CHAPTER IX

BACK ANALYSIS

In this study, stability of slope was analyzed in terms of effective stress by limit equilibrium method, and the performance of slopes was evaluated in terms of factor of safety. Stability methods in which the failure surfaces were assumed to be one-plane segments, curved and composite or arbitrary shape were carried out and compared. Computer programs of slope stability analysis were used to help calculating the values of factor of safety.

9.1 Slope Stability Analyses of the Study Area.

As mentioned earlier, this study area has a past record of old natural landslide within the colluvial footslope. The embankment fill of 5-9 meters high was constructed on this old natural landslide mass (Figure 9.1). In order to understand the stability condition, the study is divided into 3 stages, namely the preconstruction stage, the stage of embankment failures in 1983 and in 1985-1986.

Because of the previous large shearing displacement that had been occurred at the base of these old natural landslide masses, the shear strength of the sheared materials along these surfaces should be close to the residual shear strength (Wu and Sangrey, 1978, Gray et al., 1971, Patton et al., 1974). The decrease of shear strength from a peak to a residual one leads to the further progressive failures in these slopes (Chowdhury, 1982, Gray et al., 1971, Skempton, 1964). Failure may start as a consequence of local yield

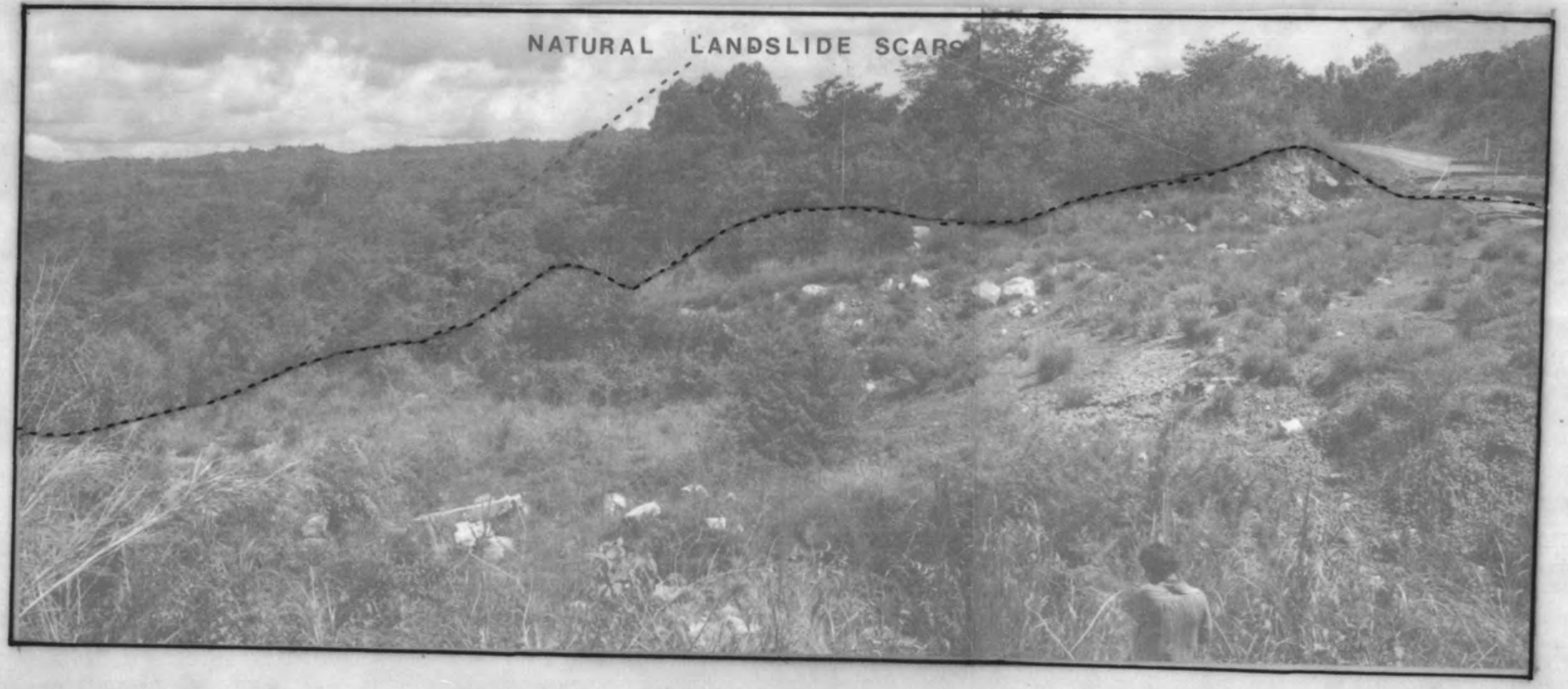


Figure 9.1 Natural landslide scars of the embankment failures in the study area.

in a weak zone, near a fault, within a shear zone, etc. (Chowdhury, 1982).

In the present stability analysis, the slopes were analysed using Janbu's (1973), Sliding Block (Duncan et al.,1975) and Simplified Bishop (1955) methods. As Janbu's (1973) method was generally used,the several failure surfaces were analysed by trial-and-error with the aid of the computer programs "Stable" to find the one surface that gave the least factor of safety. The stability analysis of Simplified Bishop methods was also analysed using the computer program "Stable". The results of both methods were compared to get a reasonable view.

The shear strength used in the analysis is the average value of the laboratory-measured effective stresses. The residual shear strength parameters with $Ø'_r$ = 21 degrees and C'_r = 9.16 kN/m^2 was used for the strength of old slip surfaces or existing failure surfaces which were assumed to be located at the colluvium-bedrock interface or within shear zone soil. As recommended by Patton et al. (1974), the angle of residual shearing resistance,$Ø'_r$, is generally in a stability analysis for slopes with existing failure surfaces and was used in this study.

9.1.1 Analysis of failure for preconstruction stage.

The data gathered from air-photographic interpretation and original slope profiles lead to the reconstruction of natural slope which used in the stability analysis.

9.1.1.1 Ground water condition: The groundwater condition of seepage parallel to slope was assumed to be the natural groundwater condition. This groundwater condition is often reach in the lower portion of natural slopes (Lambe, 1979).

9.1.1.2 Stability analysis for regular sliding block: The calculations of factor of safety both in graphical and numerical by wedge or sliding block method (Duncan et al.,1975) was performed. The result of analysis for failure plane of minimum F.S. was 1.15 and presented in Figure 9.2

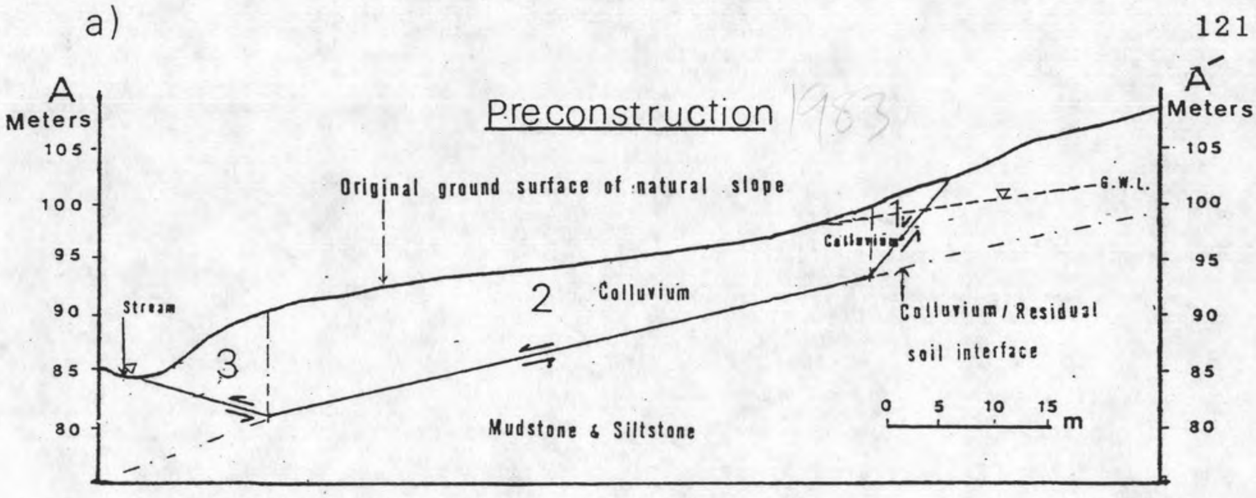
9.1.1.3 Stability analysis for irregular surface: Twenty seven failure surfaces were tried by Janbu's (1973) method. The computer calculation on stability of slope for minimum F.S. is shown in Appendix G. The results of analysis were summarized and presented in Figure 9.3. It is apparent from the analysis that the failure surface 5B with F.S.= 0.98 has the ground position coinciding with a major natural landslide scarp.

The stability analyses for both the regular sliding block and irregular surface gave the same failure surface of minimum factor of safety of 1.15 and 0.98 which is in a close agreement with the field observation. This stability analyses result revealed that the natural colluvial slope was unstable even in the preconstruction stage.

9.1.2 Analysis of failure for 1983.

A typical cross section parallel to the direction of failure along A-A' in Figure 6.1 was used in this slope stability analysis.

a)



Notes.

1 Shear strength parameters used:

$\phi' = 22^\circ$ $c' = 47.56$ kN/m^2 (Embankment)

$\phi' = 25^\circ$ $c' = 12.6$ " (Colluvium)

$\phi'_r = 21^\circ$ $c'_r = 9.16$ " (Col./Rs. interface)

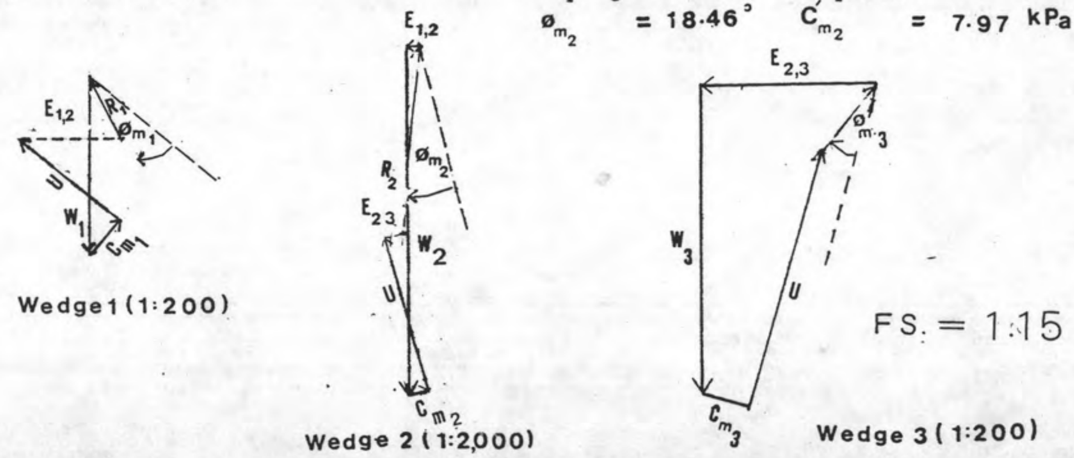
$\phi'_{m_1}, \phi'_{m_3} = 22.07^\circ$ $C'_{m_1}, C'_{m_3} = 10.96$ kPa

$\phi_{m_2} = 18.46^\circ$ $C'_{m_2} = 7.97$ kPa

b)

Graphical method:

Assume F.S. = 1.14



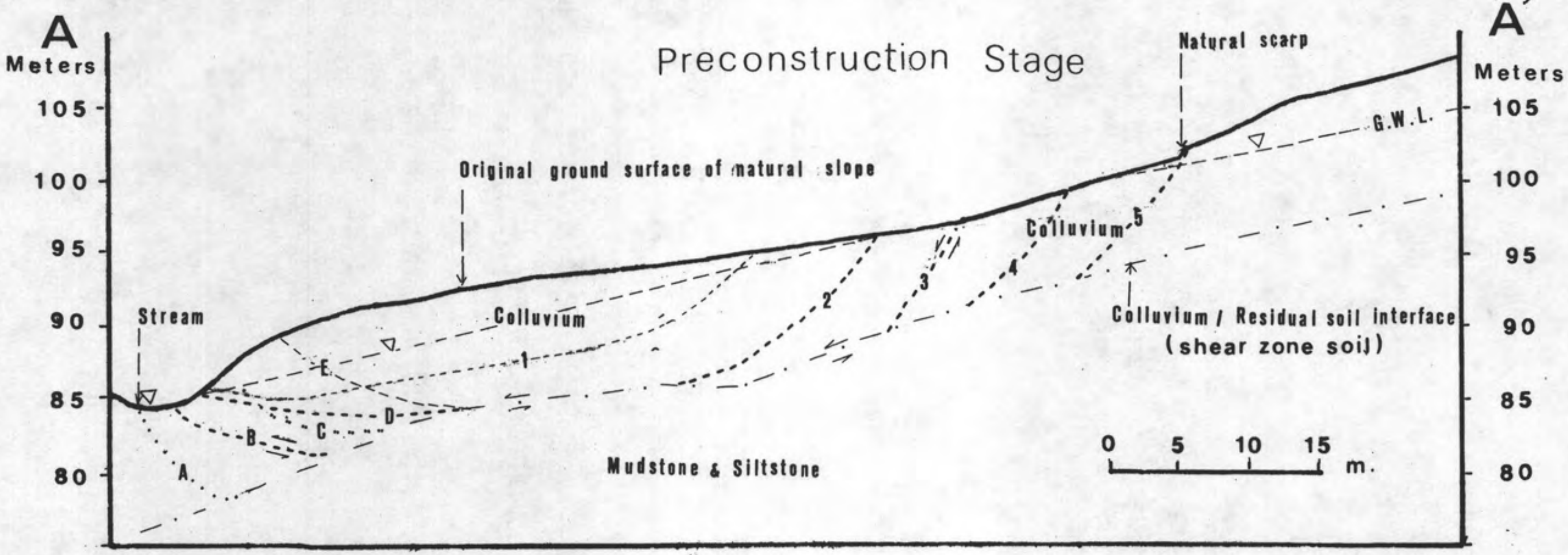
Numerical method:

Note: The computation of F.S. is presented in appendix G

Figure 9.2 Stability analysis by the wedge method for preconstruction stage.

a) The wedges to solved for F.S. by means of numerical and graphical technique.

b) Force polygons for wedges.



Notes.

1 Shear strength parameters used:

$\phi'_r = 25^\circ$ $c'_r = 12.60$ kN/m^2 (Colluvium)

$\phi'_r = 21^\circ$ $c'_r = 9.16$ kN/m^2 (Col./Rs. interface)

2 Minimum factor of safety:

F.S. = 0.98

Failure Surface	F.S.
5B	0.98
4B	1.04
4A	1.03
3A	1.09
2B	1.11
5C	1.19
3D	1.37
3C	1.48
4E	1.49
3E	1.74
1	1.85
2E	1.99

Figure 9.3 Summary of the stability analysis results by Janbu's (1973) method, for preconstruction stage.

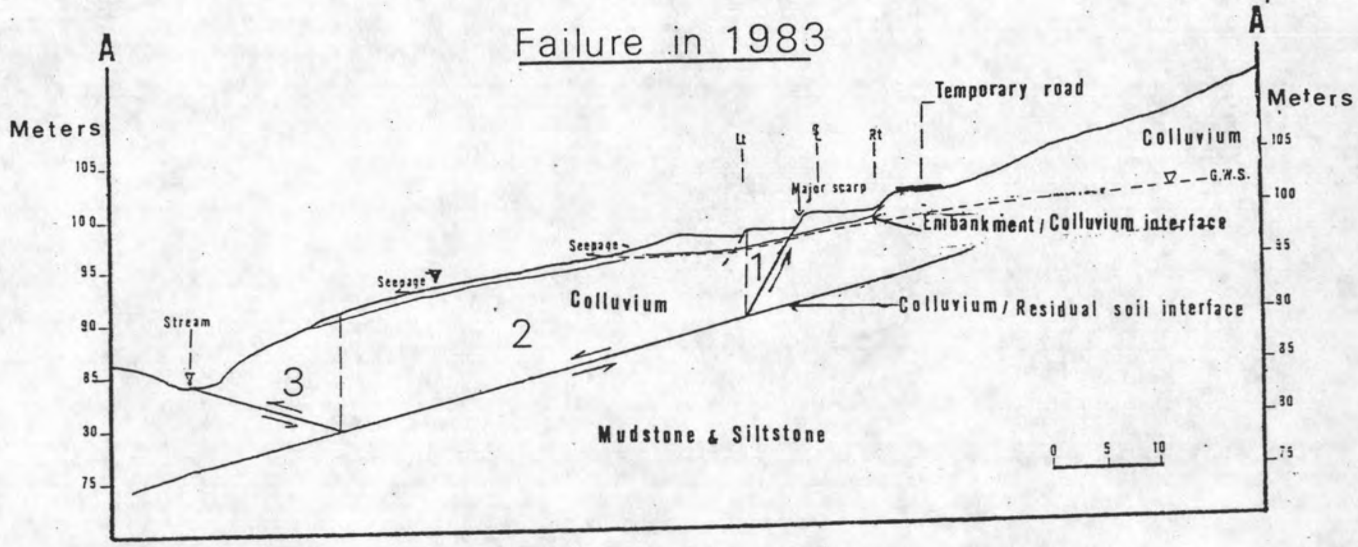
9.1.2.1 Ground water condition.: Because the investigation was done in the dry period, it was hard to specify the highest piezometic level. The data gathered from boring, however, revealed that the groundwater was usually trapped underneath the upper soil of filled materials and that the groundwater is sometimes artesian or confined aquifer. The assumed piezometic groundwater was marked at the colluvium-upper soil of filled material interface, or at 2 meters below road centerline. This assumed piezometic level may not represent the highest groundwater table that exists within this slope during the heavy rain period.

9.1.2.2 Stability analysis for regular sliding block: The results of stability analysis in the forms of numerical and graphical by wedge method (Duncan et al., 1975) are presented in Figure 9.4. The failure plane that gave the minimum factor of safety of 1.17 was coincided with the major crack of the 1983 failure.

9.1.2.3 Stability analysis for irregular surface: Janbu's (1973) method were used in a stability analysis for the failure model of either irregular or arbitrary shape. Twenty seven trial surfaces were analysed using Janbu's method. The failure surfaces 3D that given the minimum F.S. of 0.98 was coincided with the major crack of the 1983 failure. The results of analysis are summarized and presented in Figure 9.5 while the computer calculation of the stability of slope for minimum F.S. is shown in Appendix G.

9.1.2.4 Comparison of the results for different failure models.: The failure surfaces with the minimum factor of

a)



Notes. 1 Shear strength parameters used:

$\phi'_r = 25°$ $c'_r = 12.60$ kN/m^2 (Colluvium)

$\phi'_r = 21°$ $c'_r = 9.16$ kN/m^2 (Col./Rs. interface)

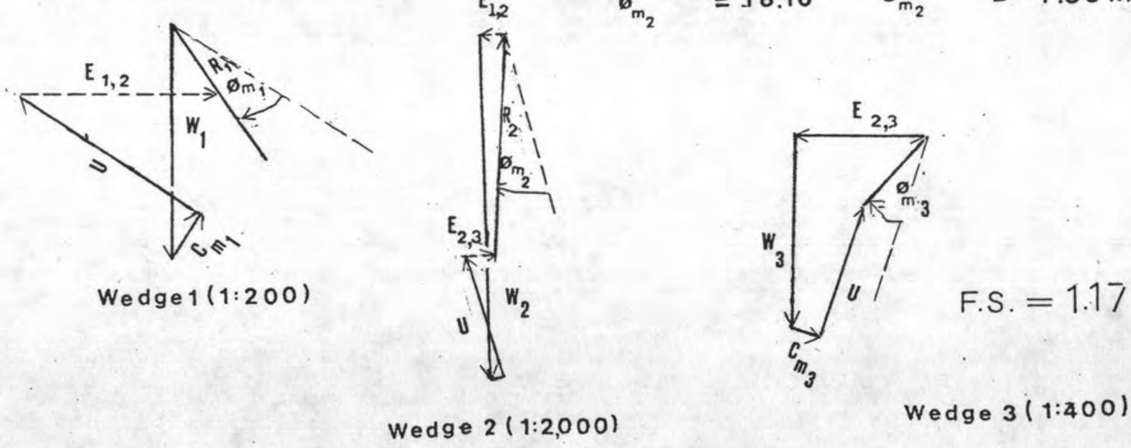
$\phi'_{m_1}, \phi'_{m_3} = 21.73°$ $C'_{m_1}, C'_{m_3} = 10.77$ kPa

$\phi_{m_2} = 18.16$ $C'_{m_2} = 7.83$ kPa

b)

Graphical method:

Assume F.S. = 1.17



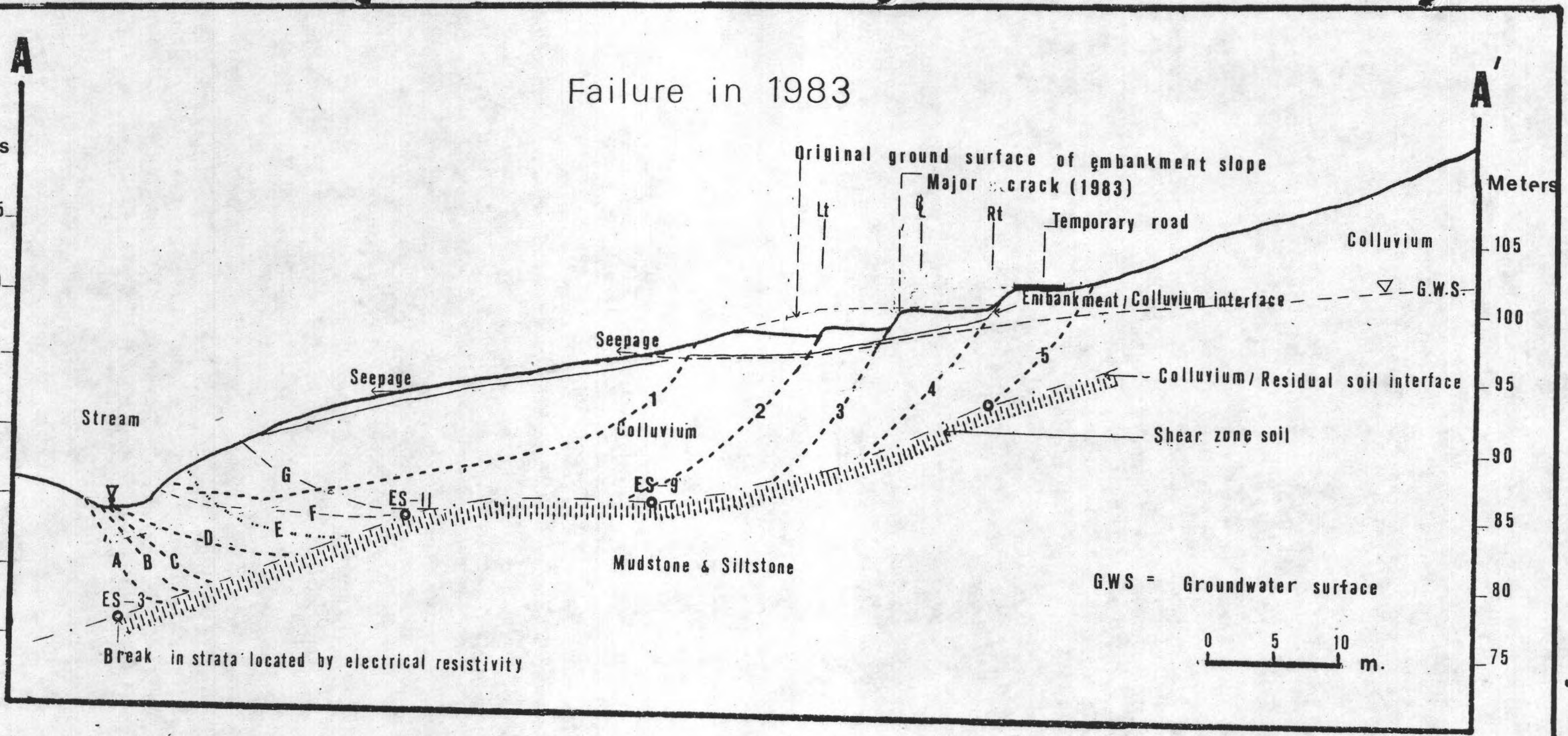
Numerical method:

Note: The computation of F.S. is presented in appendix G

Figure 9.4 Stability analysis by the wedge method for failure in 1983.

a) The wedges to be solved for F.S. by means of numerical and graphical techniques.

b) Force polygons for wedges.



Notes.

1 Shear strength parameters used:

$\phi' = 22^\circ$ $c' = 47.56$ kN/m^2 (Embankment)

$\phi' = 25^\circ$ $c' = 12.6$ " (Colluvium)

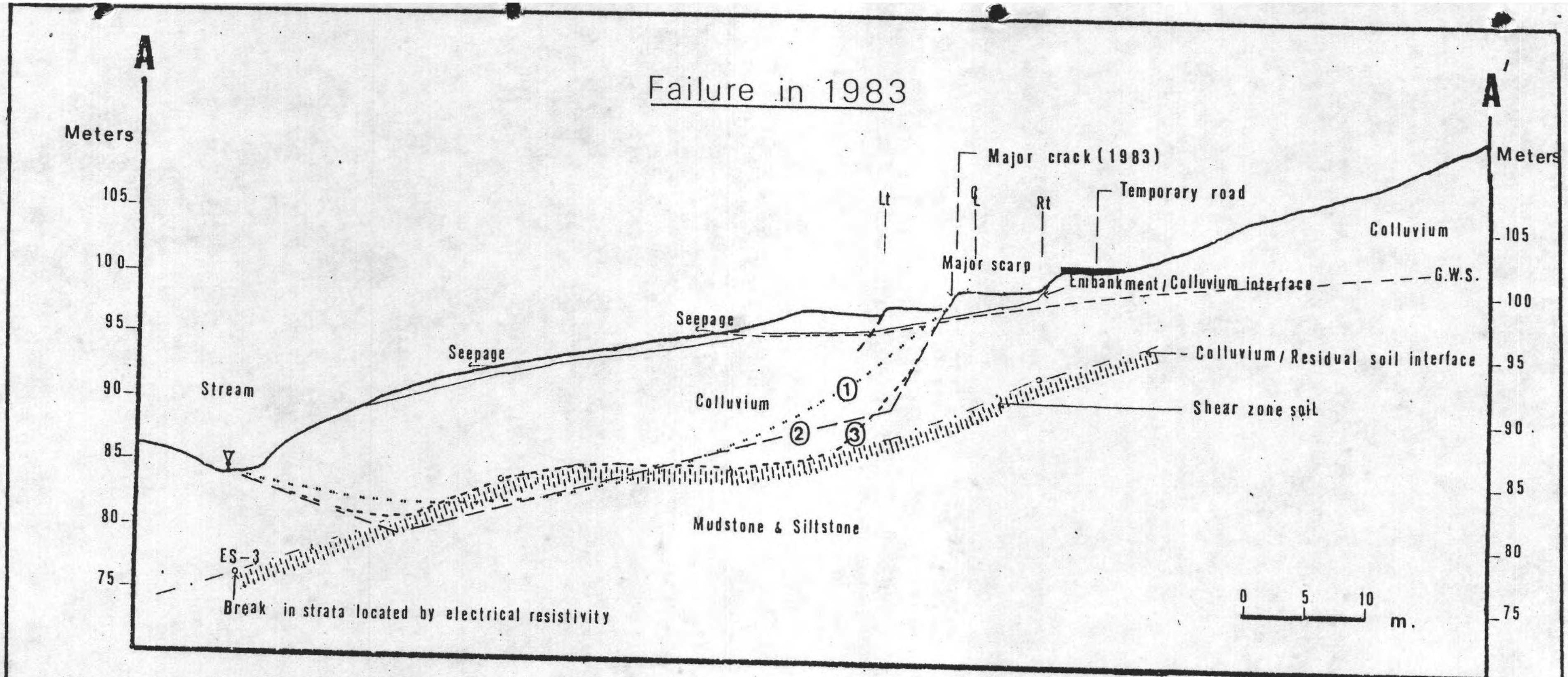
$\phi'_r = 21^\circ$ $c'_r = 9.16$ " (Col./Rs. interface)

2 Minimum factor of safety:

F.S. = 0.98

Failure surface	F.S.	Failure surface	F.S.
3 D	0.98	2 G	1.20
2 D	0.98	4 E	1.29
3 C	1.00	4 F	1.29
2 E	1.03	5 G	1.31
4 D	1.11	3 G	1.36
5 E	1.15	4 G	1.49
3 F	1.15	1	1.68

Figure 9.5 Summary of the stability analysis results by Janbu's (1973) method, for failure in 1983



Notes. 1 Shear strength parameters used:

$\phi' = 22$ $c' = 47.56$ kN/m^2 (Filled material)

$\phi' = 25^\circ$ $c' = 12.6$ kN/m^2 (Colluvium)

$\phi'_r = 21^\circ$ $c'_r = 9.16$ kN/m^2 (Col./Rs. interface)

Failure mode no.	Mode of failure	Method of analysis	F.S.	Deviation from Janbu's method
1	Circular arc	Simplified Bishop	1.04	6.12%
2	Regular sliding block	Wedge or sliding block	1.17	19.39%
3	Irregular surface	Janbu.	0.98	–

Figure 9.6 Analyses of slope failure in 1983 showing different critical failure surfaces and their factors of safety.

safety for the different analytical models are compared in Figure 9.6. All of these failure surfaces coincide at the ground surface with the major crack of the 1983 failure. However, the factor of safety derived from modes of failure of regular sliding block and circular arc are higher than that of the irregular failure surface.

The stability analysis results revealed that the critical piezometic level was at a level between 2-4 meters below the ground surface at the road centerline. All of the stability analysis results obtained from the different models of failure corresponded to the field observation. Because the residual shear strength exists along a thin weak layer at the colluvium-bedrock interface, the high calculated value of F.S. was occurred for the mode of failure of circular shape.

9.1.3 Analysis of failure for 1985-1986 failure.:

Two typical cross sections along C-C' and D-D'in Plate 6.2 were used for this stability analysis.

9.1.3.1 Ground water condition.: During the period of investigation, the data gathered from subsurface investigation and piezometic data indicated that the groundwater level was found within the gravel drained layer. This piezometic level was thus used to determine stability condition of this slope as shown in Figures 9.7 - 9.10. This piezometic level may not represent the highest groundwater table that exists within this slope during the heavy rain period, however.

9.1.3.2 Stability analysis for regular block.: The stability analysis of block sliding (Duncan et al., 1975) were performed. The results of analysis of both numerical and graphical techniques for the failure planes that gave the minimum factor of safety of 1.16 are present in Figure 9.7.

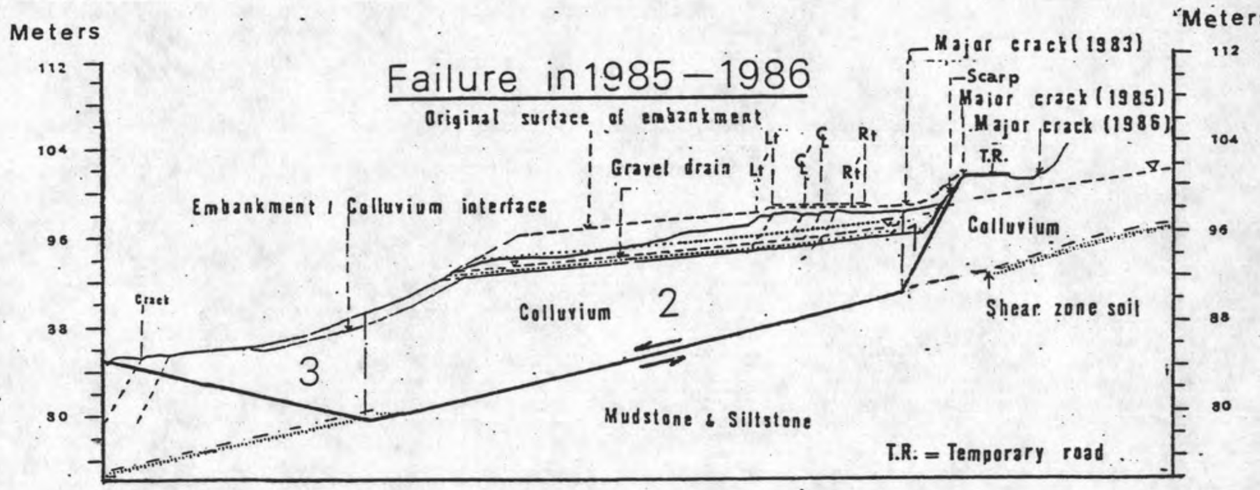
9.1.3.3 Stability analysis for irregular surface.: Seventy one and forty six trial failure surfaces for section C-C'and D-D' respectively were analysed by Janbu's (1973) method. From the stability analysis in section D-D', the calculated F.S. values on the failure surfaces that coincides with the major cracks of 1985 and 1986 failures are 0.79. The results of stability analysis by Janbu's method are summarized and presented in Figures 9.8 and 9.9. The computer calculation on the stability of slope for minimum F.S. are shown in Appendix G.

9.1.3.4 Comparison of the result for difference failure models.: The failure surfaces with the minimum factor of safety of the different analytical models along D-D' namely, circular arc, regular sliding block, and irregular surface, are compared, summarized and presented in Figure 9.10. All of these failure surfaces coincide at the groundsurface with the major crack of 1985 failure. Factor of safety for the mode of failure surface of circular arc and regular sliding block are high.

9.2 Sensitivity Analyses.

Sensitivity analyses were performed for different ground water levels to evaluate their influence on embankment stability. The study was done using the failure surfaces 3D and 4C, which are the

a)



Notes. 1 Shear strength parameters used:

$\phi' = 25^{\circ}$ $c' = 12.6$ kN/m^2 (Colluvium)

$\phi'_r = 21^{\circ}$ $c'_r = 9.16$ kN/m^2 (Col./Rs. interface)

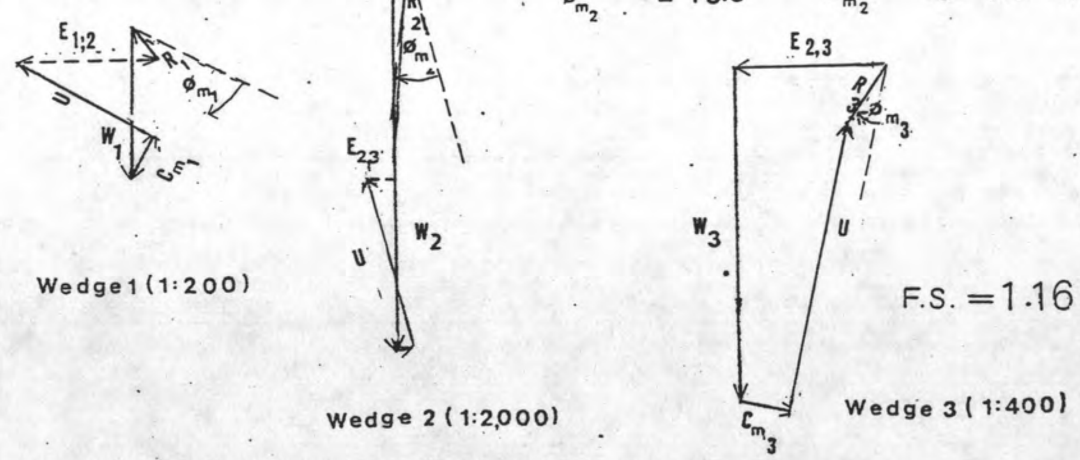
b)

Graphical method:

Assume F.S. = 1.16

$\phi'_{m_1}, \phi'_{m_3} = 21.9^{\circ}$ $C'_{m_1}, C'_{m_3} = 10.89$ kPa

$\phi_{m_2} = 18.3^{\circ}$ $C'_{m_2} = 7.9$ kPa



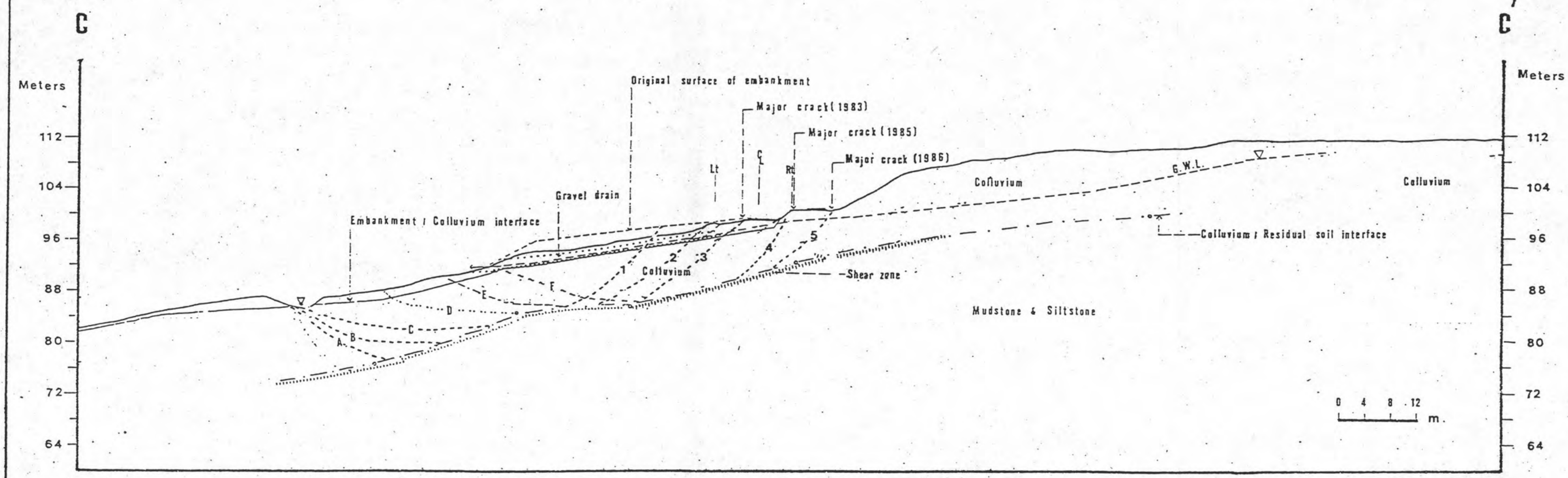
Numerical method:

Note: The computation of F.S. is presented in appendix G

Figure 9.7 Stability analysis by wedge method for failure in 1985-1986

a) The wedges to be solved for F.S. by numerical and graphical methods.

b) Force polygon for wedges.



Notes.

1 Shear strength parameters used:

$\phi' = 33^\circ$ $c' = 19.61$ kN/m^2 (Embankment)

$\phi' = 25^\circ$ $c' = 12.6$ kN/m^2 (Colluvium)

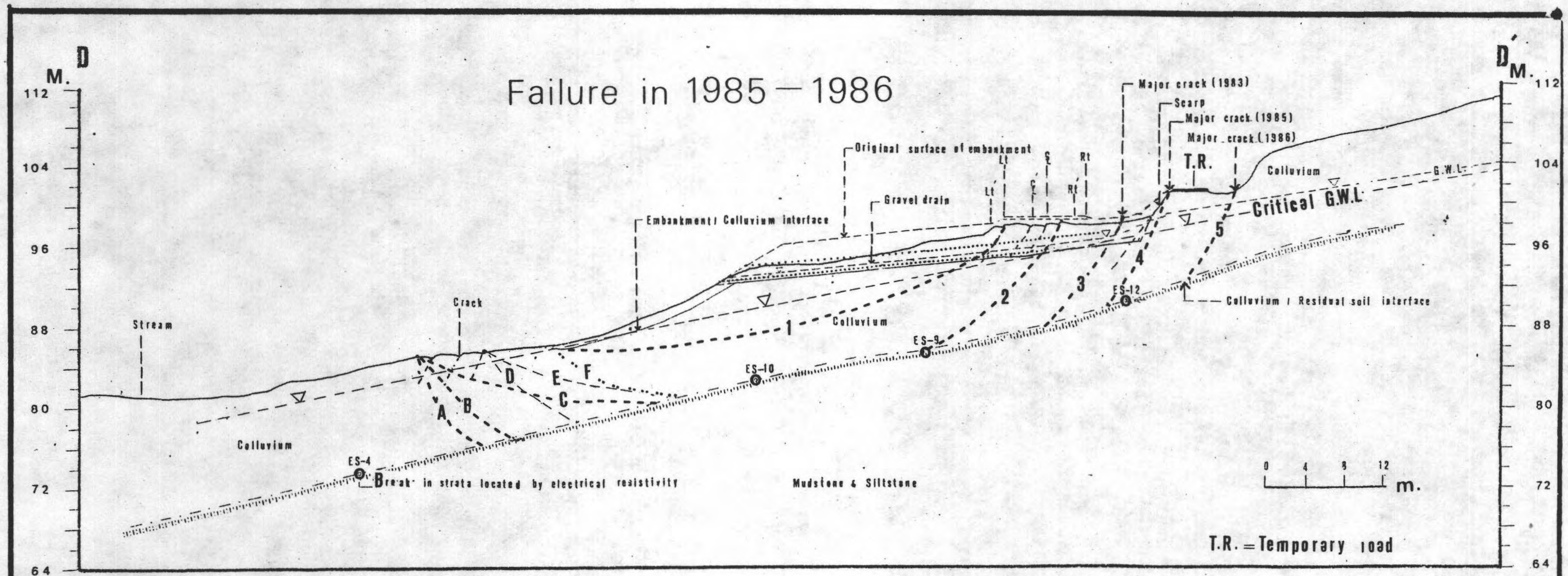
$\phi'_r = 21^\circ$ $c'_r = 9.16$ kN/m^2 (Col./Rs. interface)

2 Minimum factor of safety:

F.S. = 0.95

Failure Surface	F.S.	Failure Surface	F.S.
5C	0.95	3D	1.11
1C	0.96	5E	1.19
1B	0.97	1E	1.25
4B	0.99	3E	1.30
4C	1.00	4E	1.24
3B, 3C	1.02	5F	1.59
5A	1.04	4F	1.65
5D	1.05		

Figure 9.8 Summary of the stability analysis results by Janbu's (1973) method for failure in 1985-1986.



Notes. 1 Shear strength parameters used:

$\phi' = 25^\circ$ $c' = 12.6$ kN/m^2 (Colluvium)

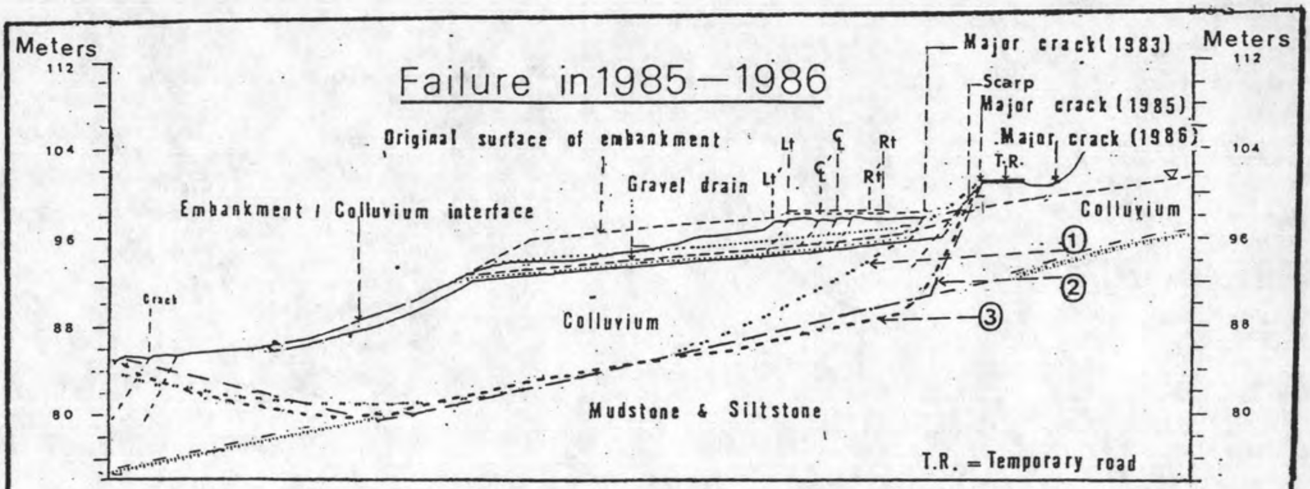
$\phi'_r = 21^\circ$ $c'_r = 9.16$ kN/m^2 (Col./Rs. interface)

2 Minimum factor of safety:

F.S. = 0.79

Failure Surface	F.S.
5D	0.79
4C	0.79
2B.	0.79
3E,4E	0.80
4D,4F	0.81
3D 3F,4B	0.82
3B	0.85
1	1.14

Figure 9.9 Summery of the stability analysis results by Janbu's (1973) method for failure in 1985-1986.



Notes. 1 Shear strength parameters used:

$\phi' = 33^\circ$ $c' = 19.61$ kN/m^2 (Filled material)

$\phi = 35^\circ$ $c = 0$ (Gravel drain)

$\phi' = 25^\circ$ $c' = 12.6$ kN/m^2 (Colluvium)

$\phi'_r = 21^\circ$ $c'_r = 9.16$ kN/m^2 (Col./Rs. interface)

Failure mode no	Mode of failure	Method of analysis	F.S.	Deviation from Janbu's method
1	Circular arc	Simplified Bishop	0.86	8.86%
2	Regular sliding block	Wedge or sliding block	1.16	46.8 %
3	Irregular surface	Simplified Janbu	0.79	–

Figure 9.10 Analyses of slope failure in 1985 - 1986 showing different critical failure surfaces and their factor of safety.

failure surfaces with the minimum factor of safety of the failures in 1983 and 1985 respectively. In the study, the road centerlines of each section were chosen as reference points.

9.2.1 Sensitivity analyses for failure in 1983.:

Table 9.1 shows factors of safety calculated for different groundwater level in slope.

Table 9.1 Factor of safety for different groundwater surface (G.W.S.), for failure in 1983.

Depth of G.W.S. from ground surface at reference point (m)	Factor of safety (Janbu's method)
2	0.98
4	1.23
6	1.65
8	2.06
10	2.24

From Table 9.1 the analysis results indicate that factor of safety for depth of groundwater level at the interface between upper soil of filled material and colluvium is 0.98. Thus, the critical groundwater level is 2 meters below ground surface of road centerline.

9.2.2 Sensitivity analyses for failure in 1985-1986.:

The failure surface 4C was chosen for sensitivity analysis. The variation in F.S. calculated for different groundwater levels in slope are summarized and presented in Table 9.2.

Table 9.2 Factor of safety for different groundwater levels (G.W.L.), for failure in 1985-1986.

Depth of G.W.L. from ground surface at reference point. (m)	Factor of safety (Janbu's method)
2	0.80
4	1.15
6	1.56
8	1.95
10	2.10

Again, the critical groundwater level is observed at the depth about 3 meters below ground surface at road centerline.

Table 9.2 shows that groundwater level is a critical factor in controlling the stability of slope. The factor of safety decreases as the water level rises. A plot of the depth to the groundwater versus factor of safety is shown in Figure 9.11.

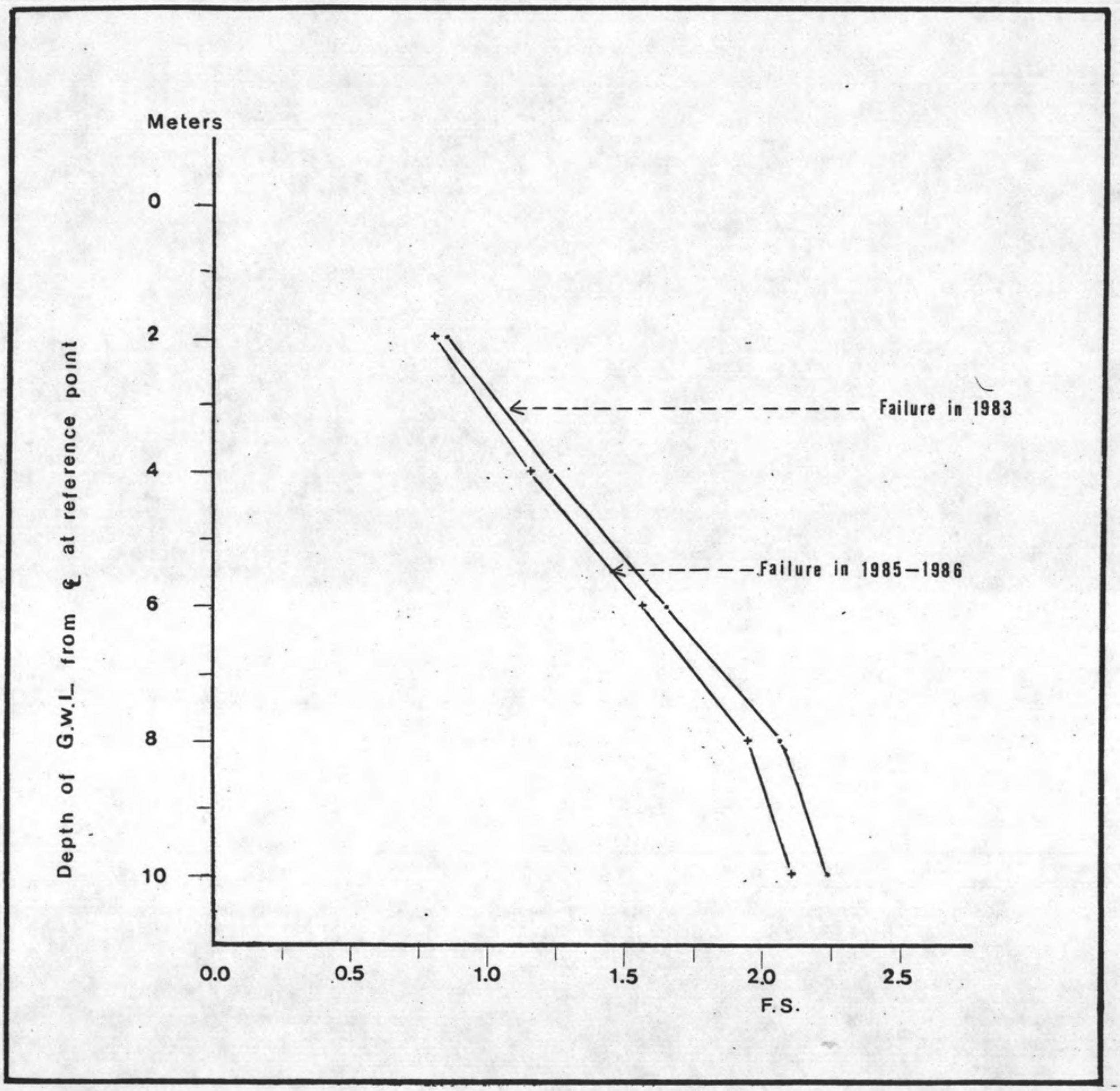


Figure 9.11 Variation of factor of safety to the depth to groundwater using Janbu's (1973) method.