From: Stig [redacted]
Sent: March-17-14 10:37 AM
To: Cheryl Blundon
Subject: Regarding stability of the North Spur, Muskrat Falls project

Ms Cheryl Blundon
Board Secretary
Public Utilities Board
Newfoundland, Canada

Dear Ms. Blundon

I have been informed by Mr Cabot Martin, (Luca Resources Inc.) that you need a directly addressed permission from the undersigned to enable publishing my presentation regarding possible hazards in respect of landslide stability along the North Spur of the Muskrat Falls Dam project.

Having no doubts about the relevance of my report to the Muskrat Falls Project, I do not object to your publishing it as you may find appropriate.

You are probably aware, that I have not claimed that the Muskrat falls project is an impossible or unrealizable enterprise.
Yet, I have considered it vital to emphasize that the risks related to the stability of the 'downstream ' side of the North Spur must be studied and analysed in a thorough and realistic way - particularly considering all types of possible 'progressive failure' formation such as ***downhill progressive landslides***, so called ***'bottleneck' slides*** and ***spreads***.
In soft (normally consolidated) sensitive clays, such as those in the North Spur, the first two of these categories are predominant.
However, in the *highly* over-consolidated clays in eastern Canada, *spreads* prevail.

As pointed out in my presentation, the conventional Limit State Plastic approach has little validity in respect of ***local*** (concentrated) ***triggering load effects*** for landslides potentially extending more than 50 to 70 metres.

It is evident from my list of references in the report, that progressive failure formation is a recognized issue also in Canadian research. (Leroueil S, Quinn P. and Locat, A.).

Best regards

Stig Bernander

A copy of this e-mail will be transmitted to Mr Cabot Martin, Luca Resources Inc., St Johns, NFL

Cheryl Blundon

From: Cabot Martin [redacted]
Sent: February-04-14 11:05 AM
To: Cheryl Blundon
Cc: Stig
Subject: Request to Add a Supplement to Pre-Hearing Conference Submission
Attachments: North Spur Landslides - Dr. Stig Bernander Januari 2014.pdf

Ms. Cheryl Blundon
Board Secretary
Public Utilities Board

Dear Ms. Blundon:

Attached hereto please find an Outline of Serious Concerns regarding landslide risks at the North Spur portion of the Muskrat Falls reservoir containment system by Dr. Stig Bernander of Sweden, a world recognized authority on landslides in sensitive clays such as found at the North Spur.

I wish to file this Outline as a supplement to, and in support of, the contention in my previously filed Pre-Hearing Conference Submission that in order to ascertain the reliability the Province's electrical system in a Post Muskrat world, the risk of a catastrophic landslide leading to a full breach in the Muskrat Falls reservoir containment system must be fully examined – which apparently it has not to date.

Any such breach could not only lead to a permanent "outage" at Muskrat Falls but could pose a very significant safety risk to downstream inhabitants.

Dr. Bernander's analysis was received by email yesterday (February 3) and I have his permission to file the same with the Board for the Pre-Hearing Conference (his email address and other contact information is contained in his Outline).

Dr. Bernander has been working on the North Spur issue since first becoming aware of the issue at the First International Workshop on Landslides in Sensitive Clays held at Laval University , Quebec City in October, 2013 when both the undersigned and SNC/Nalcor made poster presentations on the stabilization of the North Spur as part of the Muskrat Falls Project.

Dr. Bernander's presentation may be added to the Board's website with his personal contact info and email address omitted as is the Board's normal practise.

Yours truly,

Cabot Martin

OUTLINE of SERIOUS CONCERNS on the ADEQUACY of LANDSLIDE ANALYSIS at the NORTH SPUR, MUSKRAT FALLS (Januari, 2014)

By Stig Bernander, (Former adj. prof., Luleå Techn. University, PhD on '**Downhill Progressive Landslides in Long Natural Slopes**'. Former chief design engineer in Skanska West Ltd, Sweden)

Executive Summary,

There are some vital North Spur safety issues that I consider highly important. From what I have learnt so far about soil conditions and stabilisation measures in the North Spur, I am not confident that the potential risks of large slides in the downstream slope are safely taken care of..

In particular, I believe that the risk of downhill ***progressive*** landslide formation at the North Spur must be **thoroughly** investigated.

My points of view in this context are of a general character considering the fact that I still have no precise data regarding soil structure and soil properties in the North Spur. Furthermore, I have not performed any progressive analyses of my own in respect of possible slope failures in the down-slope direction. Hence, my comments will just reflect my some 40 years overall experience of landslides in normally consolidated very sensitive clays.

The following is a summary of the evidence pointing to the presence of serious, apparently unresolved safety risks associated with possible Downhill Progressive Landslide formation at the North Spur part of the reservoir containment system at the Muskrat Falls Hydro Development:

I) The features of the existing scars of extensive older 'bottleneck' landslides indicate the presence of normally consolidated, highly sensitive clays in the North Spur.

II) Considering the potential risk of possible downhill progressive landslides, triggered by relatively small load effects, should therefore be an absolute necessity.
The risk of serial retrogressive bottleneck slides should also be taken into account

III) The raised hazard, related to downhill progressive (brittle) failure formation in extensive landslides is not covered by the conventional values of safety factors, normally applicable to analyses based on the concept of Plastic Limit Equilibrium Failure.

IV) The shore-line of the down-stream water table of the tidal river does not represent ***any limit*** whatsoever to downhill progressive landslide progression.

V) The roughly 60 metres drop from the edge of the crest of the North Spur at Elevation ≈ +40 to the lake bottom elevation contour – **20** represents a mean slope gradient of about 12→ 13 %.

This is a remarkably steep gradient in a formation with massive layers of highly sensitive clays.

The risk of possible downhill progressive sliding caused by weight and disturbance related to the stabilization activities further up-slope should therefore be thoroughly investigated.

VI) The tidal river bottom from Elevation **–20** to Elevation **–50** forms a steep escarpment indicating the presence of firm soil material or rock.

However, the deep cavity in the tidal river bottom from Elevation **–20** down to below Elevation **–50** constitutes a specific element of risk considering its potential of absorbing enormous volumes of sliding soil before any build-up of passive earth resistance at the down-slope end of an on-going landslide can possibly form.

In spreads, or in possible serial retrogressive (bottleneck) slides, this condition could seriously affect the 'Retrogression Distance'. (Confer **Item 2** above about scars from bottleneck landslides.)

****

I hope that Points **I → VI** will lead to further appropriate studies based on ***progressive failure formation***, thereby considering the possible incidence of retrogressive spreads, bottleneck slides and downhill progressive landslides as well as apt associated safety measures.

A fuller explanation of these 6 points is attached.

OUTLINE of SERIOUS CONCERNS on the ADEQUACY of LANDSLIDE ANALYSIS at MUSKRAT FALLS (January, 2014)

Item 1 Use of appropriate safety factors – Progressive Failure vs Plastic Limit Model

It has been stated in this context that uncertainties in landslide modelling are taken into consideration by the application in North Spur stability analyses of safety factors (F_s) that are 30 → 50 % higher than 1, i.e. $1.3 < F_s < 1.5$.

This is generally a correct approach when the conventional method of analysis, based on the concept of the ***Limit Equilibrium Plastic Failure*** mode, is applied and considered to ***be valid.***

However, for ***Progressive Failure*** formation in ***long slopes*** with highly sensitive clay, the Plastic Limit Equilibrium Failure Approach (the PLEFA) is ***not applicable***, and for these landslides the safety factors are defined in a different way. (Confer comments on this issue in **Item 3.**)

Item 2 Evidence of *Progressive Failure* at the North Spur, Muskrat Falls: *'retrogression distances'* of previous landslides. Significance of large landslide scars in the northerly part of the North Spur. (Confer map shown on Appendix I.)

a) The phenomenon referred to by the term *'Retrogression Distance'* generallyapplies to ***retrogressive*** (*uphill progressive*) landslides – normally known in Canada as *spreads*.

In ***downhill progressive*** landslides, the ***final extent*** of the slide depends – apart from on slope geometry, soil properties and the nature of the triggering load condition – ***in particular*** on the progressive (brittle) failure mode as such.

The progression (the extent) of these slides ***can only be predicted*** by relevant methods of progressive failure analysis.

Confer e.g. References **(1)** to **(5)** below and Appendix II, (Table B III).
The abstract in Reference No **(4)** is especially instructive reading in this context.

b) The massive landslide scar in the NE part of the North Spur is of particular interest in the current context due to the fact that the contour lines for equal levels clearly indicate that this slide belongs to a category named 'Bottleneck' slides.

Such slides typically take place in *normally consolidated highly sensitive* clay formations in close vicinity of a ravine or a steep slope.
Bottleneck slides develop as ***serial retrogressive*** smaller slides, in which the disturbed sensitive (quick) clays 'liquefy' due to disturbance and ***flow away*** – usually down the escarpment or the steep slope.
Extremely large such slides have occurred in Norway, e.g. at Verdal, and at Rissa, (i.e. the third phase of the latter landslide). A large typical bottleneck landslide scar can be seen close to the river canyon of Slumpån in the Göta River valley, (Sweden).

The extremely long valley – some 1000 metres in length with three small lakes just west of the bottleneck landslide scar mentioned above – bears the features of an older bottleneck landslide, although in this case it is difficult to say whether the valley-like formation developed as a singular event or in multiple phases.

The importance of identifying these landslide scars as ***bottleneck*** slides lies in the fact that such slides clearly signify the presence of ***highly sensitive normally consolidated*** clays in the North Spur.

This indicates in turn that the other three somewhat smaller landside scars on the east side of the North Spur may very likely be ***downhill progressive*** landslides – considering that retrogressive landslides (spreads) are normally confined to areas with ***highly over-consolidated*** clays.

Confer **Item 3** for further information on these issues.

Item 3. <u>Has SNC performed any progressive failure analysis in the North Spur?</u>

It has been stated that the SNC analyses have been based on the conventional ***Limit Equilibrium Plastic Failure Approach*** (LEPFA) and that the uncertainty of this approach – in spite of the fact that the current conditions involve highly sensitive soils – is presumed to be balanced by the 30 → 50 % extra margins on the safety factor $F_s = 1$, corresponding to the failure condition.

Yet, safety factors in the order of 1.3 →1.5 are inadequate, as these values represent the safety margins that are normally stipulated for balancing various uncertainties in the conventional plastic assessment (LEPFA) of stability, applicable to landslides the extent of which should not normally exceed 50 → 60 metres for locally triggered loading effects in sensitive clays. (Cf Ref. (2), (4).

In the current case, however – i.e. for landslides in very sensitive clays, potentially extending ***hundreds of metres*** – these safety factors are totally ***irrelevant,*** as the study then has to be based on progressive failure analysis considering the possibility of brittle slope failure development.

Hence, the use of safety factors in the order of 1.3 →1.5, is not relevant in the current situation and that for the following reasons:

a) There exists no constant or fixed relationship between appropriate safety factors for *progressive* landslides (F_{progr}) and the apt f actors of safety when the analysis is based on LEPFA, i.e. on the conventional *limit equilibrium* approach ($F_{limit\ equ}$).

For instance, as shown in the appending Table B III (App. II, originating from Reference (3)), the ratio between the safety factors required ($F_{limit\ equ.}/F_{progr}$) for the studied specific loading conditions and type of geometry, can be as low as 0.288.
Yet, another kind of triggering load and another type of geometry would render different values of the ratio $F_{limit\ equ.}/F_{progr.}$ than those given in Table B III.

This means that the safety criteria required in a downhill progressive (brittle) failure event can be very ***different*** from those applicable to a situation, where the LEPFA approach is valid.

In fact, the prediction of stability in ***progressive*** slope failure analysis calls for at least ***two*** separate and ***differently*** defined failure criteria.

The degree of greater hazard associated with downhill progressive (brittle) failures has also been highlighted and dealt with in References (1), (2), (4), Locat A, (5), (6), Quinn P, (6), and Gylland A (6) and others.

b) The very fact that the clays in the North Spur appear to be normally consolidated as well as highly sensitive implies that it is ***not*** sufficient to study only the risk of ***upward progressive*** slope failures (or spreads).

As already pointed out in Item 2, downhill progressive landslides, triggered by an uphill disturbance, are likely to occur in the current types of clay.

The triggering load effect may then turn out to be astonishingly diminutive – such as a small fill, driving of a few piles, vibratory activity, a minor blasting effect or a light earthquake.

(For instance, the 600 metres long progressive landslide in Surte – a community just North of Gothenburg in western Sweden – was triggered merely by driving a few concrete piles for a family house in a critical up-slope location. (Cf References (2), (4)).

c) Moreover, it is vital to note that the presence of the lake shore-line further down the downstream slopes does not represent any kind of ***limit of progression*** in long downhill progressive landslides.

d) The risk of downhill progressive landslide formation must therefore be **thoroughly** investigated.

Progressive failure analysis may seem somewhat academic to many engineers in the consulting sector and probably few engineers in this sector actually apply progressive failure analysis in their habitual predictions of landslide hazard.

However, this cannot – ***under any circumstance*** – be a valid reason for not considering the possible incidence of downhill progressive failures with the associated significantly greater landslide hazards.

Many recent landslide investigations in Canada, Norway, Italy, Sweden and Switzerland have been, and are being, studied by applying progressive failure concepts.

For instance, the 500 m wide landslide at Småröd in western Sweden, (December 2006) was clearly explained, shortly after the slide event, in terms of progressive failure analysis by the author – the triggering cause being identified as a temporary earth fill saturated with water because of continuous raining.

Some seven months later, the triggering effect of the earth fill was confirmed by the **Independent Investigatory Group of the Swedish National Road Administration.**

The progressive failure analysis in 'Plaxis' – based on Finite Element Analysis (FEM) and additional soil investigations – was then carried out by G. Grimstad at NTNU, (Norwegian University for Technical and Natural Sciences), Trondheim, Norway.

Summary.

I) The features of the existing scars of extensive older 'bottleneck' landslides indicate the presence of normally consolidated, highly sensitive clays in the North Spur.

II) Considering the potential risk of possible downhill progressive landslides, triggered by relatively small load effects, should therefore be an absolute necessity.

The risk of serial retrogressive bottleneck slides must also be taken into account in this context.

III) The raised hazard, related to downhill progressive (brittle) failure formation in extensive landslides is not covered by the conventional values of safety factors, normally applicable to analyses based on the concept of the Plastic Limit Equilibrium Failure Approach.

IV) The shore-line of the downstream water table does not represent ***any limit*** whatsoever to downhill progressive landslide progression.

V) The roughly 60 metres drop from the edge of the crest of the North Spur at Elevation ≈ +40 to the lake bottom elevation contour – **20** represents a mean slope gradient of about 12→ 13 %.

This is a remarkably steep gradient in a formation with massive layers of highly sensitive clays.

The risk of possible downhill progressive sliding caused by weight and disturbance related to the stabilization activities further up-slope should therefore be thoroughly investigated.

VI) The lake bottom from Elevation –**20** to Elevation –**50** forms a steep escarpment indicating the presence of firm soil material or rock.

However, the deep cavity in the lake bottom from Elevation –**20** down to below Elevation –**50** constitutes a specific element of risk considering its potential of absorbing enormous volumes of sliding soil before any build-up of passive earth resistance at the down-slope end of an on-going landslide can possibly form.

In spreads, or in possible serial retrogressive (bottleneck) slides, this condition could seriously affect the 'Retrogression Distance'. (Confer **Item 2** above about scars from bottleneck landslides.)

CONCLUSIONS

There are some vital North Spur safety issues that I consider highly important
From what I have learnt so far about soil conditions and stabilisation measures in the North Spur, I am not confident that the potential risks of large slides in the downstream slope are safely taken care of.
In particular, I believe that the risk of downhill progressive landslide formation at the North Spur must be **thoroughly** investigated.

The possibility of bottleneck slides and the associated retrogression distance should also be considered.

My points of view in this context are of a general character considering the fact that I still have no precise data regarding soil structure and soil properties in the North Spur. Furthermore, I have not performed any analyses of my own in respect of possible progressive slope failures in the down-slope direction. Hence, my comments merely reflect my Hence, my comments merely reflect my about 40 years overall experience of landslides in normally consolidated very sensitive clays.

Based on what I have seen, the evidence points to the presence of serious, apparently unresolved, safety risks associated with possible Downhill Progressive Landslide formation at the North Spur part of the reservoir containment system at the Muskrat Falls Hydro Development:

Author:
Stig Bernander, (Former adj. prof., Luleå Techn. University, PhD on **'Downhill Progressive Landslides in Long Natural Slopes'**. Former chief design engineer in Skanska West Ltd, Sweden)

[redacted]

References:

(1) Bernander. Papers on Downhill Progressive Landslides (ICSMFE **1981**, 1985, 1989. ISL 1984. NGM (1984, 1988)

(2) Bernander. 2000:16 * ISSN: 1402– 1757 * ISRN: LTU –LIC: – – 00/16 – – SE

(3) Bernander. 2008:11| ISSN: 1402–1528| ISRN: LTU –FR – – 08/11 – – SE

(4) Bernander. (PhD 2011) ISSN: 1402–1528 www.ltu.se PhD
ISBN : 978–91–7439–283–8

(5) Locat A, Leroueil S, Bernander S, Demers D, Jostad H P and Quebh L (2011). Progressive Failures in Eastern Canadian and Scandinavian Sensitive Clays. Canadian Geotechnical Journal 48 (11): 1696 – 1712. (Chapitre 2)

(6) Research and papers after 2001 on downhill and uphill progressive landslides

Canada: Leroueil, S (2001, 2004,).- Locat, A (2007). - Quinn, P., Diederichs, M.S., Hutchinsson, D.J. and Rowe, R.K. (2007). - Quinn, P. (2009) – Locat, A (2012)

Italy: Urciuoli, G. (2002). - Urciuoli, G., Picarellli, L and Leroueil, S. (2007)

Norway: Andresen, L. and Jostad, H.P. (2004) and (2007). -Thakur, V. (2007). Nordal, S, (2008). - Grimstad, G. (2008).- Grimstad et al, (2009).- Gylland A et al (2009) and (2010). Jean-Sebastien L'Heureux (2013)

Sweden: Bernander, S. (2008, 2011)

Switzer-land: Saurer, E. (2009). - Puzrin, A.M. and Germanovitch, L.N. (2005). - Puzrin et al, (2006 and 2010). - Saurer, E. and Puzrin, A.M. (2007, 2008, 2010).

Interesting State-of-the Art reviews are given in the cited theses by Thakur (2007), Quinn (2009) and Saurer (2009).

Appendix I

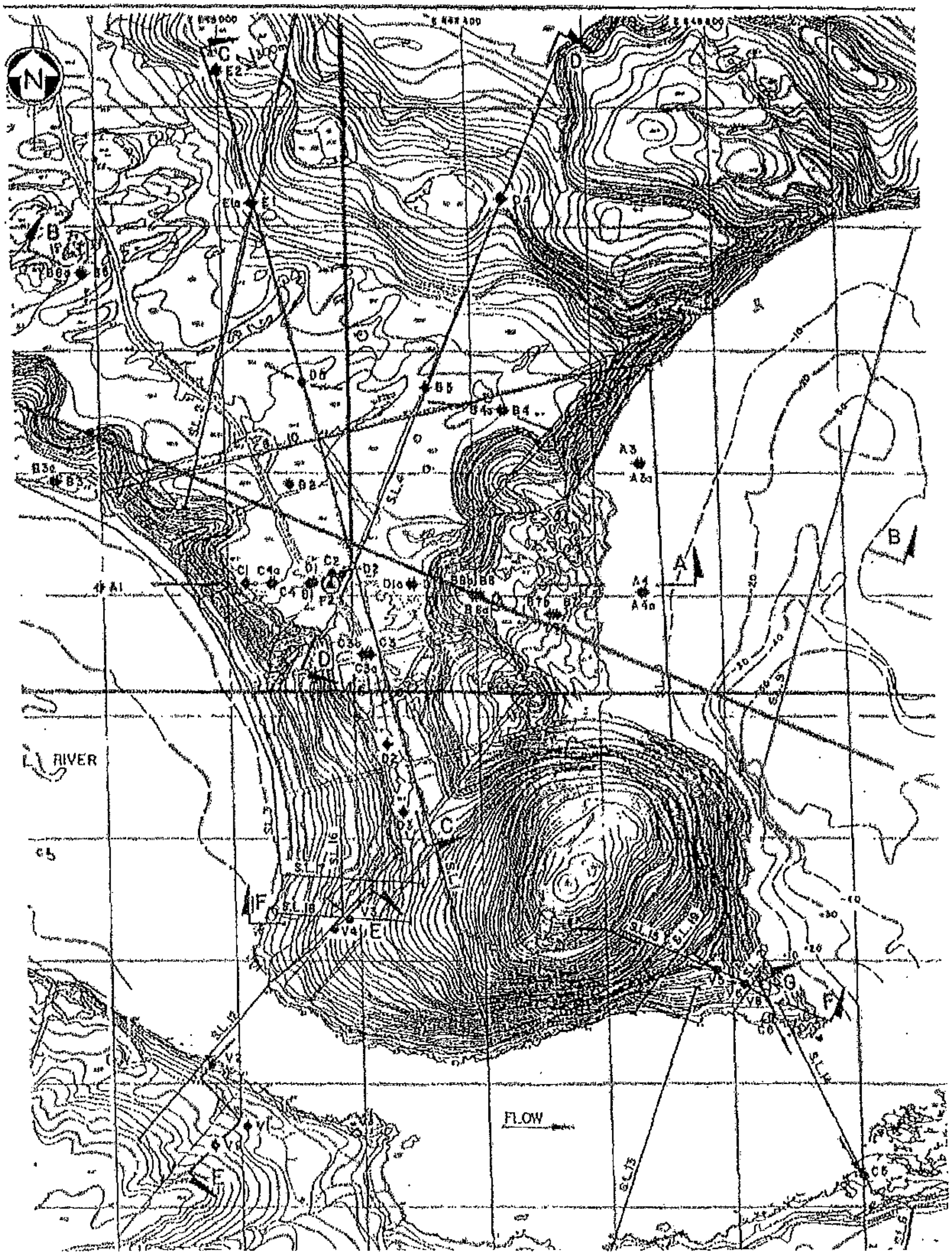

Table B.III - Downhill progressive slide - triggering loads -
Comparison of slope hazard based on PrFA analysis and
slope hazard based on conventional (IPFA) analysis.

2009 05 22
File: Triggering load - Synopsis II
Author: Stig Bernander

Legend: c = Peak shear resistance
c(lab) = Laboratory shear strength
c(R) = Residual resistance
τo = in situ shear stress

dn = Down-slope displacement at x = L
L = Influencial length of force N1
qcrit = Ncrit/H
τ(el) = Elastic limit

Safety factor based on ideal- plastic equilibrium analysis of a slopeof length L.

	Input data Depth to failure surface H = 20 m									IPFA analysis			Results from IPFA analysis #				Conventional safety factor	Progressive f. PrFA analysis #		
Case reference number	Gradient (Gr) tan(Gr)	In situ shear stress To kPa	Peak shear resistance kPa	Lab shear resistance kPa	Assoc. shear deformation %	Elastic limit τ(el) kPa	Resid. shear resist. Cr/Cfab 1	Resid. shear resist. Cr kPa	Density of clay g kN/m3	Ep-Ea =4H c kN/m	H m	sin Gr 1.00	qr kN/m2	Max. height of fill m	Fp = Qcrit/q kN/m2	q kN/m2	Fc	Qcrit kN/m2	x = L (crit) at Ncrit m	[illegible]
Case 1	0.050	15.98	30	25	3.0	16	0.400	10.0	16.0	2000	20.0	0.0499	150,43	8.36	1.081	18.0	2.23	19.5	111.8	0.484
Case 2	0.060	19.17	30	25	3.0	16	0.400	10.0	16.0	2000	20.0	0.0599	132.88	7.38	0.887	18.0	1.91	16.0	112.7	0.464
Case 3	0.070	22.35	30	25	3.0	16	0.400	10.0	16.0	2000	20.0	0.0698	114.98	6.39	0.645	18.0	1.67	11.6	112.9	0.385
Case 4	0.080	25.52	30	25	3.0	16	0.400	10.0	16.0	2000	20.0	0.0797	97.30	5.41	0.391	18.0	1.53	7.0	104.0	0.256
Case 4a	0.080	25.52	30	25	3.0	16	0.400	5.0	16.0	2000	20.0	0.0797	97.41	5.41	0.363	18.0	1.55	6.5	100.0	0.235
Case 5	0.050	15.98	30	25	3.0	16	0.600	15.0	16.0	2000	20.0	0.0499	153.46	8.53	1.226	18.0	2.20	22.1	118.5	0.557
Case 6	0.060	19.17	30	25	3.0	16	0.600	15.0	16.0	2000	20.0	0.0599	134.77	7.49	0.994	18.0	1.88	17.9	119.2	0.528
Case 7	0.070	22.35	30	25	3.0	16	0.600	15.0	16.0	2000	20.0	0.0698	115.82	6.43	0.713	18.0	1.65	12.8	119.2	0.433
Case 8	0.080	25.52	30	25	3.0	16	0.600	15.0	16.0	2000	20.0	0.0797	97.14	5.40	0.432	18.0	1.50	7.8	110.3	0.288
Case 9	0.050	15.98	30	25	3.0	16	0.800	20.0	16.0	2000	20.0	0.0499	154.84	8.60	1.425	18.0	2.19	25.6	121.6	0.651
Case 10	0.060	19.17	30	25	3.0	16	0.800	20.0	16.0	2000	20.0	0.0599	137.31	7.63	1.176	18.0	1.85	21.2	127.9	0.636
Case 11	0.070	22.35	30	25	3.0	16	0.800	20.0	16.0	2000	20.0	0.0698	117.26	6.51	0.845	18.0	1.64	15.2	130.1	0.526
Case 12	0.080	25.52	30	25	3.0	16	0.800	20.0	16.0	2000	20.0	0.0797	96.87	5.38	0.505	18.0	1.46	9.1	120.8	0.346
Case 13	0.050	15.98	30	25	3.0	16	0.900	22.5	16.0	2000	20.0	0.0499	100.00	5.56		18.0		25.6		
Case 14	0.060	19.17	30	25	3.0	16	0.900	22.5	16.0	2000	20.0	0.0599	100.00	5.56		18.0		21.1		
Case 15	0.070	22.35	30	25	3.0	16	0.900	22.5	16.0	2000	20.0	0.0698	118.50	6.58	0.956	18.0	1.58	17.2	139.4	0.605
Case 16	0.080	25.52	30	25	3.0	16	0.900	22.5	16.0	2000	20.0	0.0797	96.64	5.37	0.568	18.0	1.43	10.2	129.7	0.398
Mean values															0.87		1.87			0.49
Deviations - max/min	%																		34.2	-51.5
																				0.361

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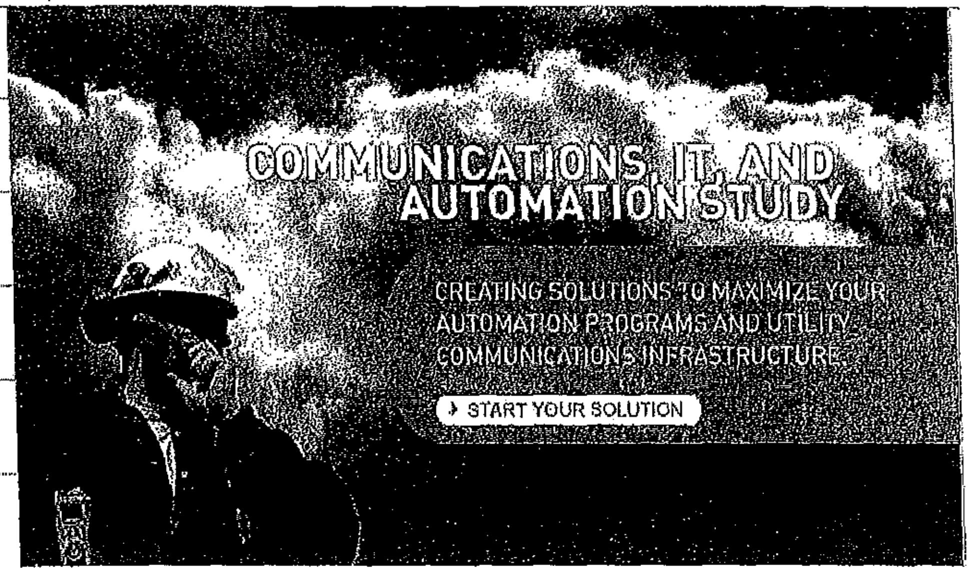

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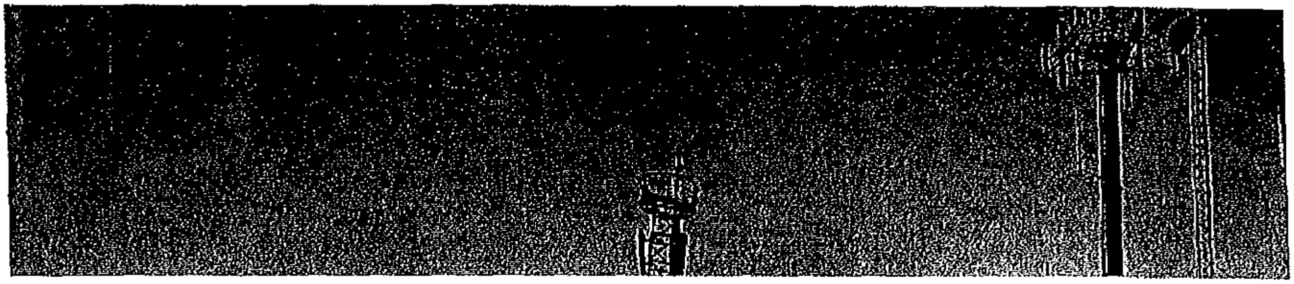

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