# ENVE 301
# Environmental Engineering Unit Operations

## Lecture 12
## Sedimentation II

SPRING 2014

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# Example - 1

A horizontal flow sedimentation tank has an overflow rate of 17 $m^3/m^2.d$. What percentatge removal should be expected for each of the following settling velocities?

a) 0.1 mm/s

b) 0.2 mm/s

c) 1 mm/s

Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

# Type II Settling
# Flocculent Settling

- Particles flocculate during settling
- These types of particles generally occur in;
  - Alum or iron coagulation
  - Wastewater primary sedimentation
  - Settling tanks in trickling filters

# Type II Settling
# Flocculent Settling

- Stoke's equation cannot be used to describe Type II settling, because n flocculating particles constantly change in size and shape
- As water trapped in the floc, specific gravity increases
- No adequate mathematical modeling to describe Type II settling
- Settling characteristics are determined by settling column tests.

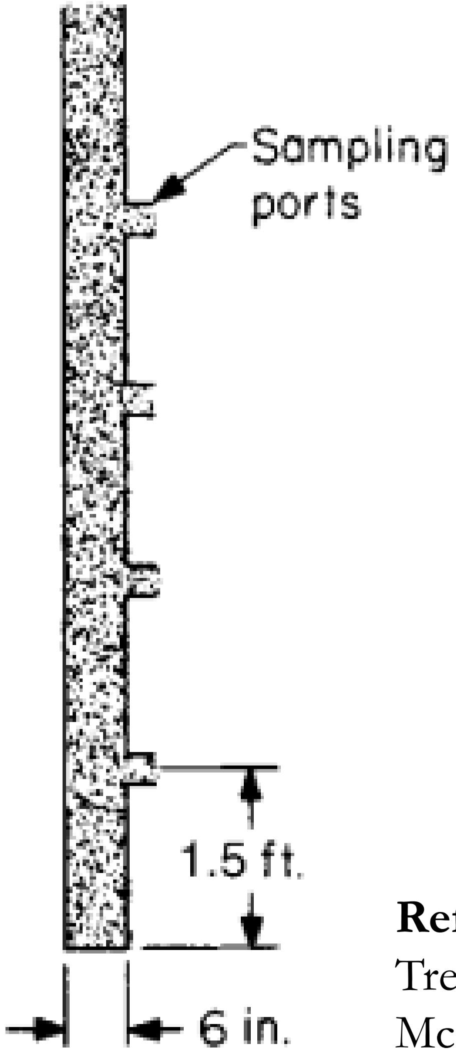
# Type II Settling
## Settling column model

Laboratory settling column tests can be used to

- Model the behaviour of flocculant settling
- Evaluation of existing settling tanks
- Developing data for plant expansion or modification

However, not pratical for the desing of new treatment plants – not easy to estimate concentration of particles that will come from the coagulation/flocculation units

# Type II Settling
## Settling column model




- Settling column: 130-205 mm in diameter to minimize side wall effects
- Height should be at least equal to the proposed sedimentation tank
- Sampling ports should be provided at equal intervals in height.

**Ref:** American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

# Type II Settling
## Settling column model

Settling column experimental procedure

- The suspension must be mixed thoroughly
- Suspended solids (SS) content should be determined
- Suspension should be poured rapidly into the column to ensure that a uniform distribution
- Suspension allowed to settle
- Temperature variation for more than 1$^{o}$C should be avoided

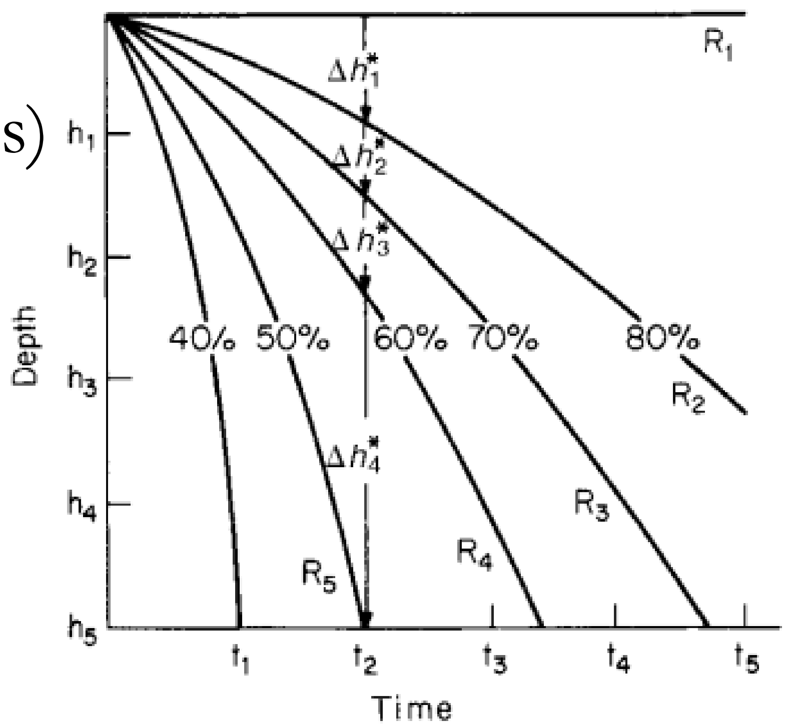
# Type II Settling
## Settling column model

- Samples should be removed from the ports at periodic time intervals, SS concentration should be determined
- Percent SS removal is calculated for each sample
- Percent removal is plotted on a "time" versus "depth of collection" graph
- Percent removal lines (R curves)

are drawn by interpolation

$$R\% = \left[1 - \frac{C_t}{C_o}\right] * 100$$

Co: initial concentration, mg/L
Ct: concentration at time t, at given depth, mg/L



# Type II Settling
# Settling column model

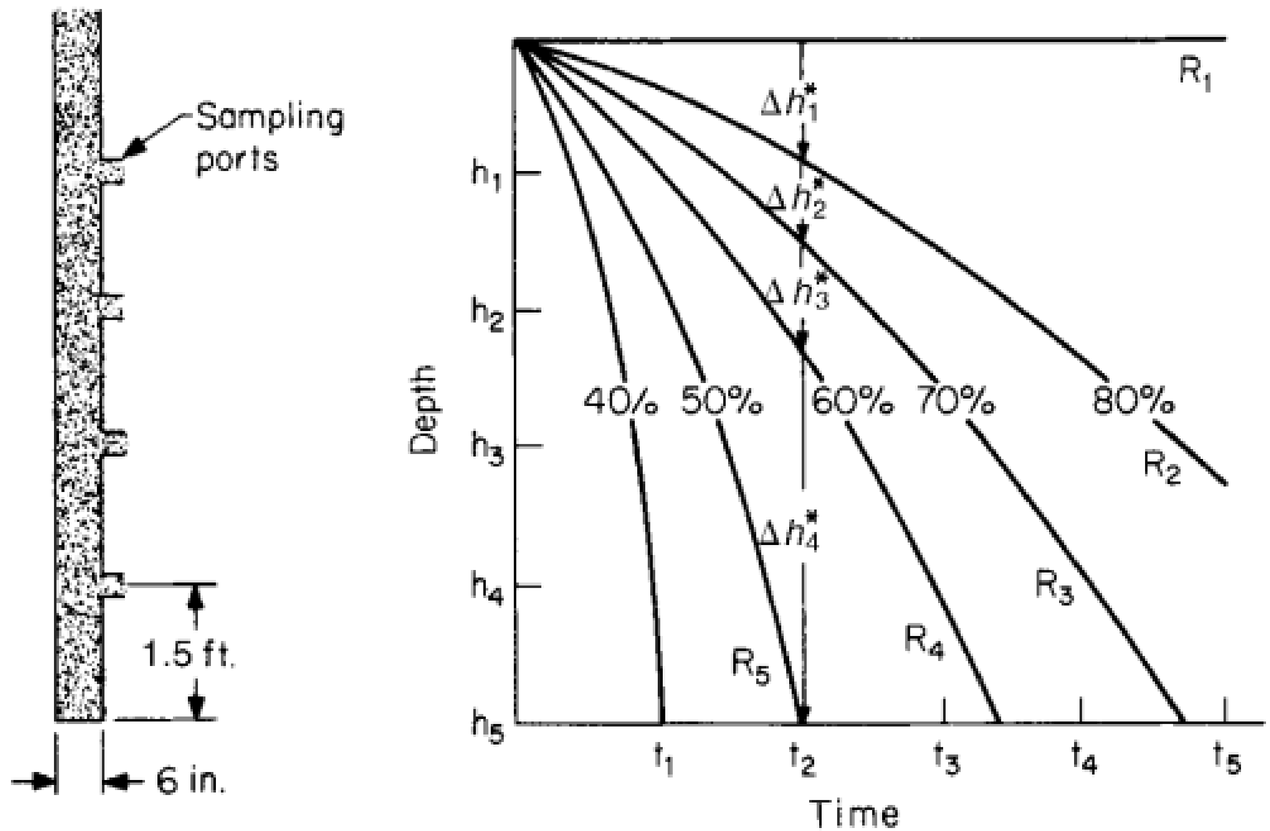



**FIGURE 7.9** Settling column and isopercentage settling curves for flocculant particles. (*Source:* Metcalf and Eddy, Engineers, 1991. *Wastewater Engineering,* 3rd ed. New York: McGraw-Hill. Reproduced by permission of the McGraw-Hill Companies.)

**Ref:** American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

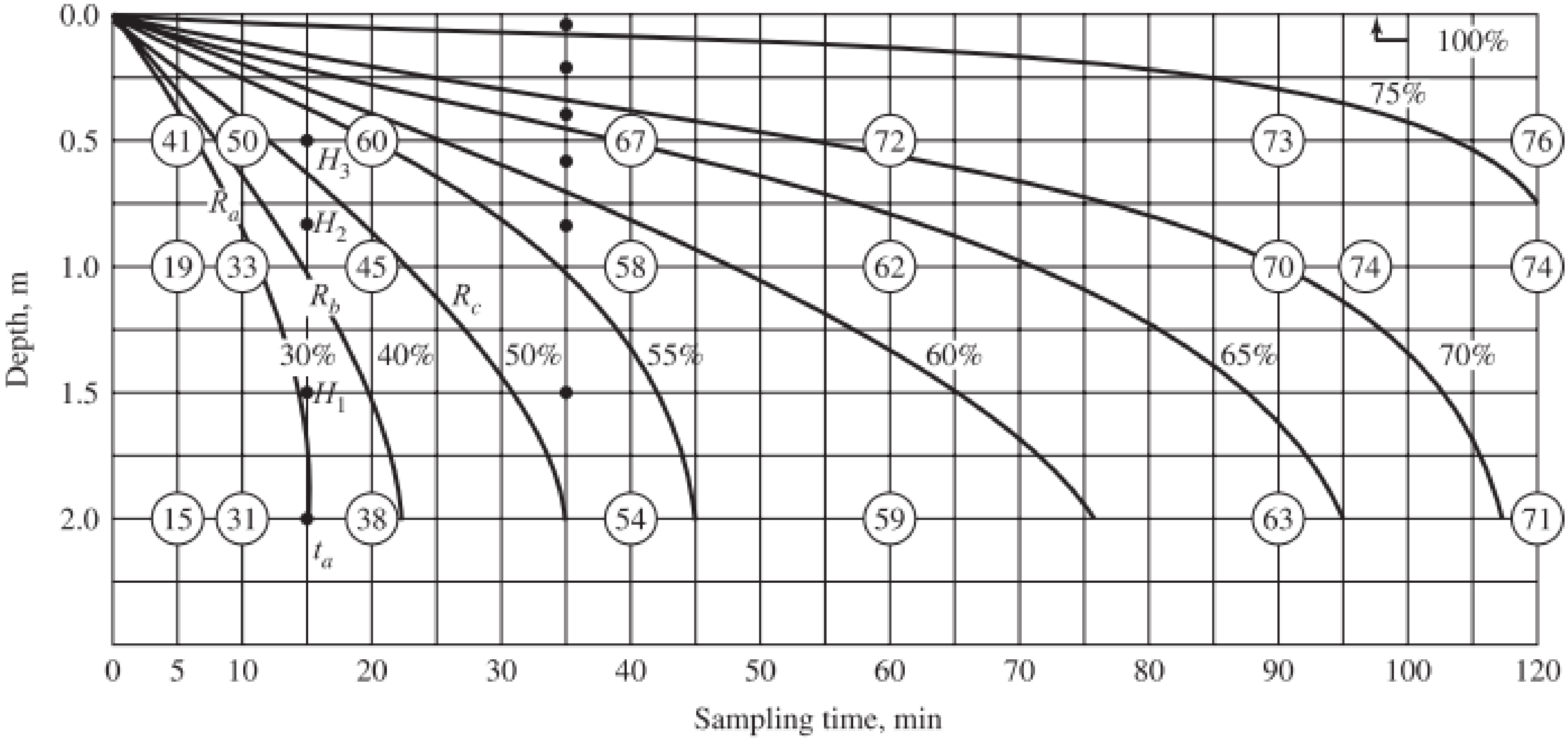



**FIGURE 10-8**

Isoconcentration lines for Type II settling test using a 2-m-deep column.

Isoconcentration lines = R curves

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Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

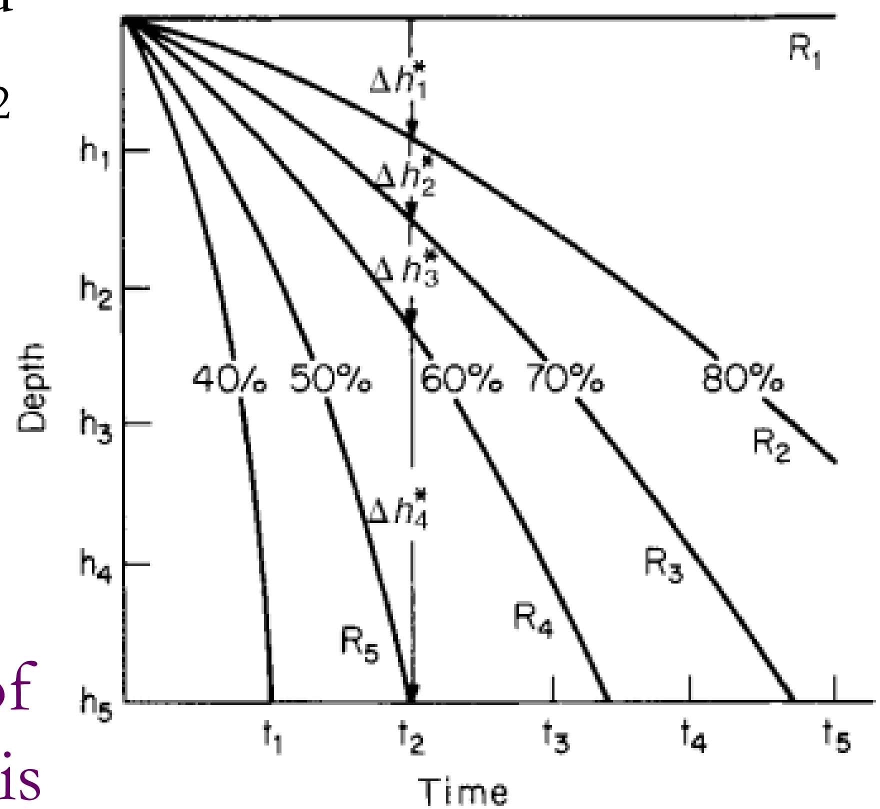
# Type II Settling
## Settling column model

- Overflow rates are determined for various settling times ($t_1$, $t_2$ etc.) where R curves intercept the x-axis
- For the curve $R_i$

  Overflow rate=$H/t_i$

H: height of the column, m

$t_i$: time defined by intersection of isoconcentration line and x-axis

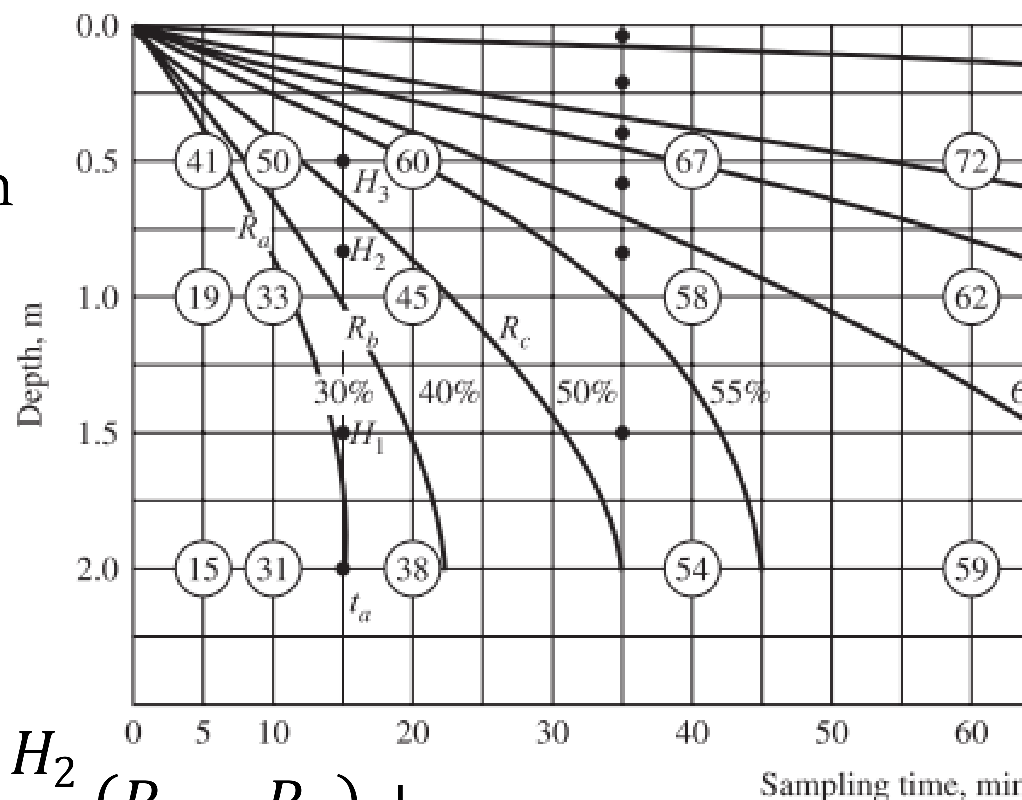



**Ref:** American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

# Type II Settling
# Settling column model

Fraction of solids removed

- A vertical line drawn from $t_i$ to intersect R curves.
- The mid points between isoconcentration lines define $H_1$, $H_2$, $H_3$ .




$$R_T = R_a + \frac{H_1}{H}(R_b - R_a) + \frac{H_2}{H}(R_c - R_b) + \cdots$$

- $R_T$:Total fraction removed for settling time of interest
- $R_a$, $R_b$, $R_c$: Isoconcentration fractions a, b, c

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# Type II Settling
# Settling column model

- Overflow rates and removal fractions are used to plot two curves
  1) Suspended solids removal versus detention time
  2) Suspended solids removal versus overflow rate
- These two plots can be used to size a settling tank.
- Scale-up factors od 0.65 for overflow rate and 1.75 for detention time can be used to design a tank.

# Example 2

A city is planning to install a new settling tank as an upgrade to their existing treatment plant. Design a settling tank to remove 65% of the influent suspended solids. Design flow rate is 0.5 $m^3/s$. A batch settling tank using a 2 m column and coagulated water from an existing plant yielded the following data.

**Percent removal as a function of time and depth**

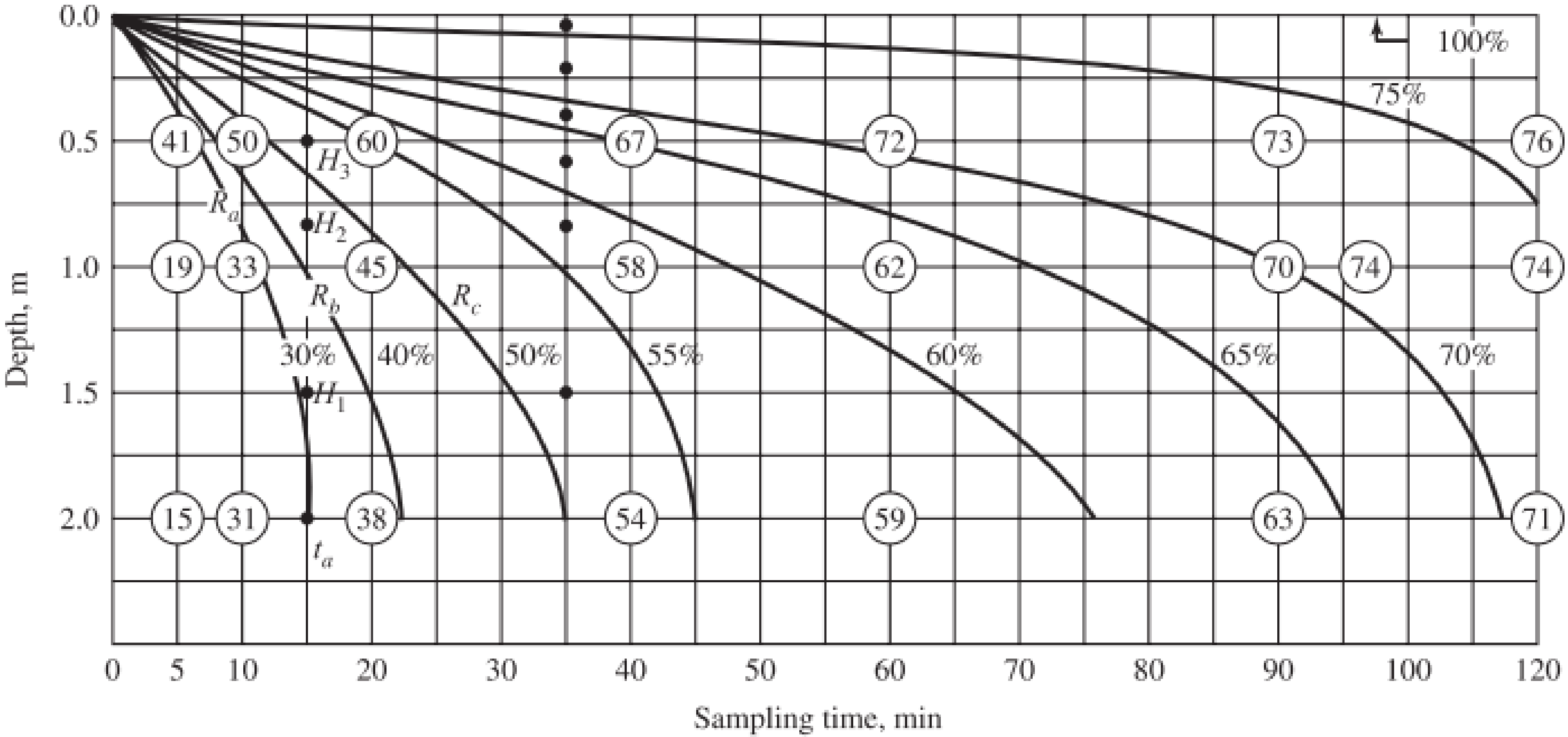
| | Sampling time, min | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth, m | 5 | 10 | 20 | 40 | 60 | 90 | 120 |
| 0.5 | 41 | 50 | 60 | 67 | 72 | 73 | 76 |
| 1.0 | 19 | 33 | 45 | 58 | 62 | 70 | 74 |
| 2.0 | 15 | 31 | 38 | 54 | 59 | 63 | 71 |



Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

**Percent removal as a function of time and depth**

| | Sampling time, min | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth, m | 5 | 10 | 20 | 40 | 60 | 90 | 120 |
| 0.5 | 41 | 50 | 60 | 67 | 72 | 73 | 76 |
| 1.0 | 19 | 33 | 45 | 58 | 62 | 70 | 74 |
| 2.0 | 15 | 31 | 38 | 54 | 59 | 63 | 71 |

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Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

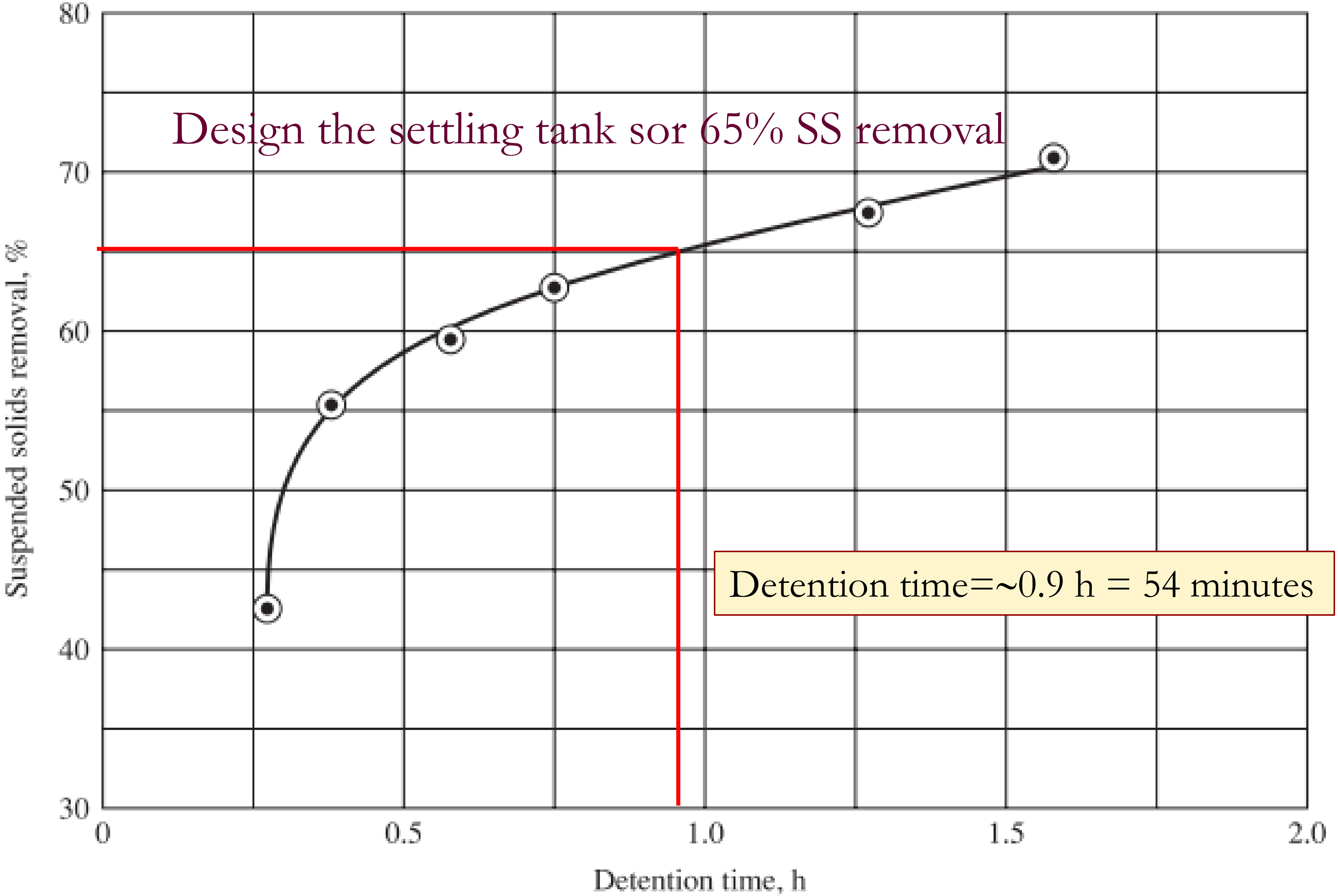
# Example 2 Solution Steps

- Calculate the overflow rate for each intersection.
- Calculate the corresponding removal percentage
- Calculation shown in class
- Construct two graphs

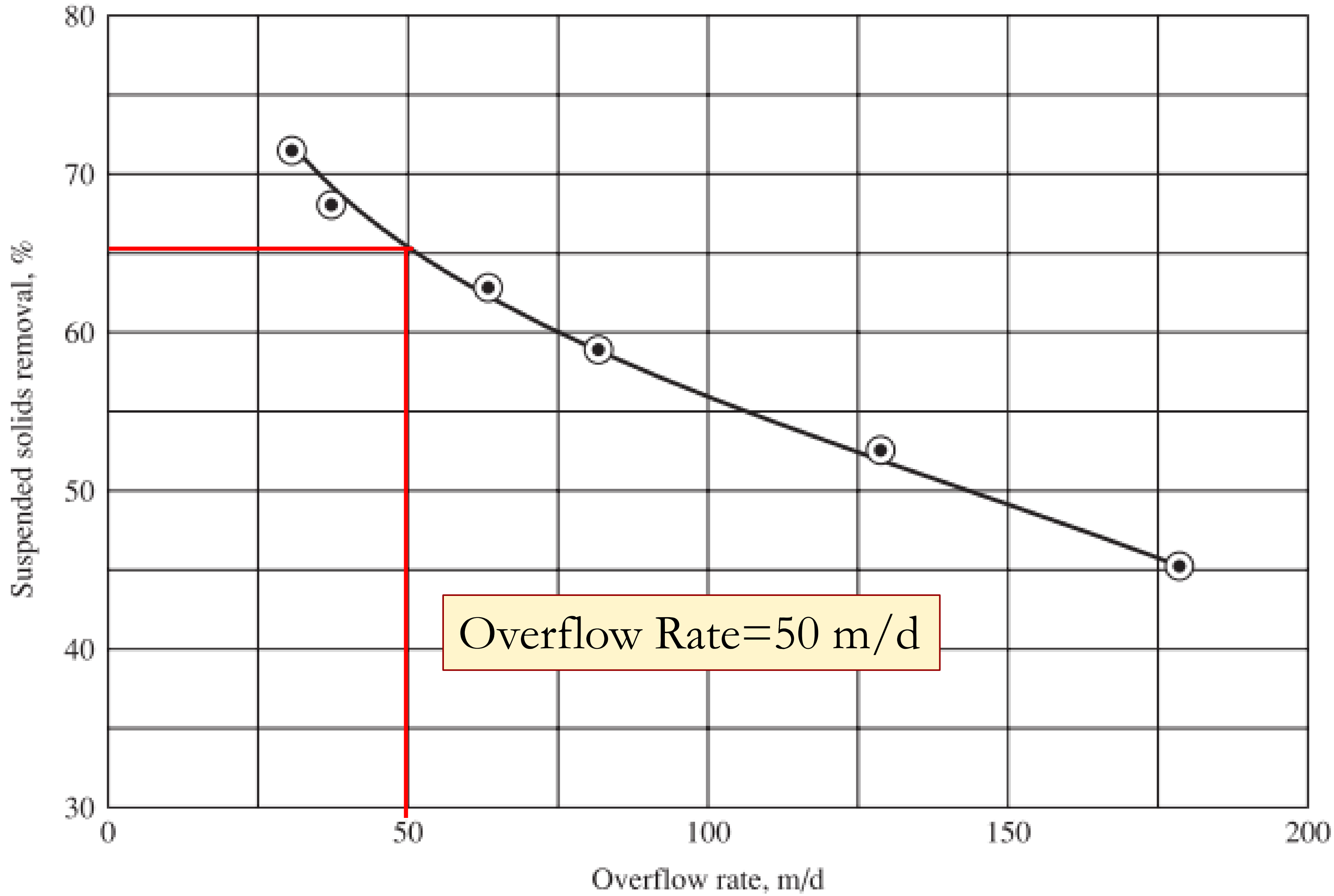
  1) Suspended solids removal versus detention time

  2) Suspended solids removal versus overflow rate

Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill



Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

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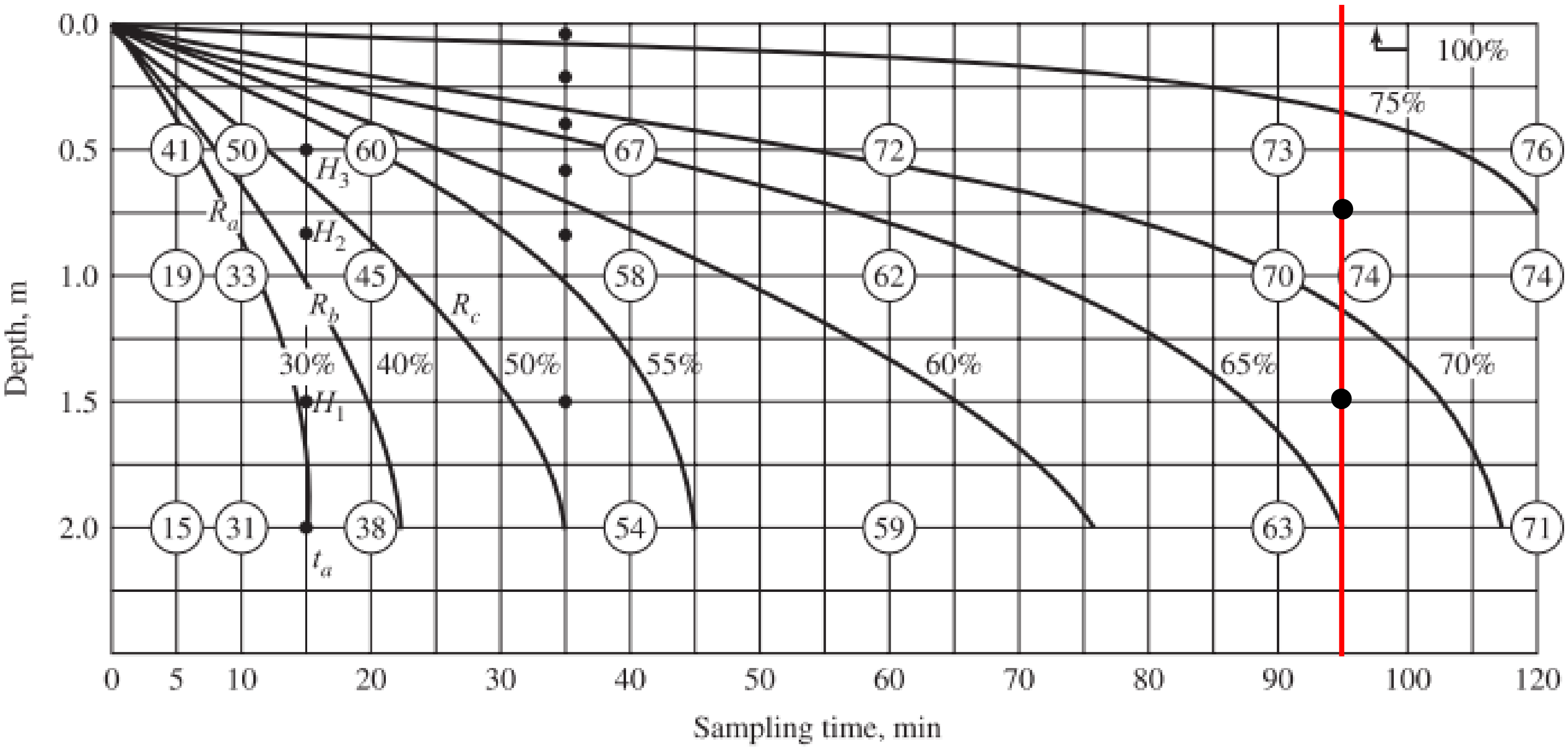
# Example 2 Solution Steps

- Detention time = 54 min
- Overflow rate = 50 m/d
- Apply scale up factors
- Detention time = 54 min * 1.75=95 min
- Overflow rate= 50 m/d * 0.65 = 32.5 m/d

# Example 3

- Calculate the overall suspended solids removal efficiency at 95 min for the designed settling tank in Example 2 (second approach).

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# Example 3

- 65% of the suspended solids will be completely removed.
- Partially removed fraction removed fraction
- 65% - 70%
- 70% - 75%
- Total suspended solids removal =completely removed + partially removed



Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

# Type III and Type IV Settling

- When the water contains high concentration of particles (>1000 mg/L) both type III and type IV settling occur along with discrete and flocculant settling
- Zone settling occurs in
  - Lime softening sedimentation
  - Activated sludge sedimentation
  - Sludge thickeners

# Type III and Type IV Settling

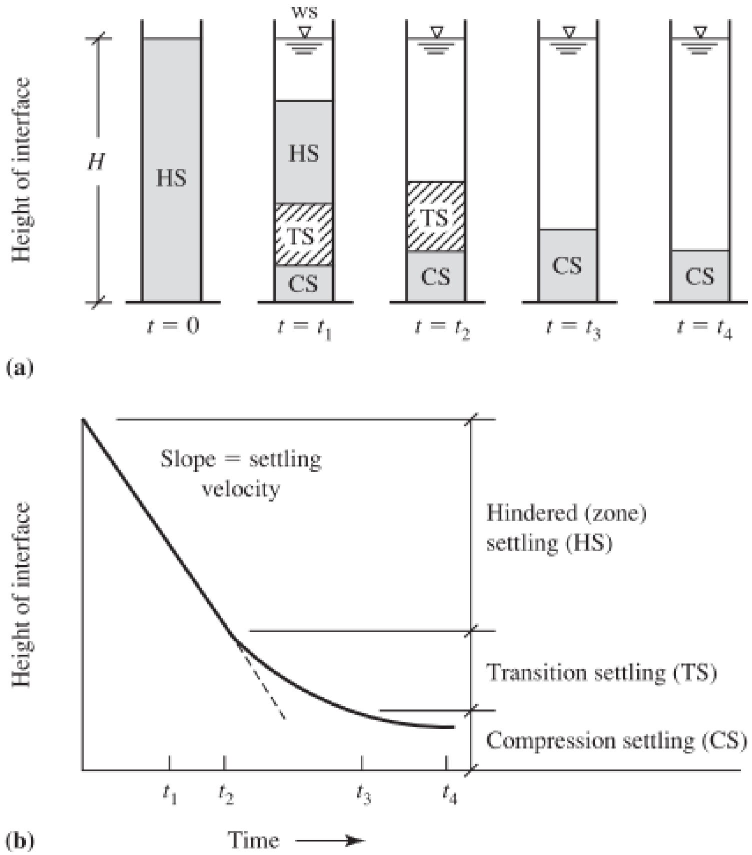


**FIGURE 10-11**
Idealized schematic of Type III and IV settling in a column (*a*) and a graph of the corresponding settling curve (*b*). (*Source:* Metcalf and Eddy, 2003.)

- When concentrated suspension placed in a column; type II, III, and IV settling takes place over time

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Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

# Type III Settling

Free area between the particles is reduced due to high particle concentration

↓

Greater interparticular fluid velocities reduce the settling velocity

↓

Due to high concentration of particles liquid tends to move up between the particles

↓

Particles that are in contact with one another settle as a zone (hindered settling)

↓

The rate of hindered settling is a function of the particles and their characteristics

# Type IV Settling

- Type III Settling continues → compressed layer of particles form
- Particles are in contact and do not really settle
- The phenomena is called compression settling
- Type IV settling occurs in the lower depths of the final clarifier or activated sludge process

# Types of Sedimentation Tanks

- Settling basins are rectangular, square, or circular in plan view.
- A single rectangular basin will cost more than a circular basin of the same size.
- If numerous tanks required—rectangular tanks can be constructed with common walls and be most economical.

# Types of Sedimentation Tanks

**TABLE 10-1**
**Alternative settling tank configurations**

| Nomenclature | Configuration or comment |
|---|---|
| Horizontal flow | Long rectangular tanks |
| Center feed | Circular, horizontal flow |
| Peripheral feed | Circular, horizontal flow |
| Upflow clarifiers | Proprietary |
| Upflow, solids contact | Recirculation of sludge with sludge blanket, proprietary |
| High-rate settler modules | Rectangular tank, parallel plates or tubes, proprietary |
| Ballasted sand | Addition of microsand, proprietary |

Adapted from Kawamura, 2000.



Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

# Types of Sedimentation Tanks

Order of preference for settling coagulation/flocculation floc is:

1) A rectangular tank containing high rate settler modules
2) A long rectangular tank
3) A high speed microsand clarifier (ballasted sand sedimentation)

For the lime-soda softenning process, the upflow solids contact unit (sludge blanket clarifier) is preffered

# Sedimentation Tanks

Sedimentation tanks can be divided into four zones:

1) Inlet Zone
2) Settling Zone
3) Sludge Zone
4) Outlet Zone

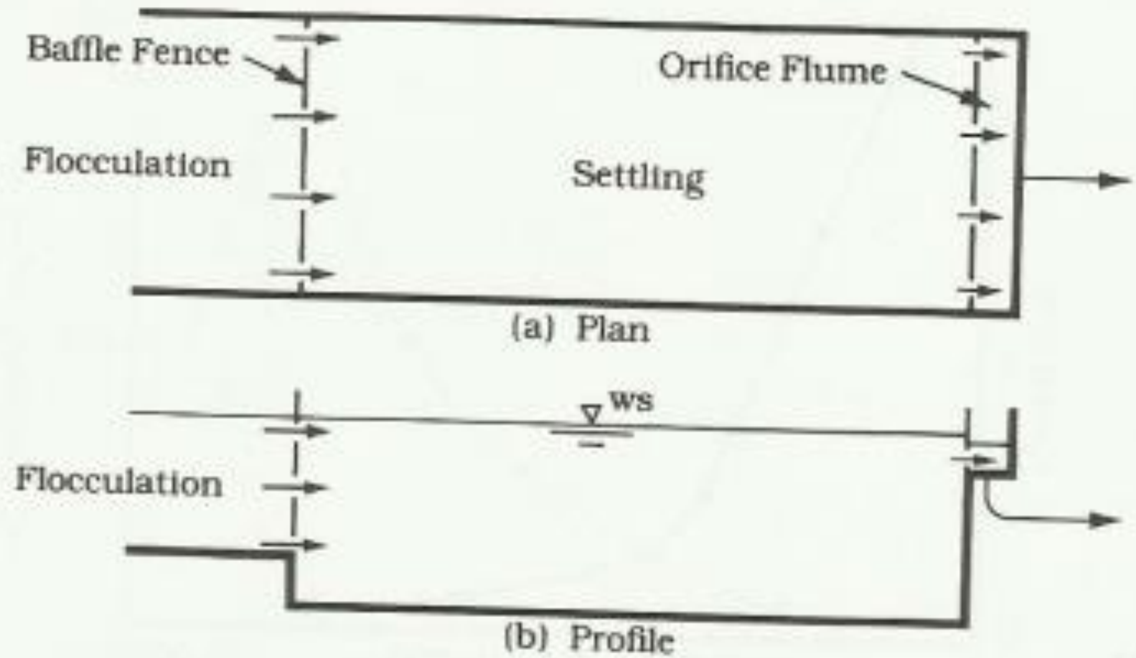



**FIGURE 9.29** *Inlet and Outlet Details for a Rectangular Settling Tank with Orifice Flume Outlet Preceded by Flocculation*

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

# Types of Sedimentation Tanks
## Horizontal Flow Tanks – Rectangular Tanks

- Long, narrow basins have been used for a long time
- Rectangular basins are not affected by wind or density currents as the square or circular sedimentation basins
- Usually two basins are placed longitudinally with a common wall.

# Types of Sedimentation Tanks
# Horizontal Flow Tanks – Rectangular Tanks

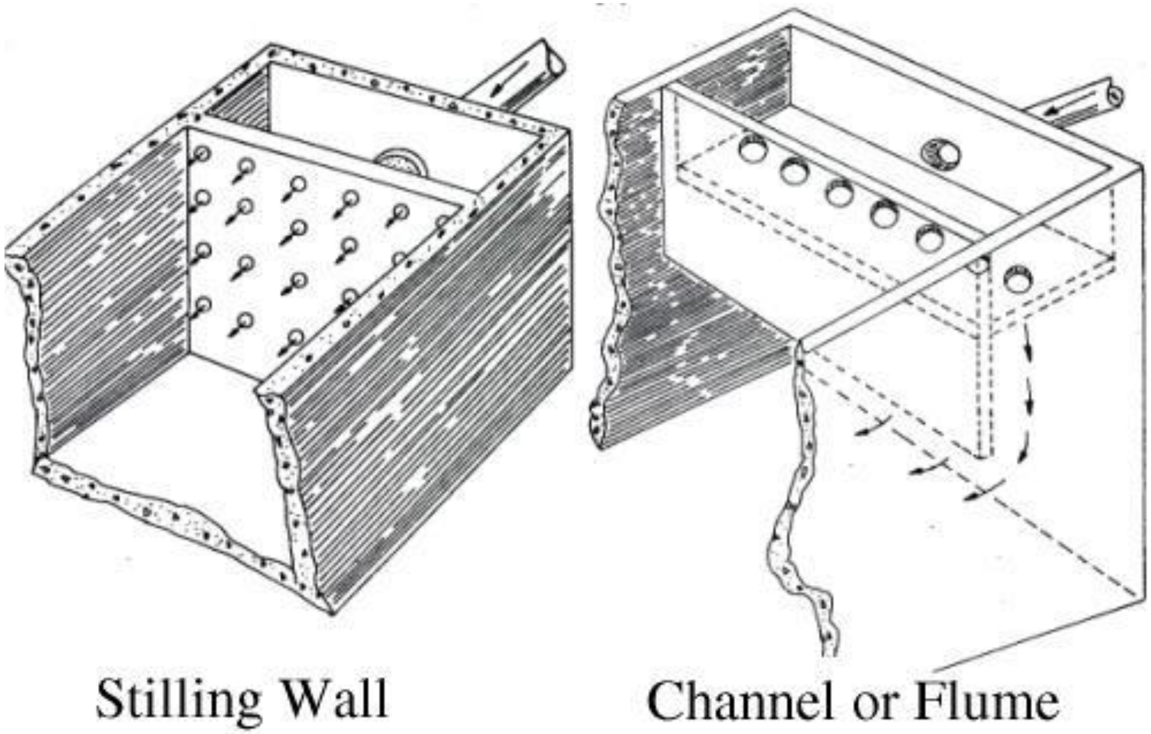
- Inlet Structures are generally used to
  - Dissimate influent energy
  - Distribute the flow
  - Lessen density currents
  - Minimize sludge disturbance

# Types of Sedimentation Tanks
# Horizontal Flow Tanks – Rectangular Tanks

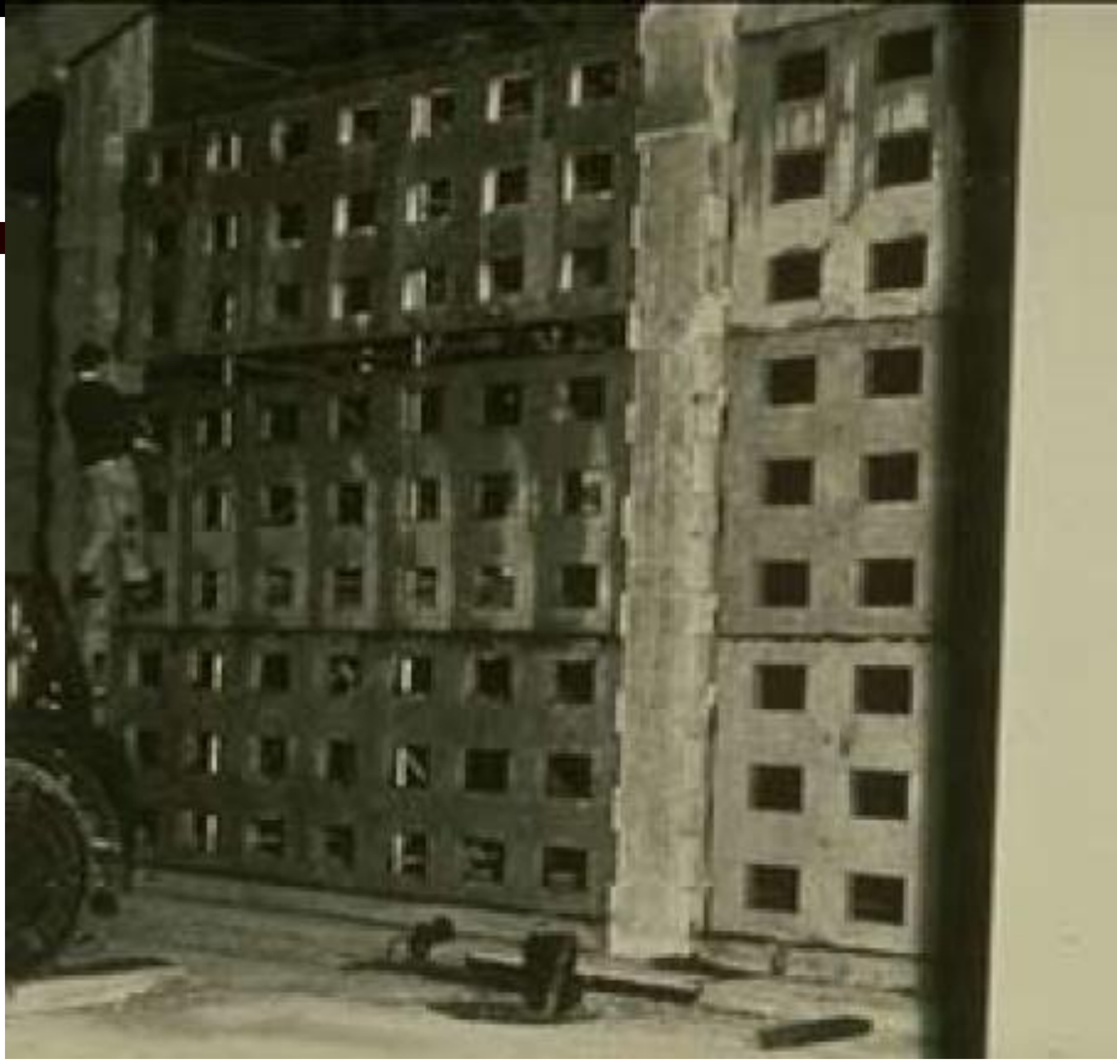
- Generally there is a direct connection between flocculation tank and sedimentation basin
- If flocculated water is piped to the sedimentation tank;
  - Velocity should be 0.15-0.6 m/s
- Diffusor walls are used to reduce velocity and distribute flow evenly
- Depth of inlet channel=Depth of flocculation tank

# Types of Sedimentation Tanks
## Horizontal Flow Tanks – Rectangular Tanks-Inlet

- Inlet structures are designed to distribute water over the entire cross section.




Ref: http://water.me.vccs.edu/concepts/sedzones.html



Ref:http://ocw.tudelft.nl/courses/watermanagement/drinking-water-treatment1/lectures/lectures/

- Diffuser walls placed approximately 2 m downstream of the inlet
- Headloss through the holes should be 4-5 times the velocity head of approaching flow
- Port velocity → 0.2-0.3 m/s
- Holes
  - 0.1-0.2 m in diameter
  - 0.25-0.6 m apart

Lowest port should be 0.6 m above the basin floor

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# Types of Sedimentation Tanks
# Rectangular Tanks-Settling Zone

- Overflow rate is the primary desing parameter
- Basins with mechanical settling devices, depth is 3-5m
- To prevent short circuiting minimum L:W=4:1

**TABLE 10-2**
**Typical sedimentation tank overflow rates**[a]

| Application | Long rectangular and circular, $m^3/d \cdot m^2$ | Upflow solids-contact, $m^3/d \cdot m^2$ |
|---|---|---|
| **Alum or iron coagulation** | | |
| Turbidity removal | 40 | 50 |
| Color removal | 30 | 35 |
| High algae | 20 | |
| **Lime softening** | | |
| Low magnesium | 70 | 130 |
| High magnesium | 57 | 105 |

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Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

# Types of Sedimentation Tanks
# Rectangular Tanks-Sludge Zone

- Bottom of the rectangular tanks is slightly sloped to facilitate sludge scraping
- Scraping devices continuously pull the settled material into a sludge hopper where it is pumped out periodically
- Scraper movement may resuspend lighter particles
- Horizontal velocity should be less than 9 m/h for flocculant dispersions and ~36 m/h for heavier discrete suspensions --- excessive horizontal velocity may move settled particles to outlet zone

# Types of Sedimentation Tanks
# Horizontal Flow Tanks – Rectangular Tanks

- Cross flow baffles may be added to prevent the return of surface currents from the end of the tank.
- Mechanical collectors for sludge removal are;
  1) A travelling bridge with sludge scraping squeegees and a mechanical cross collector
  2) A travelling bridge with sludge collection headers and pumps
  3) Chain and flight collector
  4) Sludge suction headers sported by floats

# Types of Sedimentation Tanks
## Horizontal Flow Tanks – Rectangular Tanks

- Allowance between 0.6-1 m is made for sludge accumulation and sludge removal equipment
- Bottom is slightly sloped→ 1:600 (when mechanical equipment used)
- Chain-flight collectors
  - → max 60 m
  - Flight widths 0.3m increments, max 6m
  - Velocity should be kept less than 18 m/s

# Types of Sedimentation Tanks
# Horizontal Flow Tanks – Rectangular Tanks

- Cross collector is 1 to 1.2 m wide at the top and 0.6 to 1.2 m deep
- Either helicoid or chain and flight mechanism is used to move the sludge accross the hopper to a hydraulic or pumping withdrawal
- The hopper is steep-sided at an angle about $60^o$

# Types of Sedimentation Tanks
# Horizontal Flow Tanks – Rectangular Tanks

•http://www.mena-water.com/4_sedimentation.htm

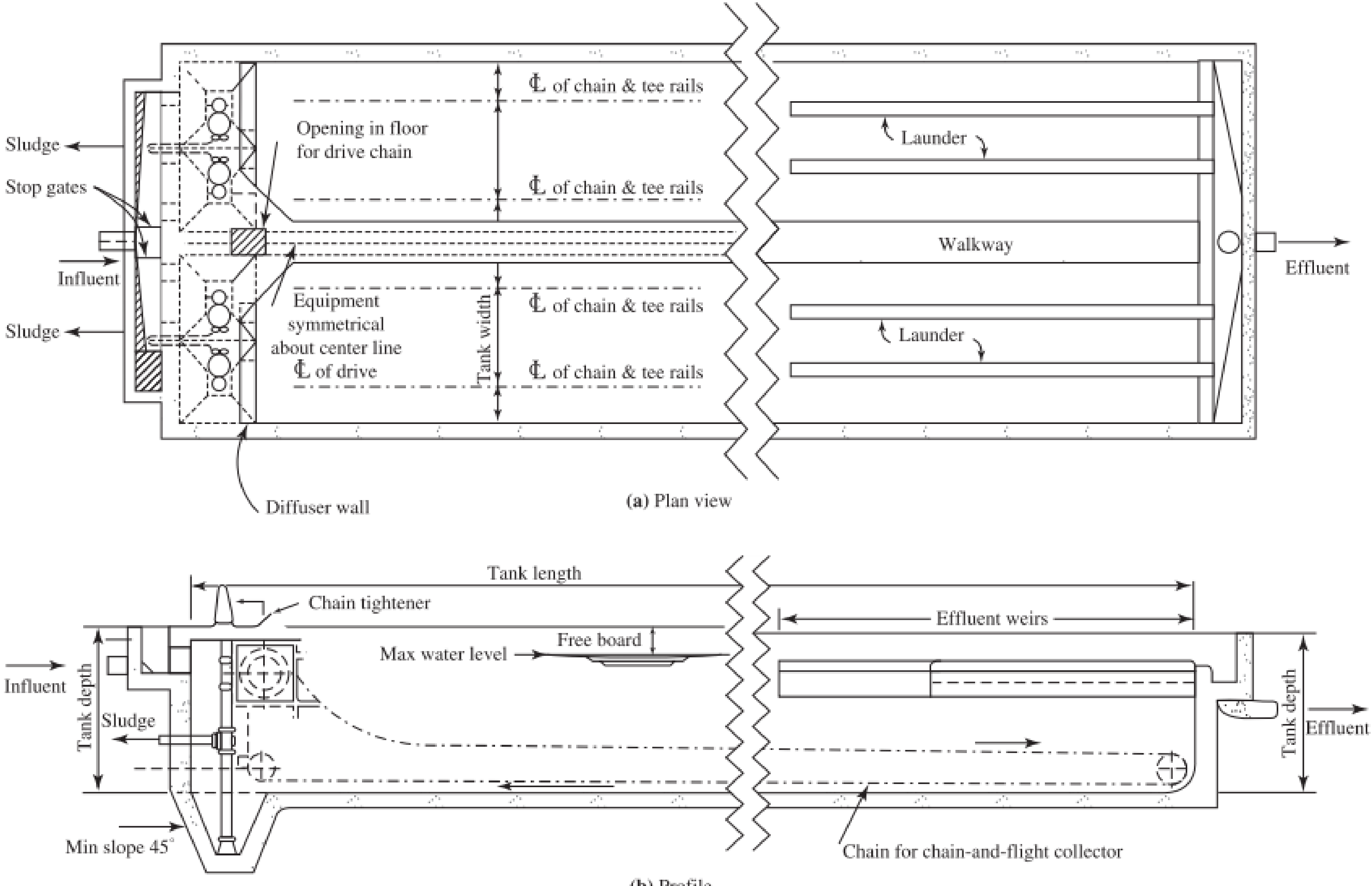


**FIGURE 10-13**

(*a*) Plan and (*b*) profile of horizontal-flow, rectangular sedimentation basin.

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Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

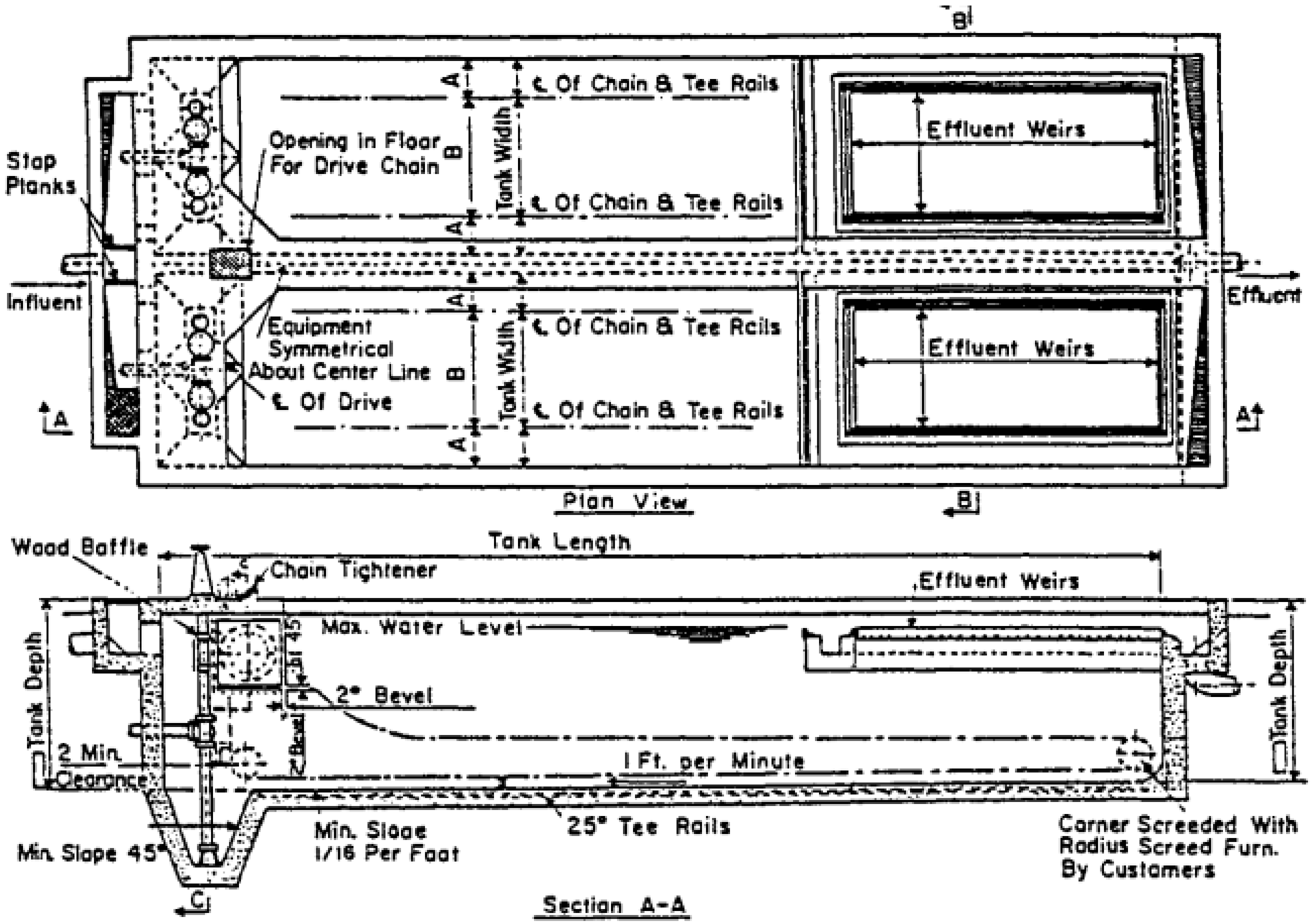


**FIGURE 7.4** Typical rectangular basin with chain-and-flight collectors with sludge hoppers.

**Ref:** American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

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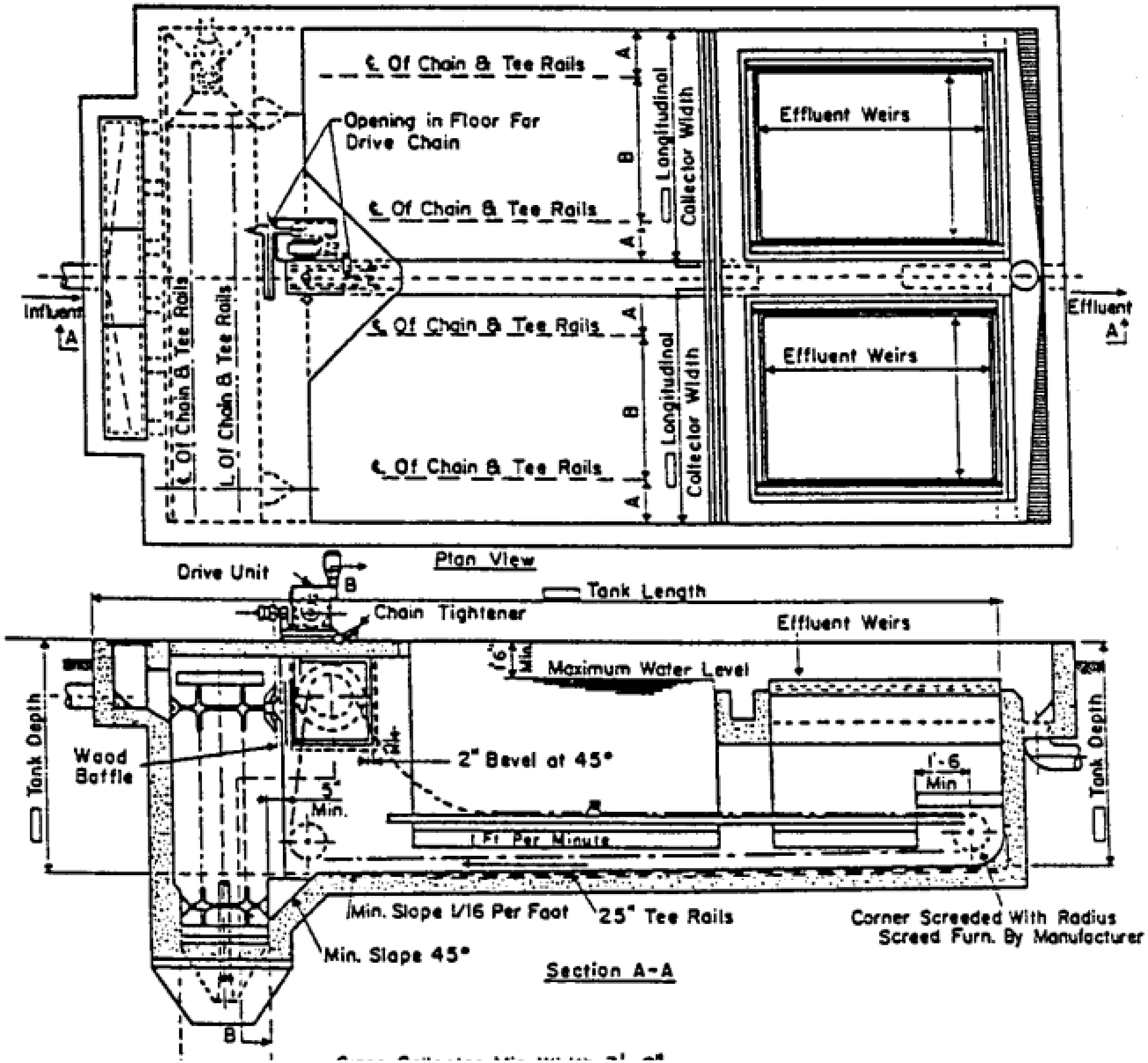


**Ref:** American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

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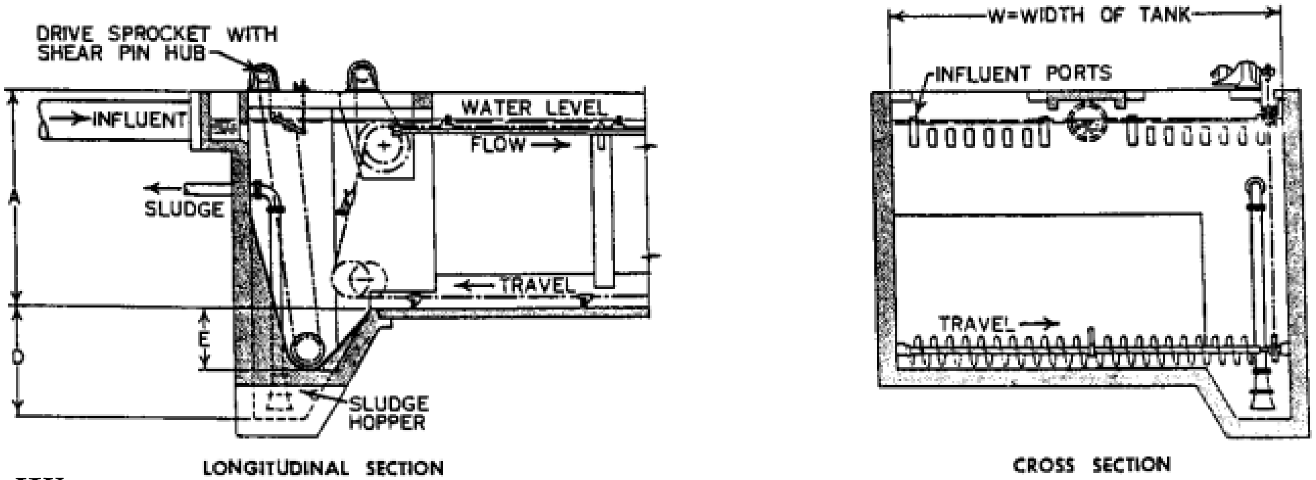
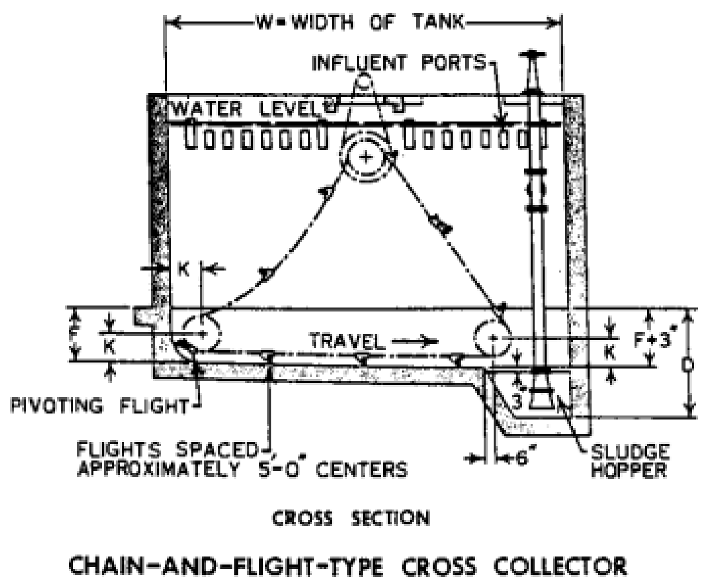



HELICAL-SCREW-TYPE CROSS COLLECTOR




CHAIN-AND-FLIGHT-TYPE CROSS COLLECTOR

**FIGURE 7.6** Typical cross-collector arrangements. (*Courtesy of USFilter, Envirex Products.*)

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**Ref:** American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

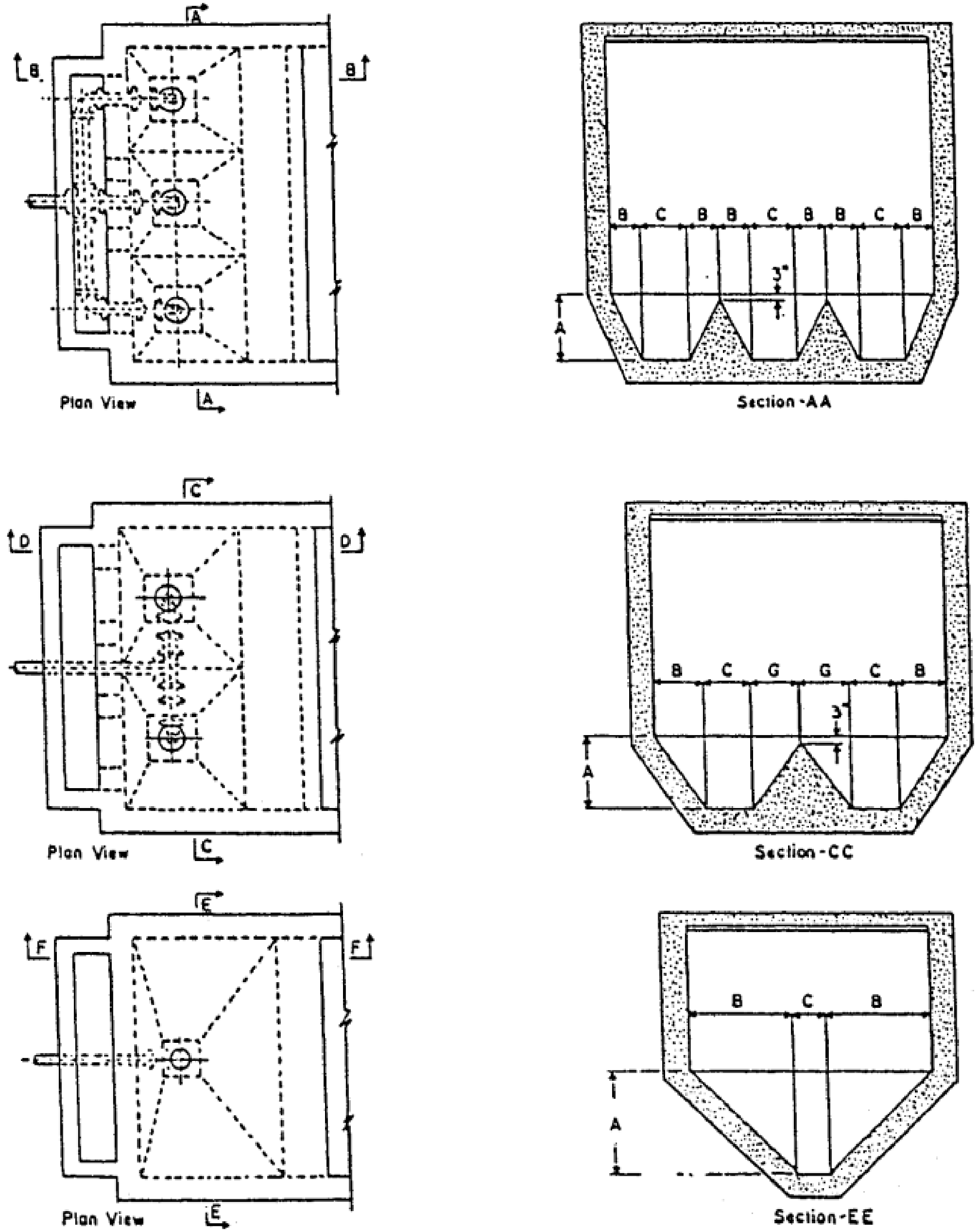


**FIGURE 7.7** Typical sludge hopper arrangements for rectangular basins.

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**Ref:** American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

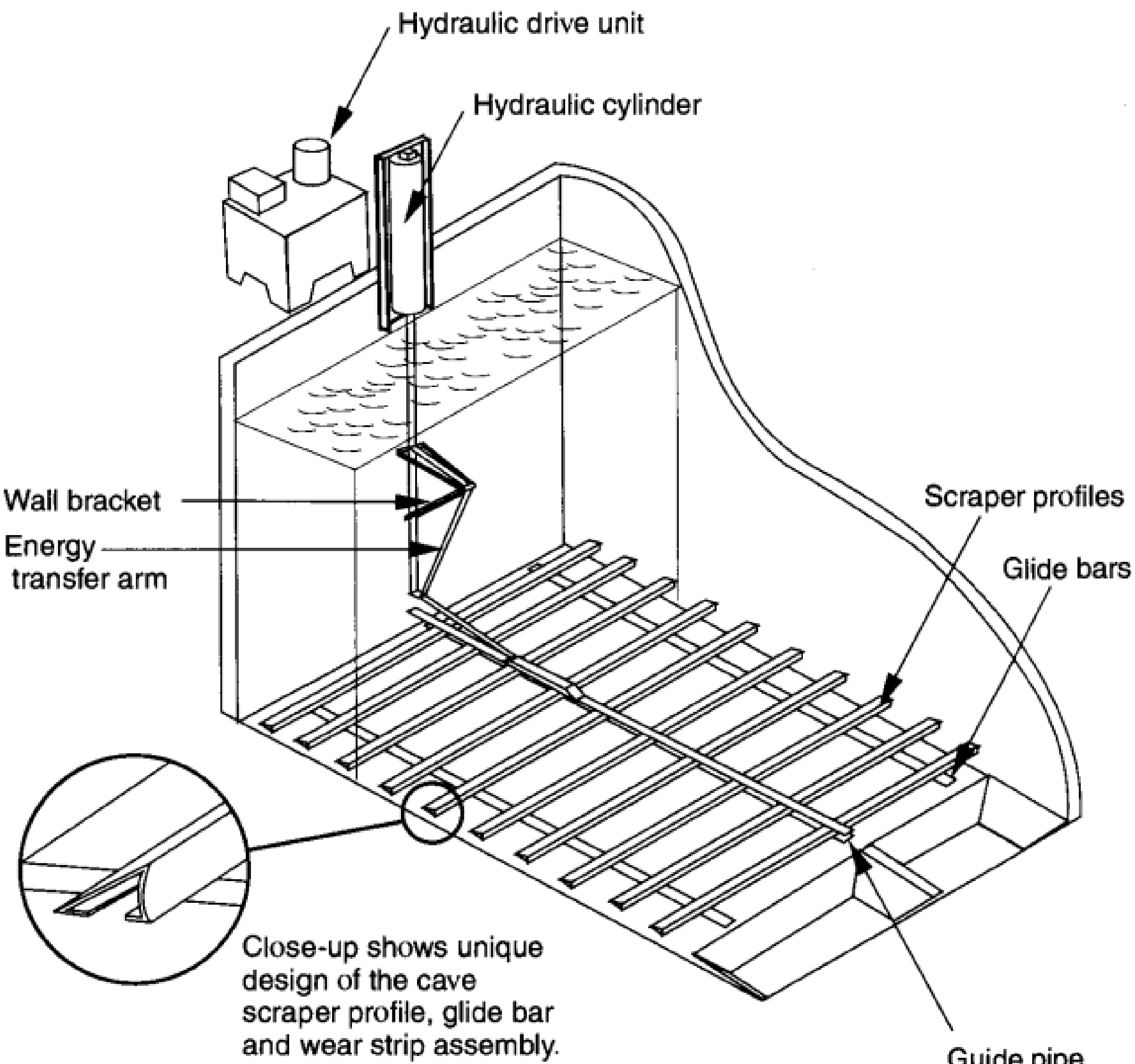


**FIGURE 7.8** Indexing grid sludge removal system. (*Courtesy of Parkson Corporation.*)

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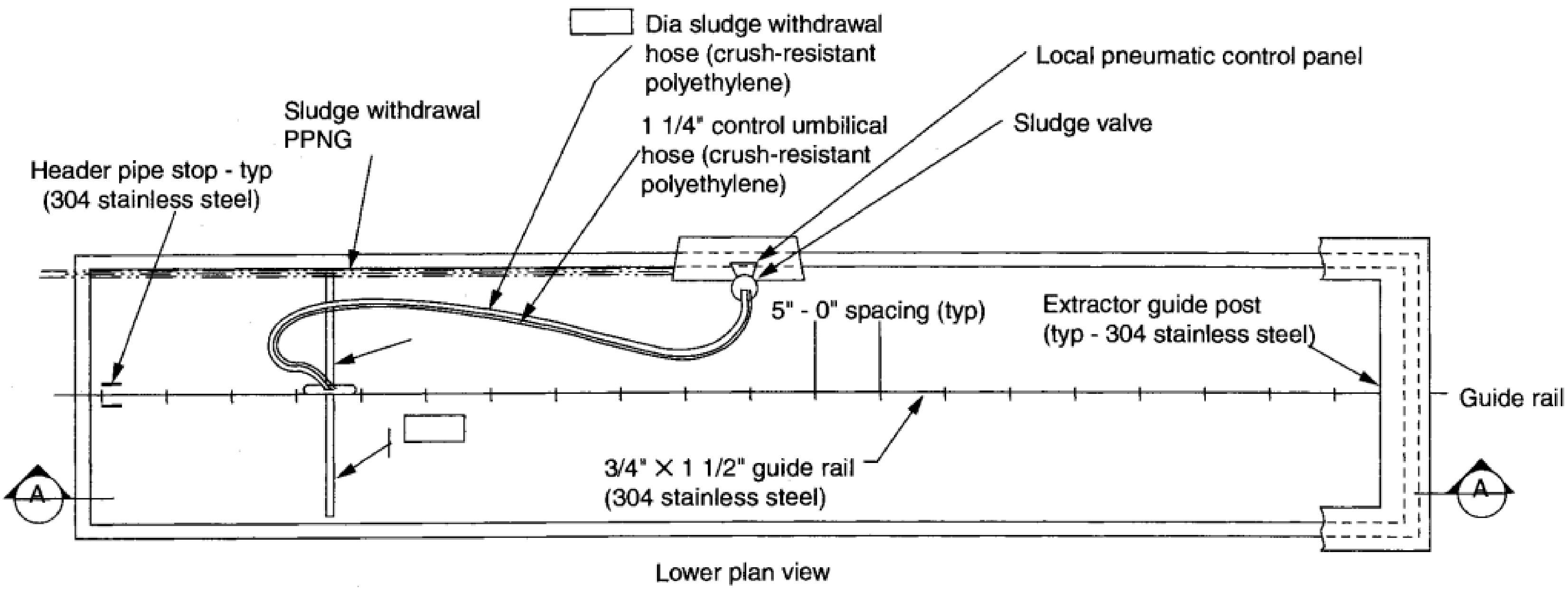


**FIGURE 7.9** Track-mounted hydraulic sludge removal system. (*Courtesy of Eimco Water Technologies.*)

**Ref:** American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

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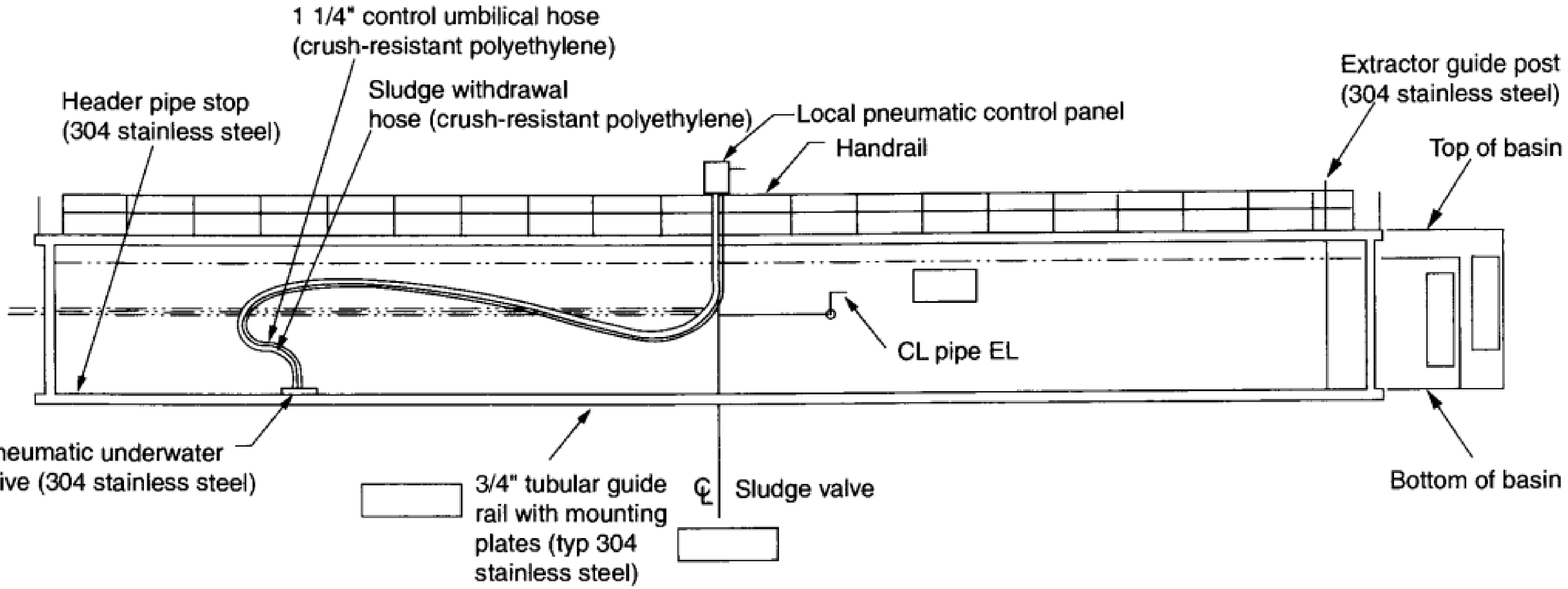


**FIGURE 7.9** (*Continued*)

**Ref:** American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

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**Ref:** American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

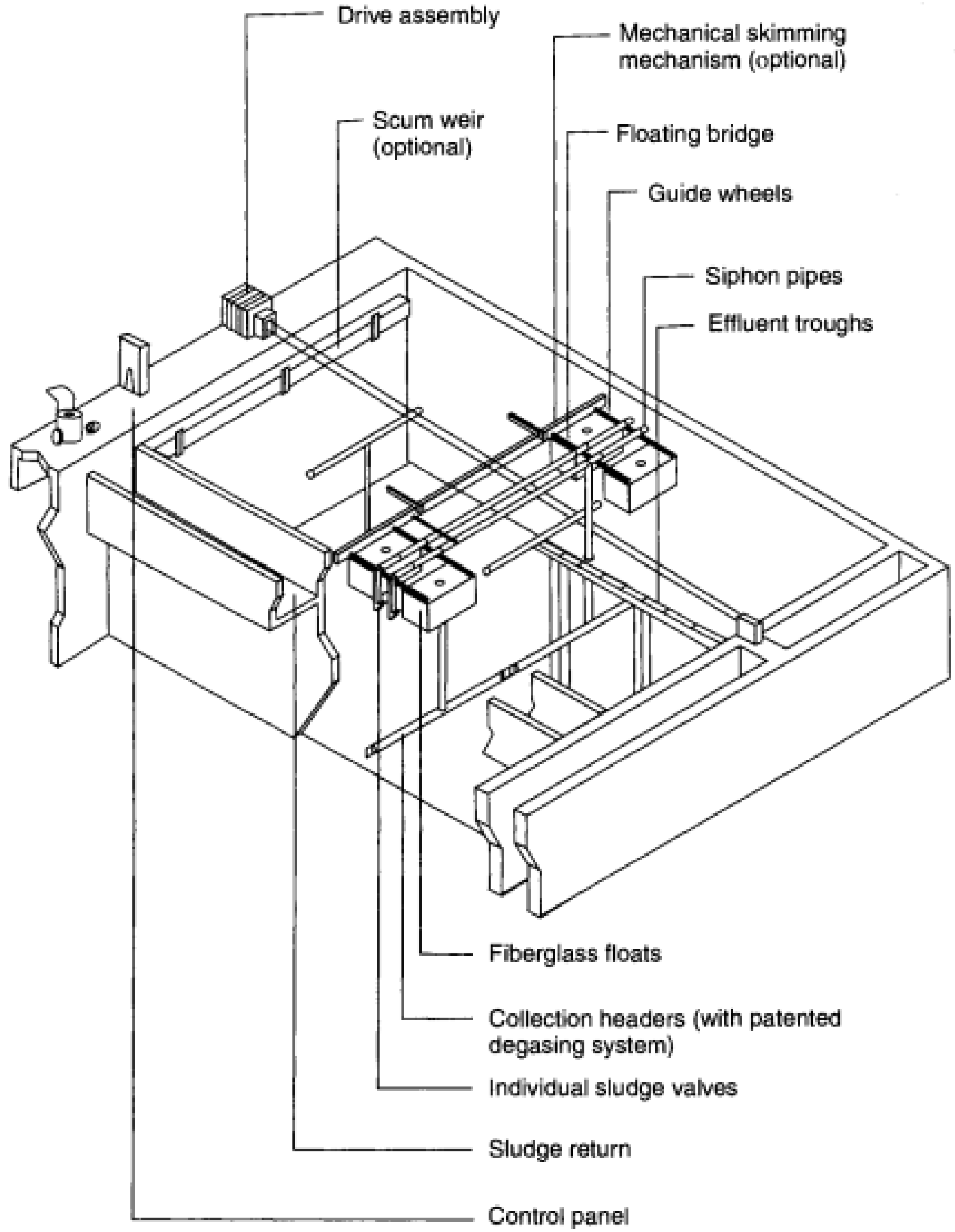
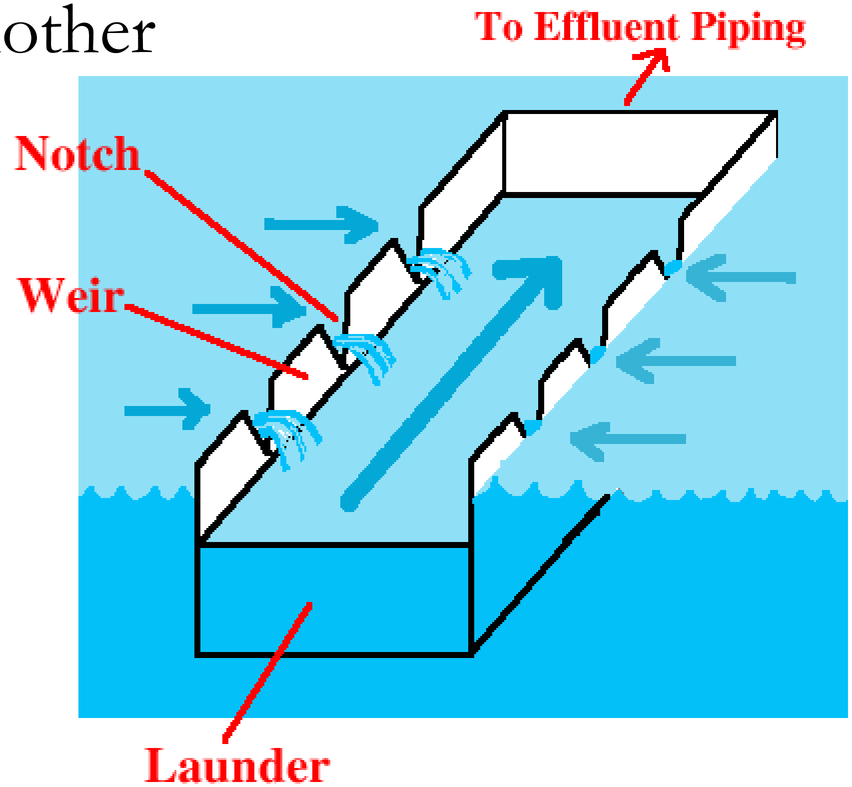



**FIGURE 7.10** Floating bridge–type collector. (*Courtesy of Leopold.*)

# Types of Sedimentation Tanks
# Horizontal Flow Tanks – Rectangular Tanks

Outlet structures for reactangular tanks generally include launders placed parallel to eachother

Ref:http://ocw.tudelft.nl/courses/watermanagement/drinking-water-treatment1/lectures/lectures/




Ref: http://water.me.vccs.edu/concepts/sedzones.html

# Types of Sedimentation Tanks
# Horizontal Flow Tanks – Rectangular Tanks

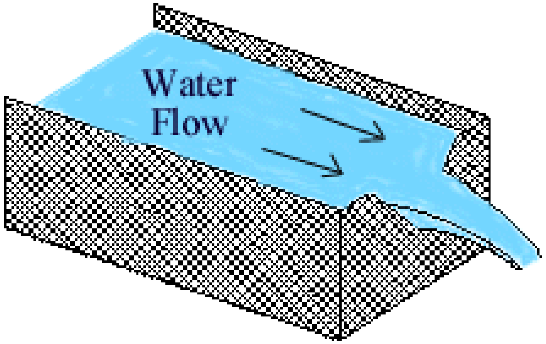
- The weirs should cover should cover at least one third (preferrably up to one half) of the basin

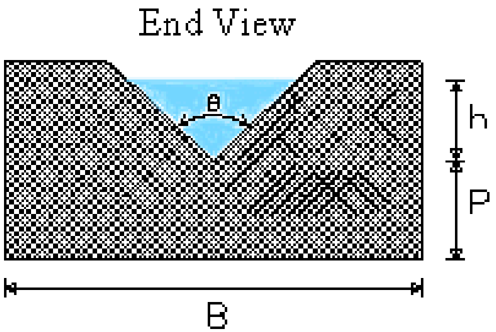
Long weirs have three advantages

1) A gradual reduction of flow velocity toward the end of the tank
2) Minimization of wave action from wind
3) Collection of clarified water located in the middle of the tank when a density flow occurs

# Types of Sedimentation Tanks
# Horizontal Flow Tanks – Rectangular Tanks

- Water level controlled by the end wall or overflow weirs
- V-notch weirs are attached to launders and broad-crested weirs are attached to the end wall
- Submerged orifices may be used on the launder






http://www.lmnoeng.com/Weirs/vweir.htm

# Types of Sedimentation Tanks
# Horizontal Flow Tanks – Rectangular Tanks

- Hydraulic loading should not exceed 250 $m^3$/m.d of outlet launder
- Submerged orifices should not be located more than 1 m below the flow line
- Enterance velocity should not exceed 0.15 m/s

**TABLE 10-3**
**Typical weir hydraulic loading rates**

| Type of floc | Weir overflow rate, $m^3/d \cdot m$ |
|---|---|
| Light alum floc (low-turbidity water) | 140–180 |
| Heavier alum floc (higher turbidity water) | 180–270 |
| Heavy floc from lime softening | 270–320 |

*Source:* Davis and Cornwell, 2008.

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Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

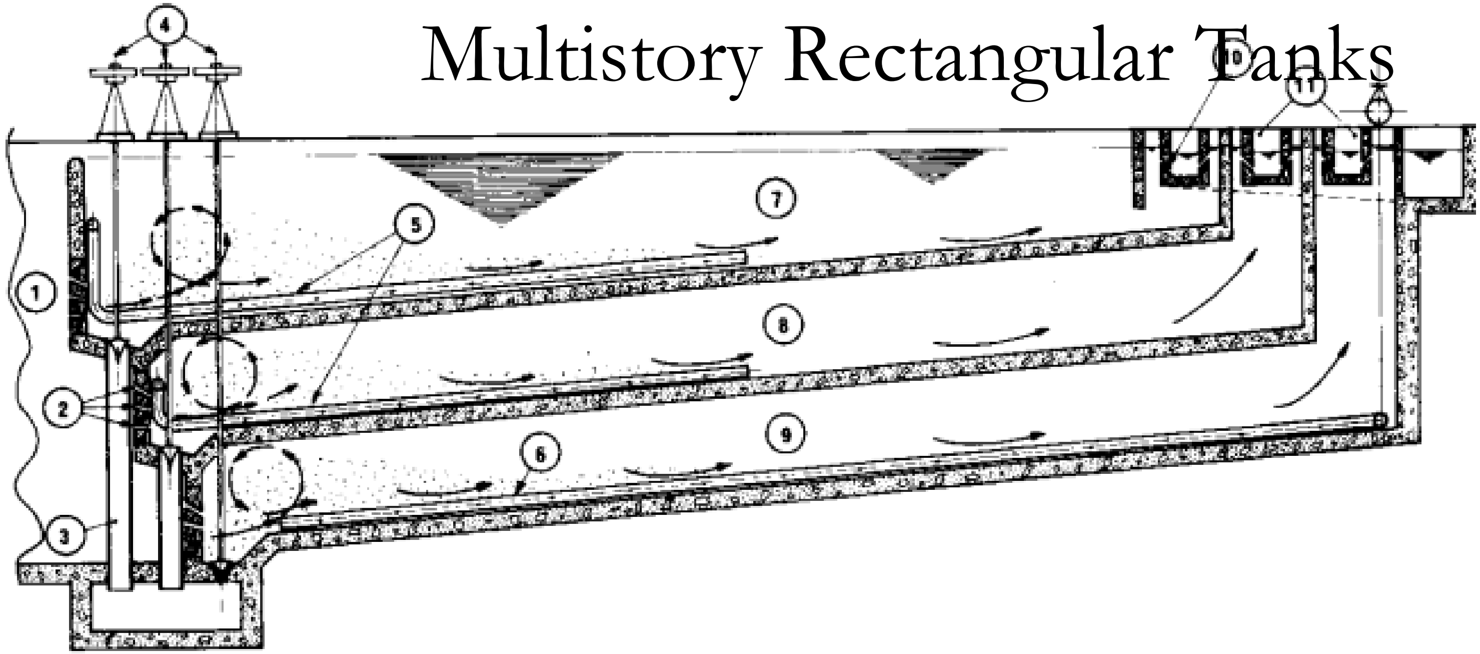
**TABLE 10-4**
**Typical design criteria for horizontal-flow rectangular sedimentation basins**

| Parameter | Typical range of values | Comment |
|---|---|---|
| **Inlet zone** | | |
| Distance to diffuser wall | 2 m | |
| Diffuser hole diameter | 0.10–0.20 m | |
| **Settling zone** | | |
| Overflow rate | $40–70\ m^3/d \cdot m^2$ | See Table 10-2 |
| Side water depth (SWD) | 3–5 m | |
| Length | 30 m | Wind constraint |
| | 60 m | Chain-and-flight |
| | ≥80–90 m | Traveling bridge |
| Width | 0.3 m increments | Chain-and-flight |
| | 6 m maximum per train | Chain-and-flight |
| | 24 m maximum = 3 trains per drive | Chain-and-flight |
| | 30 m maximum | Traveling bridge |
| L:W | 4:1 to 6:1 | ≥6:1 preferred |
| L:D | 15:1 | Minimum |
| Velocity | 0.005–0.018 m/s | Horizontal, mean |
| Reynolds number | < 20,000 | |
| Froude number | $> 10^{-5}$ | |
| **Outlet zone** | | |
| Launder length | 1/3–1/2 length of basin | Evenly spaced |
| Launder weir loading | $140–320\ m^3/d \cdot m$ | See Table 10-3 |
| **Sludge zone** | | |
| Depth | 0.6–1 m | Equipment dependent |
| Slope | 1:600 | Mechanical cleaning |
| Sludge collector speed | 0.3–0.9 m/min | |

Sources: AWWA, 1990; Davis and Cornwell, 2008; Kawamura, 2000; MWH, 2005; Willis, 2005

Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

# Types of Sedimentation Tanks
# Multistory Rectangular Tanks




① Flocculation tank
② SPLIT-ROLL inlets
③ Upper floor sludge drain
④ Manually controlled TOP VALVE
⑤ COMBCET: Sludge suction system (optional)
⑥ WATERINSE: Water flushing system (optional)
⑦ Upper clarifying compartment
⑧ Intermediate clarifying compartment
⑨ Lower clarifying compartment
⑩ DUCK-LIPS: Effluent collectors
⑪ Clarified water collecting channels

**FIGURE 7.18** Multistory horizontal tank with parallel flow on three levels. (*Source:* Courtesy of OTV, Paris, France, and Kubota Construction Co., Ltd., Tokyo, Japan.)

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

# Types of Sedimentation Tanks
# Circular Tanks

- Circular sedimentation basins become more popular
- Top-drive circular mechanisms have no bearing under water→longetivity with little maintanance
- Sizes generally do not exceed 40 m in diameter (can be built as large as 91 m in diameter)
- Circular basins are also designed based on their overflow rates
- Side water depth range from 3-3.6 m to prevent wind or thermal currents, sludge disturbances
- Sludge is typically scraped to center hoppers → slope towards to center

# Types of Sedimentation Tanks
# Circular Tanks

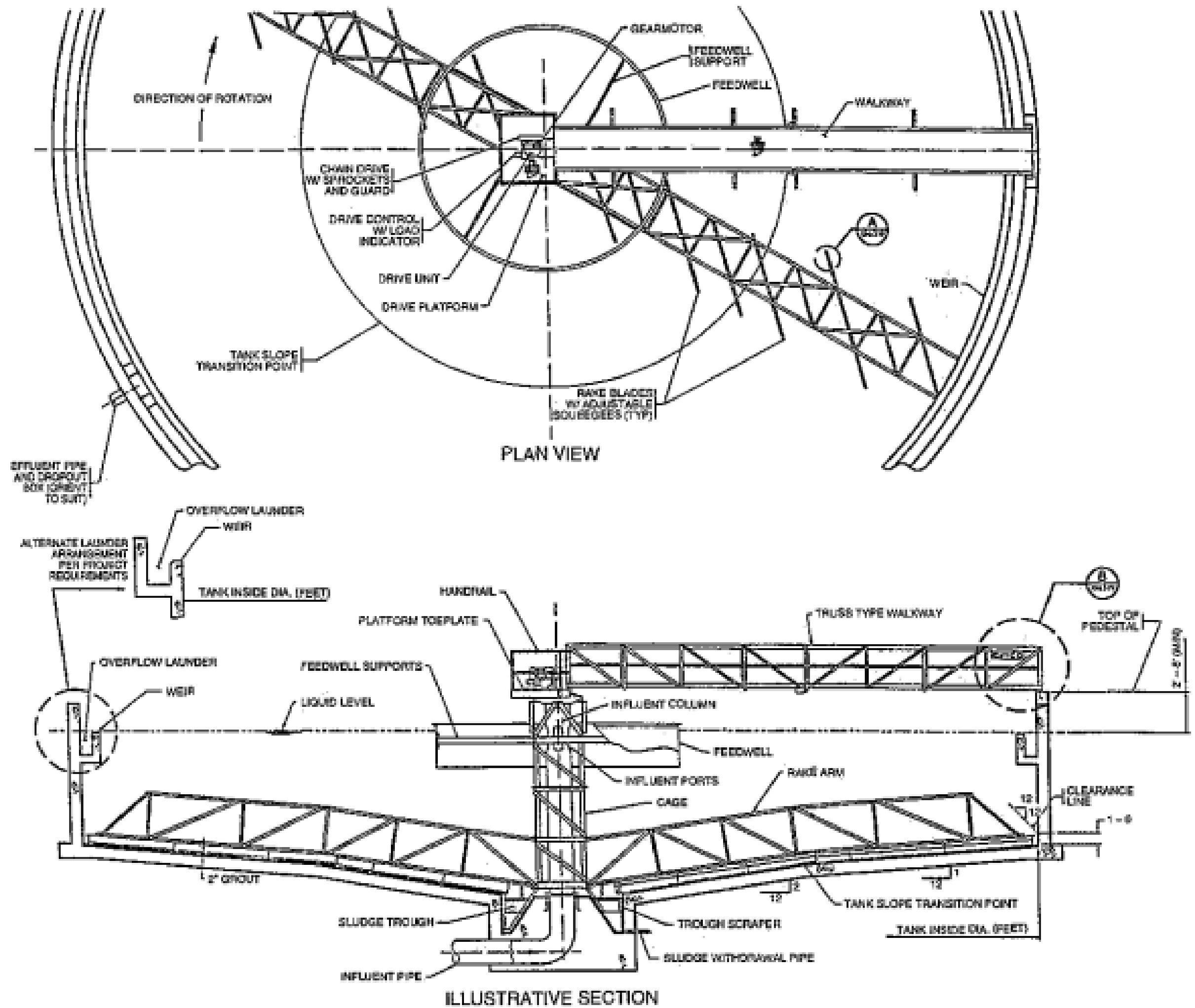
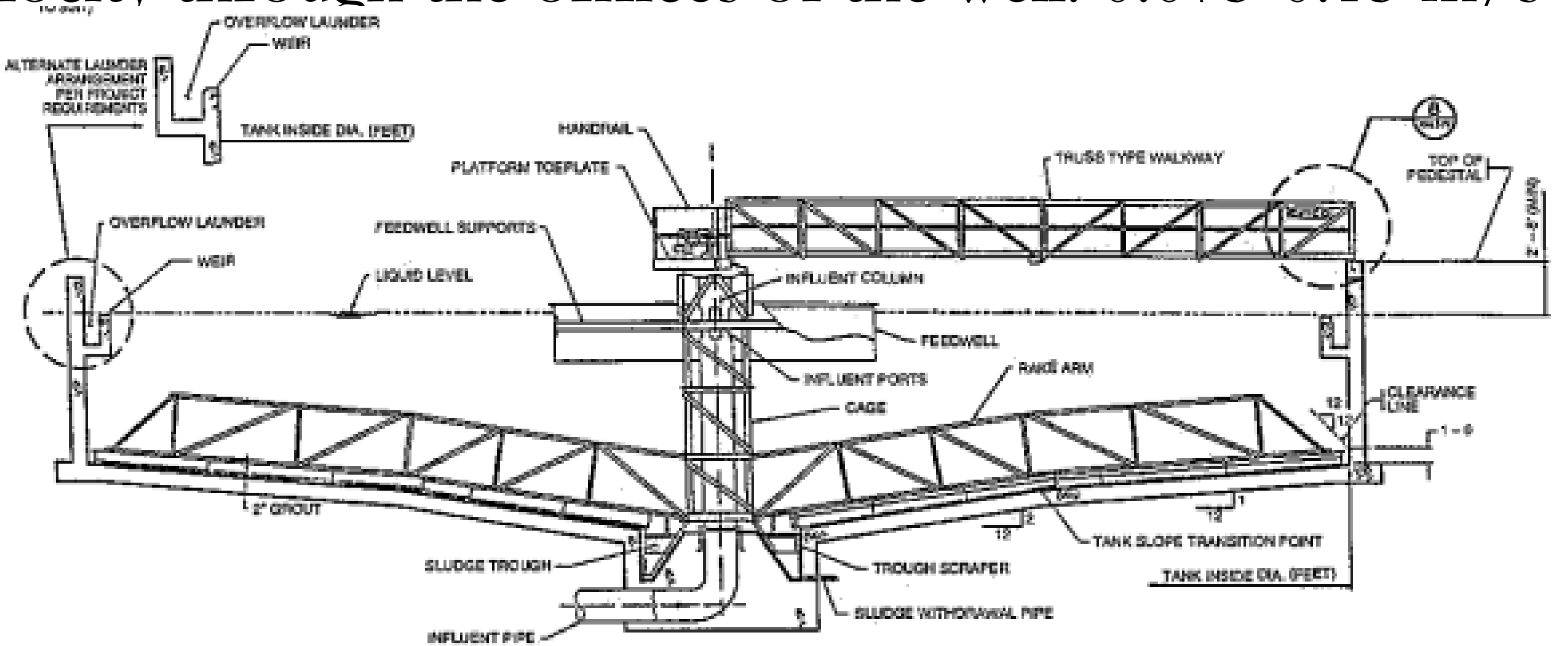



**FIGURE 7.11** Typical circular clarifier. (*Courtesy of Eimco Water Technologies.*)

# Types of Sedimentation Tanks
# Circular Tanks – Inlet Design

- Flocculated water is introduced to the center of the tank through a center riser into a circular feed well
- Diameter of Feed well: 15-10% tank diameter
- Depth of feed well: 1-2.5 m
- Velocity through the orifices of the well: 0.075-0.15 m/s



ILLUSTRATIVE SECTION

# Types of Sedimentation Tanks
# Circular Tanks – Outlet Design

- Circular through around the perimeter with V-notch weirs or with submerged orifices used
- Double sided weir can be mounted along at least 15% of tank radius – wall flow disturbances are reduced—more widely distributed overflow
- Troughs should have small diameter holes in the bottom to reduce buoyant uplift when they are empty

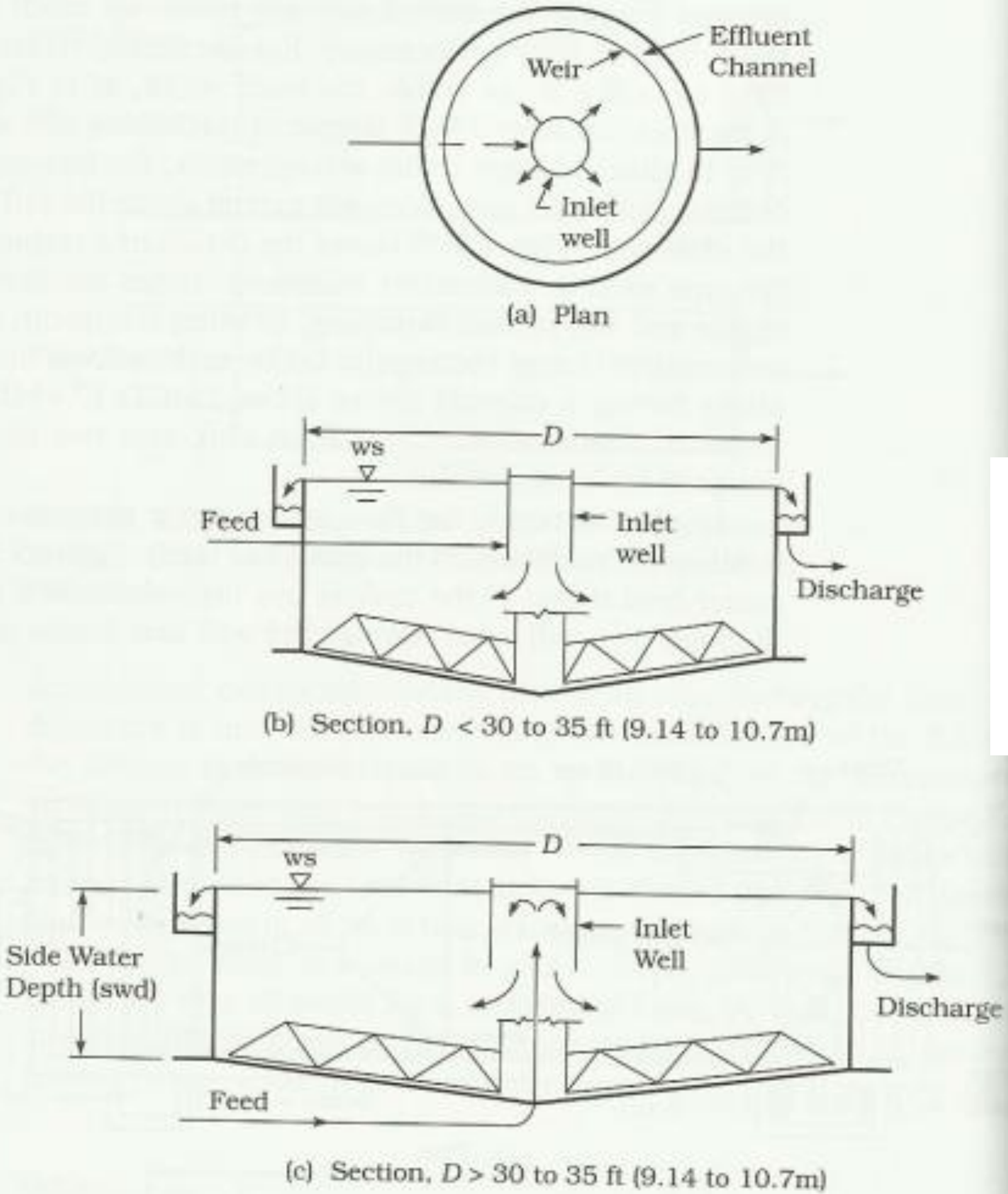



**FIGURE 9.32** ***Inlet and Outlet Details for Circular Tanks (Center Feed)***

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

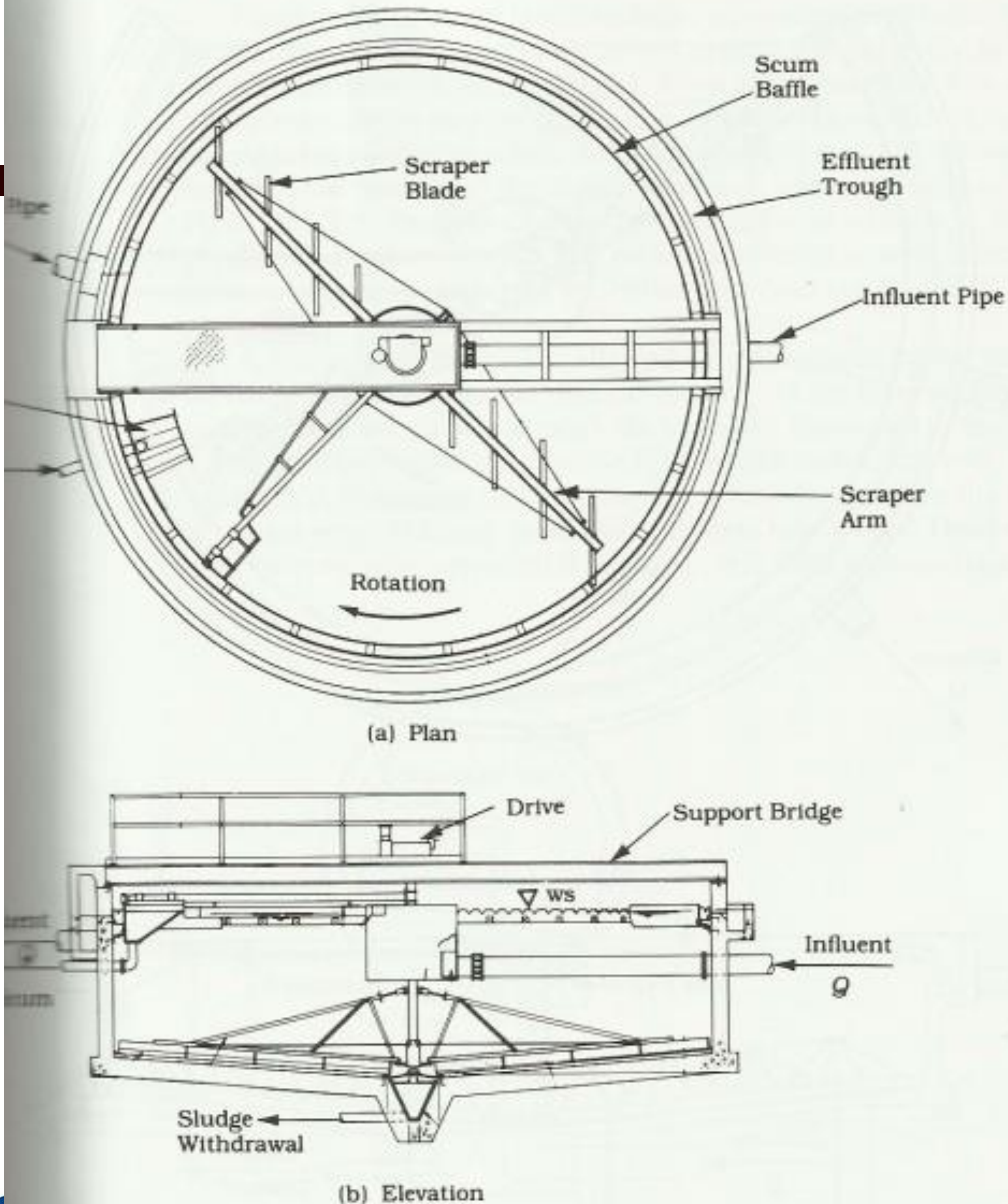



**FIGURE 9.33** *Circular Settling Tank (Center Feed by Pipe through Wall)*

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

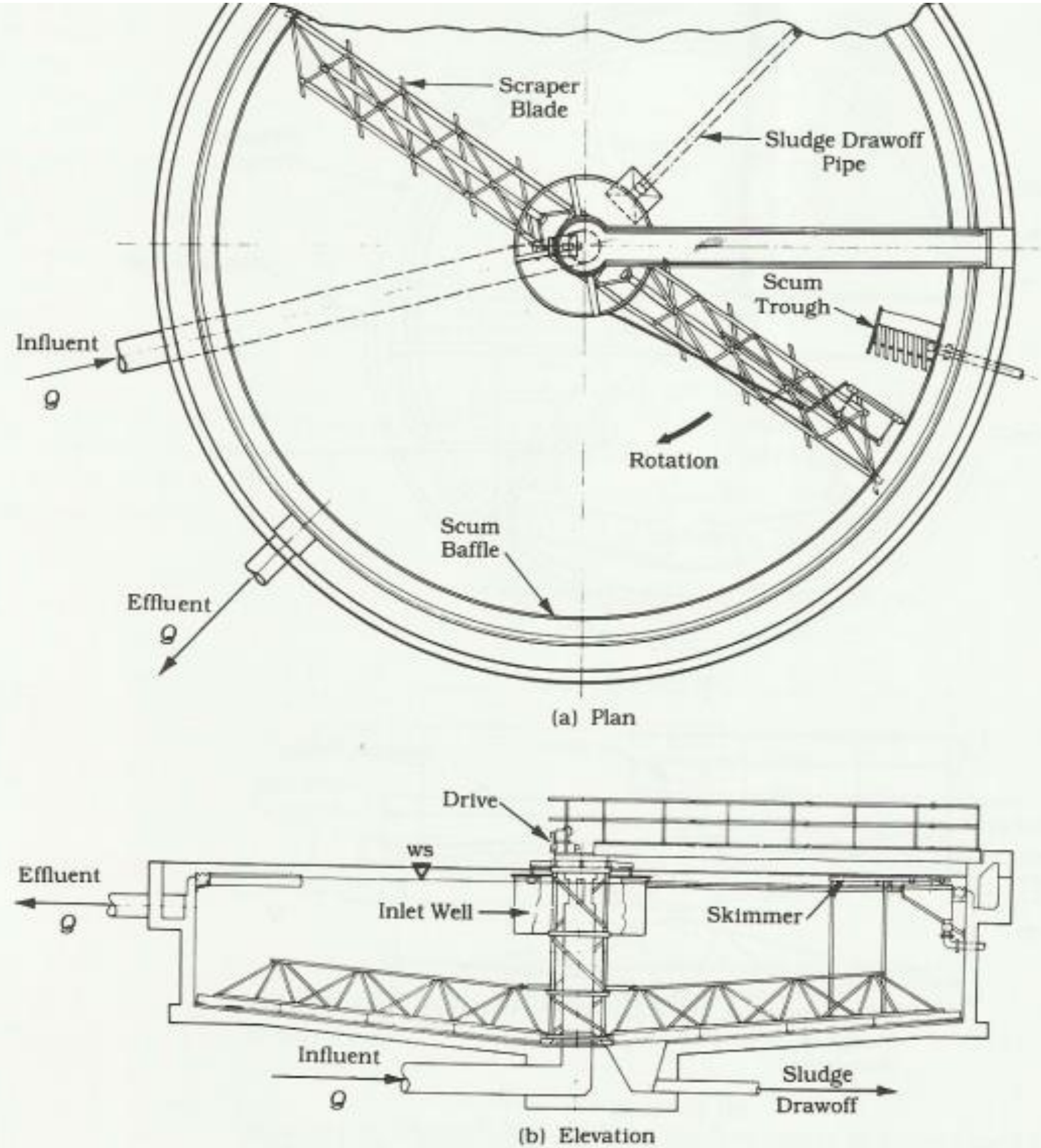



**FIGURE 9.34** *Circular Settling Tank (Center Feed by Pipe under Tank Bottom)*

Courtesy of Infilco Degremont, Inc.

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

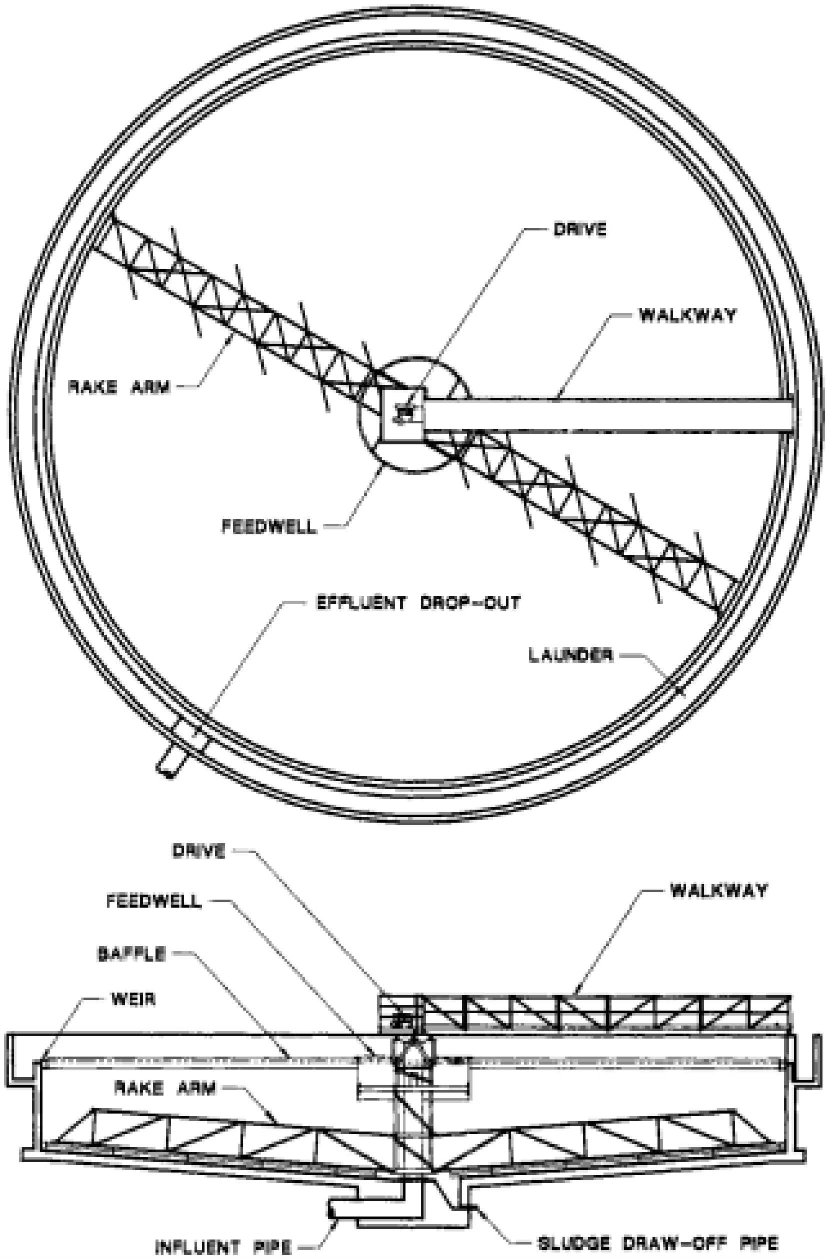



**FIGURE 7.19** Circular radial-flow clarifier. (*Source:* Courtesy of Baker Process Equipment Co., Salt Lake City, Utah.)

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

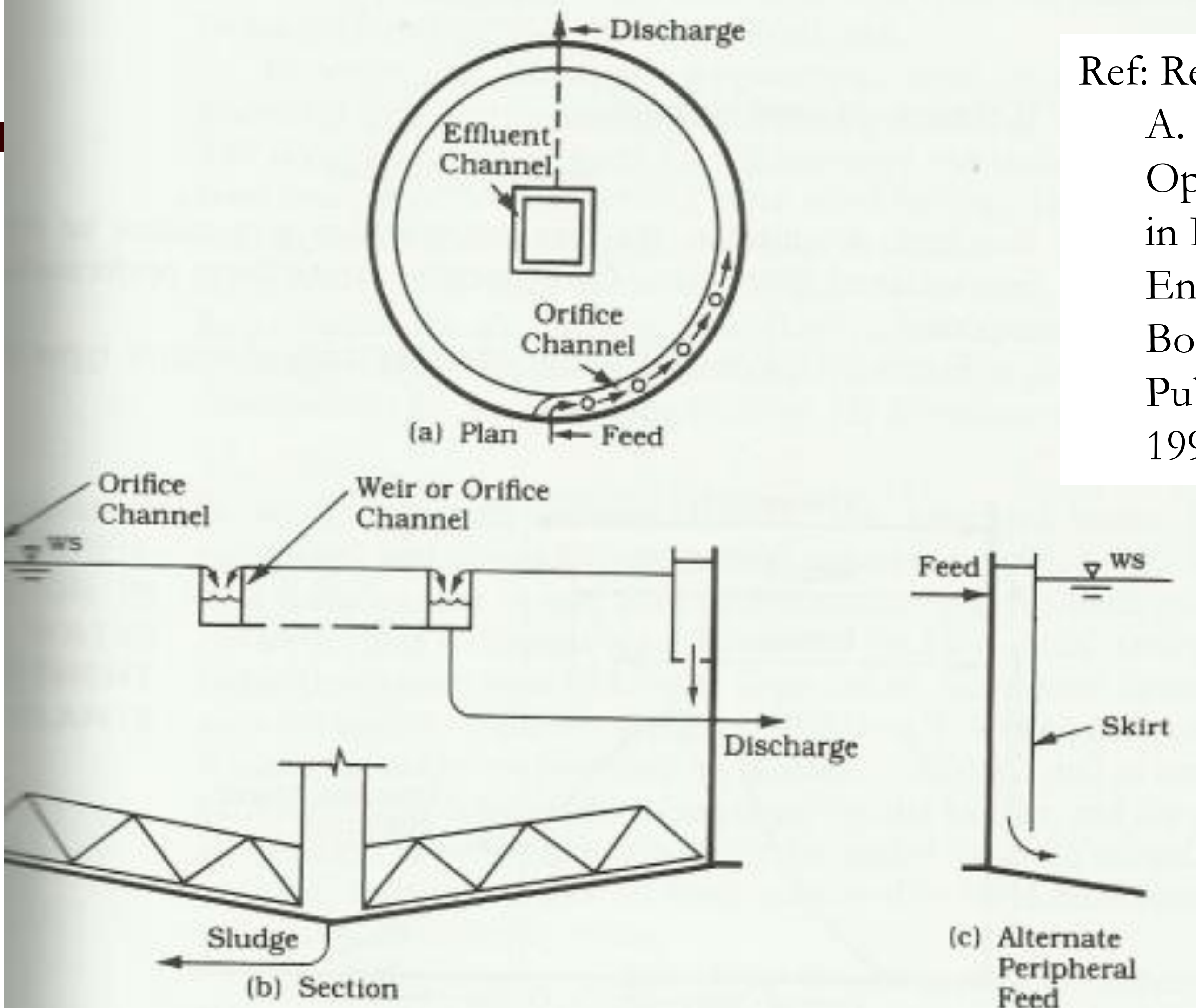
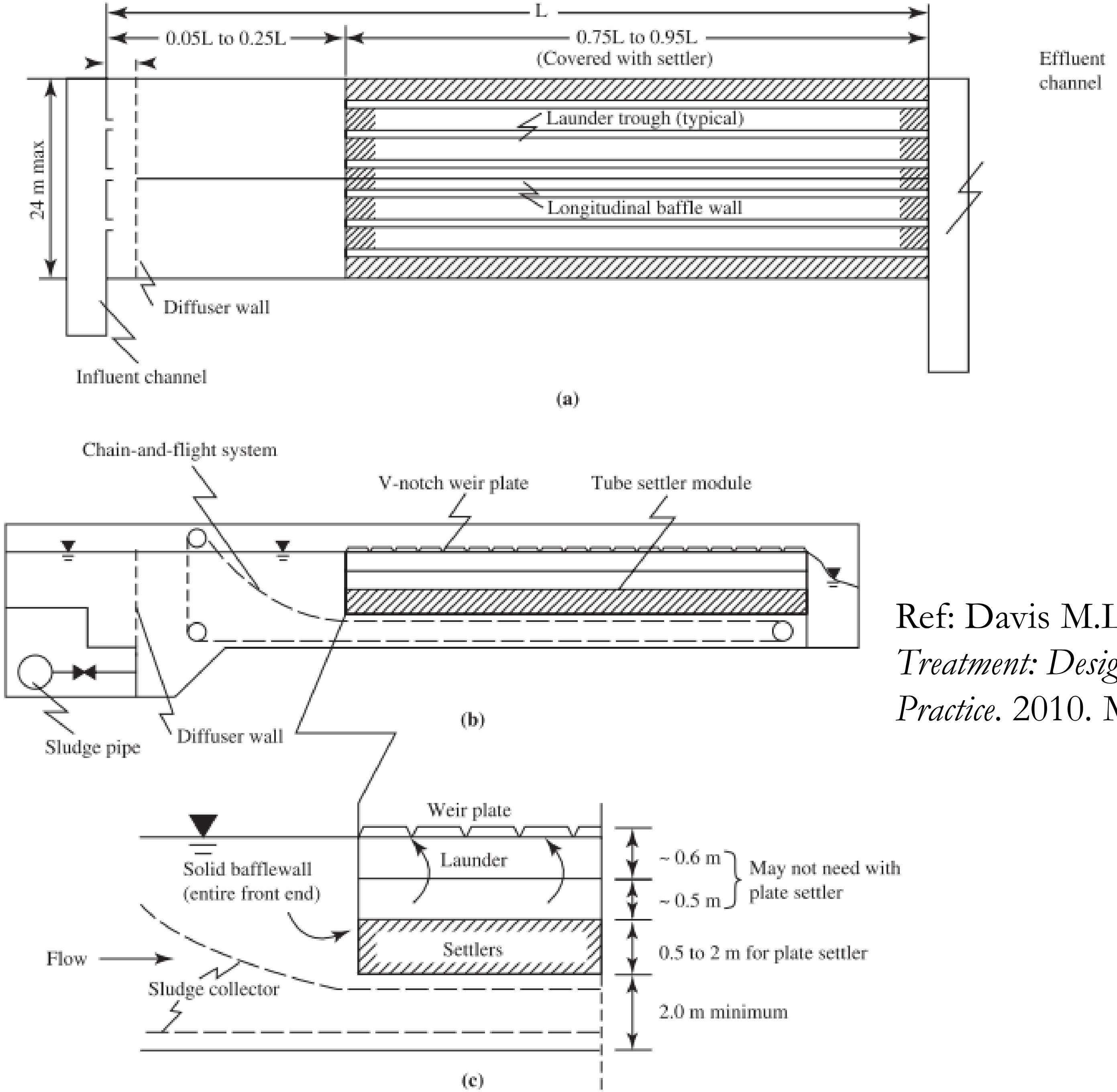



**FIGURE 9.35** *Inlet and Outlet Details for a Circular Tank (Peripheral Feed)*

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

# Types of Sedimentation Tanks
# High Rate Settler Modules – Rectangular Tanks

- High settler modules are placed in the downstream end of a rectangular horizontal flow tanks
- Modules occupy 75-95% of the tank area
- Sufficient space must be provided below the settler modules for the sludge collection mechanism




Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

# Types of Sedimentation Tanks
## Ballasted Sedimentation – Rectangular Tanks

- Alum or ferric chloride is added to form turbidity floc in the first stage .
- High molecular weight cationic polymer or microsand particles are added to the second stage