UR1984_51 1/20

1984/51. Bishop's simplified slope stability analysis with a Hewlett-Packard 41C calculator.

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Abstract

A slope stability analysis program based on Bishop's simplified method has been written for a Hewlett-Packard 41C calculator. The use of this program and input and check programs is described. No prior experience with programmable calculators is assumed. Appendices include comments on the use of Cousins' stability charts, a worked example of the calculator analysis, problems on slope stability analysis on standard computation sheets, and program listings.

INTRODUCTION

The purpose of this report is to introduce readers to slope stability analysis using a Hewlett-Packard 41C (HP-41C) calculator. No prior experience with this or any other programmable calculator is assumed. The three programs involved have been loaded into the Department of Mines HP-41C calculator and two copies of the programs have been left with the Department.

W.E. Baker, who is currently responsible for the calculator, has one copy and R.C. Donaldson has the other copy. Listings of the programs are given in Appendix 4 but a detailed description of the programs is not included in this report. If any reader is interested in further details of the programs, I will be happy to supply them.

Included in this report are draft copies of computation sheets. It is recommended that these be used when doing stability analysis. If readers are happy with the layout of these sheets they can be formally drafted as standard sheets for the Department.

This report is one of a series of four (the others are Moon 1984*b*, 1984*c* and 1984*d*) on various aspects of slope stability work in Tasmania. The Master of Science thesis (Moon, 1984*a*) is complementary to this series of reports.

LIMITATIONS OF SLOPE STABILITY ANALYSIS

It is assumed that readers have some experience of slope stability analysis and are therefore familiar with the uses and limitations of such procedures. The specific limitations of this particular program will be outlined here. Reference is also made to alternative methods of analysis available to the Department of Mines.

This particular program can only deal with one set of material parameters (cohesion, friction angle, and unit weight). Pore pressure can only be handled as a pore pressure ratio (r_u). Up to twenty slices can be considered but the slice widths have to be constant for any particular analysis.

As far as other methods of stability analysis are concerned most readers will be familiar with the Infinite Slope method which can be easily and quickly calculated by hand. Cousins' stability analysis is useful, as many natural slopes can be approximated to a simple slope. Cousins' charts can be used to roughly locate the position of the critical circle before carrying out a more accurate analysis of the actual slope. More comments on the use of Cousins' charts are given in Appendix 1.

If it is necessary to consider more than one set of material parameters or a more complicated pore water condition, the alternative methods of analysis discussed in Moon (1984*a*) may be considered. Briefly these consist of Bishop's simplified method by hand and program SLOPE for circular failure surfaces, and Janbu's method and program STABL for irregular failure surfaces. Both of the programs are available at the University of Tasmania (contact B.F. Cousins, Department of Civil and Mechanical Engineering) and all four methods of analysis are discussed in more detail (with references) in Moon (1984*a*).

HOW TO USE

Approach

As stated earlier, no prior experience with an HP-41C calculator has been assumed. The approach adopted here has been to work through an example. The computation sheet for the example is given in Appendix 2. As a first step it is suggested that readers work through the example given to reassure themselves that they can successfully operate the calculator.

Familiarity with the calculator and with stability analysis will only come with practice and to aid in this learning process several problems have been set (Appendix 3). Each problem consists of a set of questions and a computation sheet consisting of a measured or an imaginary cross-section. Readers within the Department of Mines should work through these problems, individually at first, and then compare results. If desired, these results could be published as an addendum to this report.

Before starting

The three programs involved have been loaded into the Department's HP-41C calculator. The calculator has a continuous memory and unless deliberately erased the programs will be in the calculator when you need to use it.

If you want to check that the programs are loaded you can get a catalogue of all programs in the calculator by the following procedure:

(1) SWITCH CALCULATOR ON
(2) PRESS YELLOW KEY
(3) PRESS ENTER KEY (CATALOG)
(4) PRESS 1

The calculator will then display a list of all the programs stored in its continuous memory. The three programs that you will be using are:

(1) INPUT
(2) CHECK
(3) BISHOP

If the programs are not in the calculator you will need the magnetic cards and the card reader. Although loading the calculator is a straightforward task it is suggested that you seek the assistance of W.E. Baker. The three programs require a total of 82 storage registers.

If the programs are in the calculator they will probably have been assigned to the first three keys along the top row of the calculator. This is done so that programs can be operated using a single key. To check to see that the programs have been assigned you should take the following steps:

(1) SWITCH CALCULATOR ON
(2) PRESS USER KEY (NOT NECESSARY IF 'USER' IS ALREADY IN DISPLAY)
(3) PRESS AND HOLD DOWN FIRST KEY IN TOP ROW $\boxed{\Sigma+}$.
IF A PROGRAM HAS BEEN ASSIGNED TO THIS KEY THE NAME OF THE PROGRAM WILL APPEAR IN THE DISPLAY. IF YOU HOLD DOWN THE KEY FOR MORE THAN ONE SECOND IT WILL BE REPLACED BY THE WORD 'NULL'.
IF YOU JUST PRESS THE KEY WITHOUT HOLDING IT THE PROGRAM WILL START TO RUN.
(4) BY THIS METHOD CHECK TO SEE IF THE THREE PROGRAMS NAMELY,
INPUT
CHECK
and BISHOP
HAVE BEEN ASSIGNED TO THE FIRST THREE KEYS IN THE TOP ROW RESPECTIVELY.

If you find the programs have not been assigned it is a simple matter to assign them yourself. The following steps explain how it is done:

(1) SWITCH CALCULATOR ON
(2) PRESS YELLOW KEY
(3) PRESS XEQ KEY (ASN)
(4) PRESS ALPHA KEY
(5) WRITE NAME OF PROGRAM WHICH YOU WISH TO ASSIGN USING ALPHABET SHOWN IN BLUE ON LOWER EDGE OF KEYS
(IF YOU MAKE A MISTAKE PRESS $\boxed{\leftarrow}$ KEY)
(6) PRESS ALPHA KEY
(7) PRESS KEY TO WHICH YOU WANT THE PROGRAM ASSIGNED

If you have any difficulties with any of these operations seek the advice of W.E. Baker. As stated earlier you will probably find that the programs have already been loaded and assigned and you will not need to concern yourself with any of the above procedures.

Input for the first analysis

It is assumed that the calculator has been loaded and the three programs have been assigned to the first three keys in the top row of the calculator as follows:

INPUT	in 1st key [Σ+]	(A)
CHECK	in 2nd key [$^1/x$]	(B)
BISHOP	in 3rd key [√x]	(C)

For convenience these keys are subsequently referred to as A, B, and C respectively (coinciding to the blue letters). If the programs are not loaded and assigned as described above you should read the previous section of this report and seek the assistance of W.E. Baker.

The other important key when running programs on the calculator is the key at the right of the bottom row labelled R/S (Run/Stop). When pressed this key will run or stop the current program. Thus if you want the program to continue you press the R/S key. If a program is running and you want it to stop, press the R/S key.

The computation sheet for the first analysis given in Appendix 2 should be referred to when reading this section of the report.

The first step in carrying out a stability analysis is to load the data necessary to describe the problem. This is handled by the program called INPUT.

The following instructions tell you how to load the data for the example problem given in Appendix 2. Some comments on the program are also included.

(1) SWITCH CALCULATOR ON
(2) PRESS USER KEY (NOT NECESSARY IF 'USER' IS ALREADY IN DISPLAY)
(3) PRESS A, 'DRAW CIRCLE' APPEARS IN DISPLAY. THIS IS JUST TO REMIND YOU THAT YOUR CROSS-SECTION AND YOUR INITIAL SLIP CIRCLE SHOULD BE DRAWN AND YOUR INITIAL INPUT AND SHAPE DATA SHOULD BE WRITTEN DOWN BEFORE STARTING YOUR ANALYSIS.
(4) PRESS R/S. ENTER DATA FROM COMPUTATION SHEET AS PROMPTED BY DISPLAY. PRESS R/S BETWEEN EACH ENTRY. THE DATA REQUIRED TO DESCRIBE THE SLIP CIRCLE AND THE SLOPE PROFILE IS EXPLAINED ON THE EXAMPLE COMPUTATION SHEET (APPENDIX 2).

    'Y CIRCLE' IS THE Y CO-ORDINATE OF THE CENTRE OF THE SLIP CIRCLE. THE X CO-ORDINATE IS CALCULATED BY THE PROGRAM. VARYING Y CIRCLE VARIES THE DEPTH OF THE SLIP.

    Y_1, Y_2 *etc.* ARE THE Y CO-ORDINATES OF THE MIDPOINT OF EACH SLICE. THE X CO-ORDINATE IS CALCULATED BY THE PROGRAM. THE CALCULATOR WILL CONTINUE TO PROMPT FOR UP TO TWENTY SLICES BUT YOU NEED ONLY ENTER DATA FOR THE NUMBER OF SLICES THAT YOU HAVE SPECIFIED FOR THE PARTICULAR COMPUTATION.

    YOU DO NOT HAVE TO RUN RIGHT THROUGH THE INPUT PROGRAM. GO ONLY AS FAR AS NEEDED. CHECKING TO SEE WHAT DATA HAS BEEN INPUT IS DISCUSSED BELOW.

Checking the input

Before running the stability program it is necessary to check that the data which you require to be analysed has been correctly loaded. Program CHECK has been written for this purpose. Program CHECK runs through and displays the input data and shape data currently held in the calculator. The following steps explain how to run the program:

(1) SWITCH CALCULATOR ON
(2) PRESS USER KEY (NOT NECESSARY IF 'USER' IS ALREADY IN DISPLAY)
(3) PRESS B

    THE INPUT DATA IS DISPLAYED IN THE ORDER GIVEN ON THE COMPUTATION SHEETS.

    IF YOU WISH TO STOP THE LISTING PRESS R/S. THE LISTING WILL CONTINUE FROM WHERE YOU STOPPED IF YOU PRESS R/S A SECOND TIME.

    IF YOU WISH TO RESTART THE LISTING FROM THE BEGINNING PRESS B.

Program CHECK can be run at any time independently of programs INPUT and BISHOP. Sometimes, especially when carrying out sensitivity analysis, you may find that you have completed an analysis and you have forgotten exactly what your input data was! Running program CHECK will then tell you what data you have just analysed (*i.e.* the question to the answer that you already have).

When the list is being displayed you will find it easier to compare with your computation sheet if you are not distracted by large numbers, accurate to many decimal places. For example, the number 4.0 is easier to take in and check than 4.0000. The number of figures displayed after the decimal point can be modified by the following procedure:

(1) SWITCH CALCULATOR ON
(2) PRESS YELLOW KEY
(3) PRESS 1 KEY (FIX)
(4) PRESS 1 (OR 2 *etc.*)

THE NUMBER YOU PRESS IN STEP 4 WILL BE THE NUMBER OF FIGURES DISPLAYED AFTER THE DECIMAL POINT DURING SUBSEQUENT CALCULATOR OPERATIONS.

If you only wish to check one or two items of your input data individually you do not have to run program CHECK. You simply have to recall the item required by checking the appropriate store as listed on the computation sheets. For example, if you wanted to know what the current input value is for cohesion, you should take the following steps:

(1) SWITCH CALCULATOR ON
(2) PRESS RCL KEY
(3) PRESS 07

THE NUMBER CURRENTLY LOADED IN STORE 07 IS NOW DISPLAYED.

If you want to change an item of input because you have made a mistake, or you are carrying out sensitivity analysis, a similar procedure can be followed. If you wanted to enter 5 as the value of cohesion you would:

(1) SWITCH CALCULATOR ON
(2) PRESS 5
(3) PRESS STO KEY
(4) PRESS 07

THE NUMBER 5 IS NOW LOADED INTO STORE 07

Running the first analysis

Having loaded the data and checked that it is correct you are ready to run the stability analysis program labelled BISHOP. The following steps are required:

(1) SWITCH CALCULATOR ON
(2) PRESS USER KEY (NOT NECESSARY IF 'USER' IS ALREADY IN DISPLAY)
(3) PRESS C

PROGRAM BISHOP SHOULD NOW RUN. WHILE IT IS RUNNING THE WORD 'PRGM' IS DISPLAYED AND A 'FLYING GOOSE' SYMBOL MOVES ACROSS THE DISPLAY. EACH STEP OF THE 'GOOSE' REPRESENTS THE ANALYSIS OF A SINGLE SLICE. WHEN THE ANALYSIS IS COMPLETE THERE IS A BEEPING SOUND AND THE FACTOR OF SAFETY IS DISPLAYED FOR THE FIRST ITERATION. EACH SLICE TAKES ABOUT FIVE SECONDS TO ANALYSE.

THE FACTOR OF SAFETY FOR THE FIRST ITERATION IS AUTOMATICALLY LOADED INTO STORE 11. TO CARRY OUT FURTHER ITERATIONS IT IS NECESSARY TO PRESS C AGAIN, OR TO PRESS R/S.

THE RESULTS OF EACH ITERATION SHOULD BE RECORDED AS CALCULATIONS ON THE COMPUTATION SHEET.

The first example calculation given on the computation sheet in Appendix 2 is a 'forward' analysis where the factor of safety is calculated from a complete set of input data. The second analysis is an example of back analysis. In this analysis the friction angle (ϕ) required to give a factor of safety of 1 is determined. In the case of a back analysis like this, two changes to the input data have to be made between each iteration. The factor of safety (1) has to be loaded into STORE 11 and a new value of ϕ has to be loaded into STORE 08 before each iteration.

Subsequent analysis, sensitivity and fiddling around

The real value of carrying out stability analysis on a programmable calculator results from the ease in which sensitivity analysis can be carried out. In a short space of time it is possible to determine how variations in unit weight, cohesion, friction angle, pore pressure and depth of slip circle affect the stability of a slip. The program is written in such a way as to allow each of these factors to be varied by reloading a single store (see stores 06 to 10 on computation sheets). A worked example where the depth of the slip circle is varied by changing store 10 is given on the computation sheet in Appendix 2.

Other modifications to the analysis can also be made. For example, if you want to consider the effect of a two metre deep tension crack you need only change the value of Y R.H.S. (store 03) from 15 to 13. Similarly, if you want to put in an additional slice you would have to change stores 02, 03 and 04 and enter data into store 25.

The best way to become familiar with both the calculator and the sensitivity of the factor of safety to varying input data is to fiddle around with data in the manner described above. It is important to record all your calculations. As mentioned earlier the problems in Appendix 3 are recommended for further practice.

COMMENTS ON STABILITY ANALYSIS

After carrying out a few stability analyses of real natural slopes you will realise how little is actually known about the input data and how much has to be assumed. Also, with this particular program, you have to start with the assumption of uniform material parameters before even considering your specific site data.

Assessing the quality of the input data is probably the most important part of any stability analysis. An example of input data review is given in Moon (1984*a*). One method of taking into account known uncertainties is to use probabilistic methods of analysis (Moon 1984*b*). Suggestions on how future work on landslips in Tasmania may be directed at improving the confidence in stability analysis are outlined in Moon (1984*c*).

Readers are also referred to Leroueil and Tavenas (1981) for an excellent account of the pitfalls of back analysis.

REFERENCES

LEROUEIL, S.; TAVENAS, F. 1981. Pitfalls of back-analysis. *Proceedings of the Tenth International Conference of Soil Mechanics and Foundation Engineering, Stockholm.* 1:185-190.

MOON, A.T. 1984*a*. *Investigation of Bovills Landslip, near Devonport, Tasmania*. M.Sc. thesis, University of Tasmania : Hobart.

MOON, A.T. 1984*b*. Probabilistic slope stability analysis using Rosenbleuth's method. *Unpubl.Rep.Dep.Mines Tasm.* 1984/53.

MOON, A.T. 1984*c*. Slope stability assessments in Tasmania - ideas for future work. *Unpubl.Rep.Dep.Mines Tasm.* 1984/55.

MOON, A.T. 1984*d*. Preliminary ideas on the development of guidelines for consultants undertaking slope stability assessments. *Unpubl.Rep.Dep. Mines Tasm.* 1984/56.

[30 July 1984]

APPENDIX 1

Comments on the use of Cousins' stability charts for earth slopes.

INTRODUCTION

The purpose of this Appendix is to generally recommend the use of Cousins' stability charts and to specifically point out ways in which the use of the charts is complementary to the HP-41C analysis discussed in this report.

Cousins' stability charts were originally published in journals (Cousins, 1978; 1980) and have since been published in several textbooks on geotechnical engineering. A set of transparencies of the stability charts is held in the Cartographic Office of the Department of Mines (Serial Number 5048).

RECOMMENDED USES

It is assumed that readers are familiar with the stability charts and a detailed explanation will not be given here. The notation is included on the charts themselves and worked examples are given in the references.

Three specific areas where the charts can be used in conjunction with the HP-41C programs are listed below. They all involve the approximation of the slope being analysed by a simple slope. Cousins' stability charts can be used to:

(1) Quickly get an approximate result, to get a feel for the problem and avoid gross errors,

(2) For back analysis, and

(3) To locate the critical circle.

The third point is particularly useful when you need to analyse an unfailed slope and you are uncertain where to begin your trial circles.

Some of the problems given in Appendix 3 refer to Cousins' stability charts and it is recommended that readers use the charts in the three ways listed above when working on those problems. This will help readers become familiar with the charts and also demonstrate how natural slopes can be approximated to simple slopes without grossly affecting the stability analyses.

REFERENCES

COUSINS, B.F. 1978. Stability charts for simple earth slopes. *Journal of the Geotechnical Engineering Division, American Society of Civil Engineers.* 104 (GT2) Proceeding Paper 13572:267-279.

COUSINS, B.F. 1980. Stability charts for simple earth slopes allowing for tension cracks. *Proceedings of the Third Australia New Zealand conference on Geomechanics, Wellington, New Zealand Institution of Engineers.* 2:101-105.

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APPENDIX 2

Worked example of slope stability analysis on a standard computation sheet

SLOPE STABILITY ANALYSIS - COMPUTATIONS SHEET 1 OF......

NAME OF SLIP ......BOTHAMS...... MAP REF..295..4019..........

ANALYSIS BY..A.J.M..
DATE...11.7.1984...
CHECKED BY.........

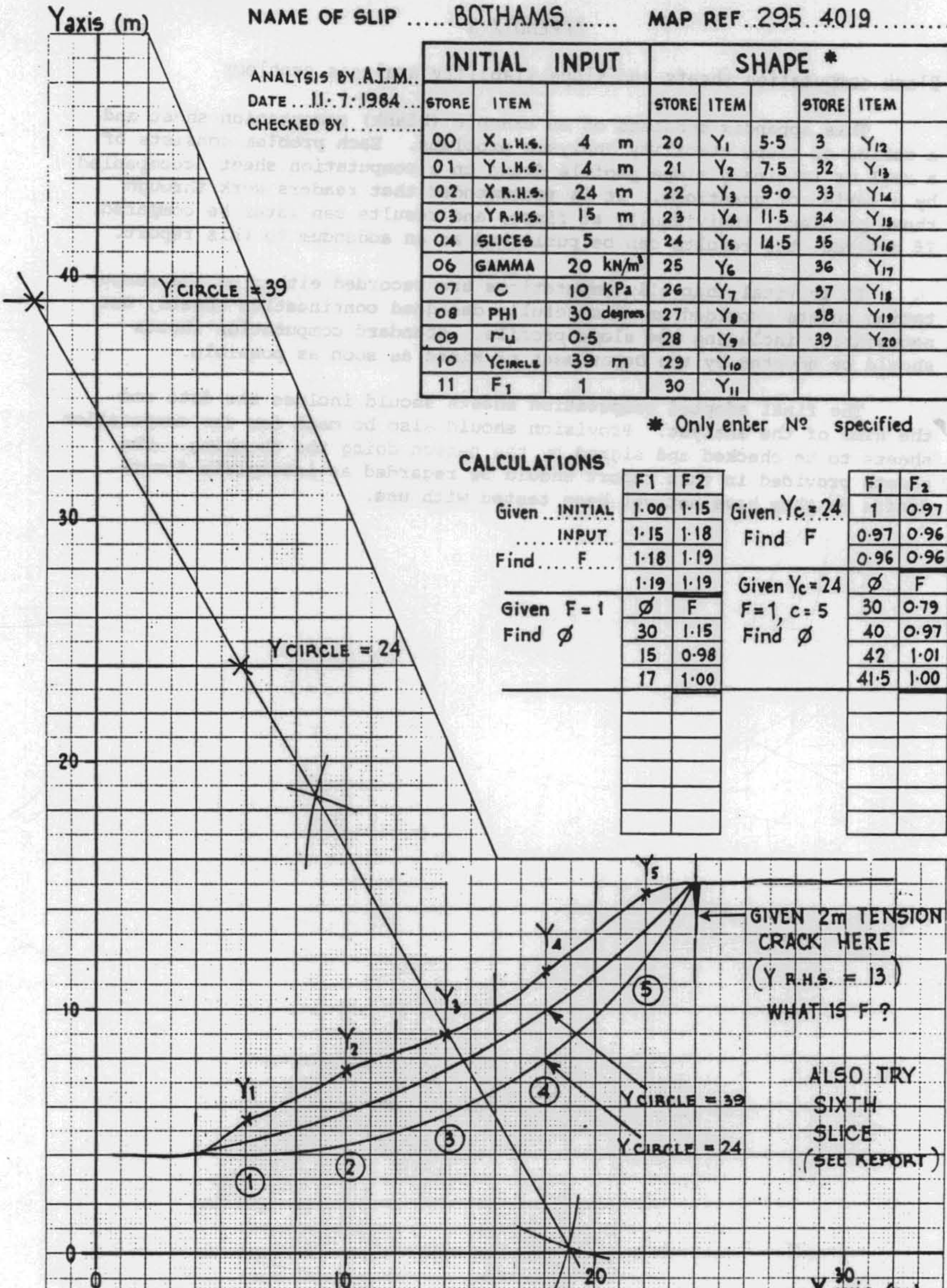
INITIAL INPUT				SHAPE *				
STORE	ITEM			STORE	ITEM		STORE	ITEM
00	X L.H.S.	4	m	20	Y_1	5·5	3	Y_{12}
01	Y L.H.S.	4	m	21	Y_2	7·5	32	Y_{13}
02	X R.H.S.	24	m	22	Y_3	9·0	33	Y_{14}
03	Y R.H.S.	15	m	23	Y_4	11·5	34	Y_{15}
04	SLICES	5		24	Y_5	14·5	35	Y_{16}
06	GAMMA	20	kN/m³	25	Y_6		36	Y_{17}
07	C	10	kPa	26	Y_7		37	Y_{18}
08	PHI	30	degrees	27	Y_8		38	Y_{19}
09	r_u	0·5		28	Y_9		39	Y_{20}
10	Y_{CIRCLE}	39	m	29	Y_{10}			
11	F_1	1		30	Y_{11}			

* Only enter Nº specified

CALCULATIONS

	F1	F2
Given...INITIAL	1·00	1·15
......INPUT	1·15	1·18
Find.....F....	1·18	1·19
	1·19	1·19
Given F = 1	Ø	F
Find Ø	30	1·15
	15	0·98
	17	1·00

	F_1	F_2
Given Y_c = 24	1	0·97
Find F	0·97	0·96
	0·96	0·96
Given Y_c = 24	Ø	F
F = 1, c = 5	30	0·79
Find Ø	40	0·97
	42	1·01
	41·5	1·00



5 cm

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APPENDIX 3

Blank computation sheets and slope stability analysis problems

This appendix consists of an example (blank) computation sheet and a series of slope stability analysis problems. Each problem consists of a real or imaginary slope profile drawn on a computation sheet accompanied by a series of questions. It is recommended that readers work through these problems, individually at first, and results can later be compared. If desired, the results can be published as an addendum to this report.

It is vital that all computations are recorded either on the computation sheets provided or on carefully designed continuation sheets, not necessarily including the slope profile. Standard computation sheets should be adopted by the Department of Mines as soon as possible.

The final adopted computation sheets should include the date and the name of the analyst. Provision should also be made for the computation sheets to be checked and signed by the person doing the checking. The sheets provided in this report should be regarded as incomplete first drafts as they have not yet been tested with use.

SLOPE STABILITY ANALYSIS - COMPUTATIONS SHEET 1 OF......

Yaxis (m)

NAME OF SLIP .... MAP REF..........................

ANALYSIS BY..........
DATE...................
CHECKED BY..........

INITIAL	INPUT		SHAPE *					
STORE	ITEM		STORE	ITEM		STORE	ITEM	
00	X L.H.S.	m	20	Y_1		31	Y_{12}	
01	Y L.H.S.	m	21	Y_2		32	Y_{13}	
02	X R.H.S.	m	22	Y_3		33	Y_{14}	
03	Y R.H.S.	m	23	Y_4		34	Y_{15}	
04	SLICES		24	Y_5		35	Y_{16}	
06	GAMMA	kN/m³	25	Y_6		36	Y_{17}	
07	C	kPa	26	Y_7		37	Y_{18}	
08	PHI	degrees	27	Y_8		38	Y_{19}	
09	r_u		28	Y_9		39	Y_{20}	
10	Y_{CIRCLE}	m	29	Y_{10}				
11	F_1		30	Y_{11}				

* Only enter Nº specified

CALCULATIONS

Given..........
....
Find..........

Given.........

Xaxis (m)

5 cm

SLOPE STABILITY ANALYSIS - COMPUTATIONS SHEET ..... OF ....

NAME OF SLIP...................... MAP REF..............................

ANALYSIS BY................. DATE............. CHECKED BY.................

PROBLEM 1 - BOVILLS SLIP

You know quite a lot about this landslip. At the time of failure r_u was about 0.44. It is an existing landslip and the residual cohesion is about 3 kPa. The maximum depth of the landslip is about 5 m. Assume the unit weight is 19 kN/m³.

Questions:

(1) Back analyse to find the residual friction angle (ϕ_r').

(2) Vary the depth of the landslip. Plot a graph of Y_{circle} against ϕ'_r. What value of Y_{circle} gives the most unstable slope? What maximum depth does this represent.

PROBLEM 2 - GROOMS SLIP

Assume the slip passes through the base of Borehole 1.

Questions:

(1) Back analyse for ϕ'. What assumptions did you make and why?

(2) Assume there is a tension crack at the headscarp. What effect does this have on the analysis?

(3) Carry out sensitivity analysis.

(4) Analyse Grooms Slip for

(a) $\phi_r = 15°$

(b) $\phi_r = 30°$

What would you conclude about the stability in each case.

PROBLEM 3 - LILLICO 'B' SLIP

Questions:

(1) Back analyse both the mid 1970's slip and the 1981 slip. Do you get similar values of ϕ'?

(2) Investigate the sensitivity of the cohesion.

(3) Try to draw the original slope and then back analyse.

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PROBLEM 1

SLOPE STABILITY ANALYSIS - COMPUTATIONS SHEET 1 OF......

NAME OF SLIP ....BOVILLS.......... MAP REF. 4497 54411........

ANALYSIS BY........
DATE........................
CHECKED BY..........

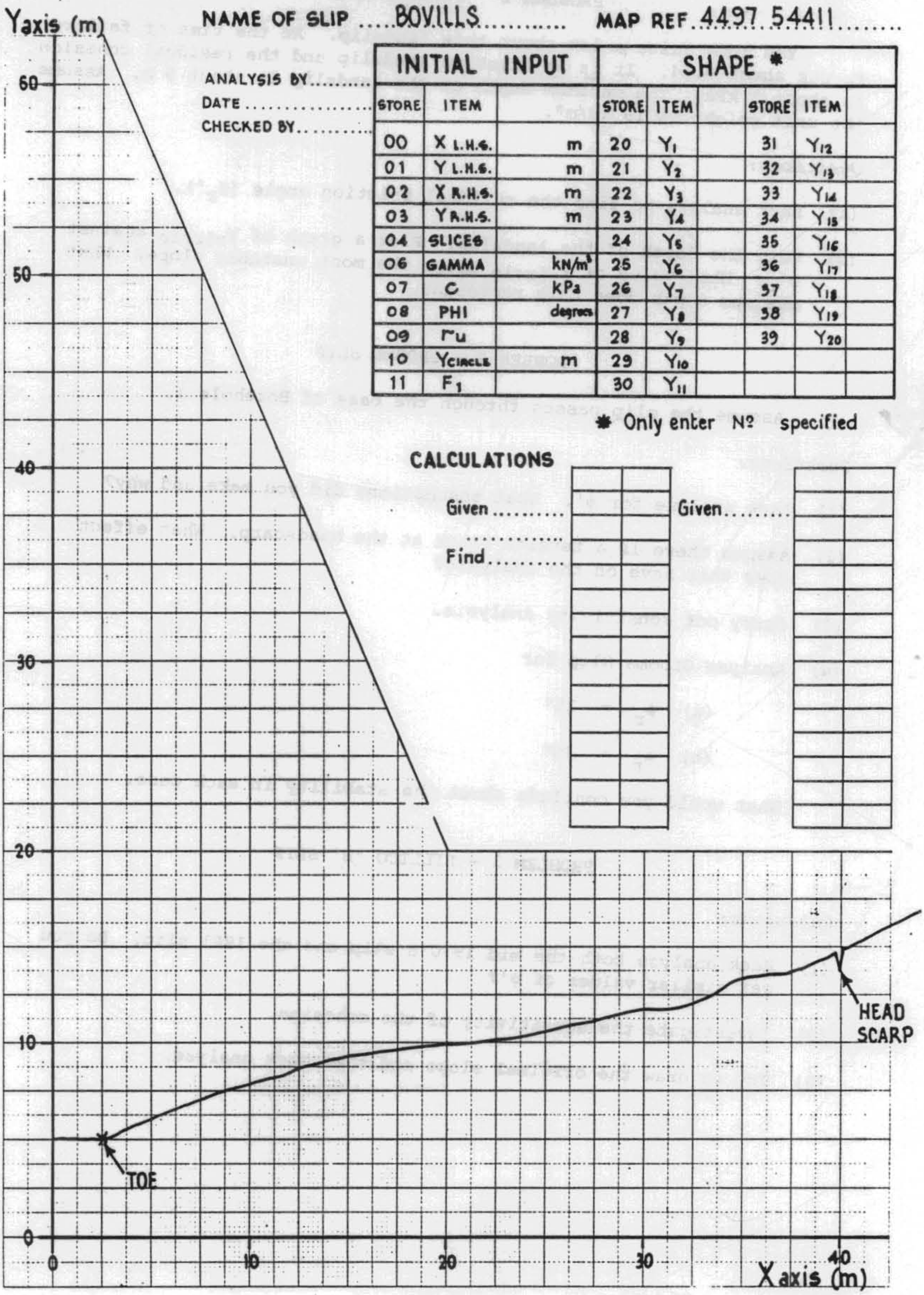
INITIAL INPUT			SHAPE *			
STORE	ITEM		STORE	ITEM	STORE	ITEM
00	$X_{L.H.S.}$	m	20	Y_1	31	Y_{12}
01	$Y_{L.H.S.}$	m	21	Y_2	32	Y_{13}
02	$X_{R.H.S.}$	m	22	Y_3	33	Y_{14}
03	$Y_{R.H.S.}$	m	23	Y_4	34	Y_{15}
04	SLICES		24	Y_5	35	Y_{16}
06	GAMMA	kN/m³	25	Y_6	36	Y_{17}
07	C	kPa	26	Y_7	37	Y_{18}
08	PHI	degrees	27	Y_8	38	Y_{19}
09	r_u		28	Y_9	39	Y_{20}
10	Y_{CIRCLE}	m	29	Y_{10}		
11	F_1		30	Y_{11}		

* Only enter Nº specified

CALCULATIONS

Given.......... Given........

Find..........



5 cm

PROBLEM 2

SLOPE STABILITY ANALYSIS - COMPUTATIONS SHEET 1 OF......

Y axis (m)

NAME OF SLIP ....GROOMS.......... MAP REF .4251 54472....

ANALYSIS BY.........
DATE.................
CHECKED BY...........

INITIAL	INPUT		SHAPE *					
STORE	ITEM		STORE	ITEM		STORE	ITEM	
00	X L.H.S.	m	20	Y_1		31	Y_{12}	
01	Y L.H.S.	m	21	Y_2		32	Y_{13}	
02	X R.H.S.	m	22	Y_3		33	Y_{14}	
03	Y R.H.S.	m	23	Y_4		34	Y_{15}	
04	SLICES		24	Y_5		35	Y_{16}	
06	GAMMA	kN/m^3	25	Y_6		36	Y_{17}	
07	C	kPa	26	Y_7		37	Y_{18}	
08	PHI	degrees	27	Y_8		38	Y_{19}	
09	r_u		28	Y_9		39	Y_{20}	
10	Y CIRCLE	m	29	Y_{10}				
11	F_1		30	Y_{11}				

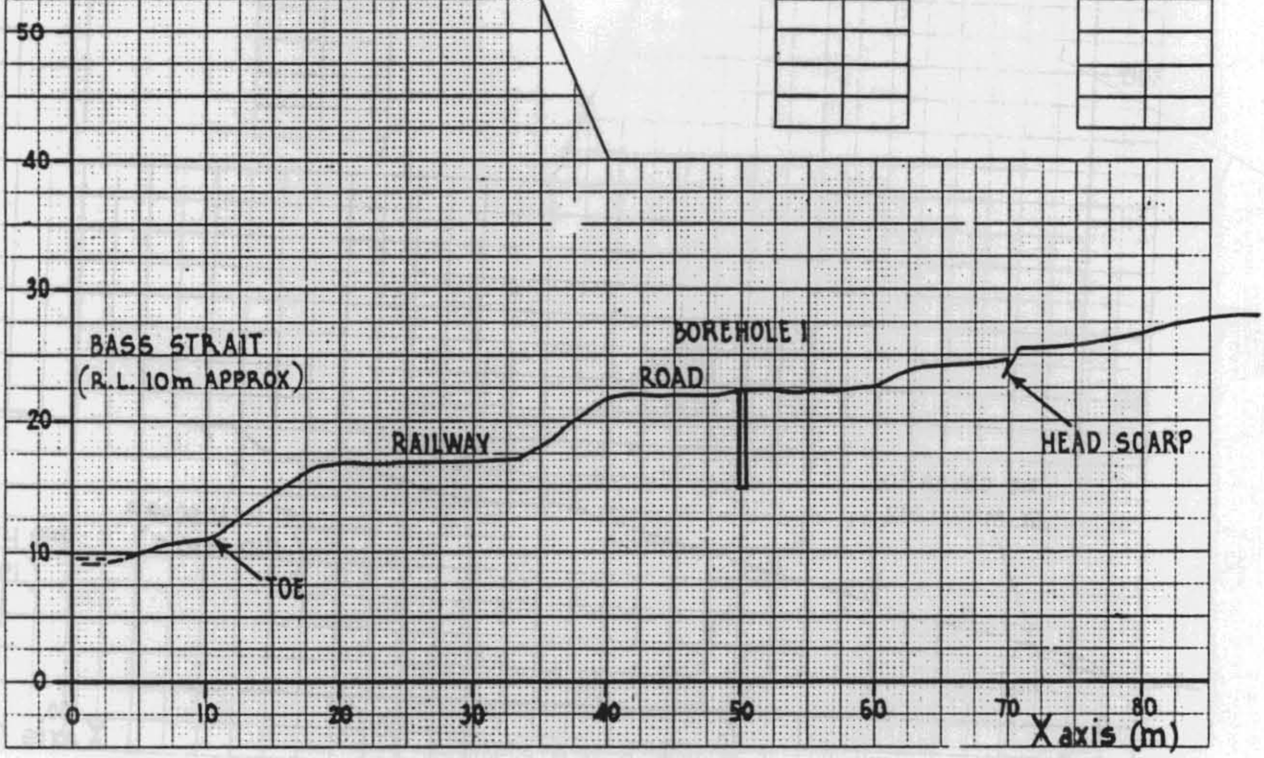
* Only enter № specified

CALCULATIONS

Given..........

Find..........

Given.........



5 cm

PROBLEM 3

SLOPE STABILITY ANALYSIS - COMPUTATIONS SHEET 1 OF.....

NAME OF SLIP ....LILLICO 'B'...... MAP REF .4401 54424.......

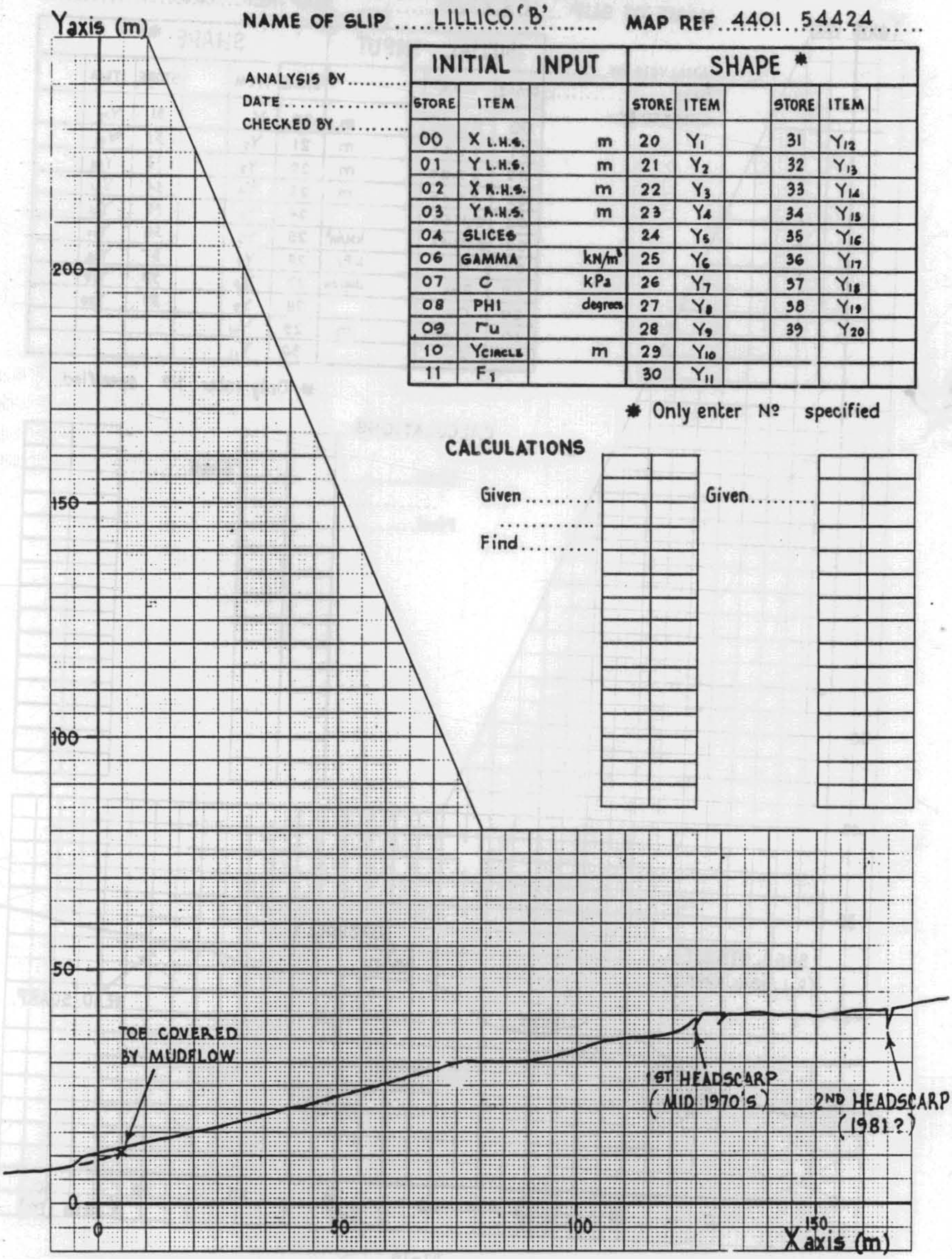
ANALYSIS BY..........
DATE....................
CHECKED BY.............

INITIAL INPUT			SHAPE *			
STORE	ITEM		STORE	ITEM	STORE	ITEM
00	X L.H.S.	m	20	Y_1	31	Y_{12}
01	Y L.H.S.	m	21	Y_2	32	Y_{13}
02	X R.H.S.	m	22	Y_3	33	Y_{14}
03	Y R.H.S.	m	23	Y_4	34	Y_{15}
04	SLICES		24	Y_5	35	Y_{16}
06	GAMMA	kN/m³	25	Y_6	36	Y_{17}
07	C	kPa	26	Y_7	37	Y_{18}
08	PHI	degrees	27	Y_8	38	Y_{19}
09	ru		28	Y_9	39	Y_{20}
10	YCIRCLE	m	29	Y_{10}		
11	F_1		30	Y_{11}		

* Only enter Nº specified

CALCULATIONS

Given.......... Given..........
....
Find..........



5 cm

PROBLEM 4 - ALL ROUNDERS SLIP

This is an unfailed slip. You have to assess the stability.

(1) Approximate the profile to a simple slope. Make some assumptions and back analyse for ϕ' using Cousins' stability charts. Use the charts to locate the critical circle.

(2) Back analyse for ϕ' with the calculator and compare results.

(3) Given a residual friction angle of 24° is the slope stable? Use both Cousins' charts and the calculator.

(4) Did you consider a tension crack? Compare results again.

PROBLEM 4

SLOPE STABILITY ANALYSIS - COMPUTATIONS SHEET 1 OF.....

NAME OF SLIP ....ALLROUNDERS.. MAP REF..2553...3756........

ANALYSIS BY..........

DATE..........

CHECKED BY..........

INITIAL INPUT			SHAPE *			
STORE	ITEM		STORE	ITEM	STORE	ITEM
00	X L.H.S.	m	20	Y_1	31	Y_{12}
01	Y L.H.S.	m	21	Y_2	32	Y_{13}
02	X R.H.S.	m	22	Y_3	33	Y_{14}
03	Y R.H.S.	m	23	Y_4	34	Y_{15}
04	SLICES		24	Y_5	35	Y_{16}
06	GAMMA	kN/m³	25	Y_6	36	Y_{17}
07	C	kPa	26	Y_7	37	Y_{18}
08	PHI	degrees	27	Y_8	38	Y_{19}
09	r_u		28	Y_9	39	Y_{20}
10	Y CIRCLE	m	29	Y_{10}		
11	F_1		30	Y_{11}		

* Only enter Nº specified

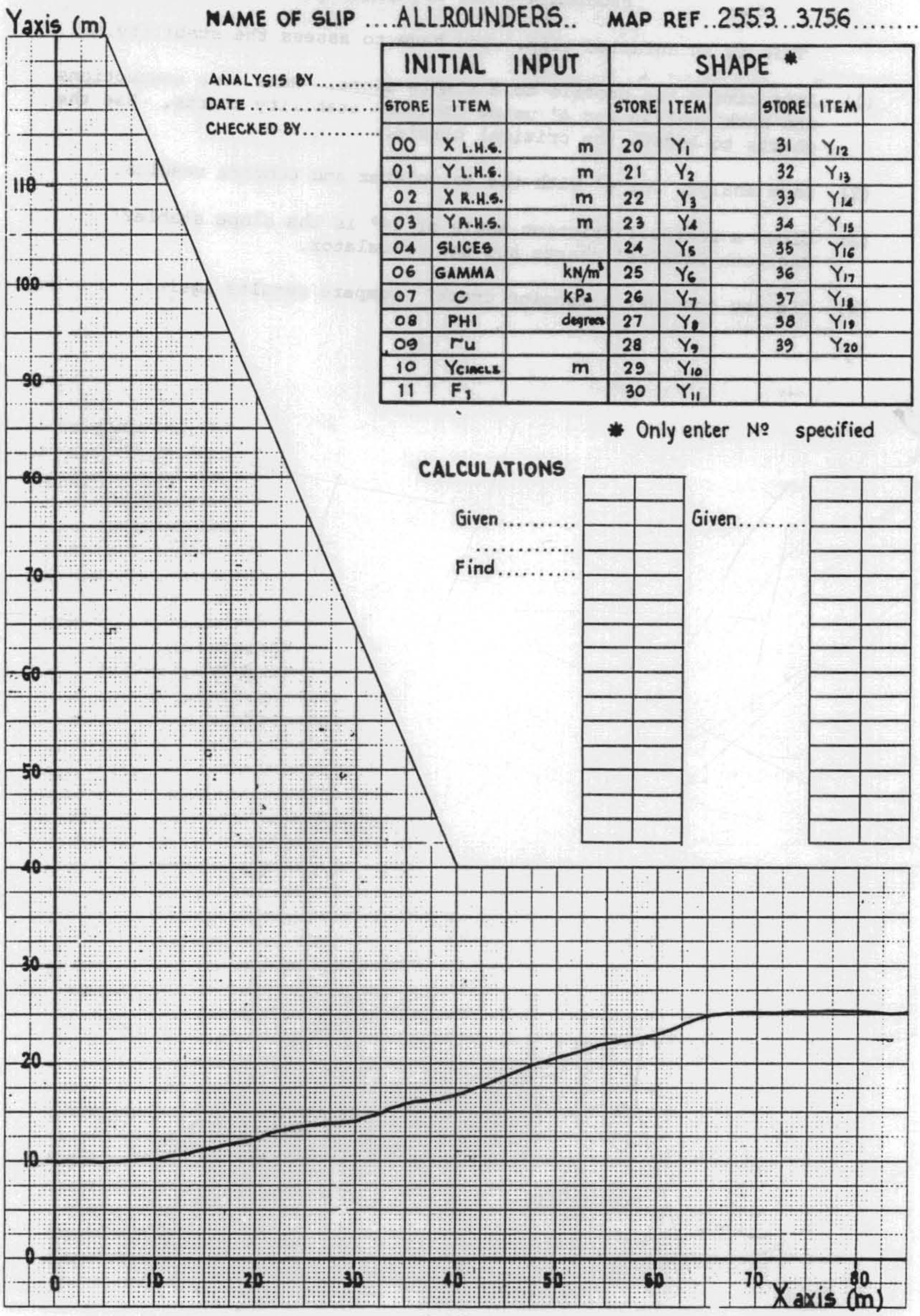
CALCULATIONS

Given..........

....

Find..........

Given..........



5 cm

APPENDIX 4

Listings of programs INPUT, CHECK and BISHOP

PRP "INPUT"

```
 01♦LBL "INPUT"
"DRAW CIRCLE"  AVIEW
STOP  "X LHS = ?"
PROMPT  STO 00
"Y LHS = ?"  PROMPT
STO 01  "X RHS = ?"
PROMPT  STO 02
"Y RHS = ?"  PROMPT
STO 03  "SLICES = ?"
PROMPT  STO 04
"GAMMA = ?"  PROMPT
STO 06  " C = ?"  PROMPT
STO 07  " PHI = ?"
PROMPT  STO 08
" RU = ?"  PROMPT
STO 09  "Y CIRCLE = ?"
PROMPT  STO 10
" F1 = ?"  PROMPT
STO 11  " Y1 = ?"
PROMPT  STO 20
" Y2 = ?"  PROMPT
STO 21  " Y3 = ?"
PROMPT  STO 22
" Y4 = ?"  PROMPT
STO 23  " Y5 = ?"
PROMPT  STO 24
" Y6 = ?"  PROMPT
STO 25  " Y7 = ?"
PROMPT  STO 26
" Y8 = ?"  PROMPT
STO 27  " Y9 = ?"
PROMPT  STO 28
" Y10 = ?"  PROMPT
STO 29  " Y11 = ?"
PROMPT  STO 30
" Y12 = ?"  PROMPT
STO 31  " Y13 = ?"
PROMPT  STO 32
" Y14 = ?"  PROMPT
STO 33  " Y15 = ?"
PROMPT  STO 34
" Y16 = ?"  PROMPT
STO 35  " Y17 = ?"
PROMPT  STO 36
" Y18 = ?"  PROMPT
STO 37  " Y19 = ?"
PROMPT  STO 38
" Y20 = ?"  PROMPT
STO 39  END
```

PRP "CHECK"

```
 01♦LBL "CHECK"
RCL 00  PSE  RCL 01  PSE
RCL 02  PSE  RCL 03  PSE
RCL 04  PSE  RCL 06  PSE
RCL 07  PSE  RCL 08  PSE
RCL 09  PSE  RCL 10  PSE
* RCL 11  PSE  RCL 20  PSE
RCL 21  PSE  RCL 22  PSE
RCL 23  PSE  RCL 24  PSE
RCL 25  PSE  RCL 26  PSE
RCL 27  PSE  RCL 28  PSE
RCL 29  PSE  RCL 30  PSE
RCL 31  PSE  RCL 32  PSE
RCL 33  PSE  RCL 34  PSE
RCL 35  PSE  RCL 36  PSE
RCL 37  PSE  RCL 38  PSE
RCL 39  END
```

* PSE HAS BEEN INSERTED AFTER RCL 11

PRP "BISHOP"

```
 01♦LBL "BISHOP"
RCL 04  STO 81  0
STO 15  0  STO 19
RCL 00  RCL 02  +  2  /
RCL 10  RCL 01  RCL 03
+  2  /  -  RCL 01
RCL 03  -  *  RCL 00
RCL 02  -  /  -  STO 12
RCL 00  -  X↑2  RCL 10
RCL 01  -  X↑2  +  SQRT
STO 13  0  STO 14

 42♦LBL 15
1  ST+ 14  RCL 02
RCL 00  -  RCL 04  /
RCL 14  .5  -  *  RCL 00
+  RCL 12  -  RCL 13  /
ASIN  STO 16  19  RCL 14
+  STO 05  RCL IND 05
RCL 13  RCL 16  COS  *
+  RCL 10  -  RCL 06  *
STO 05  RCL 16  SIN
RCL 05  *  ST+ 15  1
RCL 09  -  RCL 05  *
RCL 08  TAN  *  RCL 07
+  STO 17  39  RCL 14  +
STO 80  RCL 17
STO IND 80  RCL 16  SIN
RCL 08  TAN  *  RCL 11
/  RCL 16  COS  +
STO 18  59  RCL 14  +
STO 80  RCL 18
STO IND 80  RCL 17
RCL 18  /  ST+ 19
DSE 81  GTO 15  RCL 04
STO 81  RCL 19  RCL 15
/  FIX 2  STO 11
" FS = "  ARCL X  AVIEW
BEEP  .END.
```