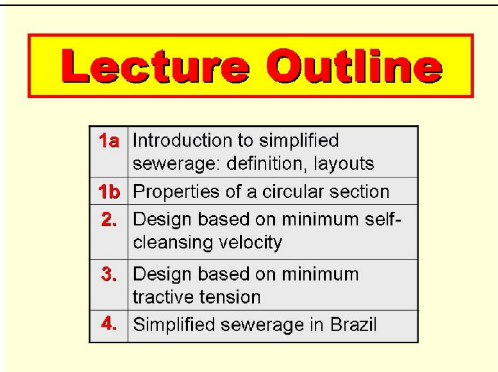
SIMPLIFIED SEWERAGE

Part 1 of 4

1.

This presentation is on simplified sewerage and it is divided into four parts:

2.

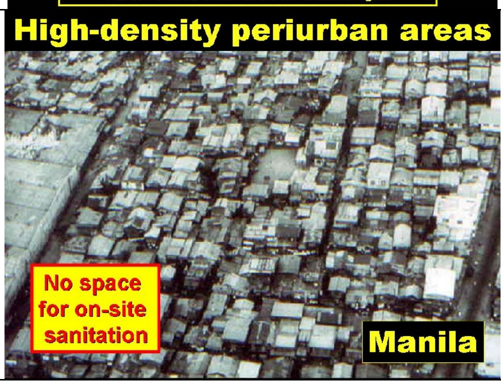


First of all, an introduction and the properties of a circular section; then the design based on a minimum self-cleansing velocity; then the design based on minimum tractive tension; and finally a case study: simplified sewerage in Brazil where it was first developed in the early 1980s.

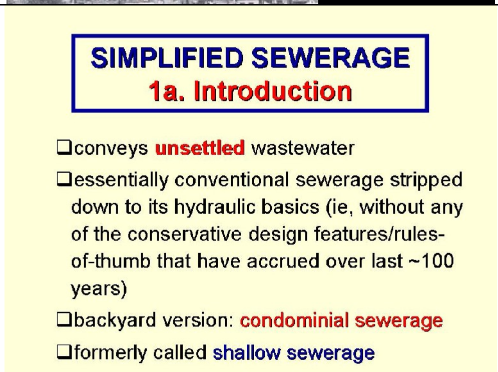
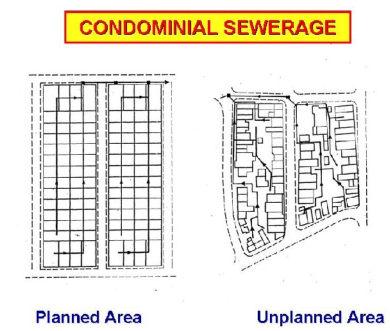
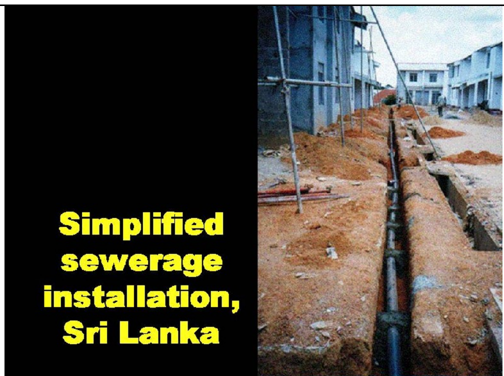
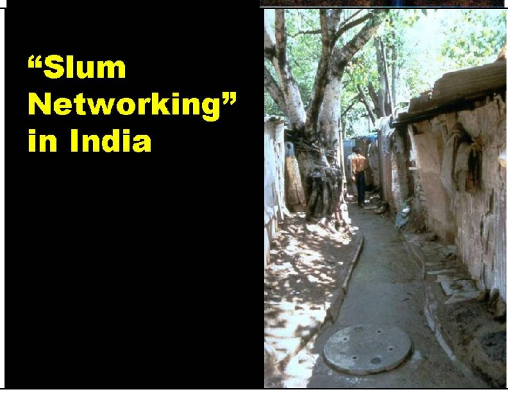
3.

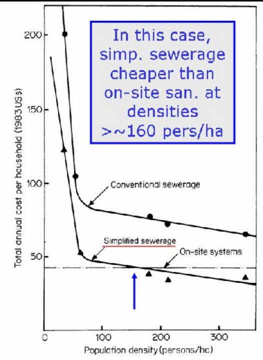
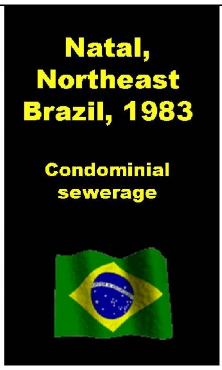
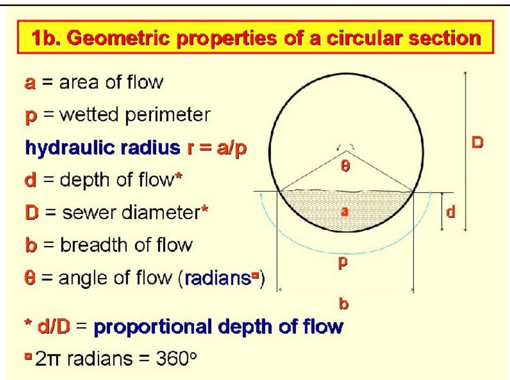
In periurban areas of developing countries sanitation is usually very inadequate. Raw wastewater is discharged into open storm water drains – if there are any. These pictures are from Indonesia and Bangladesh, but really they could be from anywhere.

4.



This slide shows a very typical, high-density urban area. It happens to be in Manila in the Philippines and it shows us that there is really no space at all for on-site sanitation systems.

5.		These are *favelas* or hillside slums in Rio de Janeiro and again there is very little space for on site sanitation.
6.		Simplified sewerage conveys unsettled wastewater, and it is essentially conventional sewerage stripped down to its hydraulic basics, that is to say without any of the very conservative design features and rules of thumb that have accrued with conventional sewerage over the last 100 or 150 years. It is sometimes called condominial sewerage and it used to be called shallow sewerage.
7.		Condominial in-block sewerage is suitable for both unplanned areas where it would normally be retro-fitted and also for planned areas with a more regular housing layout.
8.		This slide shows simplified sewerage being installed in Sri Lanka in a new housing estate,
9.		and this slide shows 'slum networking' in India, which is the Indian term for simplified sewerage or condominial sewerage in slum areas in that country.

10.		Condominial or simplified sewerage was developed in the city of Natal in northeast Brazil in the early 1980s. This chart shows how the costs per household vary with population density. When the population density is below about 100 people per ha, both conventional and simplified sewerage are very expensive; but with a population density above about 160 people per ha, simplified sewerage became in this particular case cheaper than on-site sanitation systems. This is really a very important finding and it leads us to the conclusion that in high-density, low-income periurban areas, which we find all over the developing world, simplified sewerage is most likely to be the sanitation technology of first choice.
11.		Before we can design a simplified sewer we must have a good understanding of the geometric properties of a circular section. This is because the small sewers we use are circular in cross-section and the wastewater flows in them under gravity with a free water surface. So first of all, to define the terms: *a* is the area of flow and *p* is the wetted perimeter. The ratio *a/p* is called the **hydraulic radius** and is denoted by the letter *r*. *d* is the depth of wastewater flow in the sewer and *D* is the sewer diameter, and the ratio *d/D* is called the proportional depth of flow. *b* is the breadth of flow and θ is the angle of flow measured in radians, and there are 2π radians in 360^o.
12.	$\theta = 2\cos^{-1}[1 - 2(d/D)]$ (radians) $a = D^2[(\theta - \sin\theta)/8]$ $p = D\,\theta/2$ Hydraulic radius $r = a/p$ $= (D/4)[1 - (\sin\theta/\theta)]$ $b = D\sin(\theta/2)$	The angle of flow (θ) is $2\cos^{-1}[1 - 2(d/D)]$ in radians. The area of flow is $D^2[(\theta - \sin\theta)/8]$, and the wetted perimeter is $D\theta/2$, so the hydraulic radius, which is *a/p*, equals $(D/4)[1 - (\sin\theta/\theta)]$, and the breadth of flow (*b*) is $D\sin(\theta/2)$.

13.

When the sewer is **flowing just full** (ie, d = D):

$a = A = \pi D^2/4$
$p = P = \pi D$
$r = R = D/4$

$a/A = (\theta - \sin\theta)/2\pi$ and $r/R = 1 - (\sin\theta/\theta)$

But more commonly use:
$a = k_aD^2$ $\quad k_a = (1/8)(\theta - \sin\theta)$
$r = k_rD$ $\quad k_r = (1/4)[1 - (\sin\theta/\theta)]$

When the sewer is flowing just full, so that the depth of flow = the sewer diameter, $d = D$, and $a = A = \pi D^2/4$, $p = P = \pi D$; so the hydraulic radius at full bore $R = D/4$.

We can then express the ratios *a/A* and *r/R* in terms of θ, but more commonly we use the following expressions:

$$\boldsymbol{a = k_aD^2} \text{ and } \boldsymbol{r = k_rD}$$

where both k_r and k_a are functions of θ.

14.

Hydraulic elements of a circular section

d/D	k_a	k_r	a/A	r/R	v/V	q/Q
0.02	0.0037	0.0132	0.0048	0.0528	0.1408	0.0007
0.04	0.0105	0.0262	0.0134	0.1047	0.2221	0.0030
0.06	0.0192	0.0389	0.0245	0.1555	0.2892	0.0071
0.08	0.0294	0.0513	0.0375	0.2053	0.3480	0.0130
0.10	0.0409	0.0635	0.0520	0.2541	0.4012	0.0209
0.12	0.0534	0.0755	0.0680	0.3018	0.4500	0.0306
0.14	0.0668	0.0871	0.0851	0.3485	0.4953	0.0421
0.16	0.0811	0.0986	0.1033	0.3942	0.5376	0.0555
0.18	0.0961	0.1097	0.1224	0.4388	0.5775	0.0707
0.20	0.1118	0.1206	0.1424	0.4824	0.6151	0.0876
0.22	0.1281	0.1312	0.1631	0.5248	0.6507	0.1061
0.24	0.1449	0.1416	0.1845	0.5662	0.6844	0.1263
0.26	0.1623	0.1516	0.2066	0.6065	0.7165	0.1480
0.28	0.1800	0.1614	0.2292	0.6457	0.7471	0.1712
0.30	0.1982	0.1709	0.2523	0.6838	0.7761	0.1958
0.32	0.2167	0.1802	0.2758	0.7207	0.8038	0.2217
0.34	0.2355	0.1891	0.2998	0.7565	0.8302	0.2489
0.36	0.2546	0.1978	0.3241	0.7911	0.8554	0.2772
0.38	0.2739	0.2062	0.3486	0.8246	0.8794	0.3066
0.40	0.2934	0.2142	0.3735	0.8569	0.9022	0.3369
0.42	0.3130	0.2220	0.3985	0.8880	0.9239	0.3682
0.44	0.3328	0.2295	0.4237	0.9179	0.9445	0.4002
0.46	0.3527	0.2366	0.4491	0.9465	0.9640	0.4329
0.48	0.3727	0.2435	0.4745	0.9739	0.9825	0.4662
0.50	0.3927	0.2500	0.4999	1.0000	1.0000	0.5000
0.52	0.4127	0.2562	0.5254	1.0248	1.0165	0.5340
0.54	0.4327	0.2621	0.5508	1.0483	1.0319	0.5684
0.56	0.4526	0.2676	0.5761	1.0704	1.0464	0.6029
0.58	0.4724	0.2728	0.6013	1.0912	1.0599	0.6374
0.60	0.4920	0.2776	0.6264	1.1106	1.0724	0.6718
0.62	0.5115	0.2821	0.6512	1.1285	1.0839	0.7059
0.64	0.5308	0.2862	0.6758	1.1449	1.0944	0.7396
0.66	0.5499	0.2900	0.7001	1.1599	1.1039	0.7728
0.68	0.5687	0.2933	0.7240	1.1732	1.1124	0.8054
0.70	0.5872	0.2962	0.7476	1.1849	1.1198	0.8371
0.72	0.6054	0.2987	0.7707	1.1950	1.1261	0.8679
0.74	0.6231	0.3008	0.7933	1.2033	1.1313	0.8975
0.76	0.6405	0.3024	0.8153	1.2097	1.1353	0.9257
0.78	0.6573	0.3036	0.8368	1.2143	1.1382	0.9524
0.80	0.6736	0.3042	0.8575	1.2168	1.1397	0.9775
0.82	0.6893	0.3043	0.8775	1.2171	1.1399	1.0003
0.84	0.7043	0.3038	0.8966	1.2150	1.1387	1.0209
0.86	0.7186	0.3026	0.9148	1.2104	1.1358	1.0390
0.88	0.7320	0.3007	0.9319	1.2029	1.1311	1.0541
0.90	0.7445	0.2980	0.9475	1.1921	1.1243	1.0657

See Simplified Sewerage Design Manual for clearer version

Normally we do not have to do all these calculations. Instead we use this Table which gives the hydraulic elements of a circular section.

So, for various values of *d/D* in the first column on the left, we can read off the values of k_a, k_r, *a/A*, *r/R;* and also *v/V* and *q/Q* which we will come to in a minute.

15.

Manning's equation

$v = (1/n)r^{2/3}i^{1/2}$ —— velocity (m/s) at d/D

Now $q = av$
so **$q = (1/n)ar^{2/3}i^{1/2}$** ['Manning flow eqn']

When the sewer is flowing just full:
$V = (1/n)R^{2/3}i^{1/2}$
$Q = (1/n)AR^{2/3}i^{1/2}$

The basic equation which we use is Manning's equation, and this says that the velocity in m/s at the proportional depth of *d/D* is equal to:

$$\left(\frac{1}{n}\right) \times r^{2/3} \times i^{1/2}$$

where *n* is Manning's roughness coefficient and *i* is the sewer gradient.

We know that flow = area × velocity, $q = av$, so that Manning's 'flow equation' can be expressed as:

$$q = \left(\frac{1}{n}\right) \times a \times r^{2/3} \times i^{1/2}$$

When the sewer is flowing just full we use the same equation, but write *v*, *r*, *q* and *a* in capital letters.

16.

So: $v/V = (r/R)^{2/3}$
$= [1 - (\sin\theta/\theta]^{2/3}$

$q/Q = (a/A)(r/R)^{2/3}$
$= [(\theta - \sin\theta)/2\pi)][1 - (\sin\theta/\theta)]^{2/3}$

Since θ = f(d/D),

both v/V and q/Q are also f(d/D) .....

This enables us to calculate the velocity ratio *v/V*, and *q/Q*, the flow ratio, in terms of θ. Since θ is a function of the proportional depth of flow, *d/D*, this means that *v/V* and *q/Q* are both functions of *d/D*,

<table>
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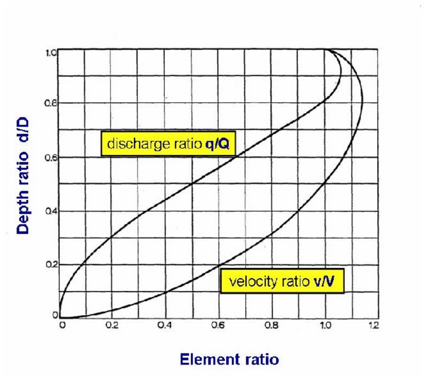
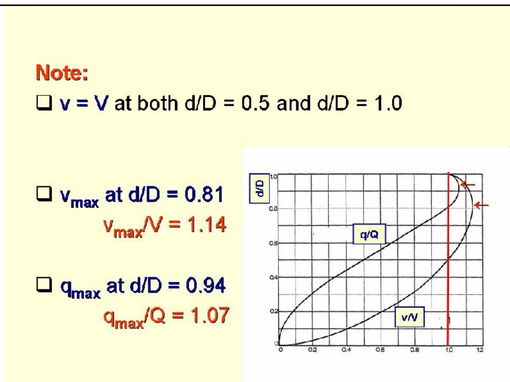
<td>17.</td>
<td>
</td>
<td>and this chart shows how the ratios q/Q and v/V vary with the depth ratio or the proportional depth of flow, d/D, as it varies from 0 to 1.</td>
</tr>
<tr>
<td>18.</td>
<td>
</td>
<td>There are three important points that this chart tells us. Firstly, $v = V$ at two values of d/D: where it equals 0.5 and where it equals 1.
Secondly, there is a maximum velocity of flow and this occurs at a d/D value of 0.81 and it is 14 percent more than the velocity of flow at full pipe.
Thirdly, there is also a maximum flow and this occurs at a d/D value of 0.94 and this is 7 percent greater than the flow at full pipe.</td>
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