CE 3372 WATER SYSTEMS DESIGN

LESSON 17: STORM SEWERS CONDUIT DESIGN (SIZE SELECTION) BY RATIONAL EQUATION METHOD FALL 2020

PURPOSES



- Pipes
- Culverts
- Open channels

CONDUIT DESIGN

• Select size, material, and slope

- Storm sewer usually desire to operate with free surface (as an open channel)
- Sanitary sewer similar usually want a free surface
- Size (diameter) is dictated by
 - Flow required
 - Burial depth relative to drop available

METHODS

- A good preliminary design can be obtained using a combination of the rational equation and manning's equation
 - Done without regard to downstream boundary conditions
 - Needs to be checked using a hydraulic model (like SWMM)



- Determine discharge in each pipe.
- Size using manning's equation (... in us customary)

D = 1.333
$$\left(\frac{Qn}{S^{1/2}}\right)^{3/8}$$

 Assumes full, but pipes will have free surface



- Layout of system
 - Drainage area and Inlets

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- Pipes
- Outfall
- elevations



- Drainage areas and inlets
 - Determine inlet time of concentration
 - Determine drainage area runoff coefficient

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- Pipes (Start upstream)
 - Select pipe size
 - Design guidelines
 - Discharge criterio: $D = 1.333 \left(\frac{Qn}{\sqrt{S}} \right)^{A_{o_{i}}}$

• Velocity criteria From criterion $V = \frac{1.49}{n} \left(\frac{D}{4}\right)^{2/3} \sqrt{S}$

• Determined is travel time $t = \frac{distrate}{V}$

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- At most upstream inlet
 - Compute Q_P=CiA to the inlet from inlet time
 - Size pipe from this inlet to hold Q_P
 - ADD pipe travel time to inlet time

0

• Move to next node



- At NEXT upstream inlet
 - Compute Q_P=CiA to the inlet from inlet time
 - Size pipe from this inlet to hold Q_P
 - ADD pipe travel time to inlet time

0

• Move to next node



AT JUNCTION AND INLET

- Choose largest of:
- 1. Local inlet time
- 2. Upstream node+travel time
- Compute Q_p LEAVING THE JUNCTION FROM:

$$Q_p = \left(CA_{local} + \sum CA_{upstream} \right) i_{T_0}$$

• SIZE next pipe from this q_p

9



- Continue downstream in same fashion (from upstream to junction) until reach outlet
- Accumulate CA values and Tc as move downstream
- Checks include that all areas add up to total area
- T_c should be increasing in value as move downstream



- At outlet should have:
 - Pipe sizes
 - Pipe discharges
- Next check hydraulics
 - SWMM enter Q_{INLET} directly and check pipe hydraulics
 - SWMM Approximate rational in SWMM to check a design hyetograph
 - Use SWMM results to adjust design and produce a HGL drawing

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DESIGN STORM SEWER FOR GOODWIN STREET

- "Rational Method Storm Sewer Design" in Mays, L.
 W. (2008) Water Resources Engineering. Pearson-Prentice Hall (pp. 613-635)
- Method: Rational Equation Design Method to make initial design for subsequent hydraulics analysis



PREPARATION STEPS

- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres. (ENGAUGE, PLANIMETER, etc)
- Determine the rational runoff coefficient for each area (TABLE LOOKUP)































CALIBRATE AREA MEASUREMENT TOOL

- Measure areas using appropriate tools
 - E.g. Acrobat Pro
 - Need to measure a known area
 - Save the conversion factor



Area =400X400/43560

= 3.67 acres

CALIBRATE AREA MEASUREMENT TOOL

• Measure areas using Acrobat Pro

- Activate the measurement toolkit
- Select Area
- Measure the orange rectangle
- Save the conversion factor:
 2.43 sq.in. == 3.67 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres. (G3DATA; PLANIMETER, etc)
- Area = 1.50*3.67/2.43 = 2.26 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres. (ENGAUGE, PLANIMETER, etc)
- Area = 0.84*3.67/2.43 = 1.26 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 2.58*3.67/2.43 = 3.89 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.35*3.67/2.43 = 0.53 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.45*3.67/2.43 = 0.68 acres


- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.30*3.67/2.43 = 0.45 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 1.05*3.67/2.43 = 1.58 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.

• Area =
$$1.33*3.67/2.43 = 2.01$$
 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.44*3.67/2.43 = 0.66 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.78*3.67/2.43 = 1.17 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.44*3.67/2.43 = 0.66 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 1.16*3.67/2.43 = 1.75 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.36*3.67/2.43 = 0.54 acres



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 1.44*3.67/2.43 = 2.17 acres



ESTIMATE RUNOFF COEFFICIENTS

- For each area estimate a runoff coefficient
- Usually based on a table lookup and surface description

Table 1 Runoff Coefficients for the Rational Method

	FLAT	ROLLING	HILLY
Pavement & Roofs	0.90	0.90	0.90
Earth Shoulders	0.50	0.50	0.50
Drives & Walks	0.75	0.80	0.85
Gravel Pavement	0.85	0.85	0.85
City Business Areas	0.80	0.85	0.85
Apartment Dwelling Areas	0.50	0.60	0.70
Light Residential: 1 to 3 units/acre	0.35	0.40	0.45
Normal Residential: 3 to 6 units/acre	0.50	0.55	0.60
Dense Residential: 6 to 15 units/acre	0.70	0.75	0.80
Lawns	0.17	0.22	0.35
Grass Shoulders	0.25	0.25	0.25
Side Slopes, Earth	0.60	0.60	0.60
Side Slopes, Turf	0.30	0.30	0.30
Median Areas, Turf	0.25	0.30	0.30
Cultivated Land, Clay & Loam	0.50	0.55	0.60
Cultivated Land, Sand & Gravel	0.25	0.30	0.35
Industrial Areas, Light	0.50	0.70	0.80
Industrial Areas, Heavy	0.60	0.80	0.90
Parks & Cemeteries	0.10	0.15	0.25
Playgrounds	0.20	0.25	0.30
Woodland & Forests	0.10	0.15	0.20
Meadows & Pasture Land	0.25	0.30	0.35
Unimproved Areas	0.10	0.20	0.30

Note:

- Impervious surfaces in bold
- Rolling = ground slope between 2 percent to 10 percent
- Hilly = ground slope greater than 10 percent

from "Oregon Hydraulics Manual (Chapter 7, Appendix F), 2014."

- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres. (ENGAUGE, PLANIMETER, etc)
- Area = 1.50*3.67/2.43 = 2.26 acres
- C = 0.65



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres. (ENGAUGE, PLANIMETER, etc)
- Area = 0.84*3.67/2.43 = 1.26 acres
- C = 0.80



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 2.58*3.67/2.43 = 3.89 acres
- C= 0.70



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.35*3.67/2.43 = 0.53 acres
- C = 0.80



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.45*3.67/2.43 = 0.68 acres
- C = 0.70



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.30*3.67/2.43 = 0.45 acres
- C = 0.85



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 1.05*3.67/2.43 = 1.58 acres
- C = 0.65



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 1.33*3.67/2.43 = 2.01 acres
- C = 0.75



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.44*3.67/2.43 = 0.66 acres
- C = 0.85



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.78*3.67/2.43 = 1.17 acres
- C = 0.70



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.44*3.67/2.43 = 0.66 acres
- C = 0.65



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 1.16*3.67/2.43 = 1.75 acres
- C = 0.55



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 0.36*3.67/2.43 = 0.54 acres
- C = 0.75



- Identify the individual drainage areas.
- Determine the area of each contributing area, in acres.
- Area = 1.44*3.67/2.43 = 2.17 acres
- C = 0.70



IDENTIFY AND MEASURE CONDUIT LENGTHS

- Use ACROBAT to measure distances between Node ID
- Select distance tool
- Measure the 400 foot scale
- Save scale factor
 1.51 in == 400 feet



PIPE 1.1

- Connects 1.1 to 2.1
- Length = 1.57*400/1.51= 415 ft
- Repeat for all the other pipes



GATHER THE INFORMATION INTO A SPREADSHEET

- Build a sheet with the information
- Note the naming convention (a bit awkward, but faithful to the original example)

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4	1.1	2.26	0.65	1.1			1.1	1.1-2.1	415	;
5	1.2	1.26	0.80	1.2			1.2	1.2-2.1	195	i
6	2.1	3.89	0.70	2.1			2.2	2.2-3.1	213	5
7	2.2	0.53	0.80	2.2			2.1	2.1-3.1	188	-
8	3.1	0.68	0.70	3.1			3.2	3.2-4.1	223	
10	3.2	1.58	0.65	3.2			3.3	3.1-4.1	156	-
11	4.1	2.01	0.75	4.1			4.2	4.2-5.1	213	
12	4.2	0.66	0.85	4.2			4.1	4.1-5.1	193	
13	5.1	1.17	0.70	5.1			5.2	5.2-6.1	74	1
14	5.2	0.66	0.65	5.2			5.3	5.3-6.1	138	6
15	5.3	1.75	0.55	5.3			5.1	5.1-6.1	245	i -
16	6.1	0.54	0.75	6.1			6.1	6.1-7.1	149)
17	7.1	2.17	0.70	7.1			7.1	7.1-8.1	266	i
18	Total	19.61								
	Ready				-			0	+ 100%	

DETERMINE INLET TIMES FOR EACH DRAINAGE AREA

Measure actual best-guess flow path

- Find Slope (737.5 732.3)/(0.92*400/1.51)
 - = 5.2ft/243.7 ft = 0.021 (2.1%)
- Determine some kind of cover
- Apply NRCS Velocity, NRCS Upland, or Kerby-Kirpich
- Use method that makes most sense



DETERMINE INLET TIMES FOR EACH DRAINAGE AREA

- NRCS Upland Method
- Measure actual best-guess flow path
 - Path = 243.7 ft
 - Slope = 0.021 (2.1%)
- Inlet Time ~ 11 minutes
- Repeat for each drainage area, populate spreadsheet



DETERMINE INLET TIMES FOR EACH DRAINAGE AREA

 Repeat for each drainage area, populate spreadsheet

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2	Drainage /	Area ID	Drainage Area (acres)	Runoff Coefficient	Inlet ID	Inlet Time (min)		PipelD	NodelD-NodelD	Pipe Length (ft) Pi
4		1.1	2.26	0.65	1.1	11		1.1	1.1-2.1	415
5		1.2	1.26	0.80	1.2	9.2		1.2	1.2-2.1	195
6		2.1	3.89	0.70	2.1	13.7		2.2	2.2-3.1	213
7		2.2	0.53	0.80	2.2	5.2		2.1	2.1-3.1	188
8		3.1	0.68	0.70	3.1	8.7		3.2	3.2-4.1	223
9		3.2	0.45	0.85	3.2	5.9		3.3	3.3-4.1	138
10		3.3	1.58	0.65	3.3	11.8		3.1	3.1-4.1	166
11		4.1	2.01	0.75	4.1	9.5		4.2	4.2-5.1	213
12		4.2	0.66	0.85	4.2	6.2		4.1	4.1-5.1	193
13		5.1	1.17	0.70	5.1	10.3		5.2	5.2-6.1	120
14		5.2	0.00	0.65	5.2	11.8		5.3	5.3-0.1	138
15		5.5	1.75	0.55	5.5	17.0		5.1	5.1-0.1	243
17		7 1	2 17	0.75	7.1	14.5		71	71-81	266
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ESTIMATE PIPE SLOPES

 Use the node elevations and topographic map to estimate pipe slopes



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ESTIMATE PIPE SLOPES

Use the node

 elevations and
 topographic map
 to estimate pipe
 slopes

 Populate the spreadsheet

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7	2.2	0.53	0.80	2.2	5.2		2.1	2.1-3.1	188	0.0245	8	
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9	3.2	0.45	0.85	3.2	5.9		3.3	3.3-4.1	138	0.0300		725. 2.2
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1	4.1	2.01	0.75	4.1	9.5		4.2	4.2-5.1	213	0.0026	Calif	1.2 2.1 ×72
2	4.2	0.66	0.85	4.2	6.2		4.1	4.1-5.1	193	0.0041		730
3	5.1	1.17	0.70	5.1	10.3		5.2	5.2-6.1	74	0.0250		
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15	5.3	1.75	0.55	5.3	17.6		5.1	5.1-6.1	245	0.0028		735
16	6.1	0.54	0.75	6.1	7.3		6.1	6.1-7.1	149	0.0030		
18	7.1 Total	2.17	0.70	7.1	14.5		7.1	7.1-8.1	266	0.0030		0000
10	Total	15.01										

Ready

Average: 10.19285714 Count: 14 Sum: 142.7 📰 🗉

- Next we will need to precipitation information for the design.
- Easiest for this example is to build an IDF curve for the location.
- The basin in the example is in Urbana, Illinois – Use NOAA Atlas 14
- For the example use a 2-yr ARI

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	5-min (4.91 (5.82 6.90 (6.40-7.50) (6.40-7.50) (7.76 8.89 9.76 (8.17-9.64) (8.93-10	10.6 11.5 12.7 13.7 0.6) (9.67-11.5) (10.4-12.5) (11.4-13.8) (12.2-14.7)										
	10-min (3.54-4.12) (4.22-4.93) (4.97-5.83) (5.99 6.80 7.40 (6.25-7.37) (6.76-8.	7.99 8.60 9.36 9.94 .00) (7.28-8.64) (7.78-9.29) (8.41-10.1) (8.87-10.7)										
	15-min 3.12 3.70 4.39 (2.89-3.37) (3.44-4.02) (4.07-4.77) (4.92 5.60 6.10 (5.14-6.07) (5.58-6.	6.62 7.13 7.79 8.28 6.60 (6.02-7.16) (6.45-7.71) (6.99-8.42) (7.39-8.94)										
	30-min (1.91-2.23) (2.30-2.69) (2.78-3.27) (3.41 3.95 4.36 3.15-3.70) (3.63-4.28) (3.99-4.	4.78 5.20 5.77 6.21 7.2) (4.35-5.17) (4.71-5.62) (5.18-6.24) (5.54-6.70)										
	60-min (1.17-1.36) (1.41-1.65) (1.75-2.05) (2.00-2.36) (2.36-2.78) (2.63-3. 1.29 1.54 1.76	3.19 3.53 3.99 4.36 (2.91-3.45) (3.20-3.82) (3.58-4.31) (3.89-4.71) 2.01 2.20 2.72 2.00										
	2-hr (0.692-0.816) (0.834-0.984) (1.03-1.21) (0.536 0.645 0.795	1.18-1.40) (1.41-1.67) (1.61-1. 0.920 1.11 1.28	91) (1.83-2.17) (2.07-2.47) (2.44-2.93) (2.76-3.34) 1.47 1.68 2.01 2.30										
	3-hr (0.492-0.586) (0.593-0.705) (0.731-0.870) (0 0.318 0.382 0.469	0.844-1.01) (1.01-1.21) (1.16-1. 0.543 0.654 0.752	39) (1.32-1.59) (1.51-1.82) (1.79-2.18) (2.04-2.50) 2 0.863 0.989 1.19 1.36										
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- Download the table
- Use the 2-nd column

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17	15-min:	3.12	3.7	4.39	4.92	5.6	
18	30-min:	2.06	2.48	3.01	3.41	3.95	
19	60-min:	1.26	1.52	1.89	2.17	2.56	
20	2-hr:	0.751	0.904	1.11	1.29	1.54	
21	3-hr:	0.536	0.645	0.795	0.92	1.11	
22	6-hr:	0.318	0.382	0.469	0.543	0.654	
23	12-hr:	0.184	0.221	0.27	0.311	0.373	
24	24-hr:	0.107	0.128	0.155	0.18	0.216	
25	2-day:	0.062	0.074	0.089	0.102	0.122	
26	3-day:	0.044	0.053	0.063	0.072	0.086	
27	4-day:	0.035	0.042	0.05	0.057	0.068	
28	7-day:	0.024	0.028	0.033	0.037	0.043	
29	10-day:	0.019	0.023	0.026	0.029	0.034	
30	20-day:	0.013	0.015	0.018	0.019	0.022	
31	30-day:	0.011	0.013	0.014	0.016	0.018	
32	45-day:	0.009	0.01	0.012	0.013	0.015	
33	60-day:	0.008	0.009	0.011	0.012	0.013	
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- Download the table
- Use the 2-nd column
- Use solver to fit

 $I = \frac{B}{(T_c + D)^E}$

• Use this equation for estimating intensity and runoff

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Intensity function for the example:

 $I = \frac{54.82}{(T_c + 9.21)^{0.844}}$

 This can be coded into an analysis spreadsheet directly

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- Intensity Equation
- Rational Method
- Discharge to Inlet