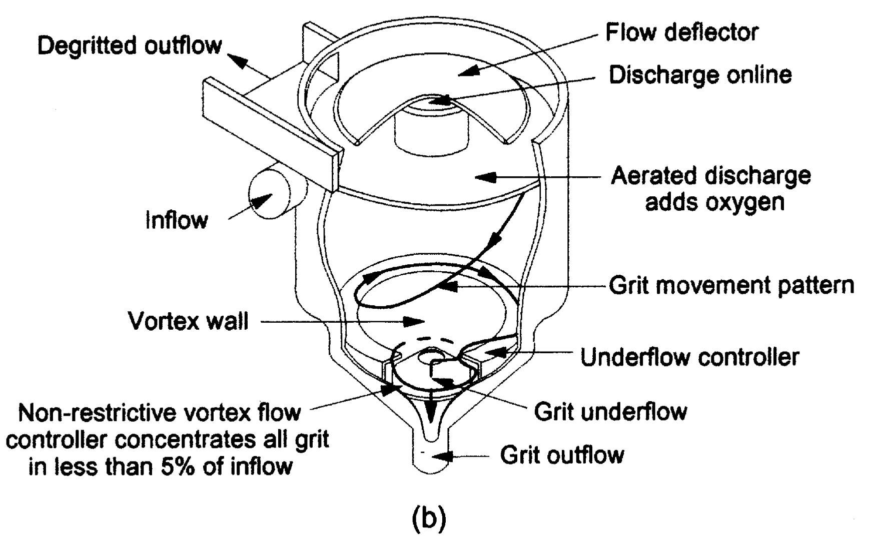


Hydraulic Head Losses

- Depend primarily on control downstream
- If proportional weir is used:
  - Head loss is proportional to the maximum water depth if weir is unsubmerged
    - Less if weir is submerged
- If rectangular flume used:
  - Head loss is typically 30 - 40 % of the maximum water depth
    - Check literature on flow measurement structures

Vortex Grit Chambers





Vortex Grit Chambers

- Grit-laden flow enters the unit tangentially at the top
- The spiralling flow pattern tends to lift lighter organic particles
- This mechanically induced vortex captures grit at the centre
- The grit is removed by air-lift or through a hopper

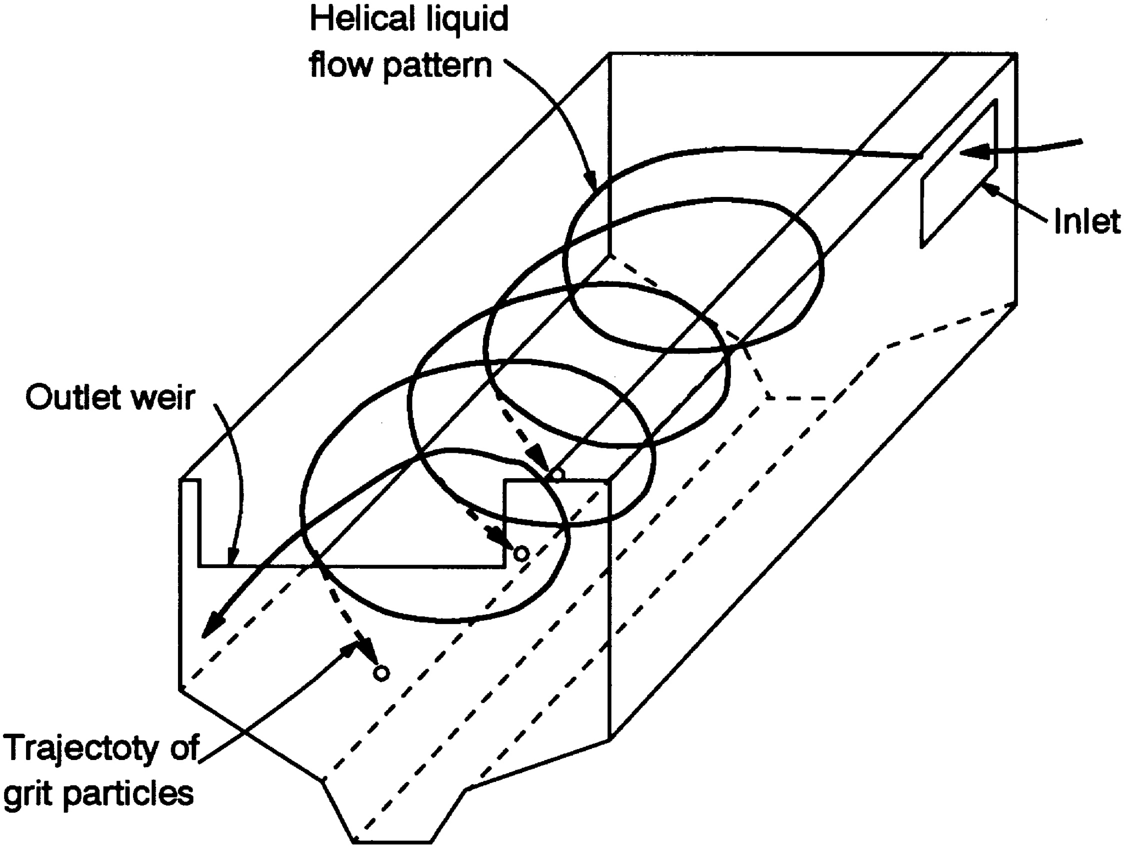
Vortex Grit Chambers

- Units are usually compact
- Design is usually proprietary
- Adjustable rotating paddles maintain the proper circulation within the unit for all flows
  - These paddles may collect rags
- Highly energy efficient
- Grit sump can become compacted and clog
  - May require high-pressure agitation water or air to clear

Vortex Grit Chambers - Hydraulic Issues

- Important to allow for head loss across unit
  - This is minimal when operating correctly and unclogged
    - 6 mm (ASCE Manual)
- Manufacturer's specifications will provide information on maximum water depth in chamber

Aerated Grit Chamber



Aerated Grit Chamber

- Commonly used in medium to large plants
- The introduction of air through a diffuser induces a spiral flow pattern in the sewage as it moves through the tank
- The roll velocity is sufficient:
  - To maintain organic particles in suspension while allowing heavier grit particles to settle
- Air supply is adjustable to provide optimum roll velocity for different conditions

Aerated Grit Chamber

- Sewage is freshened by air, leading to odour reduction
- Chamber can be used also for chemical addition, mixing, and flocculation ahead of primary treatment if desired
- Grease removal may be achieved with a skimmer
- Typical design specifications are given in the following slide

Aerated Grit Chamber

Detention time at peak flow rate	3 minutes
Depth	2 - 5 m
Length	8 - 20 m
Width	2.5 - 7 m
Width/Depth	1:1 - 5:1
Length/Width	3:1 - 5:1
Air supply	0.2-0.5m^3/min/m

Aerated Grit Chamber Hydraulic Issues

- Head loss across an aerated grit chamber is “minimal”
- Detention time of about 3 minutes is recommended
- Tank inlet and outlet are positioned so that the flow through the tank is perpendicular to the roll pattern
- Inlet and outlet baffles dissipate energy and minimise short-circuiting

Summary

- In this lecture we have looked at:
  - The three main types of grit chamber
  - The qualitative and - where appropriate - quantitative hydraulic aspects of the operation of each
  - Design aspects