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3-次元 斜面安定 解析에 관한 硏究

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A Study on Three-Dimensional Slope Stability Analysis

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Abstract

Past research has concentrated on refining two-dimensional analysis techniques. Rather extensive comparisons of various two-dimensional methods have been made.

This paper described a general three-dimensional method of analysis by which any geometrical condition and any c, phi soil can be analyzed.

The results are as follows;

1. Factors of safety computed for 3-dimensional geometry differ considerably from ordinary 2-dimensional factors of safety.

2. 3-dimensional factors of safety are generally much higher than 2-dimensional factors of safety. However, situations appear to exist where the 3-dimensional factor of safety can be lower than the 2-dimensional factor of safety.

3. The F3/F2 ratio appears to be quite sensitive to c, phi and to the slope.

1. 序 論

斜面安定 解析에 있어서 과거에는 2—次元解析에 관한 연구에 전념하였고 여러 2—次元 方法들에 관한 폭 넓은 비교가 있었다.[2),5),7),8),9),10)] 이 비교에서 2—次元 解析이 대체로 정확하다는 것을 보여줌과 同時에 어떤 평형조건이 만족 되어야 한다는 것 즉, Slices의 양측면에 作用하는 힘이 고려되어야 하고 또 Slices의 양측면에 作用하는 힘에 관한 적절한 가정이 있어야 한다는 것을 보여준다. 어떤 연구에서 Slices의 양측면에 作用하는 힘이 없다고 가정하는 보통의 方法은 더 정확한 方法 등과 비교하여 10% 이하의 차이가 남을 보여준다.[6)] 흙의 異質性, 소수의 土質상세도, Sampling과 Testing에 연관된 더 큰 不確實性에 비교할때 10% 이하의 不一致는 비교적 적은 것이다. 그러나 例外의 경우에 Slices의 보통의 方法이 35% 이상의 不一致로 나타낼 수 있다. Baligh and Azzous[2)]에 의하면 粘着力이 있는 흙에 對하여 End Effects를 고려할 경우에는 安全率에

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있어서 4~40%의 증가를 나타낼 수 있음을 보여준다. Lefebrve and Duncan[4]은 End Effects는 양쪽 경사가 3:1이상 되는 비교적 좁은 계곡에 위치한 Dam에 對하여는 아주 중요하다고 제시하였다. 앞에서 나타낸 바와같이 斜面의 파괴가 그 軸을 따라 무한히 펼쳐 일어난다는 2—次元(Plane Strain)의 가정과 Slices의 양측에 作用하는 힘에 관한 不適當한 가정에 의한 오차는 매우 크다. 本 論文에서는 흙이 Homogeneous하고 간극水壓을 고려하지 않는 경우에 對하여 c and phi가 있는 흙의 斜面에 對하여 3~次元 解析으로 검토 하였다.

2. 本 研究의 理論的 背景

2—1. 研究의 動向

(1) Sherard의 現論[1),3),4),11)]

Dam의 길이를 일련의 똑같은 길이의 마디로 나누어서 各 마디의 斷面에 對하여 2—次元 문제로 해석하였다. 이런 方法으로 2—次元 원호전단파괴 方法을 3--次元 斜面 안정문제에까지 확장하였다. (Fig.—1)

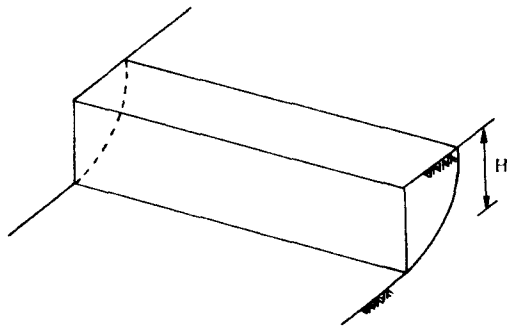


FIG. — 1

(2) Baligh and Azzouz의 理論[1),3),4),11)]

Fig.—2—a, b와 같이 양끝이 원추모양의 파괴표면(Fig.—2—a)과 타원체의 파괴표면(Fig.—2—b)의 2가지 경우에 對하여 검토하였다.

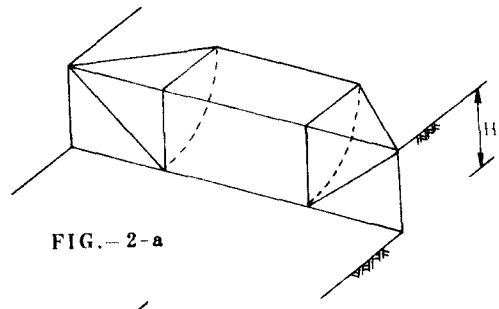


FIG.—2-a

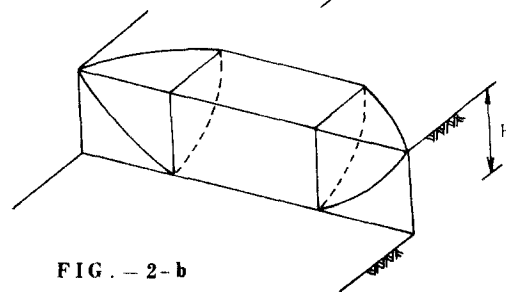


FIG.—2-b

2—2. 本 研究의 理論

(1) Safety Factor의 정의[5),8),9)]

$$F=\frac{\tau_f}{\tau_m}$$

τ_f : available shear strength

τ_m : shear strength which must be mobilised to maintain a condition of limiting equilibrium

즉, $F=\dfrac{\Sigma \text{available resistance}}{\Sigma \text{mobilised resistance}}$

(2) Bishop simplified method

(a) 2-dimensional factor of safety, F2

Fig.—3.에서 보는 바와 같이

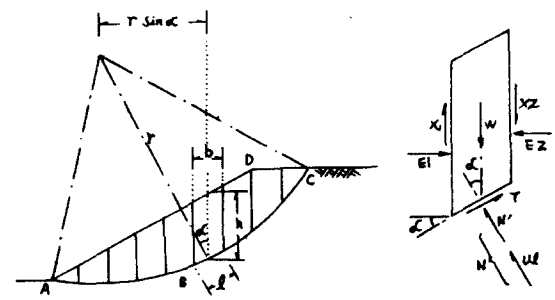


FIG.—3

$x_1 - x_2 = 0$

$$\tau = \frac{1}{F}(c \cdot l + N \tan \phi)$$

$$W_2 = N\cos \mathcal{L} + ul \cos \mathcal{L} + \frac{cl}{F} \times \sin \mathcal{L} + \frac{N}{F} \tan \phi \sin \mathcal{L}$$

$$\therefore N = (W_2 - \frac{cl}{F} \sin \mathcal{L} - ul \cos \mathcal{L}) / (\cos \mathcal{L} + \frac{\tan \phi \sin \mathcal{L}}{F})$$

$$l = b \sec \mathcal{L}$$

$$\therefore F_2 = \frac{1}{\Sigma W_2 \sin \mathcal{L}} \Sigma\{c \cdot b + (w_2 - u \cdot b) \tan \phi\} \times \left\{\frac{\sec \mathcal{L}}{1 + \frac{\tan \mathcal{L} \tan \phi}{F}}\right\}$$

(b) 3-dinensional factor of safety, F3

Potential sliding mass는 Sephere로 가정하였다. (Fig. -4-a, b, c)

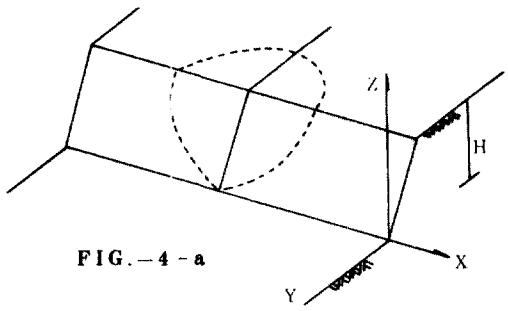


FIG. -4-a

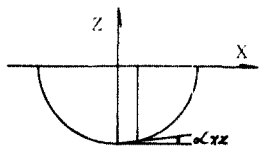


FIG. -4-b

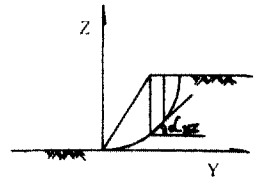


FIG. -4-c

Fig. -5에서

$$\cos(\text{Dip}) = \frac{g}{g'} = \frac{d \sin(\text{STR})}{\frac{c'}{\sin(\text{Dip})}} = \frac{\left(\frac{c'}{\tan \mathcal{L}\, yz}\right) \cdot \sin(\text{STR})}{\frac{c'}{\sin(\text{Dip})}} = \frac{\sin(\text{Dip}) \cdot \sin(\text{STR})}{\tan \mathcal{L}\, yz}$$

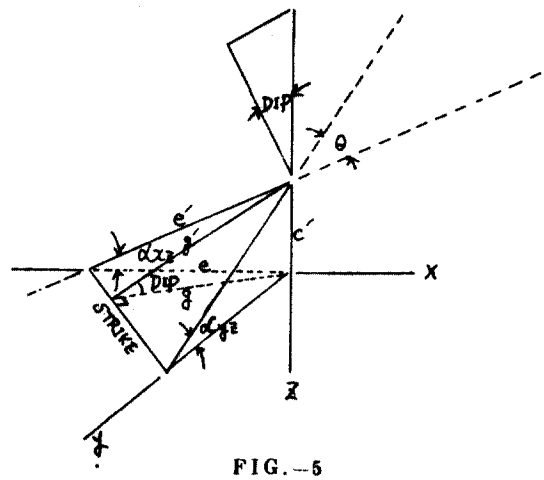


FIG. -5

$$\sec(\text{Dip}) = \frac{\tan \mathcal{L}\, yz}{\sin(\text{Dip}) \cdot \sin(\text{STR})}$$

$$\tan(\text{Dip}) = \left\{\frac{\tan \mathcal{L}\, yz}{\sin(\text{Dip}) \cdot \sin(\text{STR})}\right\}^2 - 1$$

$$W_3 = r \cdot z \cdot \triangle x \cdot \triangle y$$

$$F_3 = \frac{1}{\sum_x \sum_y W_3 \sin \mathcal{L}\, yz} \times \sum_x \sum_y \{c \cdot A_3 + (W_3 - uA_3) \tan \phi\} \times \left\{\frac{\frac{\tan \mathcal{L}\, yz}{\sin(\text{Dip}) \cdot \sin(\text{STR})}}{1 + \frac{\left\{\left(\frac{\tan \mathcal{L}\, yz}{\sin(\text{Dip}) \cdot \sin(\text{STR})}\right)^2 - 1\right\} \cdot \tan \phi}{F}}\right\}$$

(4) 本 硏究의 3-次元 斜面安定 解析

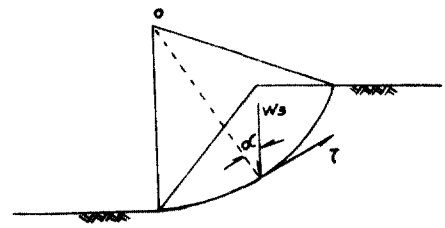


FIG. -6

Fig. -6과 같이 Potential sliding mass에 일어나는 힘을 하나로 모아 검토하였다.

$$F_3=\frac{1}{\Sigma W_3 \sin \mathcal{L}} \Sigma(c\cdot A_3+W_3 \tan \phi)\left[\frac{\sec \alpha}{1+\frac{\tan \mathcal{L} \tan \phi}{F}}\right]$$

3. 解析 方法

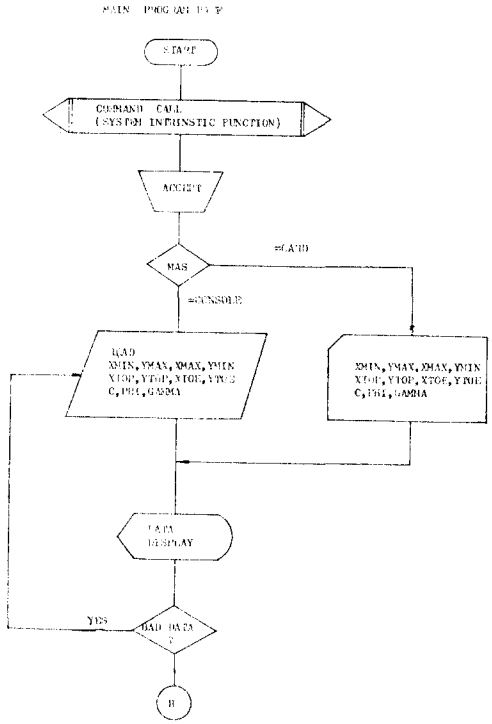
(1) 3—次元 斜面安定 解析에서는 Potential sliding mass는 Sephere로 가정하고 흙은 Homogencous하고 地下水는 고려하지 않고 Bishop simplified method로 검토하였다.

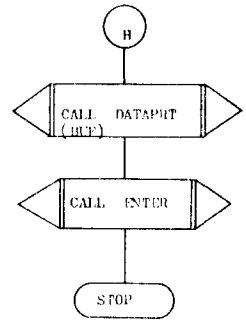
(2) Slope는 2 : 1과 3 : 1의 두가지 경우로 나누어 검토하였다.

(3) C와 ϕ는 c=5·5, 4·4, 3·3, 2·2, 1·1(t/㎡)의 각각의 경우에 對하여 ϕ=0°, 10°, 20°, 30°, 40°로 나누어 검토하였다.

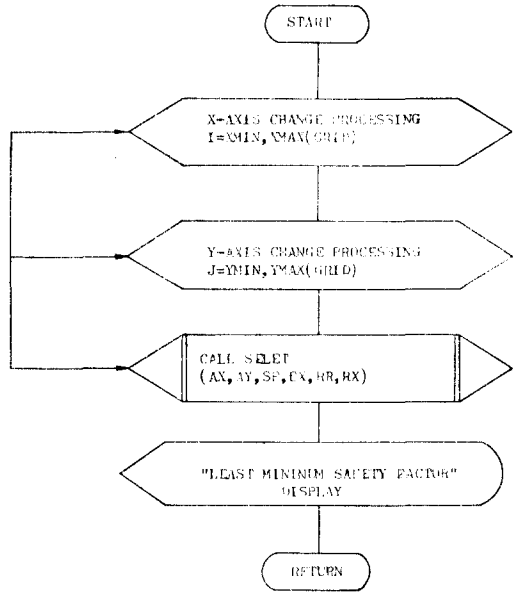
(4) Slices로 나누지 않고 한 덩어리로 생각하였다.

(5) 本 論文에 使用된 Computer Program의 Flow Chart는 다음과 같다.

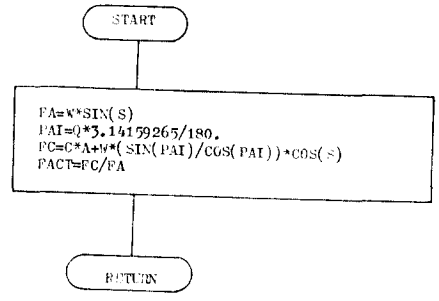


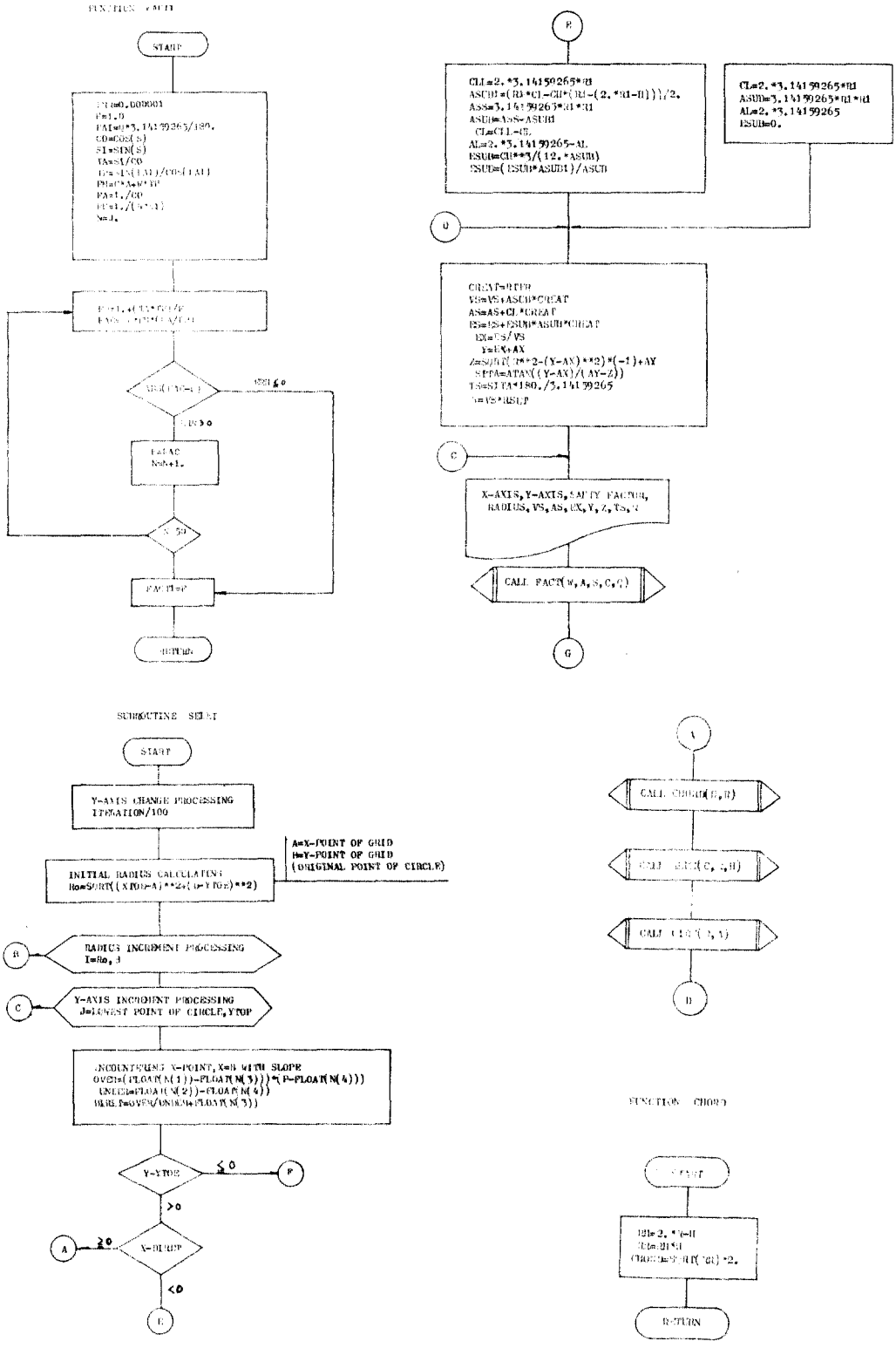


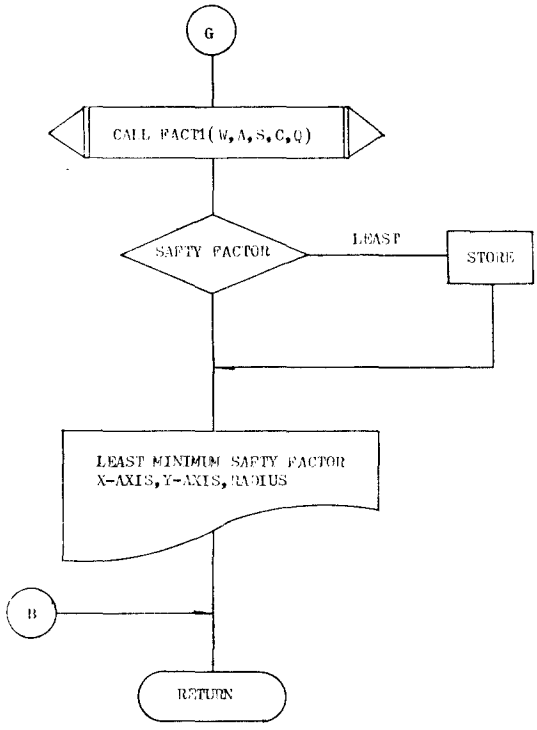
SUBROUTINE ENTER



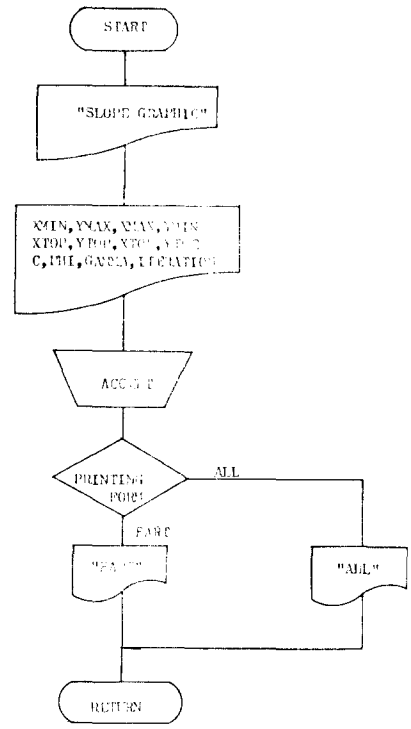
FUNCTION FACT



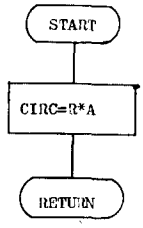

START
RETURN
CL=2.*3.14159265*R1
ASUB=3.14159265*R1*R1
AL=2.*3.14159265
ESUB=0.
X-AXIS,Y-AXIS,SAFTY FACTOR,
RADIUS,VS,AS,EX,Y,Z,Ts,Y
CALL FACT(W,A,S,C,Y)
SUBROUTINE SELECT
START
Y-AXIS CHANGE PROCESSING
ITERATION/100
A=X-POINT OF GRID
B=Y-POINT OF GRID
(ORIGINAL POINT OF CIRCLE)
RADIUS INCRIDENT PROCESSING
I=Ro, 1
Y-AXIS INCRIDENT PROCESSING
J=LOWEST POINT OF CIRCLE,YTOP
Y-YTOP
Y-BOTTOM
FUNCTION CHORD
START
RETURN



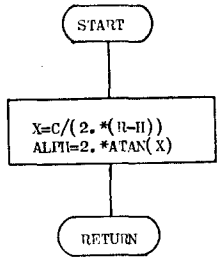
SUBROUTINE



FUNCTION CIRC



FUNCTION ALPH



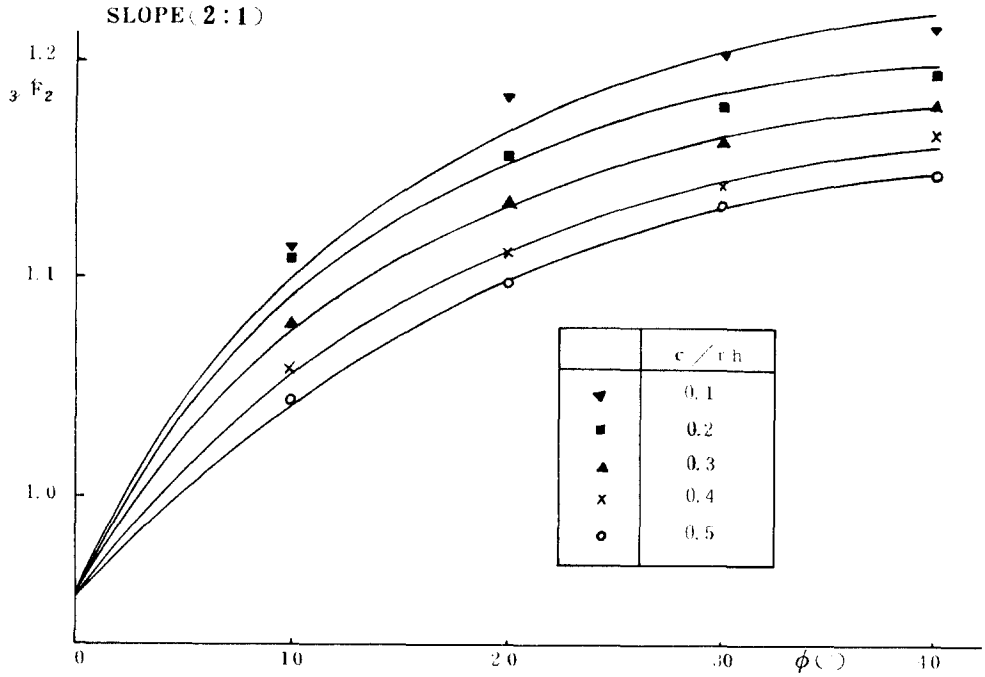
4. 結果 分析

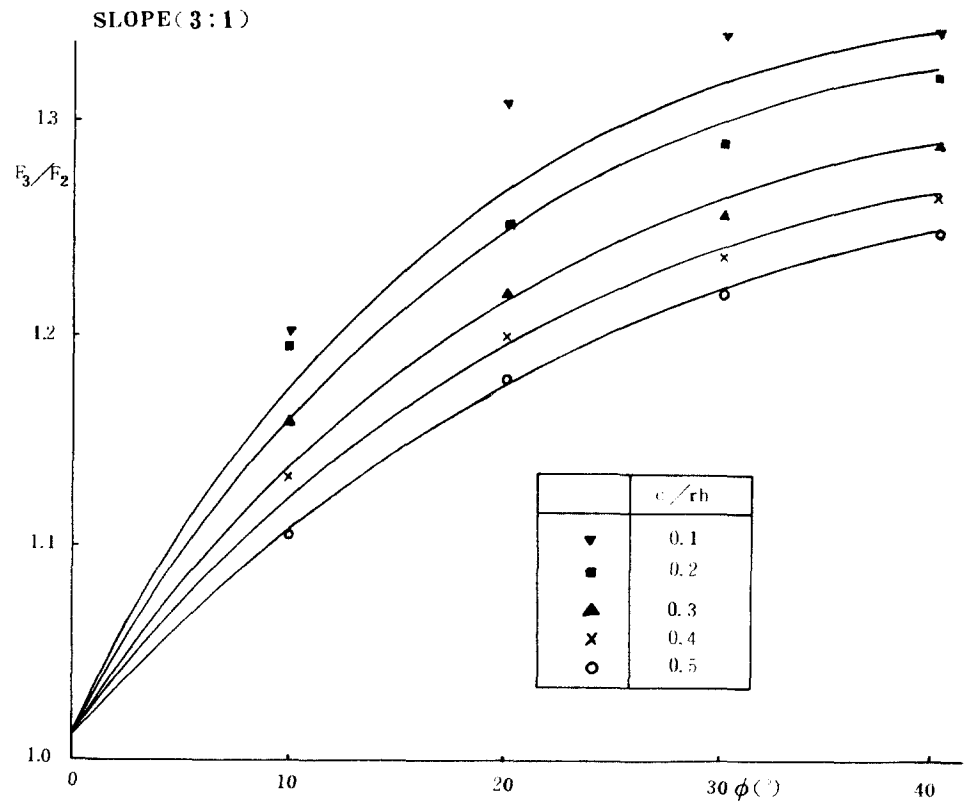
SLOPE(2 : 1)

C(t/㎡)	ϕ(°)	F_2	F_3	F_3/F_2
5·5	0	1.227	1.216	0.952
	10	1.528	1.592	1.043
	20	1.767	1.932	1.093
	30	2.023	2.279	1.127
	49	2.321	2.644	1.139
4·4	0	1.022	0.973	0.952
	10	1.269	1.341	1.057
	20	1.505	1.668	1.108
	30	1.755	1.996	1.137
	40	2.038	2.363	1.159
3·3	0	0.766	0.729	0.952
	10	1.008	1.086	1.077
	20	1.235	1.394	1.129
	30	1.472	1.701	1.156
	40	1.743	2.042	1.172
2·2	0	0.511	0.486	0.951
	10	0.746	0.825	1.106
	20	0.959	1.105	1.152
	30	1.180	1.383	1.172
	40	1.428	1.693	1.186
1·1	0	0.391	0.372	0.951
	10	0.496	0.546	1.10
	20	0.663	0.782	1.179
	30	0.853	1.021	1.197
	40	1.068	1.288	1.206

SLOPE(3 : 1)

C(t/㎡)	ϕ(°)	F_2	F_3	F_3/F_2
5·5	0	1.184	1.366	1.01
	10	1.392	1.958	1.113
	20	1.590	2.359	1.174
	30	1.805	2.733	1.213
	40	2.052	3.166	1.241
4·4	0	0.947	1.093	1.01
	10	1.152	1.64	1.131
	20	1.345	2.081	1.195
	30	1.553	2.441	1.232
	40	1.790	2.859	1.258
3·3	0	0.710	0.819	1.01
	10	0.909	1.361	1.157
	20	1.101	1.658	1.215
	30	1.297	2.098	1.251
	40	1.520	2.484	1.282
2·2	0	0.637	0.644	1.01
	10	0.667	1.034	1.192
	20	0.846	1.38	1.248
	30	1.028	1.67	1.285
	40	1.232	2.004	1.314
1·1	0	0.555	0.562	1.012
	10	0.624	0.749	1.2
	20	0.574	0.961	1.303
	30	0.729	1.194	1.335
	40	0.914	1.373	1.335


SLOPE(2 : 1)
1.2
F_3/F_2
1.1
1.0
0
10
20
30
ϕ( )
40
c / γ h
0.1
0.2
0.3
0.4
0.5


SLOPE(3 : 1)
1.3
F_3/F_2
1.2
1.1
1.0
0
10
20
30 ϕ( )
40
c / γh
0.1
0.2
0.3
0.4
0.5

5. 結　論

1) 3—次元 解析으로 求한 Safety Factor, F_3와 2—次元 解析으로 求한 Safety Faetor, F_2는 다르다.

2) 3—次元 解析으로 求한 Safety Factor, F_3가 2—次元 觀析으로 求한 Safety Factor, F_2보다 대체로 크다. 그러나 경우에 따라서는 더 작게 나타낸다.

3) F_3/F_2의 비는 c, ϕ값과 Slope에 따라 아주 민감하게 나타내고 있다.

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