UNIVERSITAS
GADJAH MADA

Water Infrastructure Maintenance Engineering

Presented by

RIAN MANTASA SALVE P.
Universitas Gadjah Mada
rian.mantasa.s.p@ugm.ac.id

Week Plans

Week	Learning Outcomes	Material
6	Students able to design earth-fill dam for maintenance knowledge Students able to create and design the dam according to seepage factor	Dam design Stability of dam: Slices method, Geo-studio Software: AutoCAD, SEEP2D GMS
7 - 8	Students could create rainfall design for drainage/ water works maintenance Students able to decide channel design for maintenance	Hydrology Rainfall analysis Software: HEC-RAS
9	Watershed Protection Low Impact Development River Embankment maintenance	Hydrology Rainfall analysis Green infrastructure Software: HEC-RAS, LID (Low Impact Development)

Assessment

UNIVERSITAS GADJAH MADA

- Tugas 1: Analisis Seepage, Geo-Slope
- Tugas 2: Analisis Hujan, Rancangan Banjir
- Tugas 3: Simulasi HEC-RAS, Geo-slope, rekayasa desain dan pemeliharaan
- Tugas Besar: Studi Kasus

Nilai Akhir

- Hanya bila sudah mengumpulkan semua tugas

Kelengkapan Tugas	Nilai
4	Lengkap
3	0
2	0
1	0

Penalty

- Melewati deadline (ditentukan asisten)
- Melewati deadline dosen

Pre-village

- Top 5-10

Alur Tugas Besar

- Soal dibagikan
- Asistensi ke asisten
- Asistensi ke dosen
- Selesai

Reservoir

Elemen Utama

- Dam
- Intake
- spillway

Dam

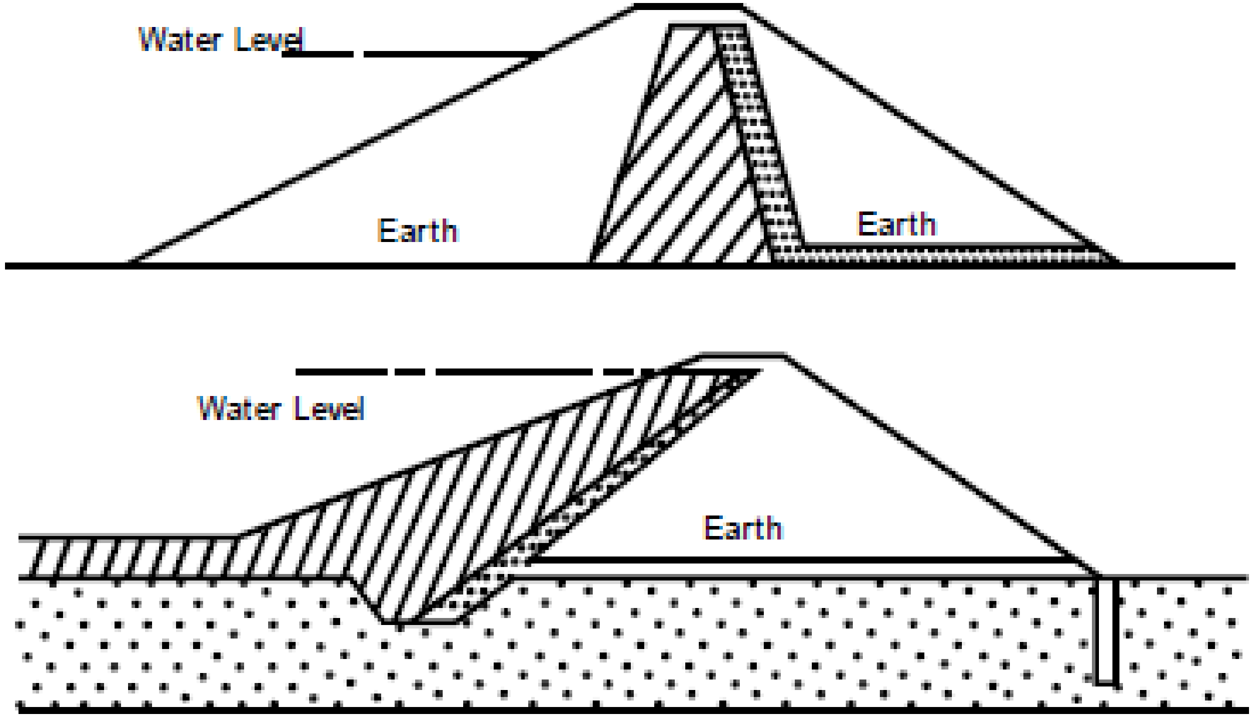
Type

- Urugan, embankment dam
- Gravitasi, gravity dam
- Plat penahan, buttress dam
- Arches dam

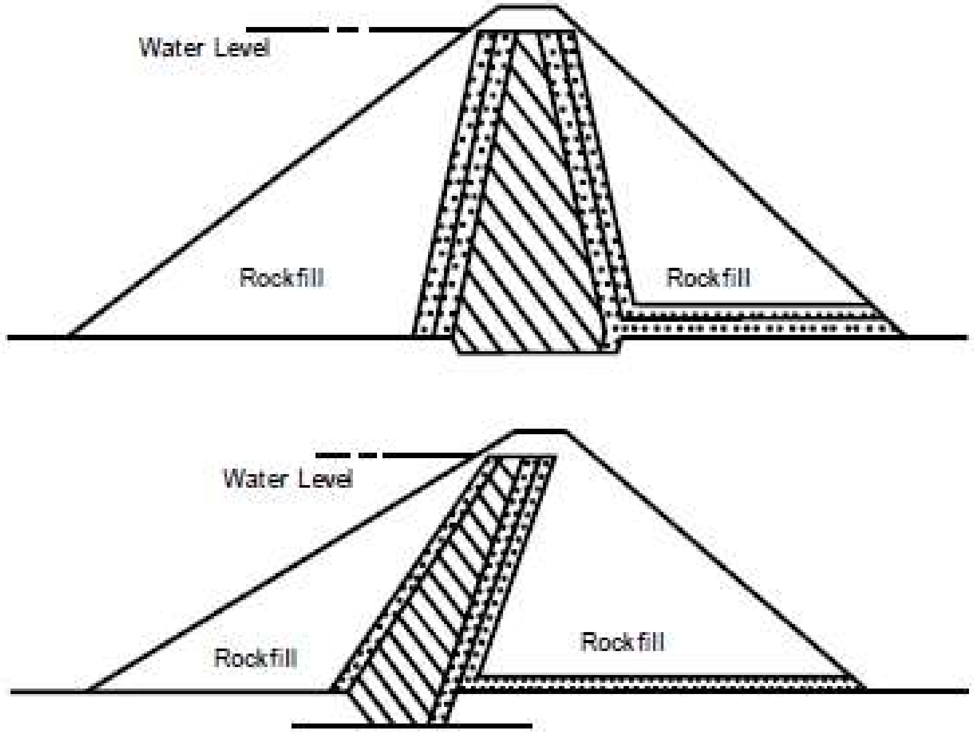
Dam; Beberapa catatan

- every dam, large or small, is quite unique; foundation geology, material characteristics, catchment flood hydrology etc. are each sitespecific.
- dams are required to function at or close to their design loading for extended periods.
- dams do not have a structural lifespan; they may, however, have a notional life for accounting purposes, or a functional lifespan dictated by reservoir sedimentation.
- the overwhelming majority of dams are of earthfill, constructed from a range of natural soils; these are the least consistent of construction materials.
- dam engineering draws together a range of disciplines, e.g. structural and fluid mechanics, geology and geotechnics, flood hydrology and hydraulics, to a quite unique degree.
- the engineering of dams is critically dependent upon the application of informed engineering judgement.

Bendungan Urugan



Earth Fill Type



Rock Fill Type

Bendungan Beton dan Pasangan Batu (Concrete and masonry)

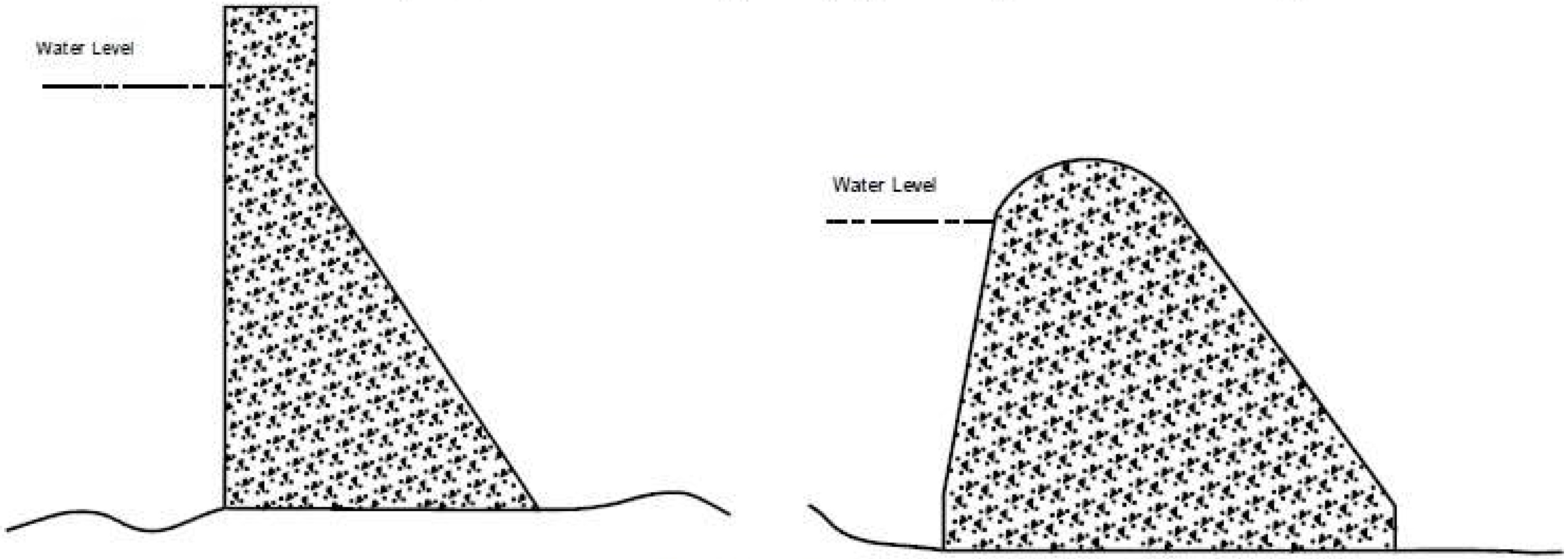


Figure 2. Gravity Type.

Bendungan Beton dan Pasangan Batu (Concrete and masonry)

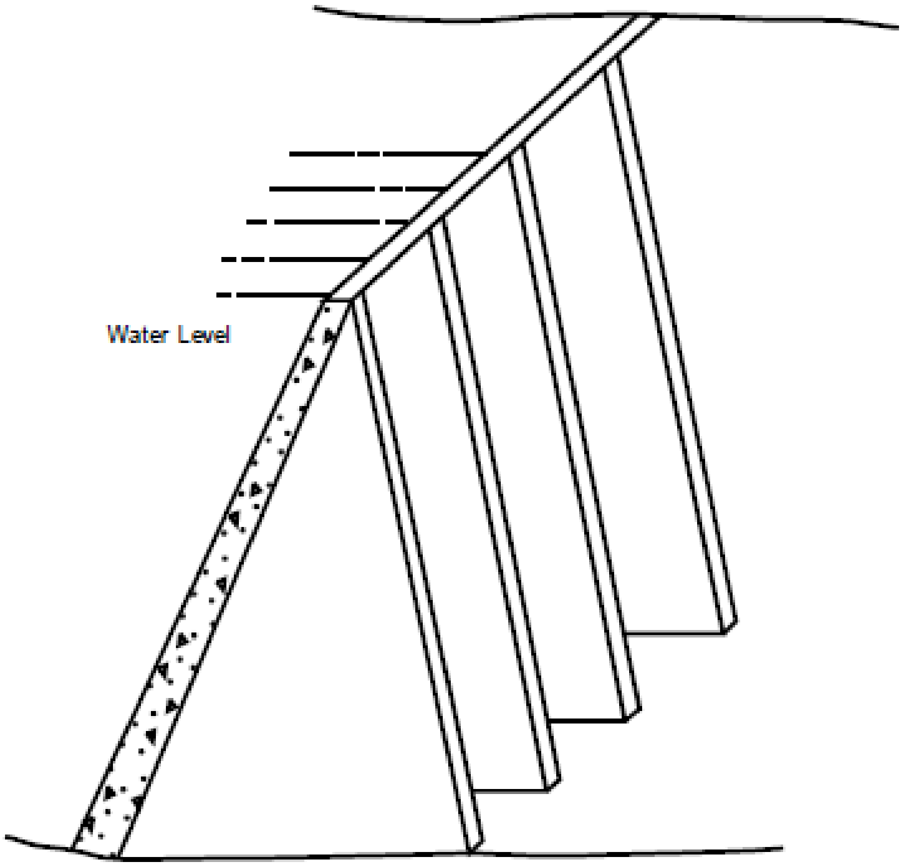


Figure 3. Flat Slab – Buttressed.

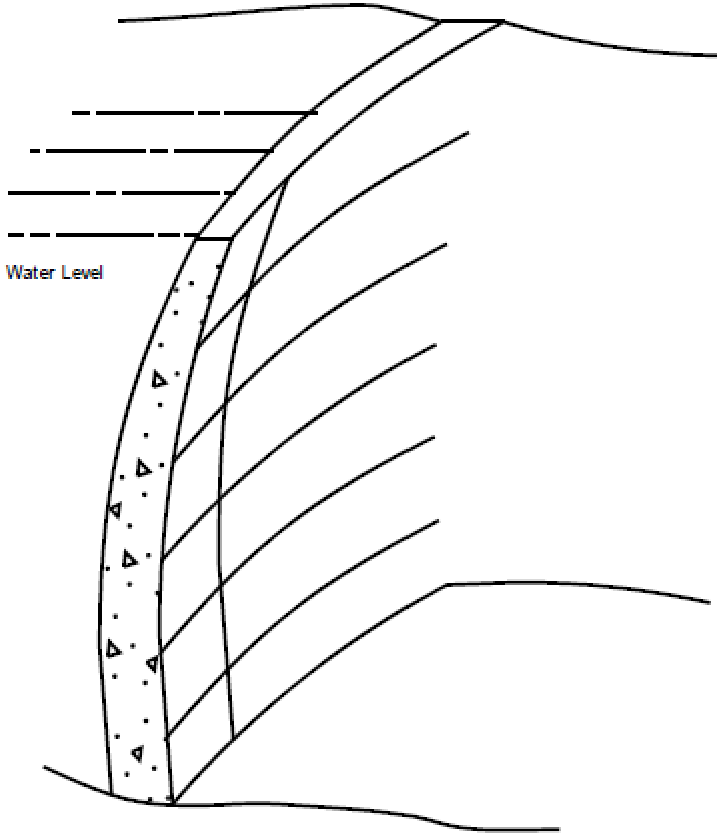
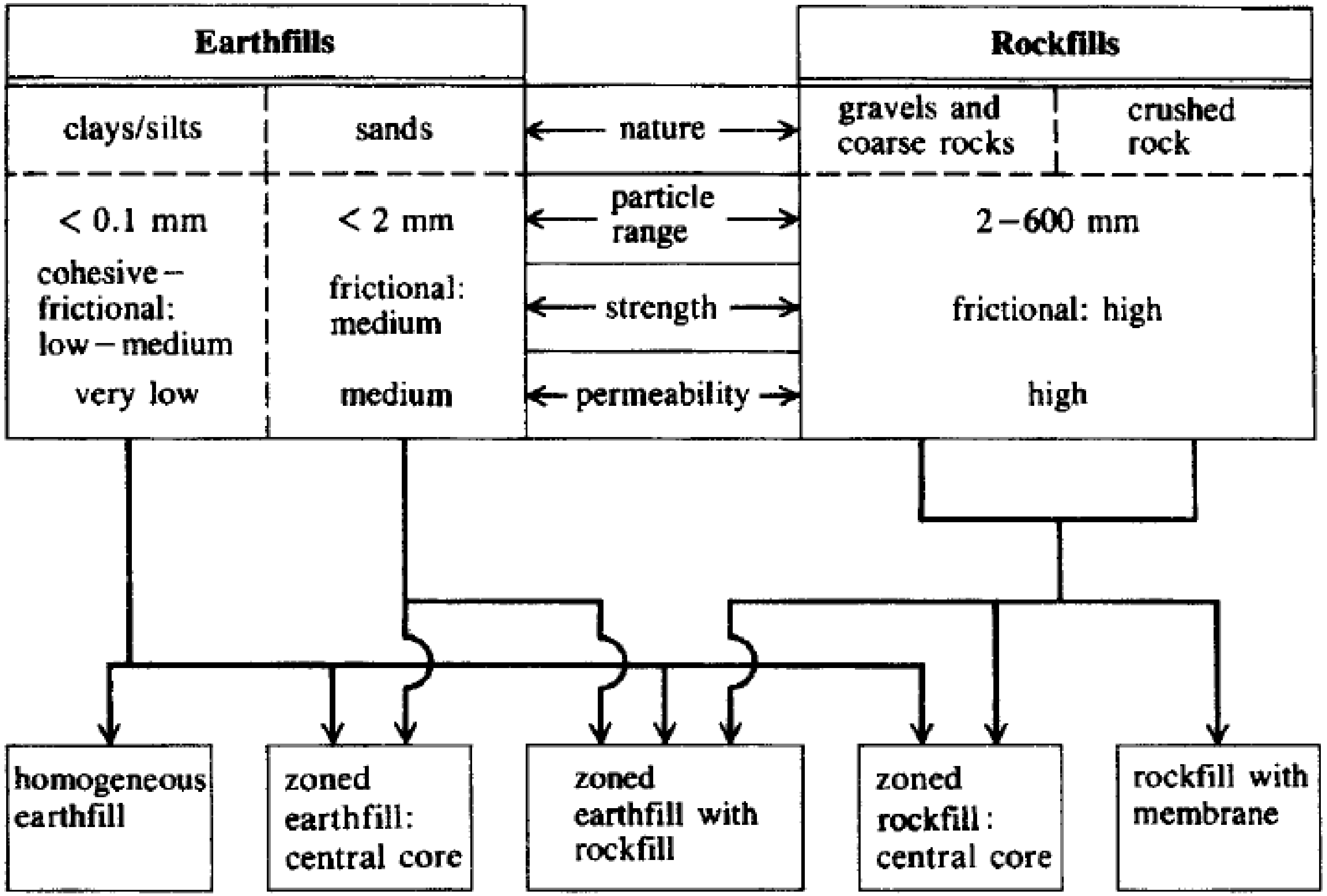
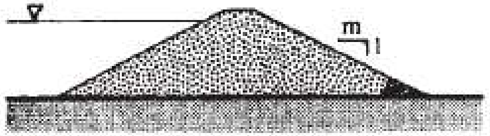


Figure 4 Arch Type

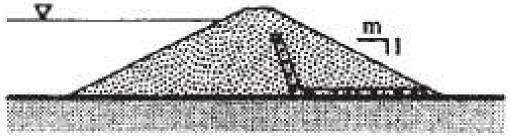
Material Urugan



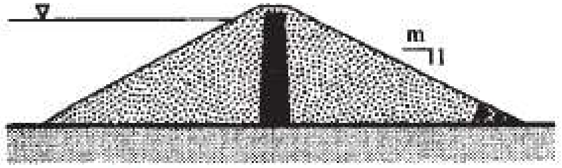
Variasi Pelapisan Urugan Tanah dan Kombinasi Tanah-Batu



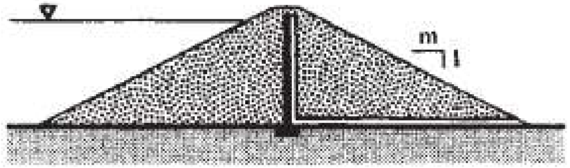
(a) **Homogenous with toedrain: small secondary dams**
$m = 2.0–2.5$



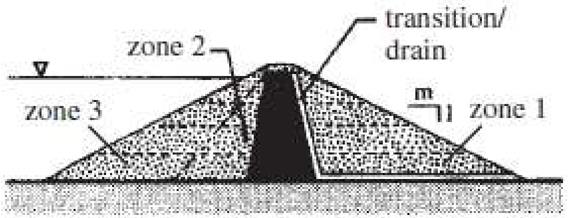
(b) **Modern homogeneous with internal chimney drain**
$m = 2.5–3.5$



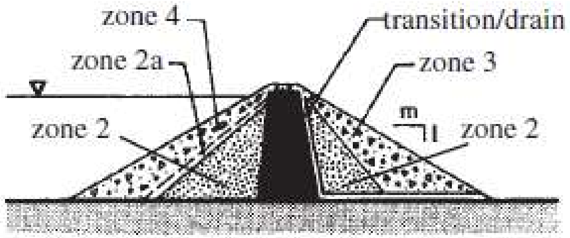
(c) **Slender central clay core: 19th-century 'Pennines' type – obsolete post 1950**
$m = 2.5–3.5$



(d) **Central concrete core: smaller dams – obsolescent**
$m = 2.5–3.5$

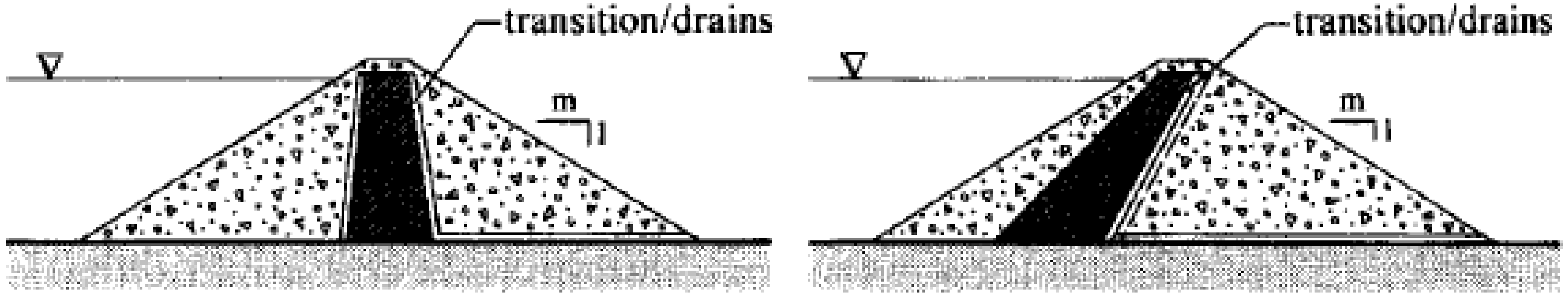


(e) **Wide rolled clay core: zoned with transitions and drains: note base drain**
$m = 2.5–3.5$



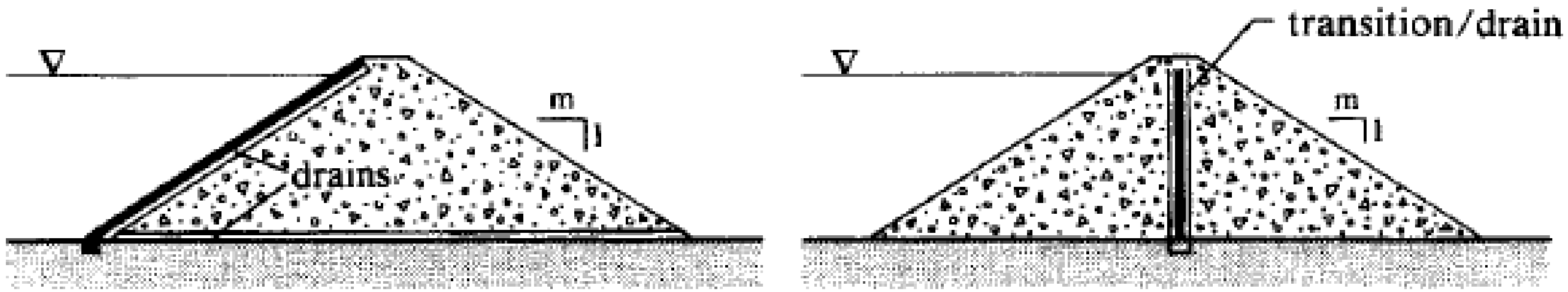
(f) **Earthfill/rockfill with central rolled clay core: zoned with transitions and drains**

Variasi Pelapisan Urugan Batu



(a) **Central rolled clay core**
$m = 1.6 - 2.0$

(b) **Inclined rolled clay core**
$m = 1.6 - 2.0$



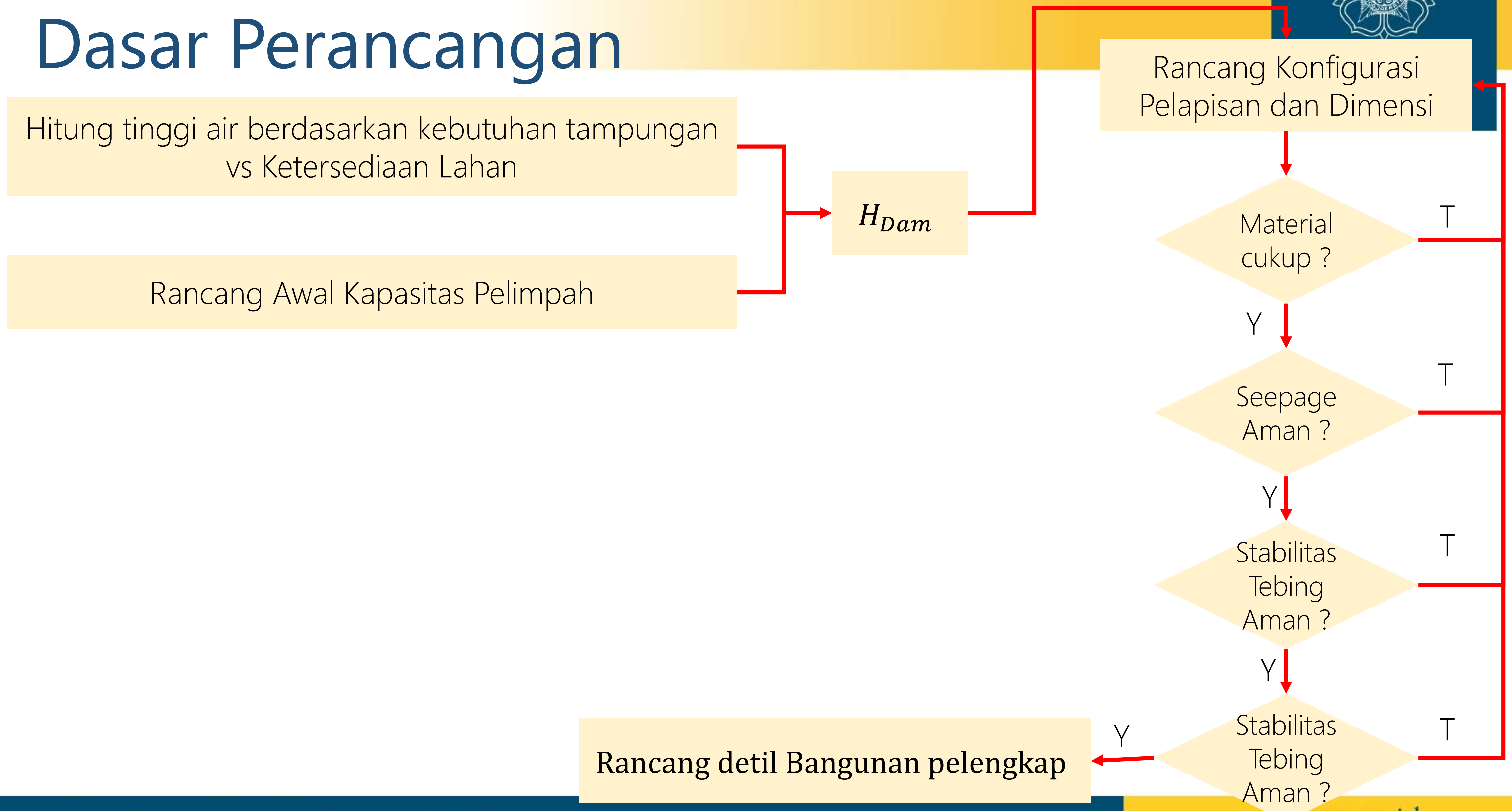
(c) **Decked: upstream asphaltic or concrete membrane**
$m = 1.6 - 2.0$

(d) **Central asphaltic membrane**
$m = 1.6 - 2.0$

Pemilihan Jenis Urugan

1. the suitability of the type to sites in wide valleys and relatively steepsided gorges alike;
2. adaptability to a broad range of foundation conditions, ranging from competent rock to soft and compressible or relatively pervious soil formations;
3. the use of natural materials, minimizing the need to import or transport large quantities of processed materials or cement to the site;
4. subject to satisfying essential design criteria, the embankment design is extremely flexible in its ability to accommodate different fill materials, e.g. earthfills and/or rockfills, if suitably zoned internally;
5. the construction process is highly mechanized and is effectively continuous;
6. largely in consequence of 5, the unit costs of earthfill and rockfill have risen much more slowly in real terms than those for mass concrete;
7. properly designed, the embankment can safely accommodate an appreciable degree of deformation and settlement without risk of serious cracking and possible failure.

Dasar Perancangan



Rumus Kerja Perancangan Dimensi Tubuh Bendung

$$H_{Dam} = H_{water} + H_{freeboard} + H_{\text{dead storage utk sedimentasi}}\ (\approx 15\% H_{water})$$

$$H_{water} = \text{Kebutuhan tampung} + \text{Hasil dari pool routing berdasar rancangan awal pelimpah}$$

Prediksi $H_{\text{dead storage utk sedimentasi}}$ dpt dipertimbangkan berdasarkan

$$Weight_{SedimentLoad} = Weight_{initial\ SedimentLoad}\, e^{-KL/yV}$$

U = Kecepatan angin pada ketinggian 10 m diatas muka tanah (km/jam)

F = Panjang Fetch, bidang kontak terbuka permukaan air dgn angin (km)

$$H_{freeboard} = 2 \times 10^{-6} \frac{U^2}{gH_{water}}$$

$$H_{freeboard} = 0.34F^{1/2} + 0.76 - 0.34F^{1/4}$$

$$H_{freeboard} = 0.034(UF)^{1/2} + 0.76 - 0.34F^{1/4}$$

$$H_{freeboard} = \frac{U\ F^{1/2}}{1760}$$

$$H_{freeboard} \geq 1 \text{ meter}$$

Gunakan F terbesar

Rumus Kerja Perancangan Dimensi Tubuh Bendung

$$W_{Crest}(feet) = \frac{H_{Dam}\,(feet)}{5} + 10$$

Kemiringan typikal
- Hulu 1:2.5 sampai 1:4
- Hilir1:2 sampai 1:3

$$W_{core\ base} = C_1 \times H_{Dam} \qquad C_1 = 0.2 - 0.4$$

$$\Delta h_{core} < 1.5 H_{water} \text{ sampai } 2.5 H_{water}$$

$$h_{tebal\ lapisan\ cimney\ drain} = 1.5\ H_{water} \sqrt{\frac{k_{core}}{k_{core}}}$$

Contoh Soal

Given data to compute the dimension as follows.

Water depth	= 60 m
U wind	= 30 km/hour
Fetch	= 15 km
Upstream slope	= 1:2.5
Downstream slope	= 1:2

UNIVERSITAS GADJAH MADA

Firstly, we calculate the height of freeboard

1. $2x10^{-6}x\frac{U^2}{gH_{water}} = 2x10^{-6}x\frac{30^2}{9.81x60} = 3.06x10^{-6}meter$

2. $0.34xF^{\frac{1}{2}} + 0.76 - 0.34xF^{\frac{1}{4}} = 0.34x15^{\frac{1}{2}} + 0.76 - 0.34x15^{\frac{1}{4}} = 1.4077meter$

3. $0.034x(UF)^{\frac{1}{2}} + 0.76 - 0.34xF^{\frac{1}{4}} = 0.034x(30x15)^{\frac{1}{2}} + 0.76 - 0.34x15^{\frac{1}{4}} = 0.8121meter$

4. $\frac{UF^{\frac{1}{2}}}{1760} = \frac{30x15^{\frac{1}{2}}}{1760} = 0.066meter$

5. ≥ 1 meter

So, according to the above computation, the best design dimension of freeboard height is 1.41 meters.

Height of dead storage for sedimentation is 15% H water = 15% x 60 = 9.00 meters

$H_{dam} = H\ water + H_{freeboard} + H_{dead.storage.for.sedimentation} =$ 60 m + 1.40 m + 9.00 m = 70.40 meters = 231.0039 ft

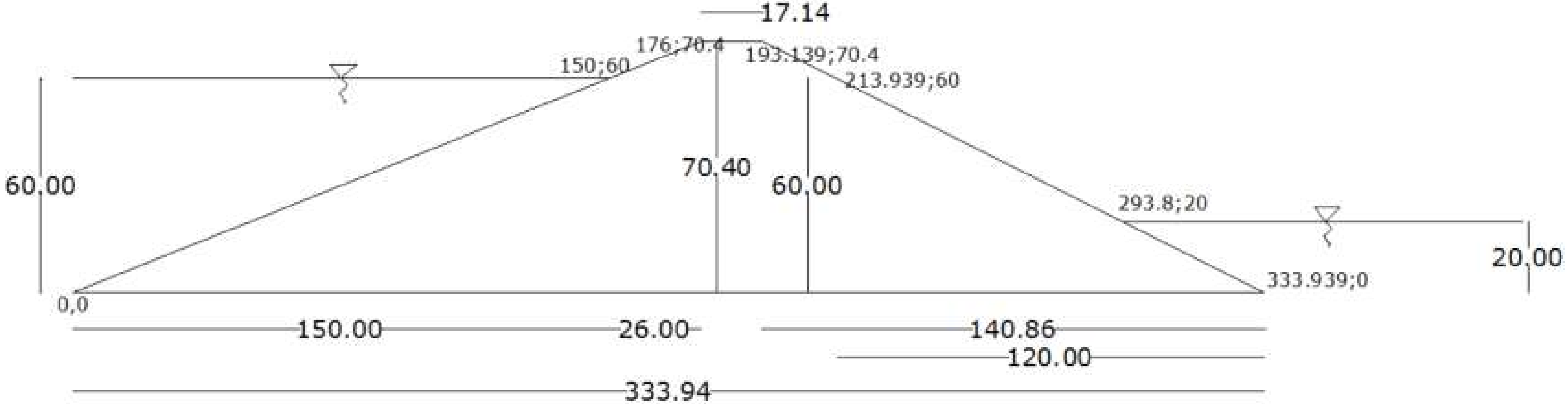
$$W_{crest}(ft) = \frac{H\ dam}{5} + 10 = \frac{231.0039\,ft}{5} + 10 = 56.2008\,ft = 17.14 meters$$

$W_{corebase} = C_1 x H_{dam} = (0.2 - 0.4) x 70.41 = 14.082m - 28.164m$ (We take 25 meters)

Δh core < 1.5 Hw – 2.5 Hw

Δh core < 1.5 x 60 – 2.5 x 60

Δh core < 90 m – 150 m

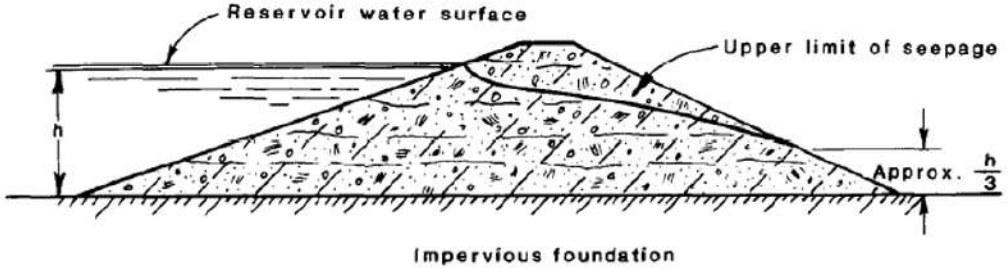

17.14
176;70.4
193.139;70.4
150;60
213.939;60
60,00
70,40
60,00
293.8;20
20,00
333.939;0
0,0
150.00
26.00
140.86
120.00
333.94

Perancangan Dimensi Type Urugan

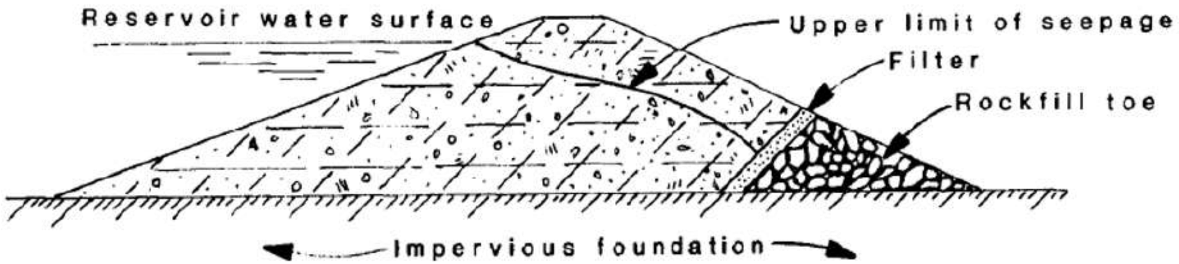
UNIVERSITAS GADJAH MADA

Seepage

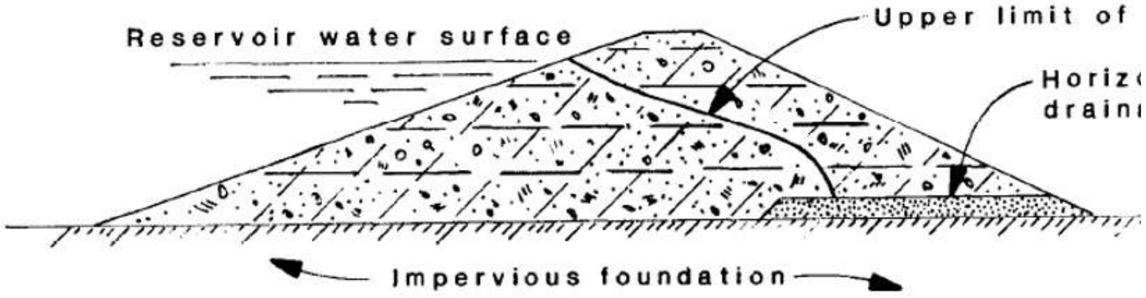
Typikal Rancangan Konfigurasi Pelapisan Tubuh Bendungan Urugan



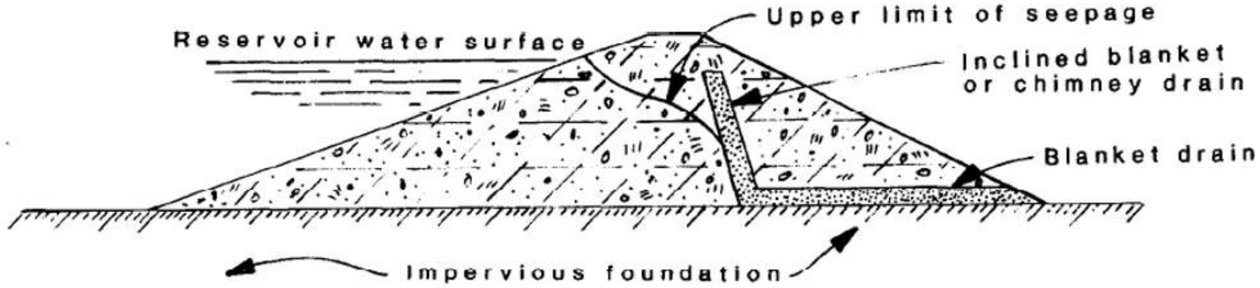
(a)



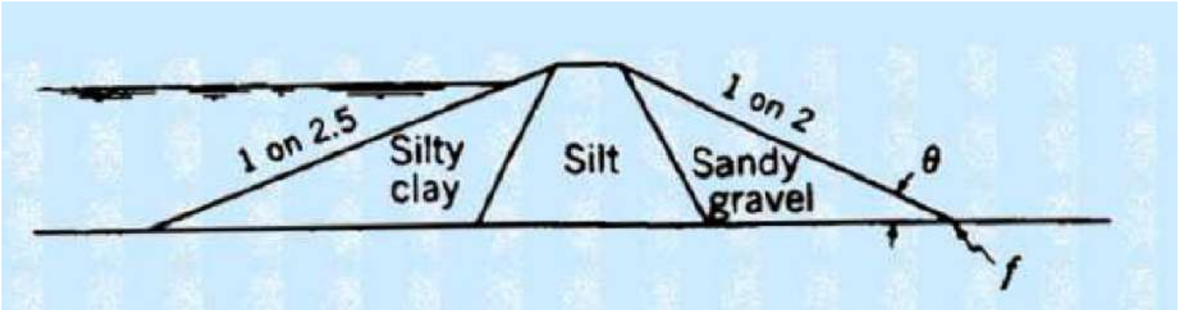
(b)



(c)

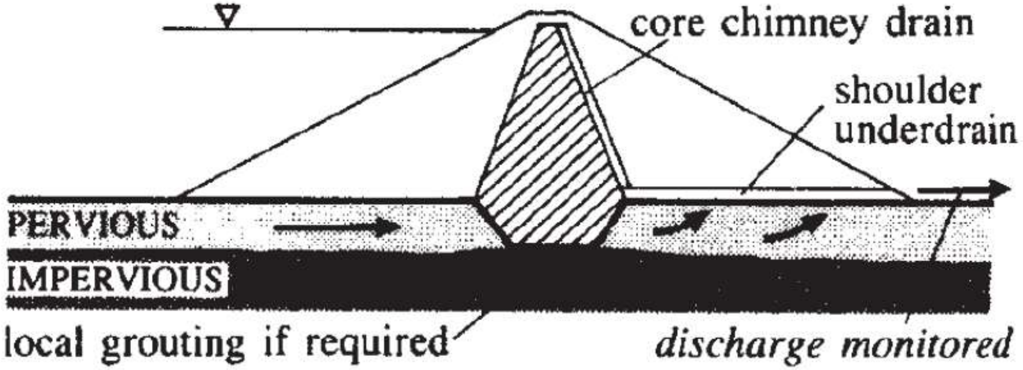


(d)

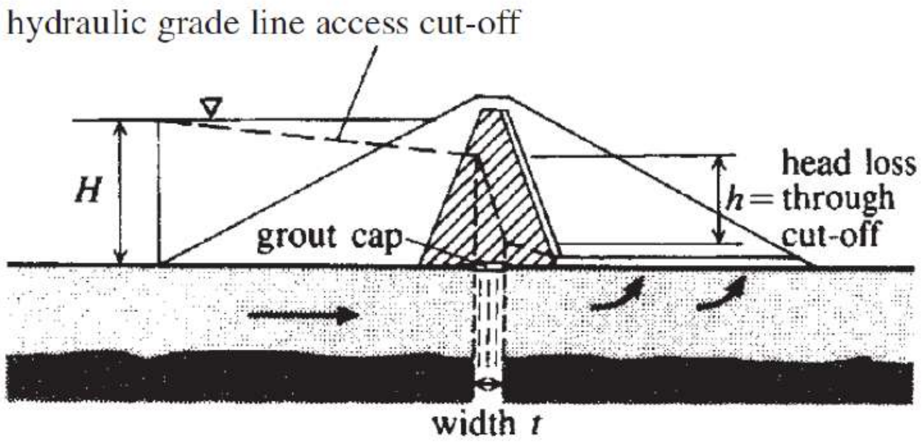


(f)

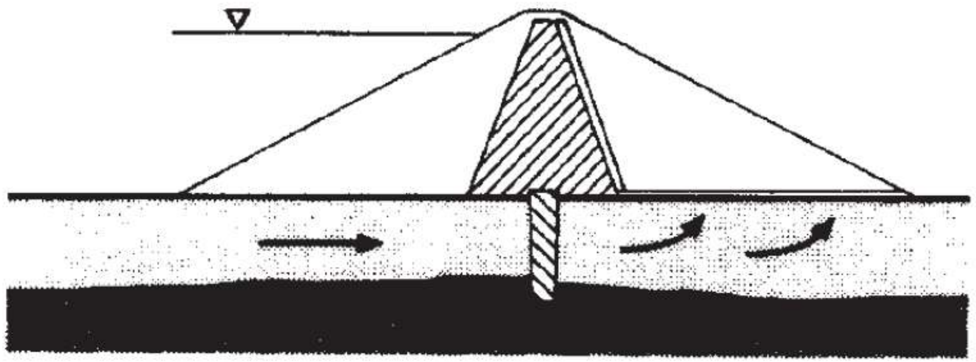
Konfigurasi Tipikal Blanket, Grouting dan Chimney Drain pada Bendungan Urugan dengan Inti (core)



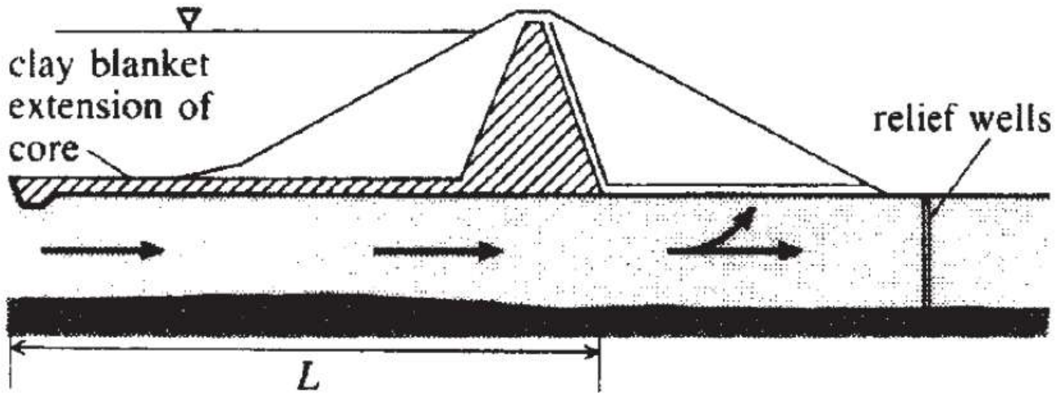
(f-1)



(f-2)



(f-3)



(f-4)

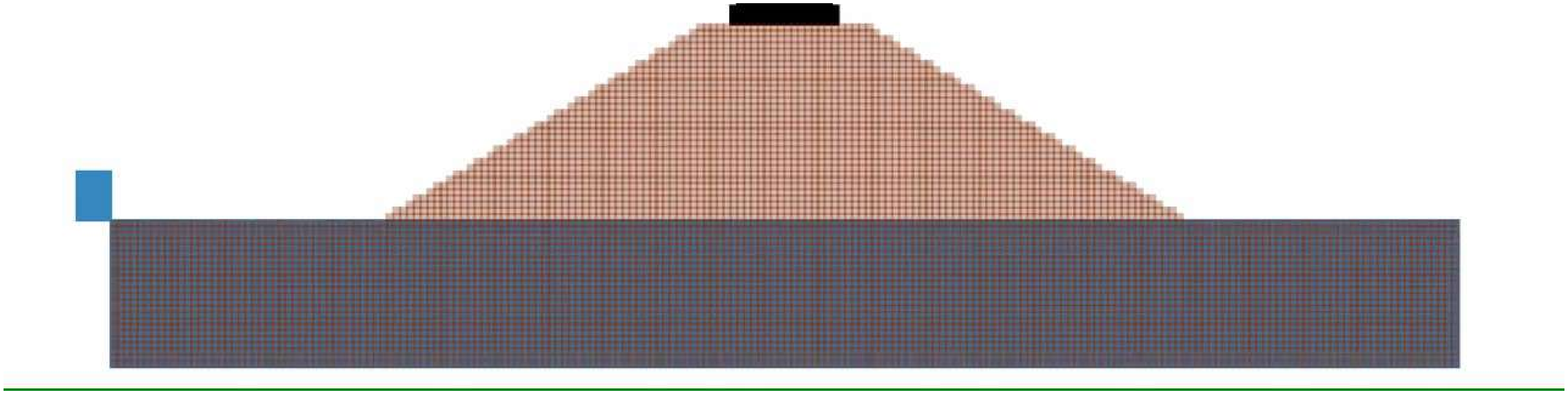
Material Tubuh Bendung Urugan

Table 2.6 Indicative engineering properties for compacted earthfills (compare with Table 2.3)

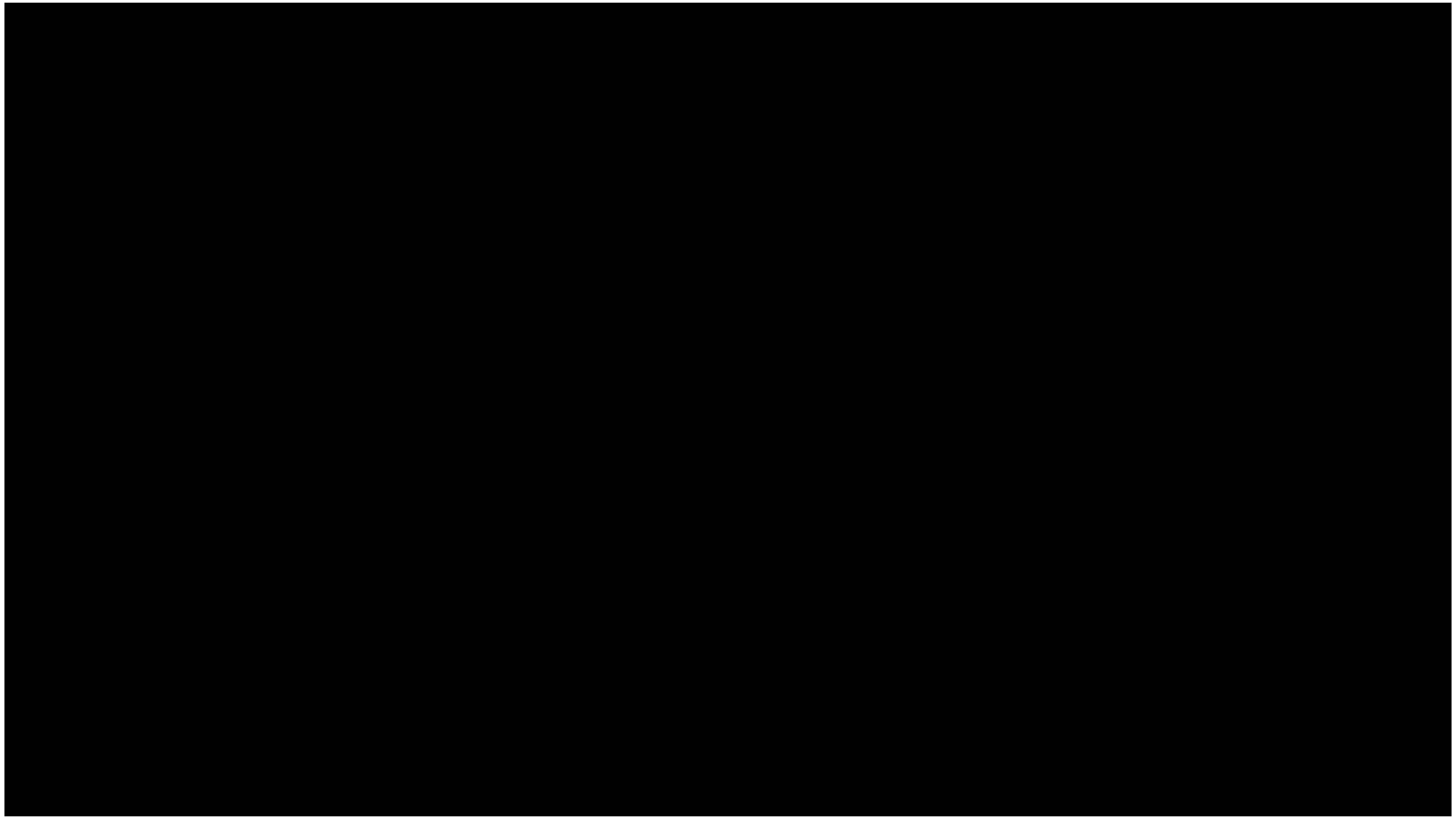
Fill type (BS 5930)	*Compaction characteristics*		*Shear strength (effective stress)*		*Coefficient of compressibility, m_v ($\times 10^{-4} m^2 kN^{-1}$)*	*Coefficient of horizontal permeability, $k_h (ms^{-1})$*	*Drainage characteristics (relief of u_w)*
	Unit weight, $\gamma_{d\,max}$ ($kN m^{-3}$)	*Water w_{opt} (%)*	*Cohesion, c' ($kN m^{-2}$)*	*Friction, ϕ' (degrees)*			
Gravels (GW–GC)	18–22	5–10	0	35–40	0.1–1.0	10^{-3}–10^{-5}	excellent
Sands (SW–SP)	16–20	10–20	0	35–40	0.5–1.5	10^{-4}–10^{-6}	good → fair
Silts (ML–MH)	16–20	15–30	<10	25–35	0.5–2.5	10^{-5}–10^{-8}	fair → poor
Clays (CL–CH)	16–21	15–30	<20	20–30	0.5–3.0	10^{-7}–10^{-10}	very poor → impervious
Crushed rockfill (2–600 mm size range)	17–21	N/A	0	40–55	N/A	10^{-1}–10^{-2}	free-draining: excellent

Crushed rockfill is shown here for comparative purposes only – refer to Section 2.9

Dam Failure

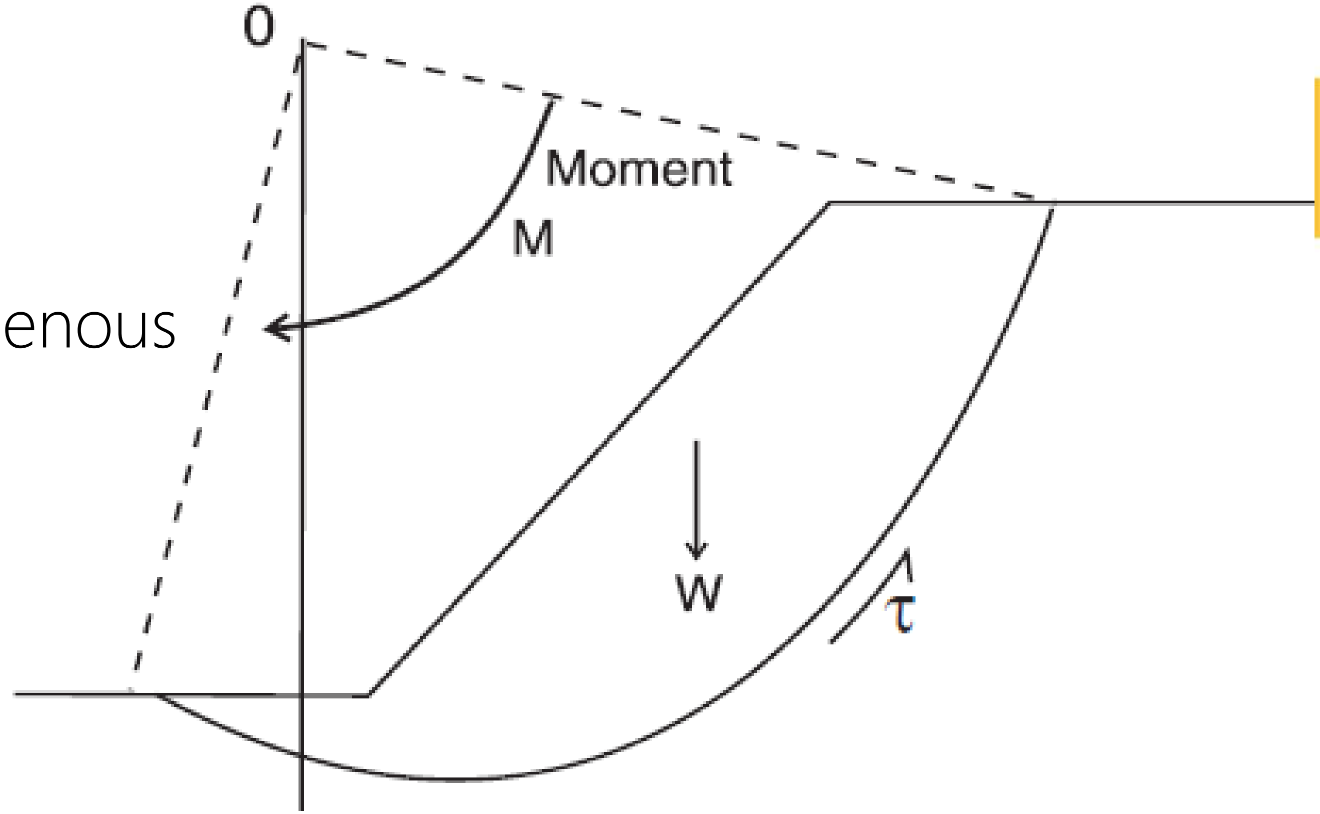


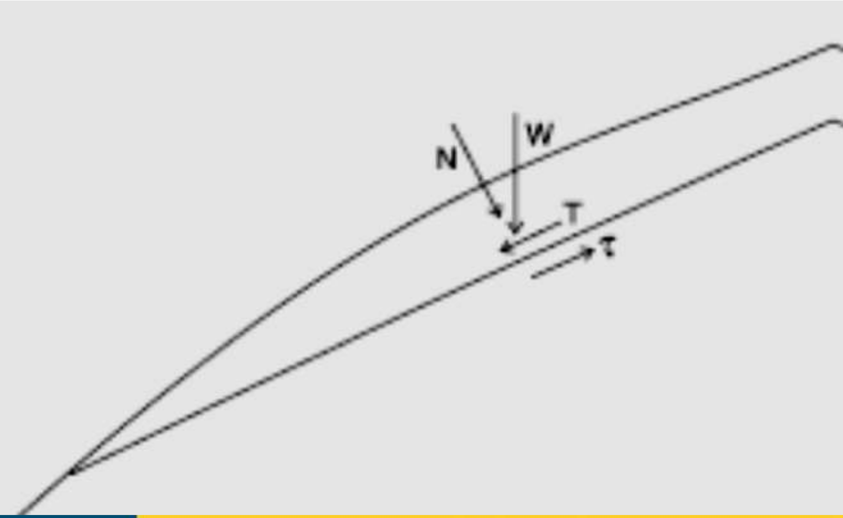
Dam Failure



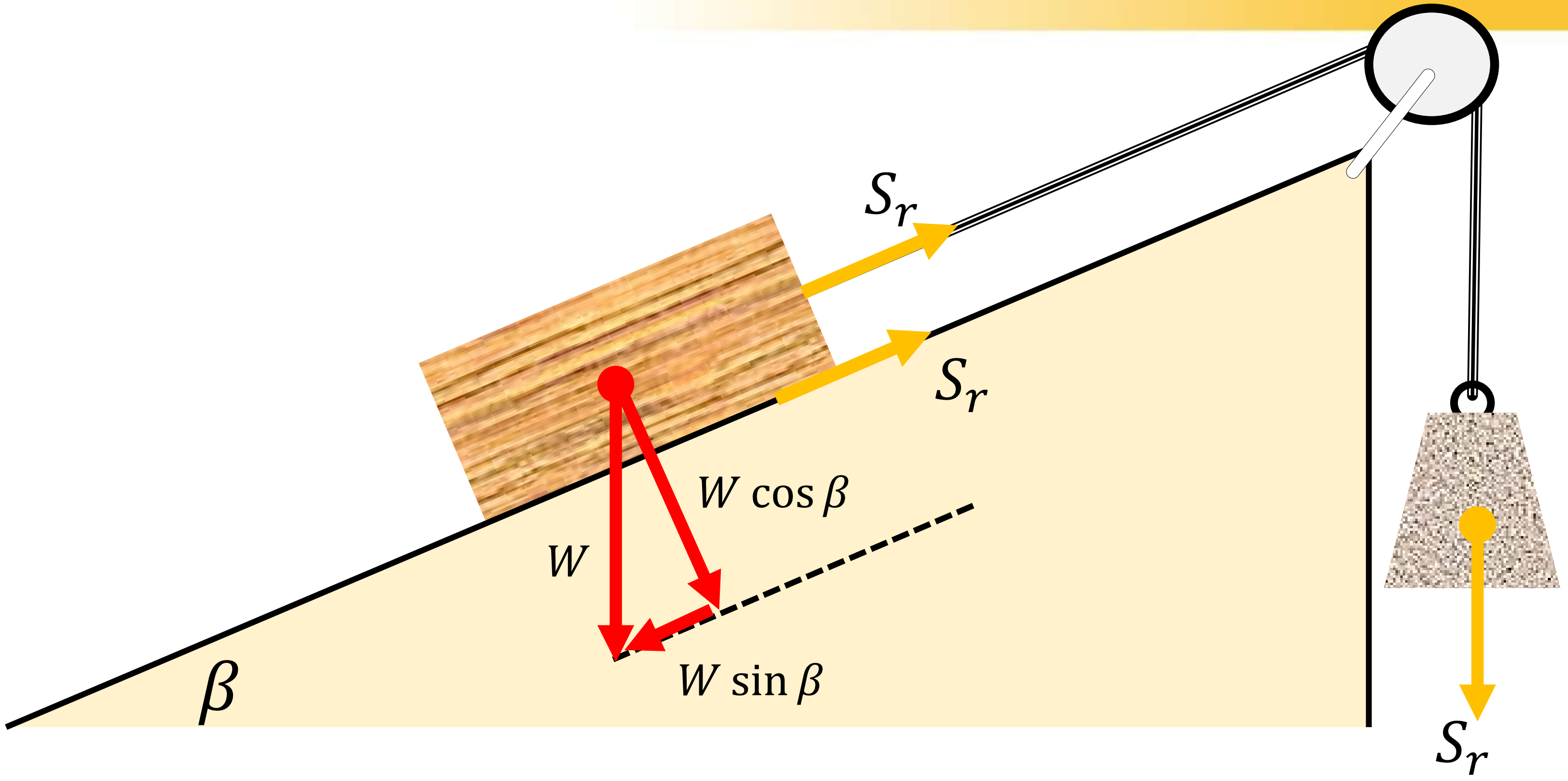
Slope Stability

- Circular failure : occured in homogenous soil





- Plane failure : occurred in layer soil or rock where one layer is weaker than the others.



$$S_a = W \sin\beta$$

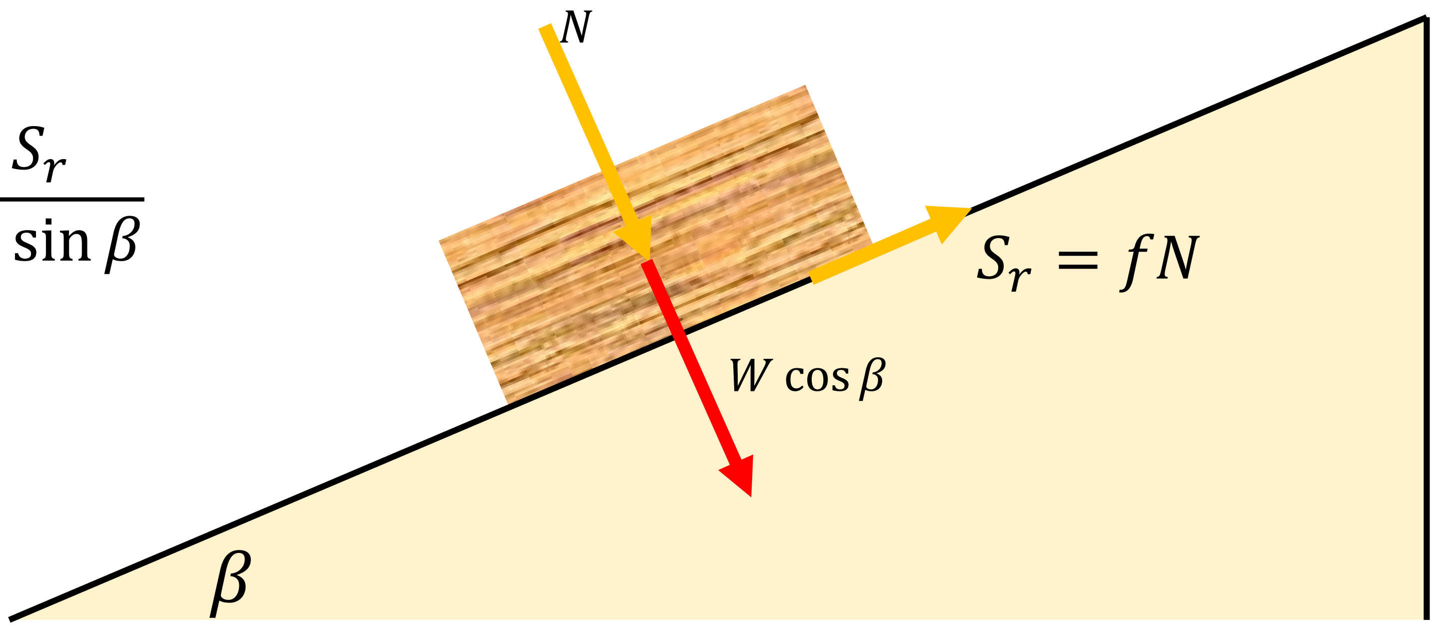
Safety factor F_S

$$F_S = \frac{S_r}{S_a} = \frac{S_r}{W \sin\beta}$$

Safety factor F_S

$$S_a = W \sin \beta$$

$$F_S = \frac{S_r}{S_a} = \frac{S_r}{W \sin \beta}$$



$$N = W \cos \beta$$
$$f = \tan \emptyset$$

$$S_r = W \cos \beta \tan \emptyset$$

lengketan tanah = kohesi c

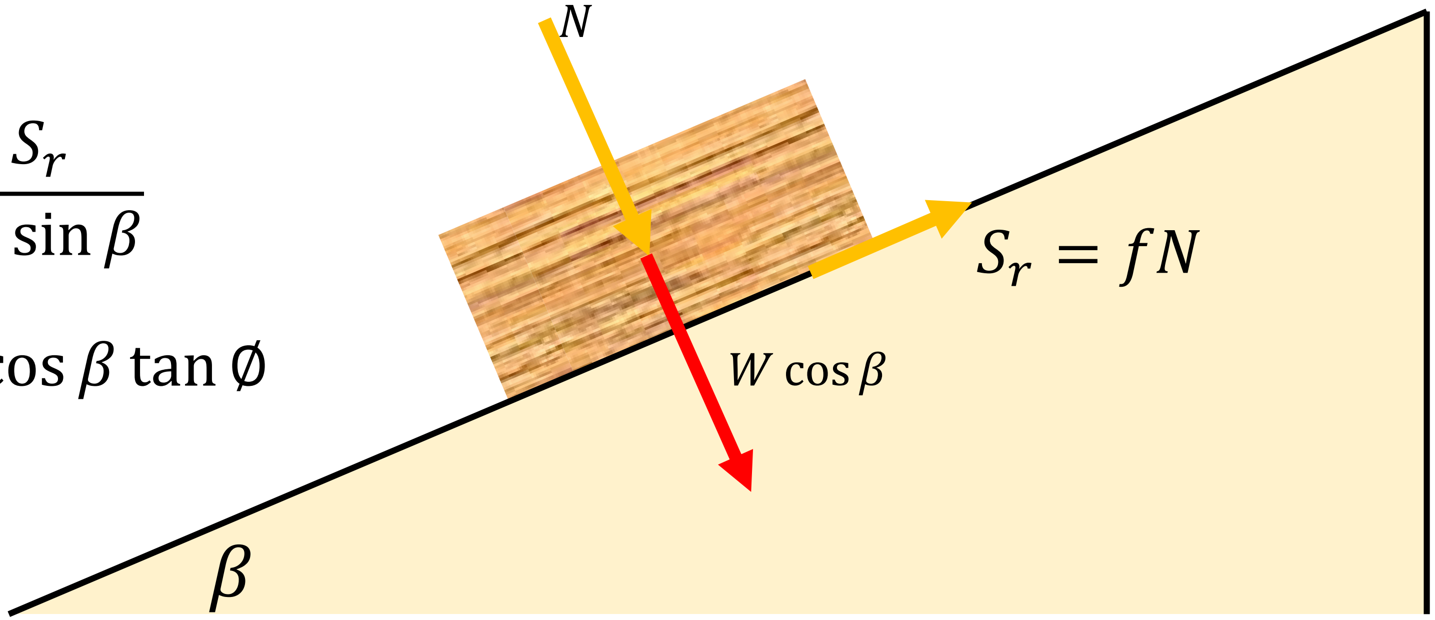
$$S_r = c + W \cos \beta \tan \emptyset$$

Safety factor F_S

$$S_a = W \sin\beta$$

$$F_S = \frac{S_r}{S_a} = \frac{S_r}{W \sin\beta}$$

$$S_r = cL + W \cos\beta \tan\emptyset$$



$$F_S = \frac{cL + W \cos\beta \tan\emptyset}{W \sin\beta}$$

The Driving Force:

$$S_a = \sum_{1}^{n} W_n \sin \beta_n$$

The Resisting Force:

$$S_r = cL + \sum_{1}^{n} W_n \cos \beta_n \tan \varphi$$

cohesion — slice weight — slope angle — angle of Internal friction

Factor of Safety

$$Fs = \frac{Sr}{Sa} = \frac{W \cos \beta \tan \phi + cL}{W \sin \beta}$$

The Resisting Force:

$$S_r = cL + \sum_{1}^{n} W_n \cos \beta_n \tan \varphi$$

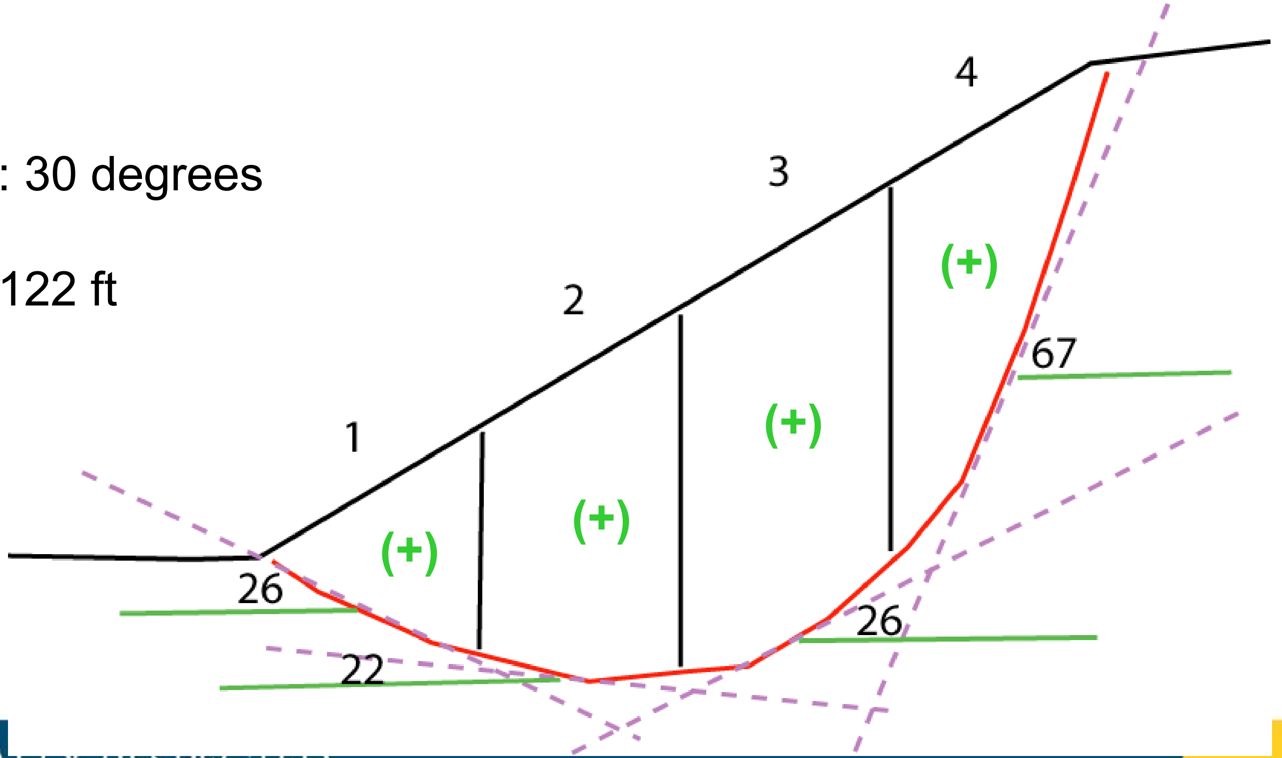
cohesion

slice weight

slope angle

angle of Internal friction

Angle of internal friction: 30 degrees
Cohesion: 50 lbs/ft2
Length of failure plane: 122 ft



13.8 METHOD OF SLICES

Procedures to determine the factor of safety of a slope using Bishop's method. Click on each step in order. You must click End before moving to any other page or section.

Step 1 Draw the slope to scale including the soil layers.

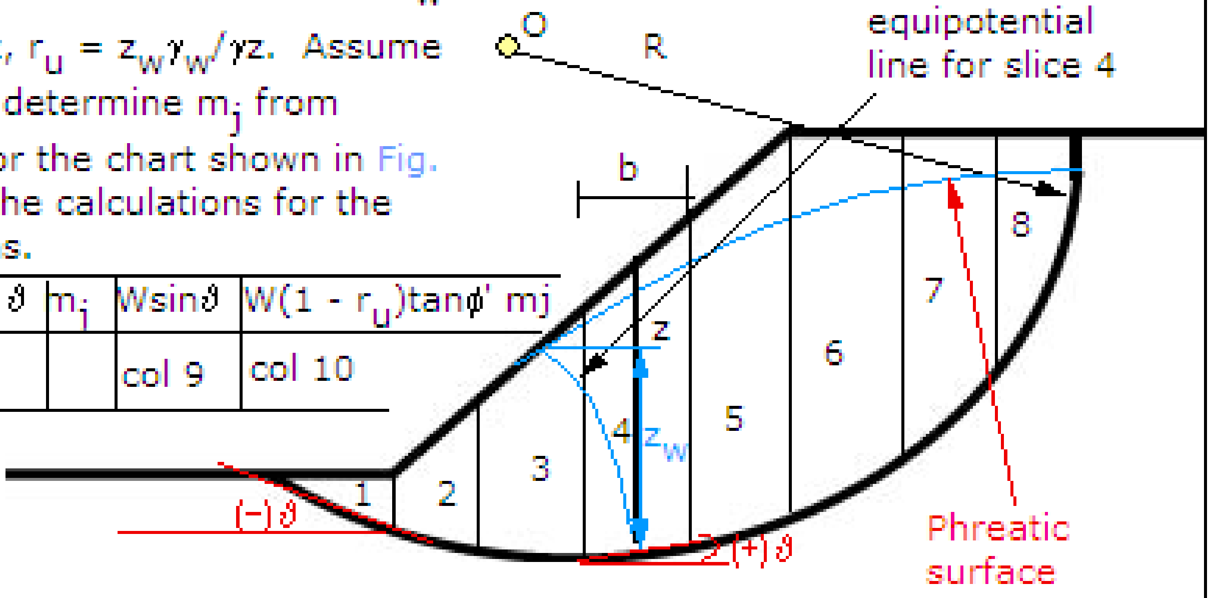
Step 2 Arbitrarily draw a possible slip circle (actually an arc) of radius R and locate the phreatic surface (see Chapter 9 for determining the phreatic surface)

Step 3 Divide the circle into vertical slices. For ease of calculations, try to make as many slices as possible of the same width. About 10 slices are satisfactory for most hand calculations.

Step 4 Make a table as shown and record b, z, z_w and ϑ for each slice.

Step 5 Calculate $W = \gamma b z$, $r_u = z_w \gamma_w / \gamma z$. Assume a value of FS and determine m_j from equation (13.26) or the chart shown in Fig. 13.13. Complete the calculations for the next three columns.

Slice	b	z	W	z_w	r_u	ϑ	m_j	$W\sin\vartheta$	$W(1 - r_u)\tan\phi'$ mj
								col 9	col 10



Step 6

Divide the sum of column 10 by the sum of column 9 to get FS. If FS is not equal to the assumed value, reiterate until FS calculated and FS assumed are approximately equal.

$$F = \frac{c' + (\gamma_d z_d + \gamma_{sat} z_w - \gamma_w z_w)\cos\beta \tan\phi}{(\gamma_d z_d + \gamma_{sat} z_w)\sin\beta}$$

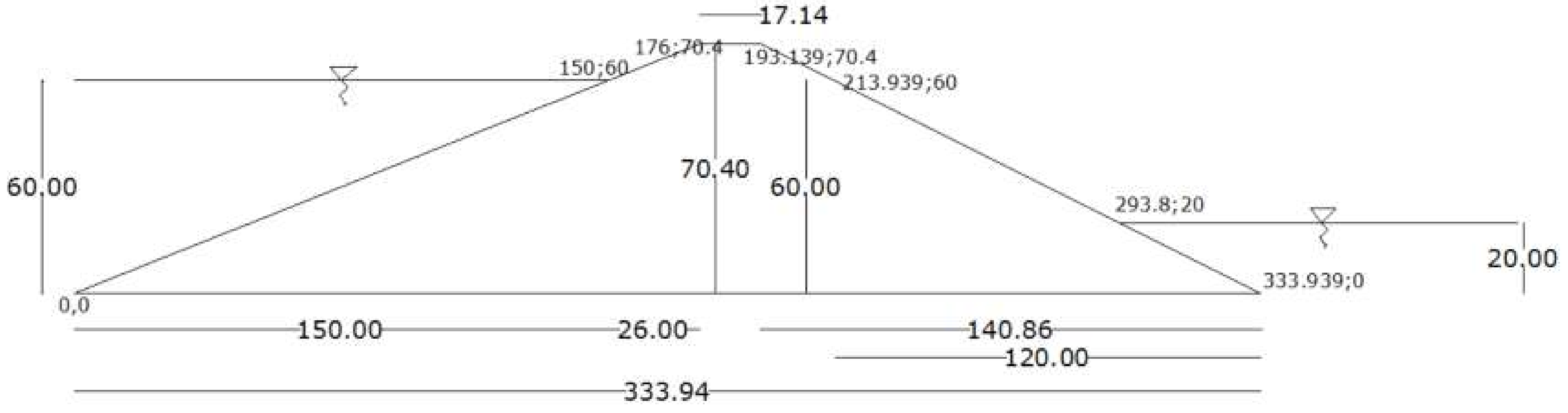
γ_w = unit weight of water (9.81 kN/m^3)

γ_d = dry unit weight of soil (15-20 kN/m^3)

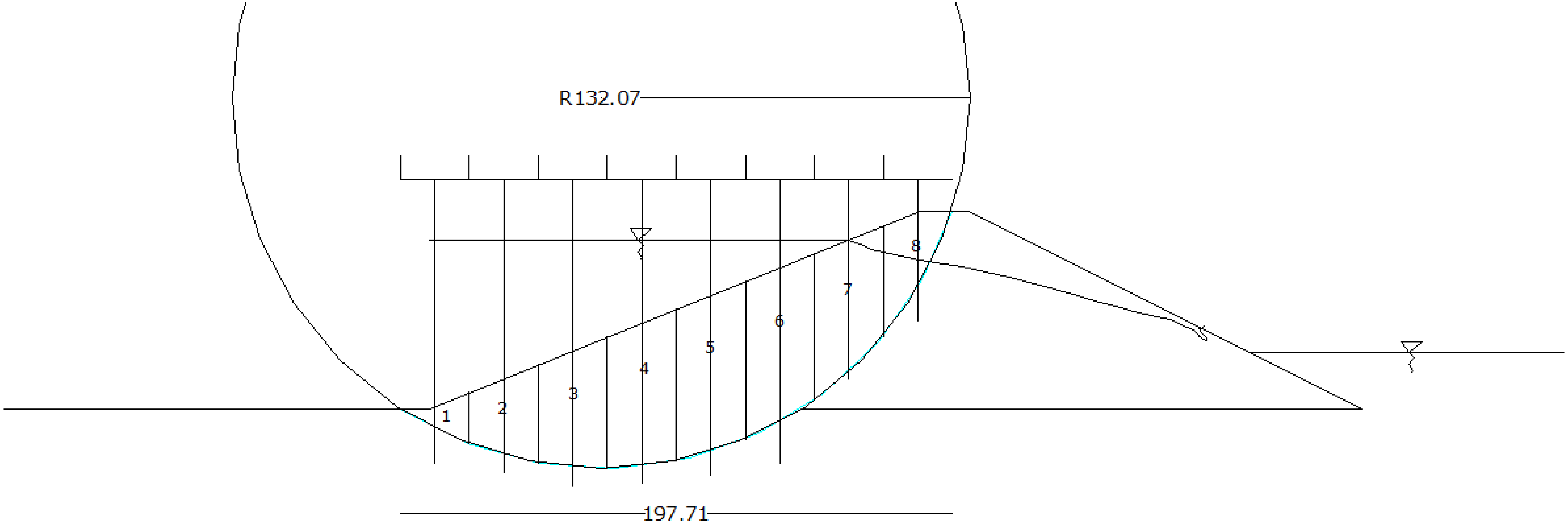
γ_{sat} = saturated unit weight of soil (20-23 kN/m^3)

Note: the soil column is assumed to be 1m wide perpendicular to paper

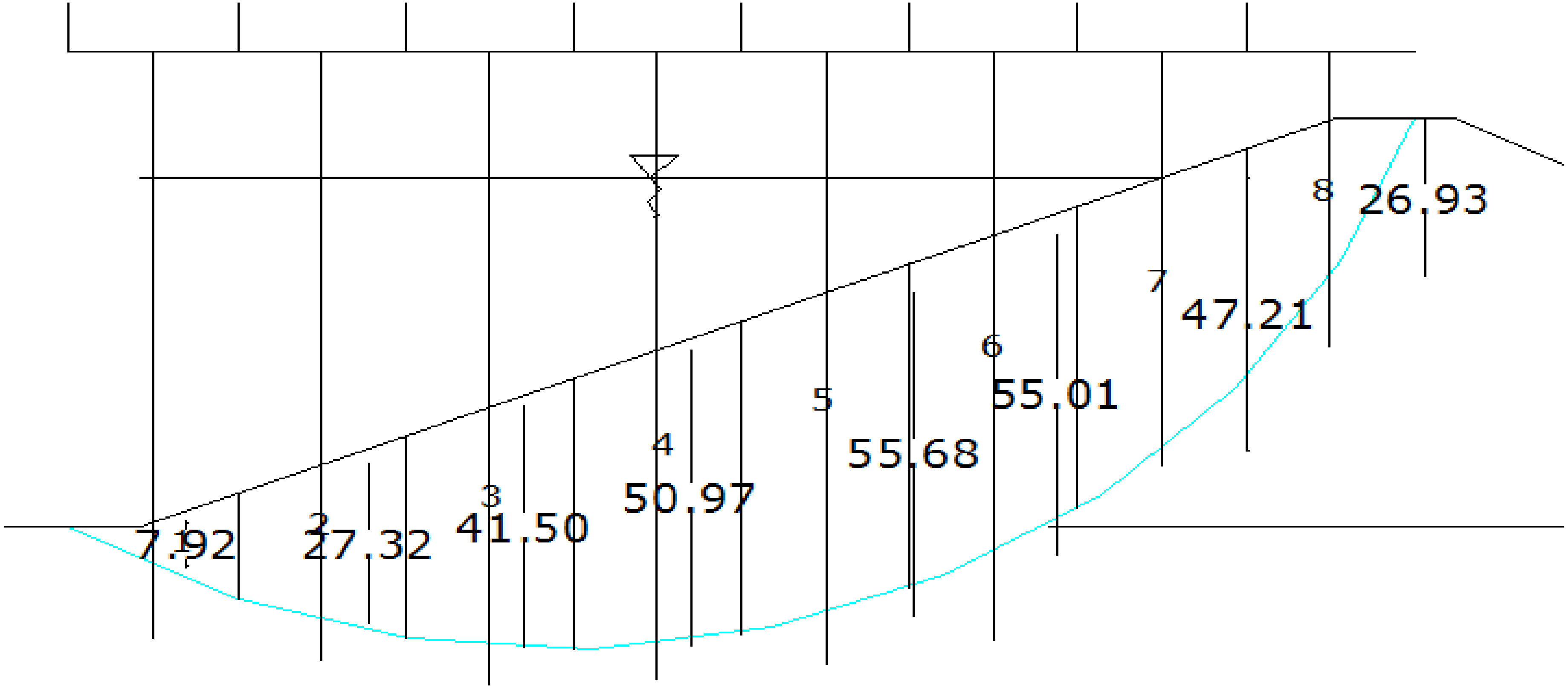
Contoh Soal


17.14
176;70.4
193.139;70.4
150;60
213.939;60
60.00
70.40
60.00
293.8;20
20.00
333.939;0
0,0
150.00
26.00
140.86
120.00
333.94

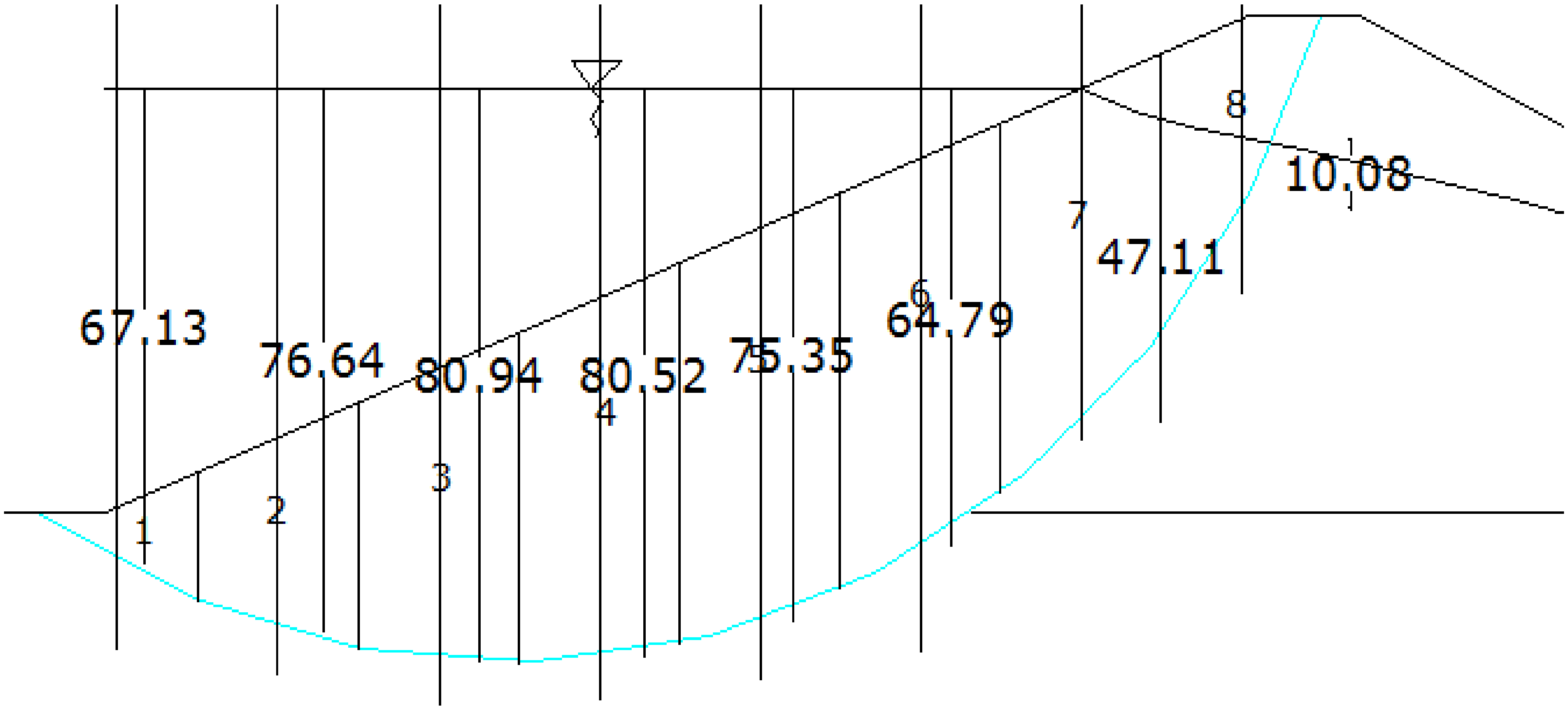
Membuat irisan



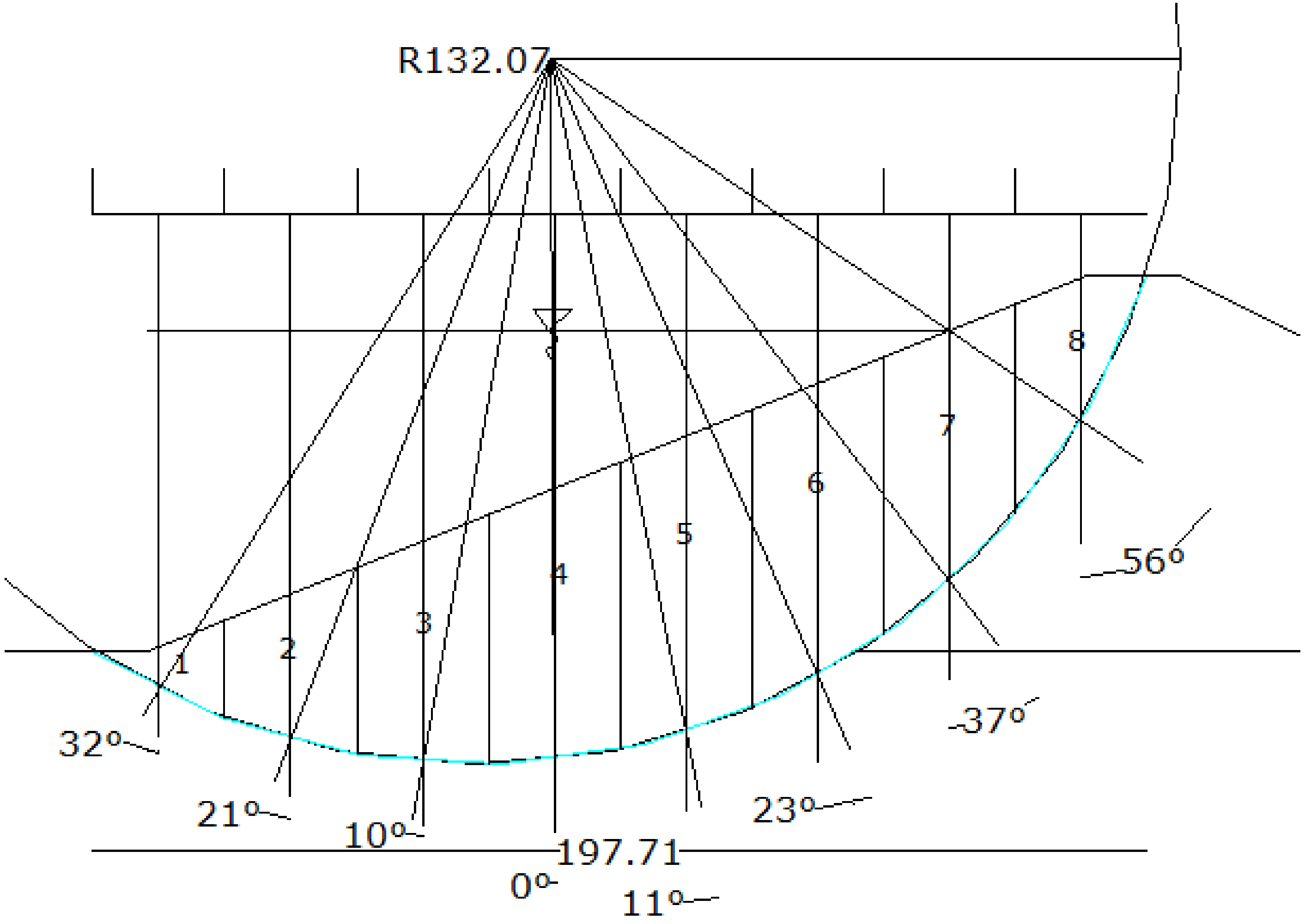
Z



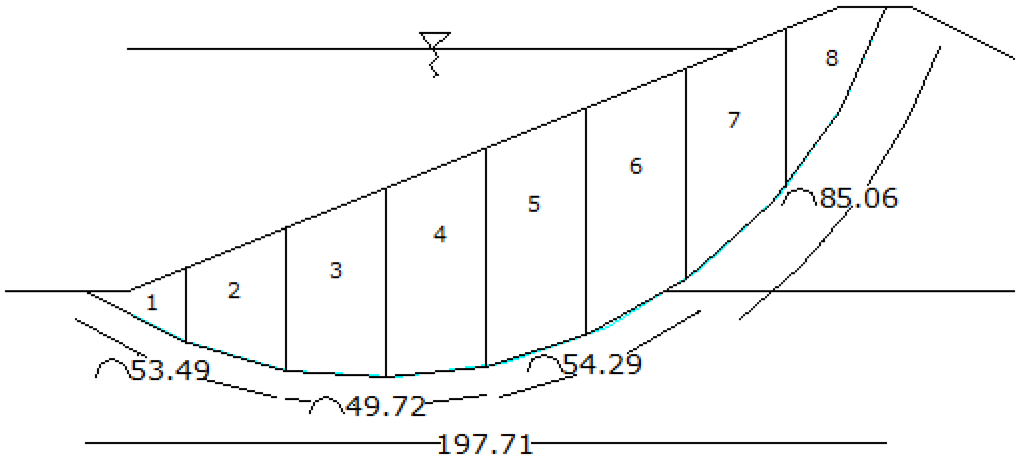
ZW



Sudut irisan



Menghitung panjang busur irisan



Method of Slices

γ_d 21 Kn/m^3

Slice	b	z	W	z_w	r_u	δ	Wsinδ	Wcosδ	ℓ	uℓ $\gamma_w z_w \ell$	Wcosδ - $\gamma_w z_w \ell$
1	24.71	7.92	4110.391	67.13	3.959508	-32	-2178.96	3485.319	26.745	17612.79	-14127.47461
2	24.71	27.32	14178.77	76.64	1.310462	-21	-5083.17	13236.27	26.745	20107.92	-6871.643135
3	24.71	41.5	21538.03	80.94	0.911097	-10	-3741.53	21210.56	24.86	19739.37	1471.187214
4	24.71	50.97	26452.86	80.52	0.73797	0	0	26452.86	24.86	19636.94	6815.912756
5	24.71	55.68	28897.29	75.35	0.63217	11	5516.056	28365.94	27.145	20065.14	8300.806653
6	24.71	55.01	28549.57	64.79	0.550194	23	11159.45	26278.22	27.145	17253.09	9025.12823
7	24.71	47.21	24501.46	47.11	0.466153	37	14750.43	19563.9	42.53	19655.2	-91.29941997
8	24.71	26.93	13976.37	10.08	0.174853	56	11590.01	7810.926	42.53	4205.571	3605.355854
							32012.29		242.56		8127.973544

Safety factor

$$F = \frac{c' L_a + \tan\phi' \Sigma(W\cos\alpha - ul)}{\Sigma W \sin\alpha}$$

c'	10
La	242.56
ϕ'	29
ϕ'cv	31

F	0.2166

- Belum aman. Bagaimana agar aman?

Method of Slices

Slice	b	z	W	z_w	r_u	δ	Wsinδ	Wcosδ	ℓ	uℓ Yw zw ℓ	Wcosδ - Yw zw ℓ
Yd	21	Kn/m^3									
1	24.71	7.92	4110.391	67.13	3.959508	-32	-2178.96	3485.319	26.745	17612.79	-14127.47461
2	24.71	27.32	14178.77	76.64	1.310462	-21	-5083.17	13236.27	26.745	20107.92	-6871.643135
3	24.71	41.5	21538.03	80.94	0.911097	-10	-3741.53	21210.56	24.86	19739.37	1471.187214
4	24.71	50.97	26452.86	80.52	0.73797	0	0	26452.86	24.86	19636.94	6815.912756
5	24.71	55.68	28897.29	75.35	0.63217	11	5516.056	28365.94	27.145	20065.14	8300.806653
6	24.71	55.01	28549.57	64.79	0.550194	23	11159.45	26278.22	27.145	17253.09	9025.12823
7	24.71	47.21	24501.46	47.11	0.466153	37	14750.43	19563.9	42.53	19655.2	-91.29941997
8	24.71	26.93	13976.37	10.08	0.174853	56	11590.01	7810.926	42.53	4205.571	3605.355854
							32012.29		242.56		8127.973544

Method of Slices											
Ɣd	21	Kn/m³								u ℓ	
Slice	b	Area	W	z_w	r_u	δ	Wsinδ	Wcosδ	ℓ	Ɣw zw ℓ	Wcosδ - Ɣw zw ℓ
1	20.17	326.14	6848.913	1.55	0.00222	50	5248.118	4400.553	38.15	580.0898	3820.463284
2	20.17	666.28	13991.81	30.6	0.021454	39	8808.308	10871.26	26.94	8087.011	2784.252247
3	20.17	828.96	17408.16	0	0	28	8175.659	15368.89	22.86	0	15368.88513
4	20.17	899.27	18884.61	0	0	19	6150.611	17854.93	20.70	0	17854.9299
5	20.17	902.15	18945.22	0	0	10	3291.114	18657.17	19.46	0	18657.17183
6	20.17	849.38	17837.02	0	0	2	622.7535	17826.15	18.78	0	17826.14742
7	20.17	746.70	15680.61	0	0	-6	-1639.73	15594.64	18.52	0	15594.63849
8	20.17	596.20	12520.13	33.84	0.026515	-18	-3870.44	11906.86	18.63	6184.609	5722.254017
9	20.17	397.06	8338.355	30.48	0.035859	-27	-3786.94	7428.81	19.11	5714.058	1714.751944
10	20.17	145.28	3050.968	24.29	0.078101	-36	-1793.94	2467.832	20.08	4784.761	-2316.929273
							26786.4		223.23		97628.74232

$$F = \frac{c' L_a + \tan\phi' \Sigma (W \cos\alpha - ul)}{\Sigma W \sin\alpha}$$

$$F = \frac{10X223.23 + \tan 29x97628.74232}{26786.4} = 2.1118$$