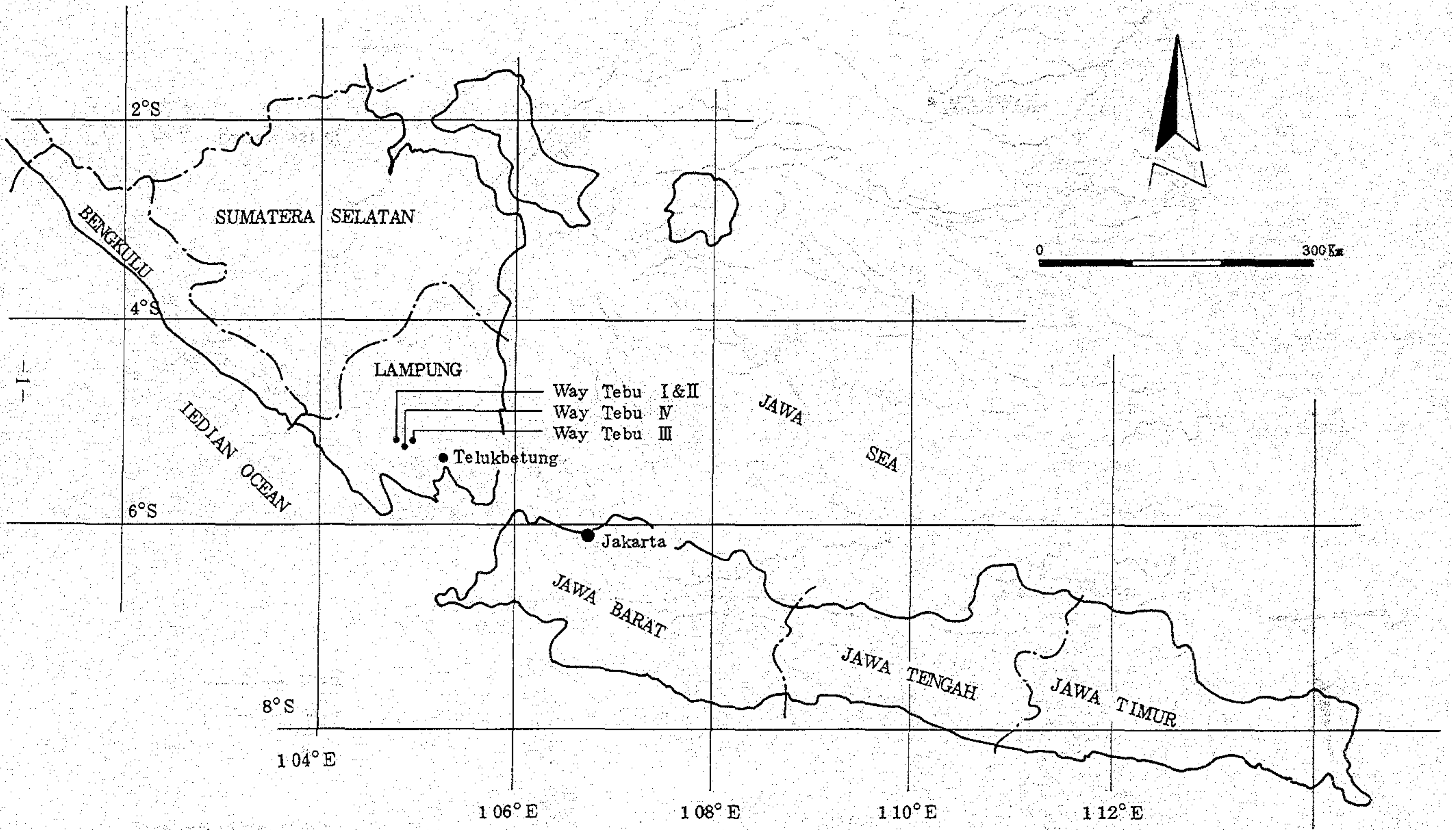
IRRIGATION AND RELATED STRUCTURES
— FINAL REPORT —

Akira YAMAZAKI
D.P.U.P. LAMPUNG, INDONESIA
Colombo Plan Expert from JICA

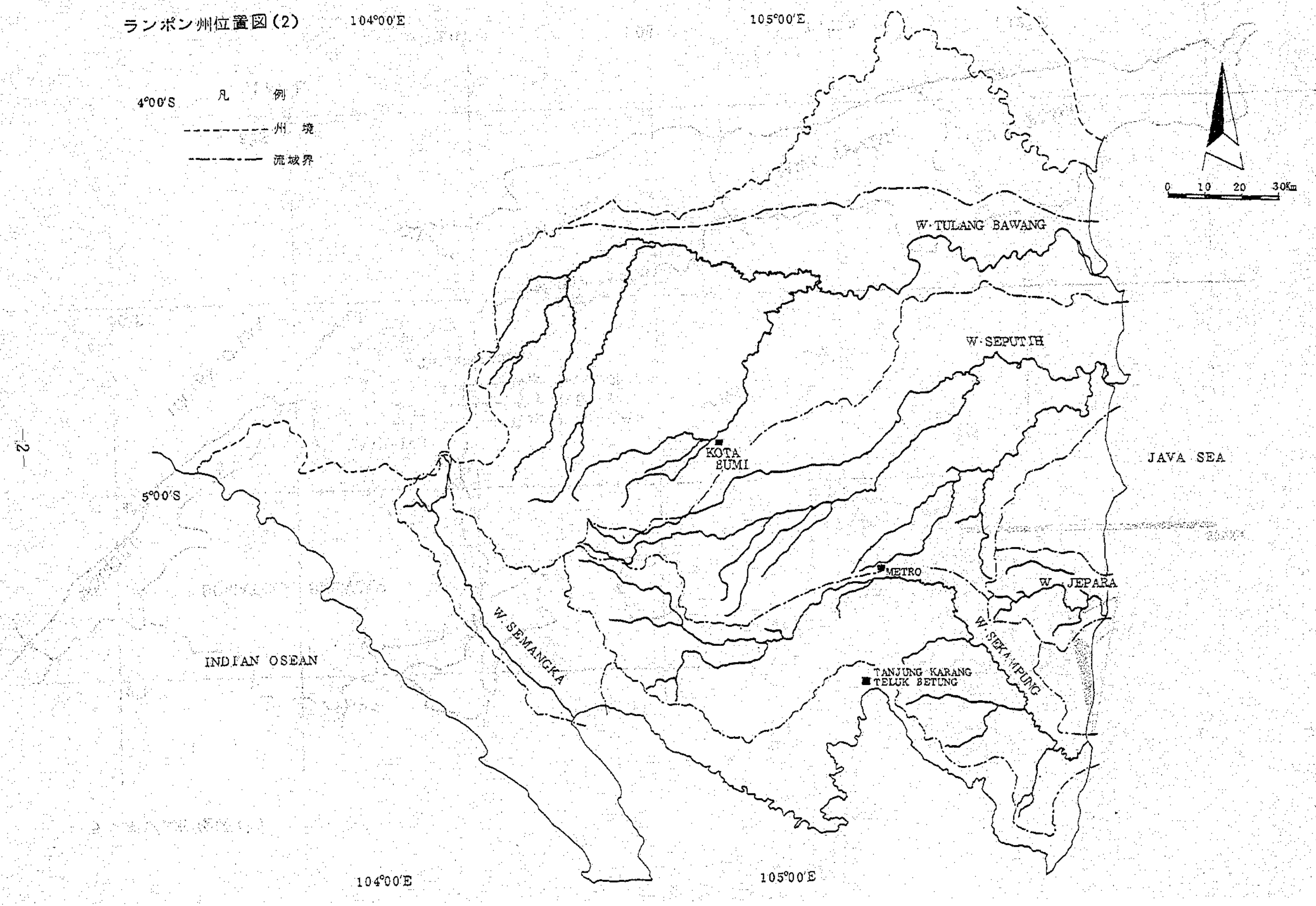
Term of Assignment from October 3rd, 1979 to October 2nd, 1981
After Extension to March 29th, 1982

Contents

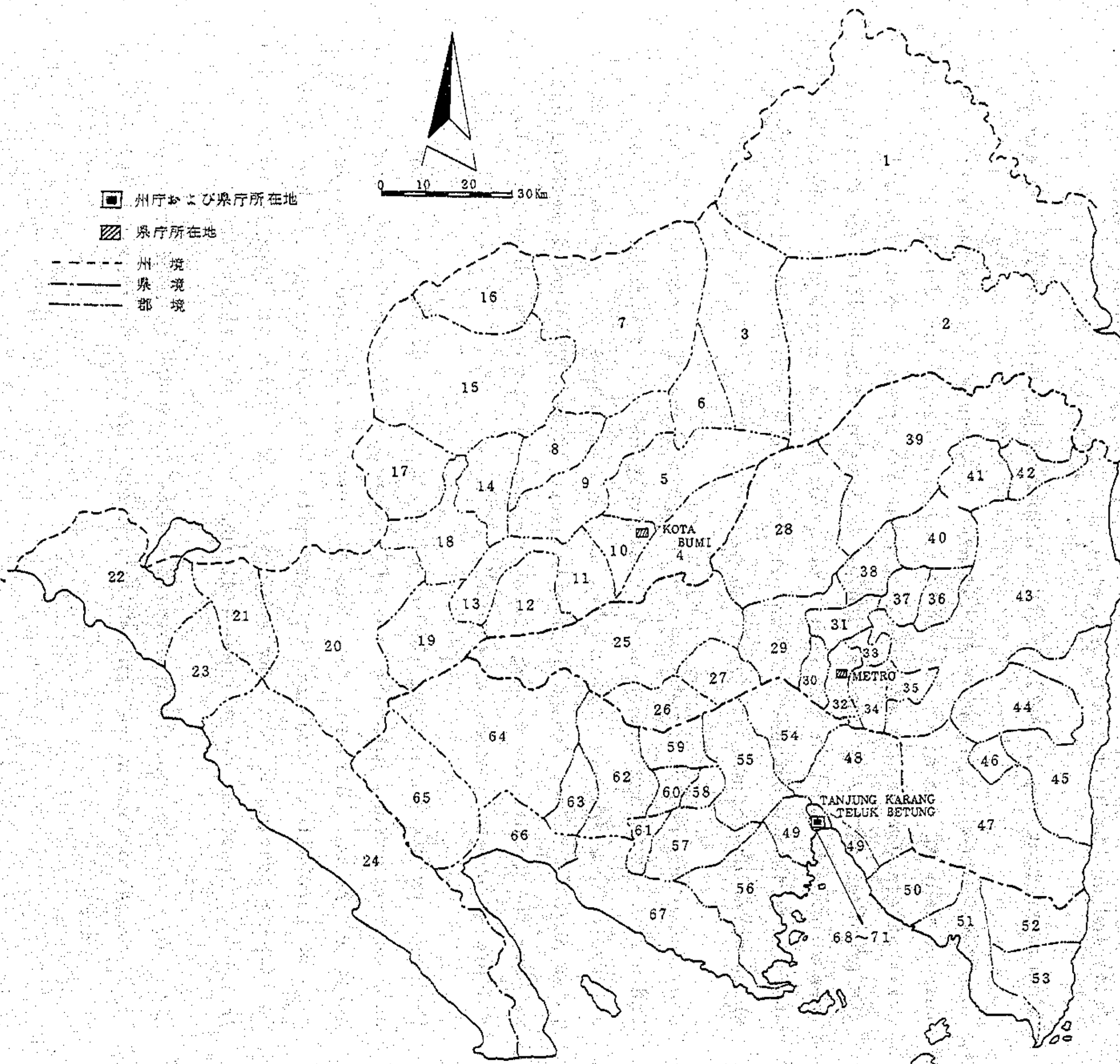
ランポン州位置図（1）


2°S
4°S
6°S
8°S
104°E
106°E
108°E
110°E
112°E
0
300Km
SUMATERA SELATAN
BENGKULU
LAMPUNG
Way Tebu I&II
Way Tebu Ⅳ
Way Tebu Ⅲ
Telukbetung
IEDIAN OCEAN
JAWA SEA
Jakarta
JAWA BARAT
JAWA TENGAH
JAWA TIMUR

ランポン州位置図(2)



104°00'E
105°00'E
4°00'S
凡　例
州　境
流域界
0 10 20 30Km
W. TULANG BAWANG
W. SEPUTIH
JAVA SEA
KOTA BUMI
METRO
W. JEPARA
W. SEKAMPUNG
TANJUNG KARANG
TELUK BETUNG
W. SEMANGKA
5°00'S
INDIAN OSEAN
104°00'E
105°00'E



NAMA-NAMA KECAMATAN

KABUPATEN LAMPUNG UTARA:

1. Mesuji Lampung
2. Menggala
3. Tulang Bawang Tengah
4. Abung Selatan
5. Abung Timur
6. Tulang Bawang Udik
7. Pakuon Ratu
8. Sungkai Utara
9. Sungkai Selatan
10. Kota Bumi
11. Abung Barat
12. Tanjung Raja
13. Bukit Kemuning
14. Baradatu
15. Blambangan Umpu
16. Bahuga
17. Kasui
18. Banjit
19. Sumber Jaya
20. Belalau
21. Balik Bukit
22. Pesisir Utara
23. Pesisir Tengah
24. Pesisir Selatan

KABUPATEN LAMPUNG TENGAH:

25. Padang Ratu
26. Kalirejo
27. Bangun Rejo
28. Terbanggi Besar
29. Gunung Sugih
30. Trimurjo
31. Punggur
32. Metro
33. Pekalongan
34. Batang Hari
35. Sekampung
36. Purbolinggo
37. Raman Utara
38. Seputih Raman
39. Seputih Mataram
40. Seputih Banyak
41. Rumbia
42. Seputih Surabaya
43. Sukadana
44. Way Jepara
45. Labuhan Maningai
46. Gunung Balak
47. Jabung

KABUPATEN LAMPUNG SELATAN:

48. Kedaton
49. Panjang
50. Katibung
51. Kalianda
52. Palas
53. Penengahan
54. Natar
55. Gedong Tataan
56. Padang Cermin
57. Kedondong
58. Gading Rejo
59. Sukoharjo
60. Pringsewu
61. Pardasuka
62. Pagelaran
63. Talang Padang
64. Pulau Panggung
65. Wonosobo
66. Kota Agung
67. Cukuh Balak

KOTAMADYA TANJUNGKARANG-TELUKBETUNG:

68. Tanjungkarang Barat
69. Tanjungkarang Timur
70. Telukbetung Utara
71. Telukbetung Selatan

A. Preface

In D.P.U.P. Lampung, I worked as an irrigation expert from Oct. 3rd 1979 to Mar. 29th 1982. In "Lists and Summaries", all reports which we submitted to D.P.U.P. Lampung are shown. But in this report, four kinds of main reports have been selected.

By the way, the most emphasized matters of my technical transfer to my counterparts were as follows.

(i) We (irrigation engineers) should go to job sites as many times as possible.
(ii) We should work on the sites ourselves and not just observe.
(iii) And we should learn by practice.

Because irrigation, as well as civil engineering, are experience engineering.

A sample of results is shown in "Design of Drops at the Way Curup Project". When we went to job sites, we could find many cases that the lower retaining walls of fixed weirs or drops were eroded and broken. So we investigated the problems on the Indonesian design methods of fixed weirs and drops, and then we made clear that the faults were due to the shortage of length and the shape of stilling basins. And we proposed a new design method for drops, which were adopted at the Way Curup project.

Many formulas, analysis methods and design methods have been introduced to Indonesia. But they can be used effectively only if the conditions of meteorology, hydrology, topography, geology or others are the same. That is to say, we cannot design irrigation structures or analyze something until we know the conditions of job sites exactly. A sample is shown in "Slope Failure at the Way Semangka Project".

Lampung province has a long history of irrigation. So there is a lot of data on irrigation; rainfall, run-off, planted paddy field area, irrigated water and so on. But this data has not yet been utilized or analyzed. By data on rainfall and run-off, we have made clear meteorology and hydrology in Lampung province. The main subjects of the report of "Hydrologic Analysis in Lampung Province - A Revised Eddition - " are as follows.

(i) To know the general hydrologic values so as not to make any big mistakes when we design new irrigation projects or rehabilitation works.

(ii) To find the proper benefited area in proportion to run-off from the catchment area and effective rainfall in the benefited area.

But, we still do not know the realities of the paddy field irrigation; planting schedule, irrigation requirement and so on. The plan of the paddy field irrigation has been performed not by experiences but only on the table, even if they are big projects. Therefore we have studied the realities of the paddy field irrigation in the tropics by data on planted paddy field area and irrigated water and others.

The analyzed items are as follows.

(i) Paddy field land consolidation.
(ii) Planting and irrigation schedule.
(iii) Irrigated water and irrigation requirement.
(iv) Irrigable area in both rainy and dry seasons.
(v) Examination of the Way Sekampung curve (Decision of cross-section area of canal).

I have lived happily in Lampung province for two and a half years with my family who came nine months later than I. I thank from the bottom of my heart my counterparts, their families, our neighbours, and JICA which gave me a chance to work in Republic of Indonesia.

B. List and Summary

1. Way Curup Project

a. Summary

This project is a part of the Way Jepara Project and has the benefited area of 2,020ha. I have transfered how to design the head works and the canal works and how to supervise the constructions to my counterpart.

b. Counterpart

Mr. RAFLI (CABANG PERENCANAAN TEHNIK PROYEK IRIGASI WAY JEPARA)

c. Presented Reports

(1) "WAY CURUP DESIGN NOTE 1", February, 1980

(i) Selected the site of the head works.

(ii) Computated the design flood discharge and the regulated intake water discharge.

(2) "WAY CURUP DESIGN NOTE 2", March, 1980

(i) Performed the detail design of the head works (Fixed weir, Flood sluice, Intake and Scouring sluice).

(ii) Designed a part of the main canal.

(3) "REPORT ON THE TECHNICAL DISCUSSION", July, 1980

(i) Reported on the technical discussion at Bandung.

(ii) Described my personal opinion of them.

(4) "REVIEW ON DESIGN DRAWINGS OF PENGAIKAN WAY JEPARA DP. WAY CURUP", July, 1980

(i) Described the suggestion to the design drawings sent from Bandung.

(5) "DESIGN OF DROP AND SPILLWAY AT THE WAY CURUP PROJECT", March, 1981

(i) Proposed a new design method for a drop.

(i-i) To lengthen the stilling basin.

(i-ii) To construct a rectanglar shaped stilling basin.

(ii) Designed a spillway.

(6) "COMPARISON DESIGN BETWEEN SIPHON AND EMBANKED CANAL AT THE WAY CURUP PROJECT", August, 1981

(i) Performed a comparison design at the place where a canal goes across a valley.

(ii) Described the way of curing of concrete in the tropics.

(iii) Described how to design a siphon in response to my counterpart's request.

2. Way Semangka Project

a. Summary

Although this project had started in 1969, it has not yet been watered into main canal because of some disasters.

We succeeded in the provisional running test in December 1980. I have transfered how to perform rehabilitation works and a running test to my counterparts.

b. Counterparts

Mr. SUKARDI B. I. E. (KEPARA BIDANG OPERASI DAN PENGAWASAN LAPANGAN)
Mr. SOEPANGKAT (KEPARA BIDANG PERENCANAAN PROYEK IRIGASI SEDANG KECIL)

c. Presented Reports

(1) "COMMENT ON THE WAY SEMANGKA PROJECT", December, 1979

(i) Investigated the reason why this project could not be watered.

(ii) Described the rehabilitation works for the disaster area.

(2) "SLOPE FAILURE AT THE WAY SEMANGKA PROJECT", November, 1980

(i) Described the problems on the stability analysis of slope.

(ii) Investigated the stabilily of slopes at this project.

(iii) Designed the rehabilitation works at the failed slope.

(3) "REHABILITATION WORKS FOR RUNNING TEST", December, 1980

(i) Described the rehabilitation works for the coming running test.

(4) "RUNNING TEST MANUAL", December, 1980

(i) Described how to perform the coming running test.

(5) "RUNNING TEST AT THE WAY SEMANGKA PROJECT", January, 1981

(i) Reported the result of the provisional running test.

(ii) Described the rehabilitation works for watering the design canal discharge.

3. WAY NGISON PROJECT

a. Summary

This is a new project and has a benefited area of 958 ha. I have transfered how to design the head works.

b. Counterpart

Mr. SUKARDI B. I. E.

c. Presented Report

(1) "DESIGN OF THE WAY NGISON WEIR", June, 1980

(i) Designed the head works.

4. WAY NGARIP PROJECT

a. Summary

This project has a benefited area of 633 ha. Though this project had two head works, both of them were broken by floods. So Mr. T. Nakamura (Pre-C.P.E.) designed a rehabilitation works of head works.

But he left here for Japan. So I have transfered how to supervise the construction of head works to my counterparts.

b. Counterparts

Mr. SUKARDI B. I. E.
Mr. ALI B. E. (KEPARA BIDANG PERENCANAAN PERBAIKAN DAN PENYEMPURNAAN IRIGASI)

c. Presented Report

"CONSTRUCTION OF THE HEAD WORKS AT THE WAY NGARIP PROJECT", December 1981.

(i) Described the items that we pointed out and how to improve the construction of head works.

(ii) The items are as follows.

(a) Material
(b) Earth work
(c) Coffer dam

(d) Drainage

(e) Curing of mortar

(f) Other constructions

5. DIAGNOSIS SURVEY

a. Summary

There are 9 projects which were started before the Second World War in South Lampung Prefecture. We tried to recover the irrigation function of these projects.

b. Counterparts

Mr. SUKARDI B. I. E.
Mr. ALI B. E.

c. Presented Reports

(1) "DIAGNOSIS SURVEY AT THE WAY GATEL PROJECT", June, 1981

(i) Found out the problems to recover the irrigation function.
(ii) Described the rehabilitation works for them.

(2) "DIAGNOSIS SURVEY AT THE WAY TEBU PROJECT", July, 1981

(i) Found out the problems to recover the irrigation function.
(ii) Described the rehabilitation works for them.
(iii) Both reports of "5-(1)" and "5-(2)" were prepared mainly by Mr. Sukardi.

(3) "LAPORAN UNTUK: D.I. WAY PADANG RATU", December, 1981

(i) Found out the problems to recover the irrigation function.
(ii) Designed the rehabilitation works of both head works and main canal.
(iii) This report was prepared mainly by Mr. Ali.

(4) "EMERGENCY REHABILITATION WORKS AT THE WAY LALAAN PROJECT", December, 1981

(i) As we found out places which were in critical conditions, we reported them and performed rehabilitation works.

6. HYDROLOGIC ANALYSIS

a. Summary

This has been performed to roughly know the hydrologic values in Lampung province lest we should make any big mistakes.

b. Counterparts

Mr. SUKARDI B. I. E.

Mr. ALI B. E.

c. Presented Reports

(1) "HYDROLOGIC ANALYSIS IN LAMPUNG PROVINCE", June, 1981

(i) Drew up the long term rainfall isohyets.

(ii) Analyzed the relation between rainfall altitude and a year's rainfall.

(iii) Analyzed the monthly distribution of rainfall and run-off in the 5 big basins.

(iv) Drew up the isohyets of a day's maximum rainfall for ten, fifty and a hundred years' return period.

(v) Drew up the ishohyets of a month's droughty rainfall for five years' return period in both rainy and dry seasons.

(vi) Analyzed the maximum specific discharge for ten, fifty and a hundred years' return period.

(vii) Analyzed a month's droughty specific discharge for five years' return period in both rainy and dry seasons.

(2) "HYDROLOGIC ANALYSIS IN LAMPUNG PROVINCE - A REVISED EDITION-", February, 1982

This report is a revised edition of "Hydrologic Analysis in Lampung Province, June 1981", because at that time we could not collect all the data in 1980. In this report all data on rainfall and run-off in 1980 have been collected. And also we have added and analyzed data on rainfall days.

The main subjects of this work are as follows;

(A) To know the general hydrologic values so as not to make any big mistakes when we design new projects or rehabilitation works.

(B) To find the proper benefited area in proportion to the run-off from the catchment area and the effective rainfall in the benefited area.

For the subject of (A), the following drawings have been drawn up;

(i) Long Term Rainfall Ishohyets (2,000 - 3,500 mm/year)

(ii) Long Term Rainfall Day Isohyets (120 - 200 days/year)
If one day it rains, the average rainfall is about 17 mm/day.

(iii) Rainfall Isohyets in 1977 (1,800 - 3,000 mm/year)

(iv) Rainfall Day Isohyets in 1977 (100 - 200 days/year)
It is a droughty year of rainfall and rainfall days for five years' return period in 1977 in the Way Seputih and in the Way Sekampung basin.

(v) Isohyets of a Day's Maximum Rainfall for 10,50 and 100 Years' Return Period.

Return Period	Maximum Rainfall
Years	mm/day
10	100 - 180
50	120 - 220
100	130 - 230

(vi) Relation between Catchment Area and Flood Specific Discharge for 10,50 and 100 Years' Return Period.

Return Period	Maximum Specific Discharge
Years	$m^3/s/km^2$
10	0.2 - 2.1
50	0.3 - 2.4
100	0.4 - 2.5

These drawings and figures will be useful for checking the design of the new projects or rehabilitation works.

For the subject of (B), we have performed the following analyses;

(i) Monthly Rainfall, Rainfall Days and Run-off Distributions

(ii) Monthly Droughty Rainfall and Specific Discharge

Basin	Season	Droughty Rainfall
Tulangbawang	Rainy	110 - 220 mm /month
	Dry	<50
Others	Rainy	100
	Dry	<30

	Droughty Specific Discharge
Rainy Season	1.5 - 5.5 $m^3/s/100\ km^2$
Dry Season	0.5 - 2.5

As a result of these analyses, we know that we had better plant paddy in the rainy season from December to April, and that in the dry season it should be planted between May and September.

And then we estimated the proper benefited area in both rainy and dry seasons. It has been analyzed that the irrigable area in the dry season is only one fourth of that in the rainy season.

The irrigable area, of course, is due to the catchment area in a certain project and the effective rainfall in the benefited area. Therefore, we have estimated the proper benefited area at the "Sedang Kecil project" in South Lampung prefecture. To our surprise, many real irrigated paddy fields are nearly the same as the estimated area in both rainy and dry seasons. That is to say, these projects are in good geographical and hydrological conditions.

But the canals of tertiary and others are in bad conditions. So we propose to perfect these canals as soon as possible. This is the best effective way to increase the rice production by the minimum effort and budget.

7. Paddy Field Irrigation

a. Summary

In Lampung province, there are many paddy field irrigation projects, and some projects are under construction, and other projects are going to be constructed.

But we do not know yet the realities of the paddy field irrigation;

cropping schedule, irrigation requirement, and so on.

The plan of the paddy field irrigation has been performed not by experiment but only on the table, even if it was a big project.

By the way, Lampung province has a long history of paddy field irrigation and possesses data on the planted paddy field area and the irrigated water at the "Sedang Kecil Project" in South Lampung prefecture.

Therefore, at first we studied the realities of the paddy field irrigation in the tropics by this data, and then we made some proposals.

b. Counterparts

Mr. SOEDARSONO B. I. E. (KEPALA SEKSI PENGAIRAN D.P.U. PROPINSI CABANG LAMPUNG)

Mr. SUKARDI B. I. E.

Mr. ALI B. E.

c. Presented Report

"REALITIES OF THE PADDY FIELD IRRIGATION AT THE WAY TEBU PROJECT", March, 1982

1. Collection and Examination of Data

We have collected data on the planted paddy field area and the irrigated water. The former is a monthly record of puddling area, nursery bed area and paddy field area at each tertiary sector. On the other hand, the latter is a daily record of irrigated water at each canal of main, secondary and tertiary. And also this record includes daily data on the river discharge.

Then we have examined this data at the job site and on the table. But, we can rely on data on the Way Tebu project only. Therefore we have analyzed data on the Way Tebu project.

2. Paddy Field Land Consolidation

D.P.U.P. Lampung is going to construct a dense tertiary canal. At present, the number of the teriary sector is 64, on the other hand in the near future it will be devided into 277. Therefore, the average of tertiary sector size will be decreased from 66 ha to 18 ha.

3. Planting Schedule and Irrigation Schedule

3-1 Planted Period

Figures and tables make clear that planted period in the rainy season at a certain paddy field of "PELITA" and "IR-8" changes from 135 to 145 days. In the case of the dry season, the period is between 140 and 150 days. And in the rainy season of "IR-36" in 1981, the period is from 120 to 130 days. So in the dry season, paddy of "IR-36" will change between 125 and 135 days.

On the other hand, the planted period in a main canal sector was about 200 days in the case of "PELITA" and "IR-8". And the period of "IR-36" was about 175 days.

3-2 Started Day of Plant

Puddling in the rainy season was started on between December 1st and January 10th, on the other hand that in the dry season was planted on from May 20th to July 10th.

But we proposed that we should plant a paddy in the dry season from the beginning of May, because more rainfall and run-off are expected in May than those in June or in July.

3-3 Irrigation Period

The first day of irrigation was not always the same day as the first day of puddling. Sometimes farmers started puddling without irrigation water. We propose to irrigate one week before puddling.

4. Unit Duty of Water

(i) We find a tendency that the smaller a paddy field area at a certain tertiary sector is, the bigger a unit duty of water becomes.

(ii) In the rainy season, the average unit duty of water is about 1.1 l/s/ha.

(iii) In the dry season, the average is about 1.3 l/s/ha.

5. Supplied Water and Irrigation Requirement

The total supplied water is nearly the same amount every year. In the rainy season it is about 2,500 mm, and in the dry season it is about 2,000 mm. And irrigation requirement will be about 1,000 mm.

It means that only 50% of the supplied water is utilized in the rainy season, and 50% of that in the dry season.

6. Irrigable Area in Both Rainy and Dry Seasons

We can irrigate almost all the benefited area in rainy season, even if it is a droughty year. On the other hand, in the dry season, we can irrigate half of the benefited area.

In the Way Tebu I & II and IV projects, though the planted area in the dry season has been one third, we should persuade farmers at those projects to plant half of that area in the rainy season.

7. Examination of the Way Sekampung Curve

(i) There is a slight tendency that the smaller the paddy field area is, the bigger the variable (t) becomes.

(ii) The Way Sekampung curve gives the bigger variable (t) in the case that the paddy field area is smaller than 70 ha.

(iii) But, even if we perform the normal water management, the running water in the tertiary canal is sometimes 1.8 times as much as the design discharge.

(iv) And when the canal is big one, the Way Sekampung curve gives the smaller variable (t). We should construct the freeboard to cover the maximum discharge and design other canal structures that permits to flow the discharge that is 1.3 times as big as the design discharge.

I. DESIGN OF DROPS AT THE WAY CURUP PROJECT

March 1981

AKIRA YAMAZAKI
(Colombo Plan Expert)
RAFLI ARSIL
(Counterpart)

Contents

SYNOPSIS

Proposal for the following two points in the design of drops.

1. To lengthen the stilling basin.
2. To construct a rectangular shaped stilling basin.

1. Problems on the Design of Drops

A drop is provided to convey water from high elevation to low. The purposes of its strucutre are as follows.

1. To decrease cutting volume to construct a canal.
2. To keep a permissible velocity in a canal.

In Indonesia, the following formula has been used in the design of drops (Refer to Fig. 1).

If, $4/3 < Z/H < 10$

$D = L = R = 1.1\ Z + H$

$a = 0.15\ H\sqrt{H/Z}$

If, $1/3 < Z/H < 4/3$

$D = L = R = 0.6\ H + 1.4\ Z$

$a = 0.20\ H\sqrt{H/Z}$

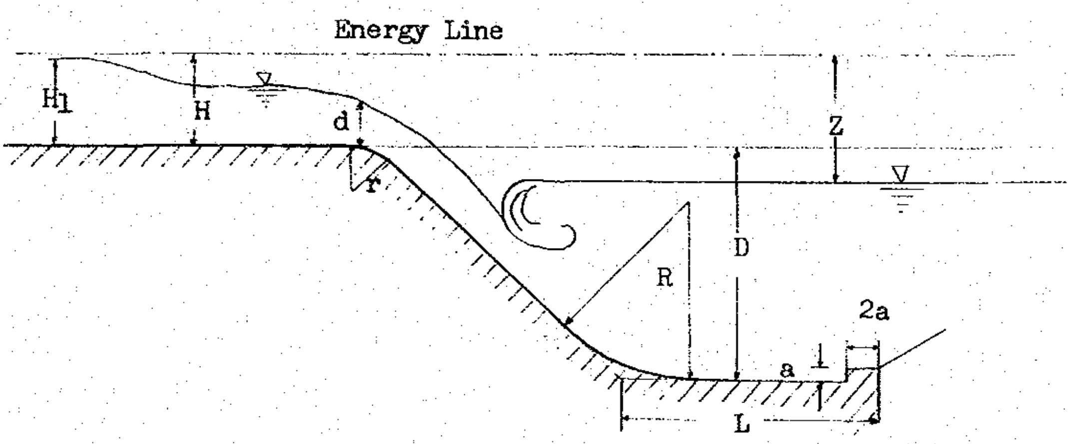


Fig. 1 Symbols and dimensions of drops.

According to this design method, however, the length of the stilling basin is not enough to change a jet flow into an ordinary flow (Refer to Example - 1).

The following experimental formula tells us the length of the hydraulic jump;

in this case the Froude number (Fr) was bigger than 1.7 (Refer to Fig. 2).

by Smenata

$l = 6\ (h_2 - h_1)$

where,

- ℓ : length of hydraulic jump (m)
- h_1 : water depth before hydraulic jump (m)
- h_2 : water depth after hydraulic jump (m)

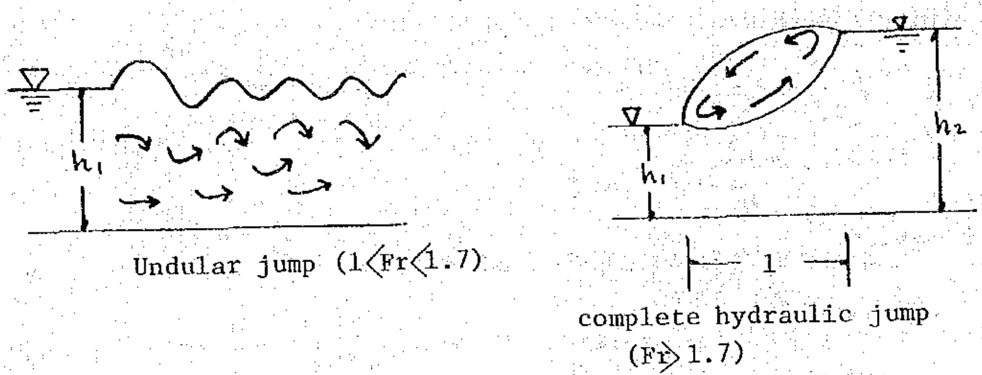
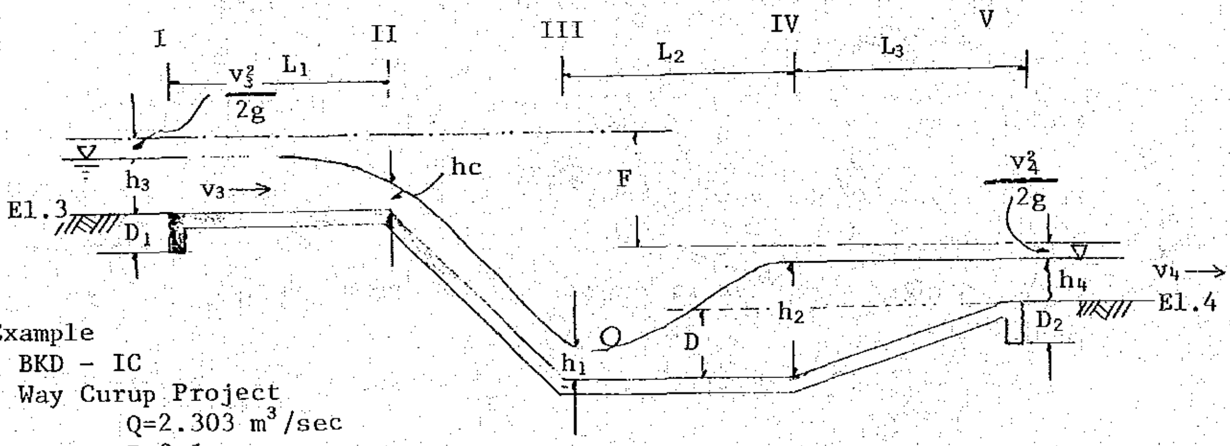


Fig. 2 Froude number and hydraulic jump.



Example
BKD - IC
Way Curup Project
$Q=2.303\ m^3/sec$
$B=2.1\ m$
$v_3, v_4=0.6\ m/sec$

Fig. 3 Sumbols and dimensions of drops.

Example - 1

Given : Fig - 3 (BKD - IC at the Way Curup Project)

Solution : To find the length of hydraulic jump and to compute the length of the stilling basin using the design method in Indonesia.

The difference of energy head : F

$$F = \{11.15 + \frac{(0.6)^2}{2x9.8}\} - \{10.60 + \frac{(0.6)^2}{2x9.8}\}$$

$$= 0.55 \text{ (m)}$$

Critical depth : hc

$$hc = \sqrt[3]{\frac{1}{9.8}\left(\frac{2.303}{2.1}\right)^2}$$

$$= 0.497 \text{ (m)}$$

Therefore,

$$F/hc = \frac{0.55}{0.497}$$

$$= 1.107 \text{ (m)}$$

then, $h_1/hc = 0.424$

$$h_1 = 0.497 \times 0.424$$

$$= 0.211 \text{ (m)}$$

$$h_2/h_1 = 4.65$$

$$h_2 = 0.211 \times 4.65$$

$$= 0.981 \text{ (m)}$$

Froude number : Fr

$$Fr = 2.303/2.1/\sqrt{9.8 \times (0.211)^3}$$

$$= 3.62 > 1.7$$

Accordingly this flow is the perfect hydraulic jump.

then,

$$l = 6 \times (0.981 - 0.211)$$

$$= 4.6 \text{ (m)}$$

Using the design method in Indonesia,

$$Z = 11.15 + \frac{(0.6)^2}{2x9.8} - 10.60 + \frac{(0.6)^2}{2x9.8}$$

$$= 0.55 \text{ (m)}$$

$$H = 11.15 - 10.60 + \frac{(0.6)^2}{2x9.8}$$

$$= 0.57 \text{ (m)}$$

$Z/H = 0.55/0.57$
$= 0.965$

then,

$D = L = R = 0.6\ H + 1.4\ Z$
$= 0.6 \times 0.57 + 1.4 \times 0.55$
≈ 1.0 (m)

That is to say, if we use this design method in Indonesia, we cannot change a jet flow into an ordinary flow within the stilling basin. The fact will cause erosion at the end of the retaining wall of the stilling basin. So we ought to construct the length of the stilling basin the same as the length of the hydraulic jump.

And then in Indonesia, the shape of the stilling basin has been designed in a trapezium.

The shape makes the length of the hydraulic jump too long.

P.S. Hsing showed the following experimental formula for the length of a hydraulic jump in a trapezoid canal (Refer to Fig. 4).

$$l = 5h_2\ (1 + \sqrt{(B_2 - B_1)/B_1}\ )$$

where, l : length of hydraulic jump (m)
h_2 : water depth after hydraulic jump (m)
B_1/B_2 : width before and after hydraulic jump (m)

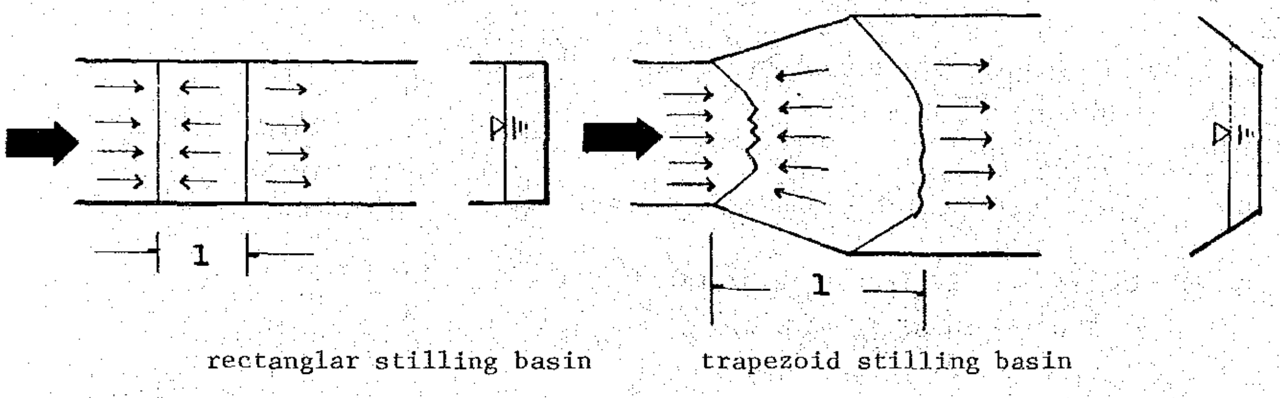


Fig. 4 Length of hydraulic jump.

Example - 2

Given : Fig. - 3 (BKD - IC at the Way Curup Project)

Solution : To find the length of the hydraulic jump.

$h_1 \doteqdot 0.211$ (m)

$h_2 = 0.981$ (m)

$B_1 = 2.1$ (m)

$B_2 = 2.1 + 2 \times 1.5 \times 0.981$

$= 5.043$ (m)

then,

$$l = 5 \times 0.981 \times (1 + \sqrt{(5.043 - 2.1)/2.1})$$
$$= 10.7 \text{ (m)}$$

If the shape of the stilling basin is a trapezium, the length of the stilling basin will be about twice that of a rectangle one.

2. Proposal for the new Design Method of Drops

I will propose the new design method of drops as follows (Refer to Fig. 3).

(1) Section I - II

A. The length of I - II: L_1

$0<Q<2.0$ (m^3/sec)	$L_1 = 1.2 + 3/2\sqrt{Q}$ (m)
$Q \geqq 2.0$ (m^3/sec)	$L_1 = 2.1 + 3/2\sqrt{Q}$ (m)
or,	$L_1 = 4F$ (m)

where,

F: difference of the specific energy between upper place and lower place of drops (m)

B. The depth of cut off: D_1

$D_1 = 0.6\sqrt{h_3} > 0.6$ (m)

where,

h_3 : water depth of the upper canal (m)

(2) Section III-IV (Stilling Basin)

A. The length of III-IV: L_2

$L_2 = 6 \times (h_2 - h_1)$ (m)

where,

h_1, h_2 : conjugate depth before and after hydraulic jump (m).

Example - 3

Given: Fig. 3 (BKD - IC at the Way Curup Project)

Solution: To find the length and depth of the stilling basin.

a) Computation of the difference of specific energy between upper place and lower place of canal: F

$$F = (El_3 + h_3 + \frac{V_3^2}{2g}) - (El_4 + h_4 + \frac{V_4^2}{2g})$$

$$= \left\{11.15 + 1.05 + \frac{(0.6)^2}{2x9.8}\right\} - \left\{10.60 + 1.05 + \frac{(0.6)^2}{2x9.8}\right\}$$

$$= 0.55 \text{ (m)}$$

b) Computation of the length of the stilling basin

critical depth : hc

$$hc = \sqrt[3]{\frac{q^2}{g}} \quad \text{(m)}$$

where,

q: discharge in unit width (m^3/sec/m)

g: acceleration of gravity (9.8 m/sec^2)

$$hc = \sqrt[3]{(2.303/2.1)^2/9.8}$$

$$= 0.497 \text{ (m)}$$

hence,

$$F/hc = 0.55/0.497$$

$$= 1.107$$

From Table - 1, read h_1/hc and K = h_2/h_1 corresponded with F/hc.

F/hc	1.081	1.134
h_1/hc	0.427	0.421
h_2/h_1	4.6	4.7

1.107 - 1.081 = 0.026

1.134 - 1.081 = 0.053

0.026/0.053 = 0.491

then,

$$h_1/hc = 0.427 + (0.421 - 0.427) \times 0.491$$

$$= 0.424$$

$$h_2/h_1 = 4.6 + (4.7 - 4.6) \times 0.491$$

$$= 4.65$$

$$h_1 = 0.424 \times hc$$

$$= 0.424 \times 0.497$$

$$= 0.211 \text{ (m)}$$

$$h_2 = 4.65 \times h_1$$

$$= 4.65 \times 0.211$$

$$= 0.981 \text{ (m)}$$

As a stilling basin is effective where the flow is a complete hydraulic jump, we have to compute the Froude number (Fr) to check whether the flow will be a complete hydraulic jump or not.

If	$Fr \geqq 1.7$	complete hydraulic jump
	$1 < Fr < 1.7$	undular jump
		(Refer to Fig. 2)

$Fr = q/\sqrt{gh_1^3}$

$= 2.303/2.1/\sqrt{9.8 \times (0.211)^3}$

$= 3.62 > 1.7$

Accordingly this flow is a complete hydraulic jump.

The necessary length of the stilling basin: L_2

$L_2 = 6 \times (h_2 - h_1)$

$= 6 \times (0.981 - 0.211)$

$= 4.6$ (m)

c) Computation of the depth of the stilling basin

The depth of the stilling basin: D

$D = 1/2\sqrt{He.F}$ (m)

where,

He: specific energy at the upper canal (m)

$He = h_3 + v_3^2/2g$

$= 1.05 + (0.6)^2/2 \times 9.8$

$= 1.07$ (m)

therefore,

$D = 1/2\sqrt{1.07 \times 0.55}$

$= 0.38$ (m)

(3) Section IV - V

A. The slope between IV and V should be made gentle. The slope is usually adopted in the ratio from 1:4 to 1:10 (vertical: horizontal).

B. The length of IV - V

The length between IV and V should be as long as the length of the stilling basin (L_2).

C. The depth of the cut off: D_2

$D_2 = 0.6\sqrt{h_4} > 0.6$ (m)

where,

h_4 : water depth of the lower canal (m).

Table - 1 Relation between F/hc and h_1/h_c or h_2/h_1

$K=h_2/h_c$		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	F/h_c	0.	.0002	.0015	.0045	.0096	.0169	.0264	.0382	.0522	.0684
	h_1/h_c	1.0	.953	.912	.874	.842	.811	.785	.758	.735	.713
2	F/h_c	.087	.107	.129	.153	.179	.206	.235	.266	.298	.331
	h_1/h_c	.693	.675	.653	.641	.626	.611	.597	.585	.573	.551
3	F/h_c	.367	.403	.440	.479	.519	.560	.602	.645	.690	.736
	h_1/h_c	.550	.540	.530	.520	.511	.502	.494	.486	.479	.471
4	F/h_c	.782	.830	.878	.928	.978	1.029	1.081	1.134	1.188	1.243
	h_1/h_c	.464	.457	.451	.444	.438	0.433	.427	.421	.416	.411
5	F/h_c	1.297	1.35	1.41	1.47	1.52	.58	1.64	1.70	1.77	1.83
	h_1/h_c	.405	.400	.396	.391	.387	.383	.378	.374	.370	.366
6	F/h_c	1.89	1.95	2.01	2.08	2.14	2.21	2.27	2.34	2.41	2.47
	h_1/h_c	.363	.359	.355	.352	.348	.345	.342	.338	.335	.332
7	F/h_c	2.54	2.61	2.68	2.75	2.82	2.89	2.96	3.03	3.10	3.17
	h_1/h_c	.329	.326	.323	.321	.318	.315	.313	.310	.308	.305
8	F/h_c	3.24	3.32	3.39	3.47	3.54	3.62	3.69	3.77	3.85	2.92
	h_1/h_c	.303	.300	.298	.296	.294	.291	.289	.287	.285	.283
9	F/h_c	4.00	4.08	4.15	4.23	4.31	4.39	4.47	4.55	4.63	4.71
	h_1/h_c	.281	.279	.277	.275	.273	.272	.270	.268	.266	.268
10	F/h_c	4.79	4.88	4.96	5.05	5.13	5.21	5.29	5.37	5.46	5.54
	h_1/h_c	.263	.261	.260	.258	.257	.255	.254	.252	.251	.249
11	F/h_c	5.63	5.71	5.80	5.88	5.97	6.06	6.14	6.23	6.32	6.40
	h_1/h_c	.248	.246	.245	.243	.242	.241	.239	.238	.237	.235
12	F/h_c	6.49	6.58	6.67	6.76	6.84	6.93	7.02	7.12	7.21	7.30
	h_1/h_c	.234	.233	.232	.230	.229	.228	.227	.226	.225	.223
13	F/h_c	7.39	7.48	7.57	7.66	7.76	7.85	7.94	8.03	8.13	8.22
	h_1/h_c	.222	.221	.220	.219	.218	.217	.216	.215	.214	.213
14	F/h_c	8.31	8.41	8.50	8.60	8.69	8.79	8.88	8.98	9.08	9.17
	h_1/h_c	.212	.211	.210	.209	.208	.207	.206	.205	.204	.204
15	F/h_c	9.27	9.37	9.46	9.56	9.66	9.76	9.86	9.96	10.06	10.16
	h_1/h_c	.2027	.2018	.2010	.2001	.1993	.1985	.1977	.1968	.1960	.1952
16	F/h_c	10.26	10.36	10.45	10.56	10.66	10.76	10.86	10.96	11.06	11.16
	h_1/h_c	.1945	.1937	.1929	.1922	.1914	.1907	.1899	.1892	.1884	.1877
17	F/h_c	11.26	11.37	11.47	11.57	11.67	11.78	11.88	11.98	12.09	12.19
	h_1/h_c	.1870	.1863	.1856	.1849	.1842	.1835	.1828	.1821	.1814	.1808
18	F/h_c	12.29	12.40	12.50	12.61	12.71	12.82	12.92	13.03	13.13	13.24
	h_1/h_c	.1802	.1795	.1789	.1782	.1776	.1770	.1764	.1757	.1751	.1745
19	F/h_c	13.35	13.46	13.57	13.67	13.78	13.89	14.00	14.10	14.21	14.32
	h_1/h_c	.1740	.1734	.1728	.1722	.1716	.1711	.1705	.1699	.1694	.1688
20	F/h_c	14.43	14.53	14.64	14.75	14.84	14.97	15.08	15.19	15.30	15.41
	h_1/h_c	.1683	.1677	.1672	.1666	.1661	.1656	.1651	.1645	.1640	.1635
21	F/h_c	15.52	15.63	15.74	15.85	15.96	16.08	16.19	16.30	16.41	16.52
	h_1/h_c	.1630	.1625	.1620	.1615	.1610	.1605	.1600	.1596	.1591	.1586
22	F/h_c	16.64	16.75	16.87	16.98	17.09	17.21	17.32	17.43	17.55	17.66
	h_1/h_c	.1581	.1576	.1572	.1567	.1563	.1558	.1554	.1549	.1545	.1541
23	F/h_c	17.78	17.89	18.01	18.12	18.24	18.35	18.47	18.59	18.70	18.82
	h_1/h_c	.1536	.1532	.1527	.1523	.1519	.1515	.1510	.1506	.1502	.1498
24	F/h_c	18.93	19.05	19.17	19.29	19.40	19.52	19.64	19.76	19.88	20.00
	h_1/h_c	.1494	.1490	.1486	.1482	.1478	.1474	.1470	.1466	.1463	.1459
25	F/h_c	20.11	20.23	20.35	20.47	20.59	20.71	20.83	20.95	21.07	21.19
	h_1/h_c	.1455	.1451	.1447	.1444	.1440	.1436	.1433	.1429	.1425	.1422
26	F/h_c	21.31	21.43	21.55	21.67	21.79	21.91	22.03	22.15	22.27	22.40
	h_1/h_c	.1418	.1414	.1411	.1407	.1404	.1400	.1397	.1393	.1390	.1386
27	F/h_c	22.51	22.63	22.75	22.87	22.99	23.12	23.24	23.36	23.48	23.61
	h_1/h_c	.1383	.1380	.1376	.1373	.1370	.1366	.1363	.1360	.1357	.1353
28	F/h_c	23.73	23.86	23.98	24.10	24.23	24.35	24.48	24.60	24.73	24.85
	h_1/h_c	.1351	.1347	.1344	.1341	.1338	.1335	.1332	.1329	.1326	.1323
29	F/h_c	24.98	25.10	25.23	25.35	25.48	25.60	25.73	25.86	25.98	26.11
	h_1/h_c	.1320	.1317	.1314	.1311	.1308	.1305	.1302	.1299	.1297	.1294
30	F/h_c	26.23	26.36	26.49	26.61	26.74	26.87	27.00	27.12	27.25	27.38
	h_1/h_c	.1291	.1288	.1285	.1282	.1280	.1277	.1274	.1272	.1269	.1266
31	F/h_c	27.51	27.64	27.77	27.90	28.02	28.15	28.28	28.41	28.54	28.68
	h_1/h_c	.1264	.1261	.1258	.1256	.1253	.1250	.1248	.1245	.1243	.1240
32	F/h_c	28.80	28.93	29.06	29.19	29.32	29.45	29.58	29.71	[illegible].84	29.97
	h_1/h_c	.1238	.1235	.1233	.1230	.1228	.1225	.1223	.1220	.1218	.1215
33	F/h_c	30.10	30.23	30.37	30.50	30.63	30.76	30.89	31.02	31.15	31.29
	h_1/h_c	.1213	.1211	.1208	.1206	.1203	.1201	.1199	.1197	.1194	.1192
34	F/h_c	31.42	31.55	31.68	31.82	31.95	32.08	32.21	32.35	32.48	32.61
	h_1/h_c	.1189	.1187	.1184	.1182	.1180	.1178	.1175	.1173	.1171	.1169
35	F/h_c	32.75	32.88	33.01	33.15	33.28	33.42	33.55	33.69	33.82	33.96
	h_1/h_c	.1167	.1166	.1162	.1160	.1158	.1156	.1154	.1152	.1149	.1147
36	F/h_c	34.09	34.23	34.36	34.50	34.63	34.77	34.90	35.04	35.18	35.31
	h_1/h_c	.1145	.1143	.1141	.1139	.1137	.1135	.1132	.1130	.1128	.1126
37	F/h_c	35.45	35.59	35.72	35.86	36.00	36.13	36.27	36.41	36.55	36.69
	h_1/h_c	.1124	.1122	.1120	.1116	.1116	.1114	.1112	.1110	.1108	.1106
38	F/h_c	36.82	36.96	37.10	37.24	37.37	37.51	37.65	37.79	37.93	38.06
	h_1/h_c	.1105	.1103	.1101	.1099	.1097	.1095	.1093	.1091	.1089	.1087
39	F/h_c	38.20	38.34	38.48	38.62	38.76	38.90	39.04	39.18	39.32	39.46
	h_1/h_c	.1086	.1084	.1082	.1080	.1078	.1077	.1075	.1073	.1071	.1069
40	F/h_c	39.60									
	h_1/h_c	.1068									

II. SLOPE FAILURE AT THE WAY SEMANGKA PROJECT

AKIRA YAMAZAKI
(Colombo Plan Expert)
SUKARDI MARGINO
(Counterpart)

Contents

1. Preface

The well known method of investigating stability of slope is the method of slices, which is simple and therefore, is more commonly used. But there are many problems in this method.

One of them is that the safety factor is commonly computated by the one circle only. Other circles must be analyzed until the circle giving the smallest safety factor is found. The circle given actually is the critical circle.

And another is due to the factors of soil mass and the influence of nature, these are unit weight, cohesion and internal friction angle of soil mass or the influence of height of slope and ground water.

In this report we explained the difference of safety factor by using the various values of each factor.

That is to say, we explained that there are many variable factors to compute the stability of slope, and the computation of stability can be used effectively only if the resultants of soil test are the same conditions to soil layer. Accordingly we introduced the prevalent gradient of cutting or banking slope.

And then, we computed the safety factor of slope before the construction of canal at the Way Semangka project by assuming the factors of soil mass. And computing the safety factor of constructed slope with the same assumption, we compared with the safety factor of slope before and after construction. And we knew that slopes are lying in critical conditions.

However, as we have stated above, there are many problems on stability computation. Then we made some field examinations to inquire into dangerous slopes and to think out a control or rehabilitation works.

As a result of field examinations, we knew that almost all slopes are lying in critical conditions, and the extension of them reaches 1.85 km. The main cause is that the gradient of slope is too steep to get a stability of slope. And if we reconstruct the gradient of slope more gentle, we should cut many volume of soil and appropriate much budget. Then we think that we had better leave the slope in it's present condition. And if the slope failure occurs in the future, we will have only to perform a rehabilitation works at the slid portion.

Finally, we stated some control works for slope failure.

2. Method of Slices

The well known method of investigating stability of slope is the method of slices, which is simple and therefore, is more commonly used. In the slice method, the whole soil mass adjoining the slope is divided into vertical slices as shown in Fig. -1.

The safety factor (Fs) of stability of slopes is defined in terms of moment about the center of the failure arc.

$$Fs = \frac{Mr}{Md}$$

$$= \frac{\text{Moment of shear strength along failure arc}}{\text{Moment of weight of failure mass}} \quad \cdots\cdots\cdots \quad (1)$$

The dominator is the driving moment. Note that the moment arm for the weight of any slice is equal to

$$r \sin \theta i$$

hence, we may write

$$Md = r\,\Sigma Wi \sin \theta i$$

where, r: radius of the failure arc

i: number of slices

wi, θi: they are defined in Fig.-2

Similarly, the resisting moment may be written as follows.

$$Mr = r\Sigma\ (c + \sigma \tan \phi\ )\ li$$

$$= r\ \ (c\Sigma\ li + \tan \phi\ \Sigma Ni)$$

where, li: length of the failure arc cut by the i th slice.

Thus Eq. (1) becomes

$$Fs = \frac{c\Sigma\ li + \tan\ \Phi \Sigma Ni}{\Sigma\ Wi\ \sin\ \Theta i} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

If any external forces other than gravity act on the failure mass (such as the weight of a building upon the slope), the moment of these forces is included in Md.

And pore pressure on the failure arc does not contribute to Md, since their resultant passes through the center of arc. It is assumed that the forces acting upon the sides of any slices have zero resultant in the direction of normal to the failure arc for that slice.

With this assumption

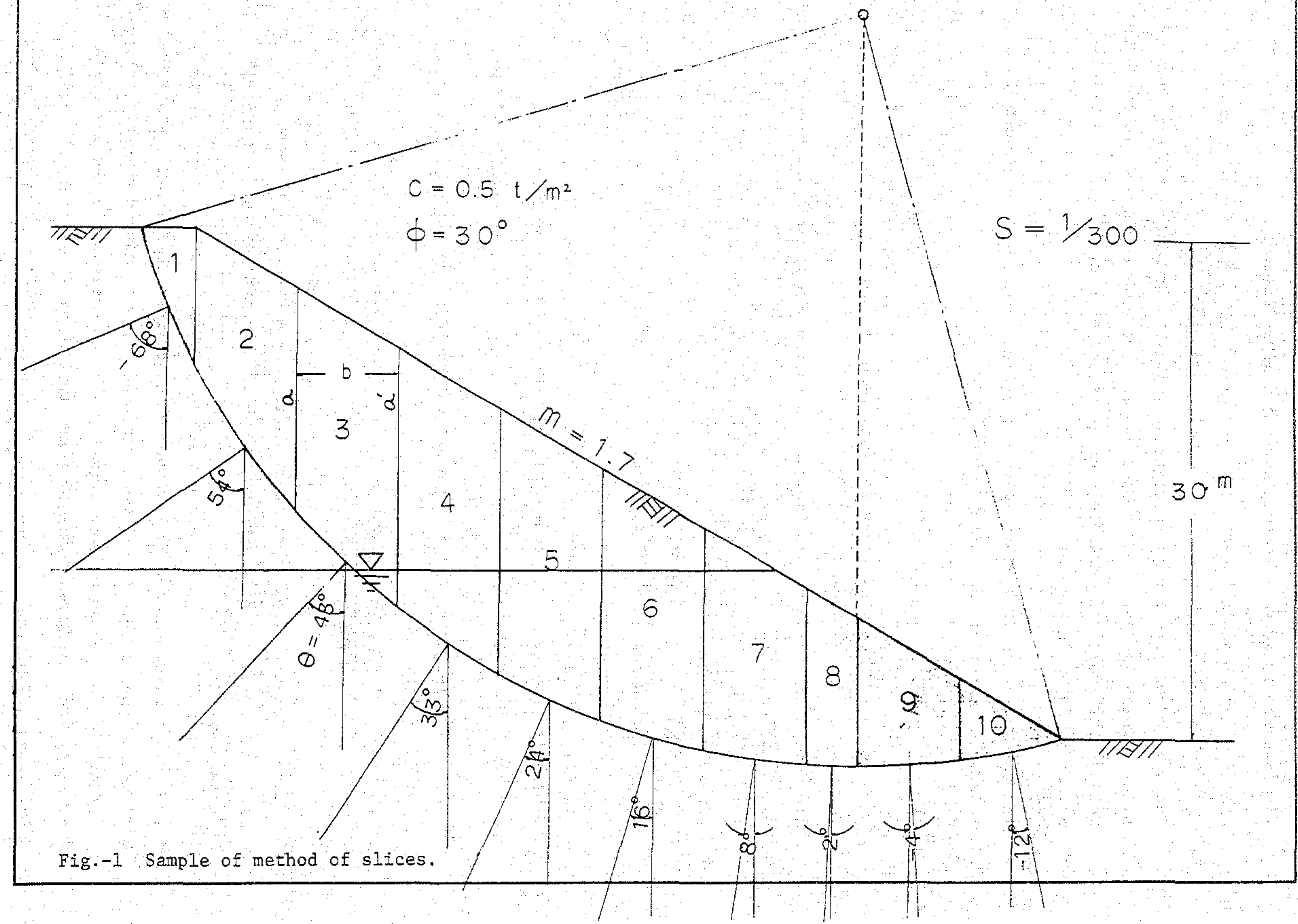


Fig.-1 Sample of method of slices.

$$Ni + Ui = Wi \cos \theta i$$

or

$$Ni = Wi \cos \theta i - Ui$$

$$= Wi \cos \theta i - ui \ \Sigma li$$

Combining Eq. (2) and (3)

$$Fs = \frac{c \ \Sigma li + \tan\phi \ \Sigma(Wi \cos \theta i - ui \ li)}{\Sigma Wi \sin \theta i}$$

The use of Eq. (3) to compute Fs is illustrated in Example of the chapter 3.

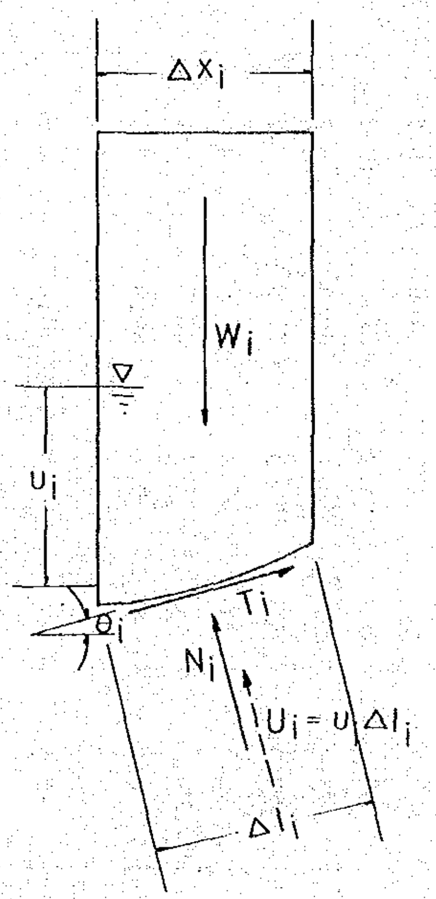


Fig.-2 Forces acting on a slice.

3. Example

3-1 Slope in Fig.-1

Given : Slope in Fig.-1

Find : Safety factor by method of slices

Solution : See Table - 1

Table - 1 Computation of stability of slope

Slice No.	ai	ai'	bi	Ai $=\frac{ai+ai'}{2}xbi$	θi	Ai sin θi	Ai cos θi	li =bi cosθi	ui	ui li
1	0	7.9	3.1	12.2	68	11.3	4.6	8.3	0	0
2	7.9	13.2	6.0	63.3	54	51.2	37.2	10.2	0	0
3	13.2	15.2	6.0	85.2	43	58.1	62.3	8.2	0	0
4	15.2	15.6	6.0	92.4	33	50.3	77.5	7.2	4.3	31.0
5	15.6	14.9	6.0	91.5	24	37.2	83.6	6.6	7.6	50.2
6	14.9	13.1	6.0	84.0	16	23.2	80.7	6.2	9.8	60.8
7	13.1	10.4	6.0	70.5	8	9.8	69.8	6.1	11.0	67.1
8	10.4	8.7	6.0	28.7	2	1.0	28.7	6.0	9.6	57.6
9	8.7	4.8	6.0	40.5	-4	-2.8	40.4	6.0	6.8	40.8
10	4.8	0	6.0	14.4	-12	-3.0	14.1	6.1	2.4	14.6
Σ						236.3	498.9	70.9		322.1

$$Fs = \frac{C\Sigma li + \tan \phi\Sigma(Wi \cos \theta i - ui\ li)}{\Sigma Wi \sin\theta}$$

Case 1, No ground water

$C\Sigma li = 0.5\ t/m^2 \times 70.9\ m$

$= 35.5\ t/m$

$\tan \phi\Sigma(Wi \cos \theta i - ui\ li)$

$= \tan\phi\Sigma\ (\gamma t\ Ai \cos \theta i - ui\ li)$

$= \tan 30° \times (1.8\ t/m^3 \times 498.9\ m^2 - 0)$

$= 518.5\ t/m.$

$\Sigma Wi \sin \theta i$

$= \Sigma\gamma t\ Ai \sin \theta i$

$= 1.8\ t/m^3 \times 236.3\ m^2$

$= 425.3\ t/m.$

$$\therefore Fs = \frac{35.5 + 518.5}{425.3}$$

$= 1.30$

Case 2, Ground water at the height as shown in Fig.-1.

$\tan\phi\ \Sigma(Wi \cos \theta i - ui\ li)$

$= \tan\phi\ \Sigma(\gamma t\ Ai\cos\theta i - ui\ li)$

$= \tan 30° \times (1.8\ t/m^3 \times 498.9\ m^2 - 322.1\ t/m)$

$= 332.5\ t/m.$

$$\therefore Fs = \frac{35.5 + 332.5}{425.3}$$

$= 0.87$

These are answers for the given circle. Now other circles must be analyzed until the circle giving the smallest safety factor is found. The circle given actually is the critical circle.

3-2 Slope in Fig -3 and Fig -4
(Actual slope, at P. 60 of the Way Semangka)

We have explained the method of slices by a simple slope. In this chapter, we will explain the method of slices by actual slope at the point of the P. 60 of the Way Semangka Project.

Fig -3 is a wrong example and Fig -4 is a right example. Fig -3 is the example cut slope by the same intervals, but in this way there are two mistakes. Those are as follows.

(1) This example does not divide the forces into failure and resistance.

(2) We replace slices with the triangle, rectangle or trapezium and compute those areas, but this example does not consider such a matter.

Table - 2 Computation of Stability of Slope
(a wrong example)

Slice No.	ai	ai'	bi	Ai $=\frac{ai+ai'}{2} \times bi$	θi	Ai sinθi	Ai cosθi	li =bi cos θi
1	0	3.0	3.0	4.5	6	0.5	4.5	3.0
2	3.0	8.1	6.0	33.0	0	0	33.0	6.0
3	8.1	9.6	6.0	53.1	9	8.3	52.4	6.1
4	9.6	7.8	6.0	52.2	18	16.1	49.6	6.3
5	7.8	7.5	6.0	45.9	27	20.8	40.9	6.7
6	7.5	7.5	6.0	45.0	37	27.1	35.9	7.5
7	7.5	5.7	6.0	39.6	48	29.4	26.5	9.0
8	5.7	0	5.0	14.8	63	13.2	6.7	11.5
Σ						115.4	249.5	56.1

Note: 1. Angle (θi) of slice No. 1 must show a minus value.
2. We cannot replace slices of No. 3,5,6 and 7 with the triangle, rectangle or trapezium.

$C\Sigma li = 0.5\ t/m^2 \times 56.1\ m$
$= 28.1\ t/m$

$\tan\phi\ \Sigma(Wi \cos\theta i - ui\ li)$
$= \tan\phi\ \Sigma(\gamma t\ Ai \cos\theta i - ui\ li)$
$= \tan 30° \times (1.8\ t/m^3 \times 249.5\ m^2 - 0)$
$= 259.3\ t/m$

$\Sigma Wi \sin\theta i = \Sigma\gamma t\ Ai \sin\theta i$

$= 1.8\ t/m^3 \times 115.4\ m^2$

$= 207.7\ t/m$

$\therefore Fs = \dfrac{28.1 + 259.3}{207.7}$

$= 1.38$

Table - 3 Computation of Stability of Slope

(a correct example)

Slice No.	ai	ai'	bi	Ai $= \frac{ai+ai'}{2} \times bi$	θi	Ai sinθi	Ai cosθi	li =bi cosθi
1	0	5.4	6.0	16.2	-5	-1.4	16.1	6.0
2	5.4	9.0	3.9	28.1	3	1.5	28.1	3.9
3	9.0	9.9	4.2	39.7	9	6.2	39.2	4.3
4	9.9	8.4	5.1	46.7	15	12.1	45.1	5.3
5	8.4	6.3	5.0	36.7	23	14.3	33.8	5.4
6	6.3	8.1	4.5	32.4	31	16.7	27.8	5.2
7	8.1	7.2	1.2	9.2	36	5.4	7.4	1.5
8	7.2	7.5	5.1	37.5	42	25.1	27.9	6.9
9	7.5	6.6	1.2	8.2	49	6.4	5.6	1.8
10	6.6	4.8	3.9	22.2	55	18.2	12.7	6.8
11	4.8	0	3.9	9.4	65	8.5	4.0	9.2
						113.0	247.7	56.3

Note: Both θi and Ai sinθi of slice No. 1 show minus values.

$c\Sigma li = 0.5\ t/m^2 \times 56.3\ m$

$= 28.2\ t/m.$

$\tan\phi\ \Sigma(Wi \cos\theta i - ui\ li)$

$= \tan\phi\ \Sigma(\gamma t\ Ai \cos\theta i - ui\ li)$

$= \tan 30° \times (1.8\ t/m^3 \times 247.7\ m^2 - 0)$

$= 257.4\ t/m.$

$\Sigma Wi \sin\theta i = \Sigma\gamma t\ Ai \sin\theta i$

$= 1.8\ t/m^3 \times 113.0 m^2$

$= 203.4\ t/m$

$\therefore Fs = \dfrac{28.2 + 257.4}{203.4}$

$= 1.40$

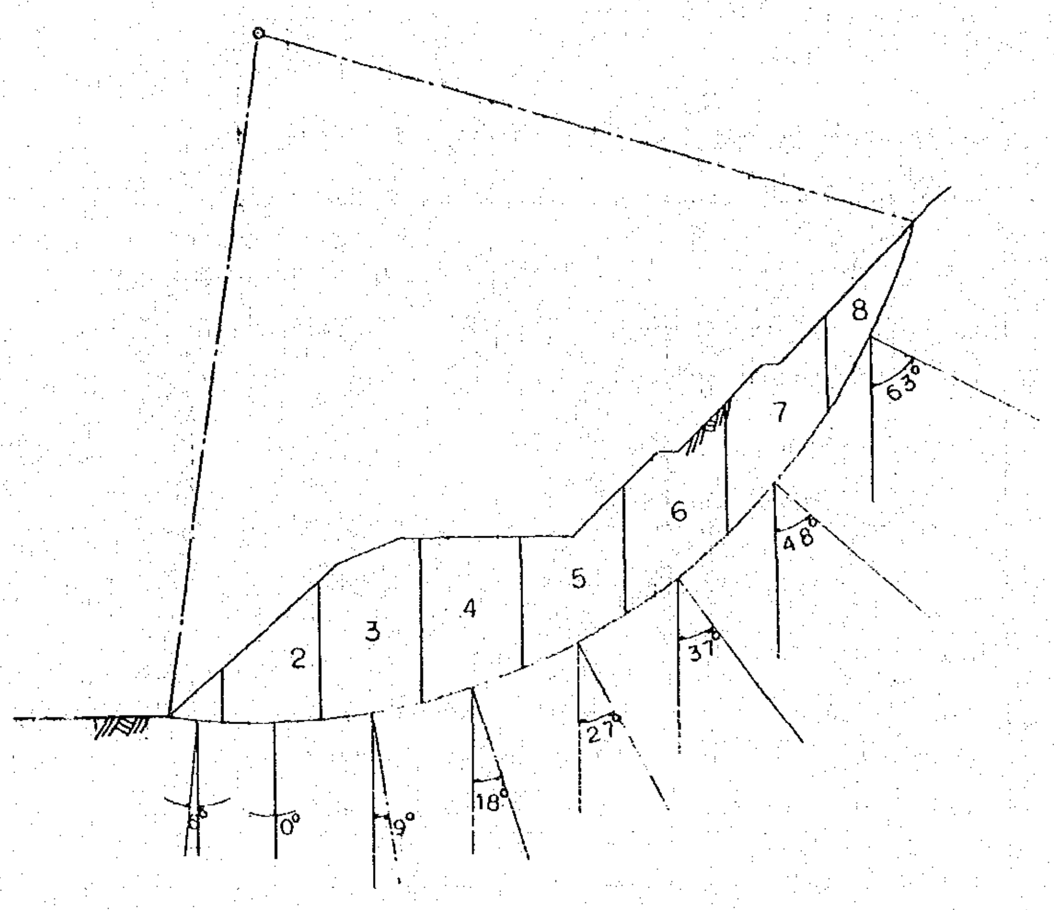


Fig.-3 Method of slices (a wrong example).

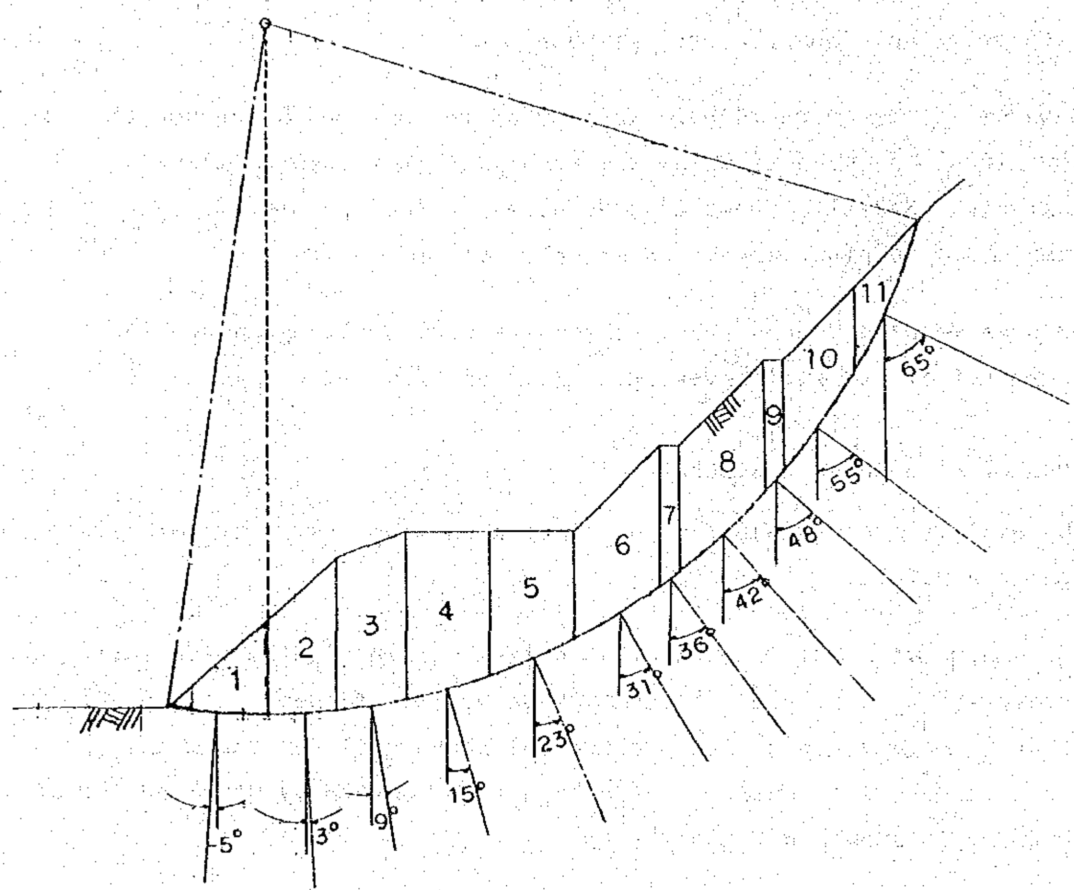


Fig.-4 Method of slices (a correct example).

4. Problems on Stability Computation of Slope

In engineering practice, stability computations serve as a basis either for the redesign of slopes after a failure, or else for choosing slope angles in accordance with specified safety requirements in advance of construction.

Slides may occur in almost every conceivable manner, slowly or suddenly, and with or without any apparent provocation.

Because of the extraordinary variety of factors and processes that may lead to slides, the condition for the stability of slopes usually defy theoretical analysis. Stability computations based on test result can be relied only when the conditions specified are strictly satisfied.

Such as we have stated above, there are many problems on stability computation. We will investigate some of them below.

4-1 Center of an are of circle

We explained the stability computation of slope by an arc of circle with a certain circle.

But there will be a number of such likely slip circles with their respective centers. We must pick up the most dangerous of these critical circles, that is to say, that circle along which the soil has the least shear resistance. The center of this circle is located by trial and error. The example is shown in Fig-5.

4-2 Unit weight of soil mass

We must test the unit weight of soil (γt) in advance of stability computation. But if we have tested soil samples, we may know only a temporal value.

If the soil is dried up, it may show less values. On the other hand, if the soil has got wet, it may show bigger value. The example is shown in Table - 4.

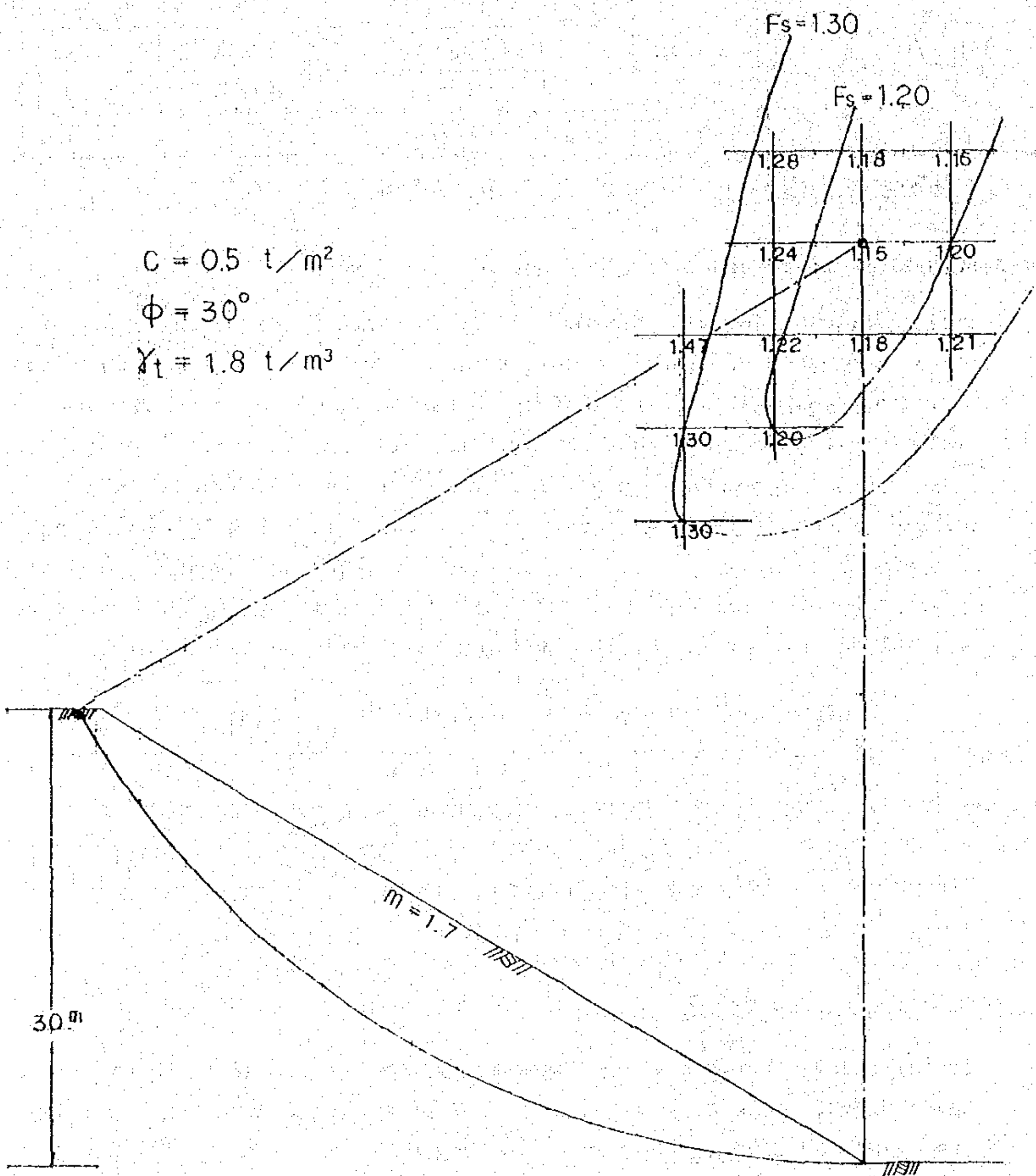


Fig-5 Centers of arc of circle.

Table - 4 Change of Fs according to γt

Computation / γt	c li ①	tan 30° (γt Ai cos θi) ②	Wi sinθi ③	Fs = (① + ②) / ③
1.6 t/m³	35.5	460.9	378.1	1.31
1.8	35.5	518.5	425.3	1.30
2.0	35.5	576.1	472.6	1.29

Note: Slope is shown in Fig-1 H = 30 m, c=0.5 t/m²

4-3 Cohesion and internal friction angle of soil mass

We, also, must decide cohesion (c) and internal friction angle (ϕ) of soil mass in advance of stability computation. But if we have performed the triaxial compression test or direct shear test, we may not know the exact value of it. Because, cohesion or internal friction angle of a soil mass has not a constant value, but it is only an experimental value depending upon a drainage condition of shear test. And if we have got a certain value by shear test, it may show only one sample of complex soil layer. However, we will know by Table - 5 that safety factors are very variable by values of cohesion and internal friction angle.

Table - 5 Change of Fs according to C and ϕ

c t/m²	0.5	1.0	0.5	1.0
ϕ°	25	25	30	30
Fs	1.06	1.14	1.30	1.38

Note: Slope is shown in Fig-1

4-4 Influence of height of slope

If the gradient of slope and the soil factor (γt, c and ϕ) is the same, the safety factors of the failure of slope are very variable according to the height of slope. The sample is shown in Table - 6.

Table - 6 Change of Fs according to Height of Slope

c t/m^2		0.5	1.0	0.5	1.0
$\phi°$		25	25	30	30
Fs	$H=5^m$	1.49	1.99	1.72	2.22
	$H=10^m$	1.22	1.46	1.46	1.70
	$H=20^m$	1.10	1.22	1.34	1.46
	$H=30^m$	1.06	1.14	1.30	1.38

Note: Slope is shown in Fig-1

4-5 Influence of ground water

In stability computation, one of the most important factors is the influence of ground water. Assuming that there is ground water at the height in Fig-1, the safety factor decreases from 1.30 to 0.87 (See Example 2-1 and 2-2). Accordingly, when we construct a new slope, one of the most important works is to construct a drainage canal. And we must consider lest rainfall should flow into the ground, and if the water flows into the ground, we must drain it as soon as we can.

4-6 Safety factor

In stability computations of slope, the necessary value of safety factor is just variable according to the scale or gravity of slope and the damage by the failure of slope. And as we have already explained, there are many variable factors to influence the safety factor.

Then it is difficult to decide the most suitable safety factor sweepingly. But the prevalent safety factors are shown in Table - 7.

Table - 7 Estimation of Safety Factor

Safety factor	estimation
$Fs<1.0$	not be stable
$1.0\leq Fs<1.2$	not be so stable
$1.3<Fs<1.4$	be stable for cutting or banking slope
$1.5<Fs$	be stable for earth dam

4-7 Prevalent gradient of slope

We have already explained that there are many variable factors to compute the stability of slope, and the computation of stability can be used effectively only if the resultants of soil tests are the same conditions to soil layer. Accordingly we will learn from the practice as well as theory. Experience has taught us Table - 8. And for banking we know Table - 9.

Table - 8 Prevalent Gradient of Cutting Slope

Soil or geology		Cutting height (m)	Slope of horizontal to vertical
Rock	hard		0.3~0.8
	soft		0.5~1.2
Sand			1.5~
Sandy soil	dense	H<5	0.8~1.0
		5≤H<10	1.0~1.2
	loose	H<5	1.0~1.2
		5≤H<10	1.2~1.5
Gravelly soil	dense	H<10	0.8~1.0
		10<H<15	1.0~1.2
	loose	H<10	1.0~1.2
		10≤H<15	1.2~1.5
Clay		H<10	0.8~1.2

Note: (1) The surface of slope is to be covered with plant.

(2) The gradient is including the berm.

Table - 9 Prevalent Gradient of Banking Slope

Soil or geology		Banking height(m)	Slope of horizontal to vertical
Sand	well-graded or gravelly soil	H<5	1.5~1.8
		5≤H<15	1.8~2.0
	uniform fine to medium	H<10	1.8~2.0
Pebble or boulder		H<10	1.5~1.8
		10≤H<20	1.8~2.0
Sandy soil or stiff clay		H<5	1.5~1.8
		5≤H<10	1.8~2.0
Soft clay		H<5	1.8~2.0

Note: (1) The gradient is including the berm.

(2) The foundation is to be enough to bear the load of embankment.

5. Slope at the Way Semangka Project

The slope before the construction of canal at the section number P. 60 of the Way Semangka Project is shown in Fig-6. Assuming that the cohesion (c), internal friction angle ($\phi°$) and unit weight (γt) of soil is severally 0.5 t/m^2, 30° and 1.8 t/m^3, we can know that the minimum safety value of its slope is 1.12.

On the other hand, computing the constructed slope with the same assumption, we have obtained some safety factors as shown in Fig-7. That is to say, though the safety factor on the land slide of whole slope is bigger than the value of natural slope, the upper slope of canal has a smaller value. Then we can know that the upper slope is lying in a critical condition.

However, as we have stated in the previous chapter, there are many problems on stability computation. Therefore, we have made some field examinations based on Table - 10 to inquire into dangerous slopes and to think out a control works or rehabilitation works for them.

As a result of the field examinations, we have known that almost all slopes are lying in critical conditions. Concretely, the area is shown in Table - 11, and the extension of it reaches 1.85 km.

Table - 11 Slopes in a Critical Condition

Station No.	Distance (m)
P. 1 - P. 11	470
P. 14 - P. 18	200
P. 24 - P. 26	100
P. 31 - P. 39	280
P. 56 - P. 71	570
P. 76 - P. 82	230
Summary	1,850

Table - 10 Table for Examination of Slope

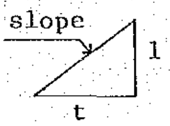
EXAMINATION OF SLOPE

Name of project :____________________

Station No: / Pr.:____________________

Month, day, year :____________________

Name :____________________

Classification of slope (jenis lereng/tebing)	1. natural (alam) 2. cutting (galian) 3. banking (timbunan)
Height of slope (tinggi lereng/tebing)	1. $H<5$ 2. $5<H<10$ 3. $10<H<20$ 4. $20<H$
Gradient of slope (miring tebing/ lereng) note: 	1. $t<1,0$ 2. $1,0<t<1,5$ 3. $1,5<t$
Condition of surface (keadaan permukaan)	1. naked land (tanah gundul) 2. grassland (banyak rumput) 3. woodland (banyak pohon)
Soil (jenis tanah)	1. rock (batu) 2. gravelly soil (tanah berkrikil) 3. sandy soil (tanah berpasir) 4. clay (tanah liat)
Flow of surface water (sifat aliran air permukaan)	1. surface water is apt to gather (merupakan lembah mudah menampung air) 2. surface water is not apt to gather (punggung tanah sulit mensmpung/ mengalirkan air)
Seepage of grand water (keadaan air tanah/rembesan)	1. exist (banyak/ada) 2. nothing (tidak ada)
Gully erosion (erosi)	1. exist (banyak/ada) 2. nothing (tidak ada)
Retaining wall (tembok penahan)	1. exist (banyak/ada) 2. nothing (tidak ada)

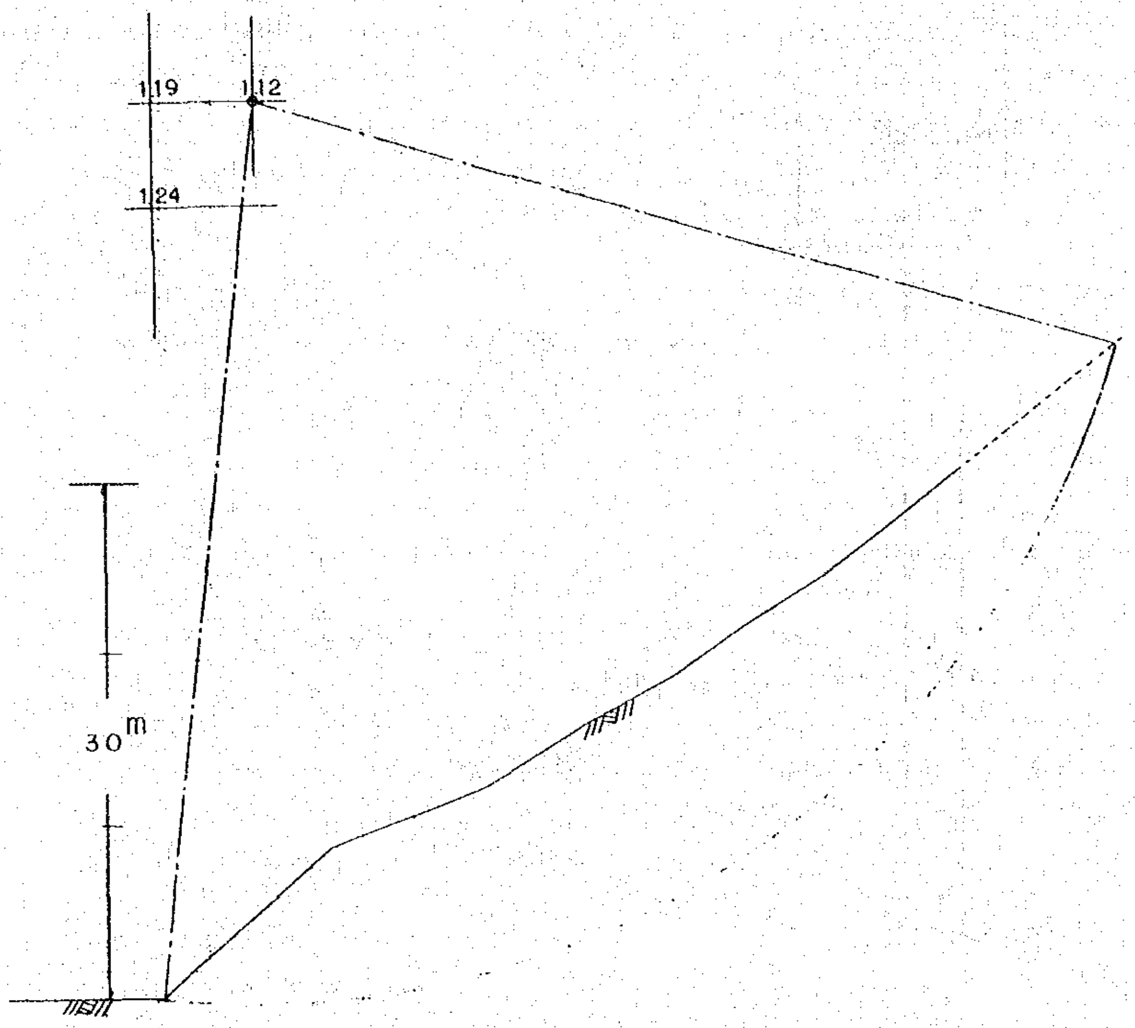


Fig-6 Slope before cutting at P. 60.

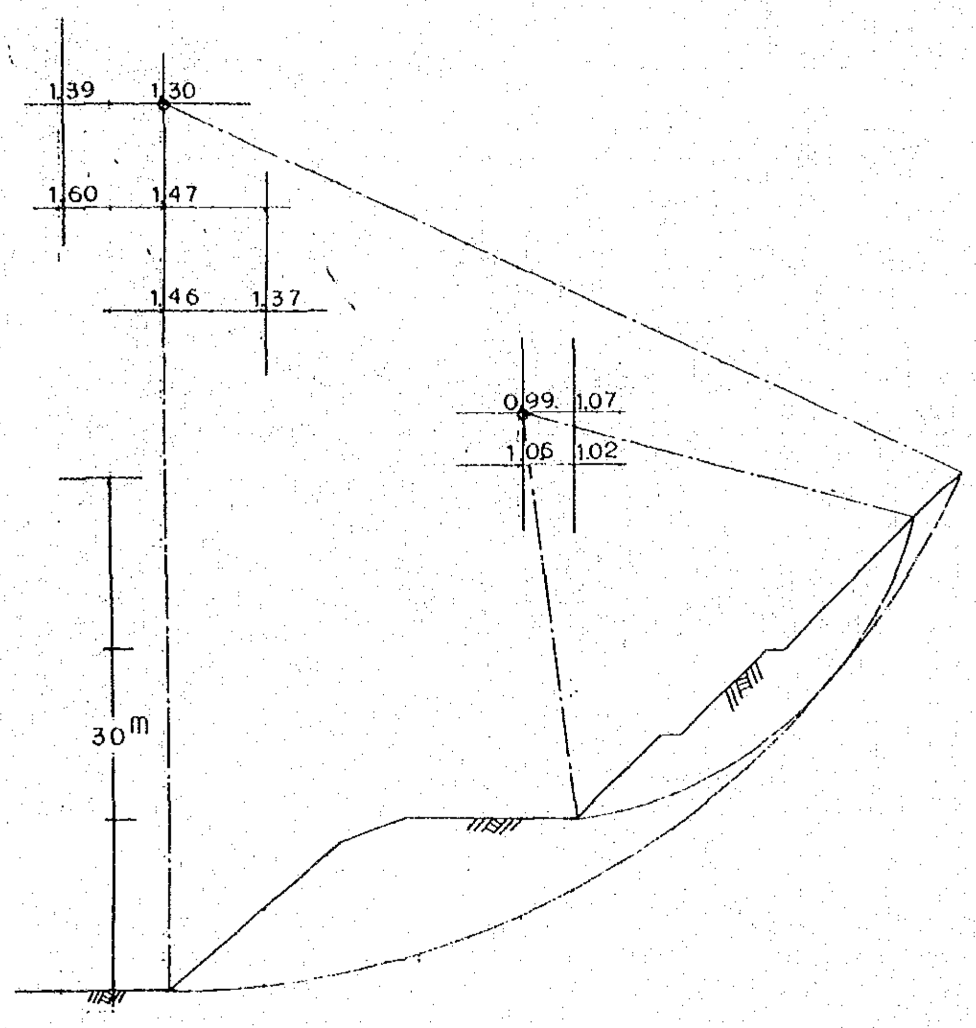


Fig-7 Slope after cutting at P. 60.

The main causes that slopes are lying in critical conditions are as follows.

(1) The gradient of slope is too steep to get a stability of slope. The cutting of the slope was designed to 1:1 in the design drawings, but there is a large distance that the slopes are more steep than t (slope of horizontal to vertical (=1.0))<1.0 at the project site. If we reconstruct slopes from $t<1.0$ to $t>1.5$ (prevalent gradient of cutting slope of sand), it should be necessary to cut much volume of soil and to appropriate much budget for the stability of slope. Then we think that we had better leave the slope in it's present condition.

And if the land slide occurs in the future, we will have only to perform a rehabilitation works at the slid portion.

(2) The retaining wall by gabion was designed as shown in Fig-8, but it has been constructed as shown in Fig-9. And comparing with the size of rock in the gabion, the opening of wire of it is too large to remain the contents. We hope to intensify a supervision and inspection business.

If we construct the retaining wall by gabion, the shape shown in Fig-10, will be more effective. If the gabion had been constructed only to protect the canal from the fallen stone or rock, it would be enough to make the construction as shown in Fig-11. Because, as a gabion is heavy and it is situated at the place of active earth pressure, its weight may cause the slope failure.

(3) Many trees have been cut near the station number P. 1. This action is a very worrying matter for the stability of slope. Because, cutting of trees on the slope will cause soil erosion and then gully erosion, what is worse, running water on the gully erosion will scoop out a toe of slope.

As a result of these continuous actions, the slope failure may occur at this porsion naturally. Accordingly, it is necessary to perform a slope protection works by replanting methods and by canal.

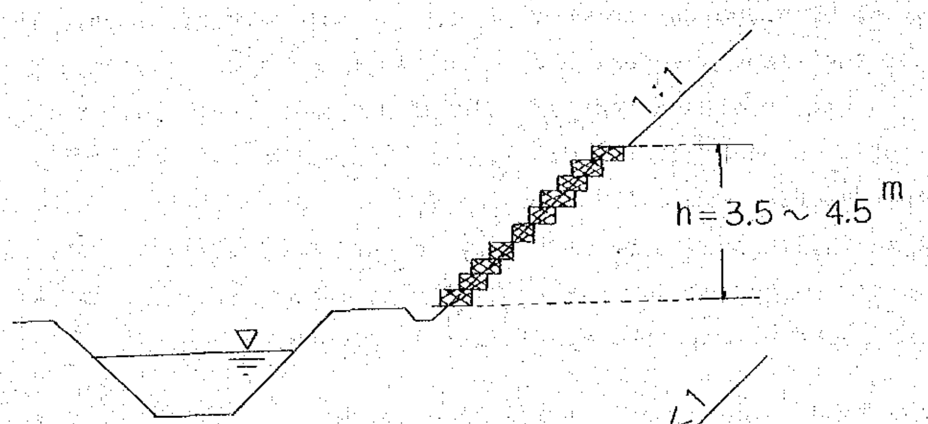


Fig-8 Design of gabion.

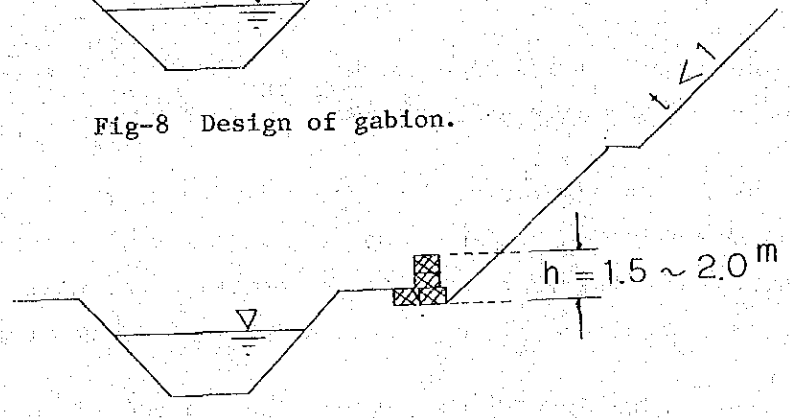


Fig-9 Construction of gabion.

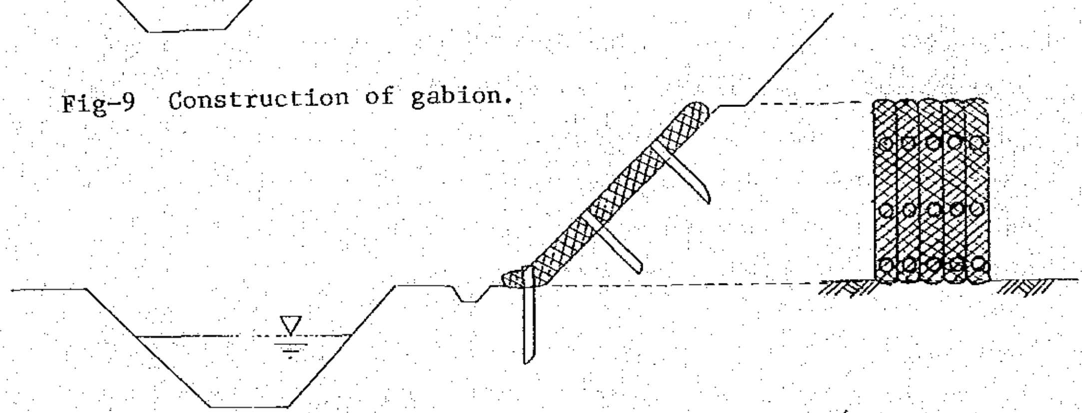


Fig-10 Proposed design of gabion.

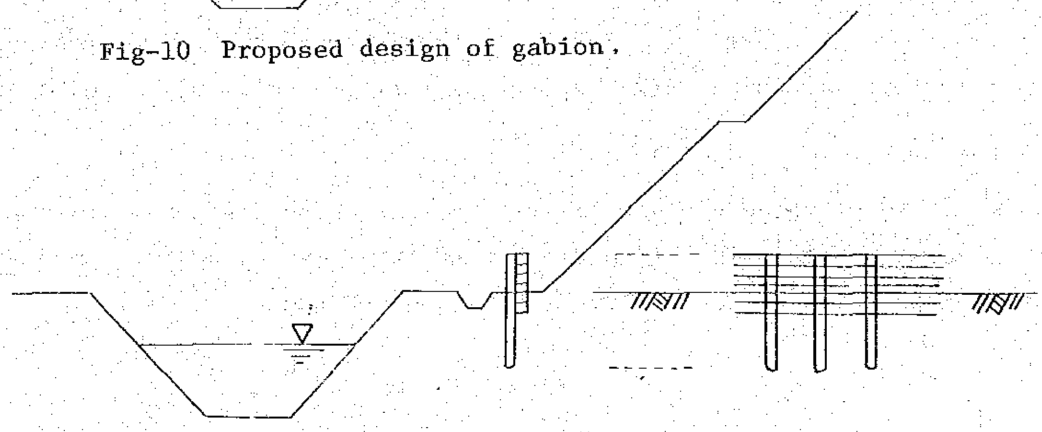


Fig-11 Protection works for fallen things.

6. Kinds of Control Works for Slope Failure

The control construction works for slope failure is classified largely into four kinds of works of drainage, control for erosion, control for slope failure or cutting. As the most cause that leads slope failure is the seepage of groundwater, we have to put stress on the treatment of groundwater.

The control works for slope failure is written in Table - 12. It is, however, rarely used by itself. Usually more than two kinds of works are used as they are more effective as protection or rehabilitation works. But in certain circumstances we would rather perform a rehabilitation works than construct a control works.

Table - 12 Kind of Control Works

Purpose	Works
Surface water treatment	Canal works
Groundwater treatment	Drainage works
Erosion protection	Ground sill dam
Control for slope failure	Retaining wall and pile drive
Cutting	Cutting

(1) Surface water treatment - Canal works

A canal works is usually constructed to prevent surface water from entering the ground and it is a fundemental and common works for all slope failure. And highly important matters are as follows.

(a) We have to make lining on the canal by masonry or mortar,
(b) to make canal below than the height of neighborhood,
(c) and to construct the foundation if the soil is not so hard.

(2) Groundwater treatment - Drainage works

A drainage works is effective when the groundwater is lying at the high level and distributed widely. And highly important matters are as follows.

(a) We usually construct the drainage works at the place where the geographical features are lower than the circumstances.
(b) And we have to connect the drainage works to the canal of the surface water treatment works at the changing point of surface

gradient.

(3) Erosion prevention - Ground sill dam

A ground sill dam is usually constructed at the toe place of slope which was eroded. And so, we can make the gradient of slope gentle and eroded place high.

(4) Control works

(4-1) Retaining wall

A retaining wall is constructed at the toe of slope but it is adopted on a small scale only.

(4-2) Pile drive works

It is a works to drive piles to the base rock under the slope failure area and to resist the earth pressure by the resistant force of piles.

This works is effective when the lower layer is not so deep and the hardness is enough to resist on the earth pressure. And this works is sometimes adopted at the area where it is difficult to construct the canal or drainage works.

(5) Cutting

The purpose of cutting is to decrease the overweight at the upper place of slope and to decrease the sliding force.

That is to say, we usually do not cut the lower place of slope, but we should cut the upper place only.

We have to construct the canal works, drainage works and planting works in haste, because the surface of the cut slope is apt to weaken by rainfall.