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GEOTECHNICAL REPORT

ABBOTSFORD LANDSLIDE

prepared for

THE EARTHQUAKE & WAR DAMAGE COMMISSION

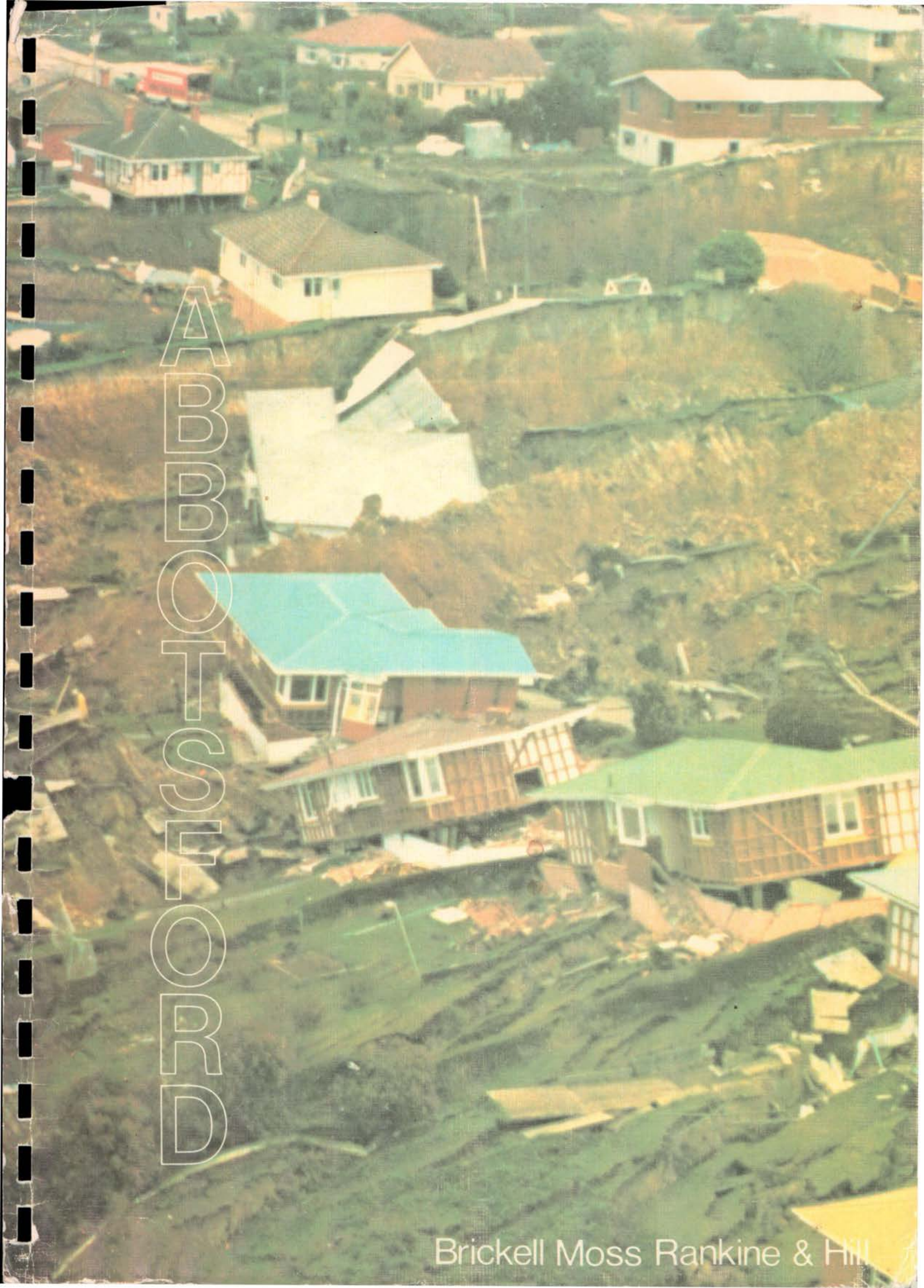
by

BRICKELL MOSS RANKINE & HILL

CONSULTING ENGINEERS

REF. 51118

November, 1979



ABBOTSFORD

Brickell Moss Rankine & Hill

TABLE OF CONTENTS

Page No.

Page No.

APPENDIX B CONT'D

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November 23, 1979

The Secretary,
Earthquake & War Damage Commission,
P.O. Box 5038,
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WELLINGTON.

Attention: Mr J.L. Gill

Dear Sir,

Geotechnical Report
East Abbotsford Landslide
Green Island, Dunedin

1.0 INTRODUCTION

At your request of June 27, 1979 we have carried out an investigation into the nature and possible causes of the above landslide. Our investigation has been carried out in close cooperation with E.R. Garden & Partners, Consulting Engineers of Dunedin, and the New Zealand Geological Survey, Dunedin.

At various stages of the investigation and subsequent to the main failure of 8 August 1979, we have reported both verbally

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and in writing on specific matters as they have arisen. In addition to carrying out the investigation into the nature and cause of the slip, we also endeavoured to assist when requested, the above-mentioned parties with engineering advice on the behaviour of the mobile slip mass up to the time of final failure and subsequently during remedial works.

Copies of preliminary reports are attached as Appendix C.

2.0 GENERAL TOPOGRAPHY

The large landslip, which became apparent during June and July and failed on August 8, 1979, occurred on the block of land located east of Christie Street in the north eastern portion of Abbotsford. The location of Abbotsford is indicated on the attached Plate 1, Locality Plan. The location of the landslide (referred to here as the East Abbotsford Landslide) with respect to nearby features is shown on Plate 2A, Site Plan - Abbotsford area.

The terrain in the area comprises a broad ridge rising northward away from Neill Street and extending approximately one kilometre to the hill top just north of Abbots Hill Road. The western margin of the ridge is defined by the edge of a broad valley, considered to be an ancient slip (West Abbotsford Landslide), while the eastern margin is abruptly terminated by the deeply incised stream valley of Miller Creek. Natural drainage paths on the ridge appear to extend more or less in a southerly direction from Abbots Hill Road to approximately the central portion of Christie Street. The eastern drainage path (East Christie St Stream) then extends south-eastward off the the ridge following Christie Street down to Miller Park.

Previous geological writers have discussed the instability of the area generally and more particularly the susceptibility of the Abbotsford Formation to failure. The Abbotsford Formation is known for its tendency to sustain failures even on very shallow slopes. Beneath the Christie Street - Miller Park area, the top of the Abbotsford Formation appears to dip south-eastward at a slope of approximately 7 degrees.

4.0 HISTORY OF AREA STABILITY

There appears to be considerable surface evidence in the general Abbotsford area of extensive landslides in geologically recent times. Close to the subject site, there is evidence of two large landslips; one being located in the West Abbotsford area and the other being the Sun Club slide located immediately north-east of the Mitchell Street area. The precise age of these slides is not known, but according to the New Zealand Geological Survey, the West Abbotsford slide is probably in the order of 9000 years old. The Sun Club slide appears to be younger than the West Abbotsford slide.

Since European settlement of the Abbotsford area, there appears to have been a history of landslips in this region. Benson (1964) details several instances of slipping. More recently, significant areas of slipping have occurred in the region. Over the last 10 years there has been an active but relatively slow-moving extensive slip on the hill slopes to the south of the Abbotsford area which has over a period of time affected a number of houses. During the construction of the Motorway (No. 1 State Highway) through Abbotsford in 1968, a part of the ancient West Abbotsford Landslide was reactivated; this movement was apparently arrested by replacing excavated material with fill which had originated from the former quarry site (Harrisons Pit).

The subject slip mass was confined to the eastern side of the ridge, the head scarps extending across Edward and Mitchell Streets (east of Christie Street), through the Education Board property (to the north of Mitchell Street), north-eastward into rural land and then eastward down into the head of Miller Creek. The eastern margin of the slip appears to have generally followed down Miller Creek, approximately through the toe of an earlier slip mass within the Sun Club property, and then across the outer edge of the former quarry floor (Harrisons Pit). The southern and south-western margins appear to have been confined to the incised stream valley (lower portion of East Christie St Stream) parallel to the central portion of Christie Street.

3.0 GEOLOGY

The geology of the Abbotsford area comprises a series of relatively weak, gently dipping sedimentary formations of Tertiary age. The upper surfaces of the partially eroded ridge in the locality of Christie Street comprise a layer of silty clay soils, presumably the remnants of weathered loess, overlying a silty boulder formation. This latter poorly-sorted material is interpreted as comprising colluvium which appears to rest as a variably thick capping on an eroded upper surface of the Green Island Sand Formation. The Green Island Sand Formation was found to vary in thickness from 0 to 12 metres over the subject slip area, with a general trend of increasing thickness towards the south-east (i.e. towards Armstrong Lane). The Green Island Sand overlies the Abbotsford Formation which, in the area investigated, appears to have a predominantly sandy upper zone. Interbedded in both the Green Island Sand and the Abbotsford Formation are thin layers of fine grained silt and clay. These layers appear to be localised and not necessarily continuous.

4.1 Aerial Photographs

A study of available aerial photographs, both stereoscopic pairs and enlargements, was carried out in order to examine the course of development on the affected land and consequent changes in the general topography.

The 1942 photographic coverage of the area (Plate 5) showed Christie Street extending up the hillside as far as Edward Street. Edward Street was only partially formed east of Christie Street and more fully formed to the west. Housing was centred largely upon the lower portion of Christie Street and Neill, John and Penrich Streets. The Miller Park rugby ground appears to have been developed, but the present day soccer field was only a rough paddock. A small quarry face was apparent at the head of Armstrong Lane and appeared to be restricted virtually to the immediate vicinity of the present-day spray painter's shed. The hill slope beyond the small quarry extended up as a steep natural slope to form a continuation of the main ridge which extended back towards the present Charles and Gordon Streets. Immediately to the north of Armstrong Lane, the crescent-shaped outline of the Sun Club slide was evident. In addition, west of the ridge which Christie Street climbs, the steep side and head scarps of the ancient West Abbotsford Landslide were evident. Much of this latter slip area was residentially developed.

1947 photos indicated that little in the way of further development had taken place upon the Christie Street ridge area between 1942 and 1947. Several houses had been constructed by this stage along Edward Street and two only on the east side of Christie Street. The course of the stream down the ridge line was evident across Edward Street, down lower Christie Street and across Miller Park. The quarry located near the head of Armstrong Lane was still, at this time, a relatively small excavation, not substantially different from the 1942 condition.

In the 1960 photo coverage, Christie Street had been extended beyond Edward Street, up to virtually its present day position. Percy Street formation showed up, as did Mitchell Street. At this stage however there was no apparent residential development on Mitchell Street east of Christie Street. The small soccer field located immediately west of Armstrong Lane had been developed.

By March 1962, substantial residential development had taken place along Edward Street. Earthworks for the formation of Gordon and Charles Street had been carried out, but no buildings had been constructed along these two streets. The quarry at the head of Armstrong Lane, involved a relatively small area. The spray painter's shed had been constructed by this time. The hill slope immediately around the head of the quarry had been partially stripped of vegetation, presumably in preparation for further excavation. The quarry workings however did not extend north of a line projected east from Charles Street.

By 1970, substantially the entire quarry face at Harrisons Pit had been excavated and benched to resemble closely the pre-slip condition of 1979. We understand from the Ministry of Works and Development that the quantity of material removed was in the order of 300,000 m^3. By this time Mitchell Street appeared to be approximately half residentially developed and only the upper portion of Gordon Street was occupied. There was no residential development over the lower end of Gordon Street or over any of Charles Street.

The topography prior to the subject slip, as at July 1979, is shown on Plate 2B, Site Plan - East Abbotsford.

4.2 History of the Slip

As from June 1, 1979, a tension crack extending more or less in a straight line across the eastern limbs of Mitchell and Edward Streets became discernible. The development of this crack was heralded by gradually increasing structural damage to homes and services overlying the path of the crack. Within two weeks a depressed zone (graben) developed over a width of some 8 to 12 metres. By the end of June one property down near the bottom of Christie Street (No. 5 Christie Street) had suffered serious structural damage and was consequently evacuated. By early July the tension cracks in the ground had progressed beyond the residential area on the north side of Mitchell Street, into the Education Board land and northward into the neighbouring rural area. By the end of July this feature formed a graben some 12 to 14 metres wide bounded by two steep tension scarps. The graben had sunk by varying amounts below the level of the adjoining ground surface. By this time all the homes straddling the slip had suffered severe structural damage. During July secondary cracking within the block was developing on the southern side of Charles Street, severely affecting two residences.

Prior to June 1, 1979, we understand that there were some earlier indications of structural damage within the zone of the tension cracking. Several reports had been made of cracking within concrete floor slabs and foundation walls at No. 16 Mitchell Street and No. 11 Edward Street during October - November 1978. As evidenced by paint-infilled fine cracks (repainted in 1974), it is considered that No. 16 Mitchell Street registered very minor damage sometime prior to 1974.

Another indication of possible movement within the affected area appears to be associated with the house at No. 5 Christie Street, which ultimately proved to coincide with the toe of the slip mass. In April 1972 this house was inspected, as a claim for landslip damage had been lodged. We understand that damage to the structure at that time was somewhat irregular and, as no visible signs of a landslip were apparent, the damage was put down to settlement. Based upon the appearance of the foundations prior to demolition in July 1979, there appeared to have been considerable repacking of the external foundations and piers beneath the northern half of house, suggesting a continuing problem of uplift. The damage, evident immediately prior to demolition in July 1979, was obviously caused by the northern side of the house being lifted while the southern side was being pushed into the ground.

We also understand that from a survey carried out on 27 June 1979, existing survey marks were found to have moved. The displacement we understand had been in a south-easterly direction and was in the order of 300 mm since the marks had last been surveyed on various dates between 1961 and 1977.

We understand that the first substantial indications of the landslide movement, observed on 1 June, were broken services in both Edward and Mitchell Streets. Soon minor cracking, within internal linings and brick exteriors of houses, became increasingly evident, particularly in No's 12, 15 and 16 Mitchell Street and No's 11 and 14 Edward Street. Once a survey control system had been established, we were told that the rate of movement in the Mitchell/Edward Street area was found to be in the order of 3 to 5 mm per day by the middle of the month and by the end of June it had increased to about 8 mm per day.

By 4 July (see Plate 6A), in addition to the obviously increasing damage to the houses previously mentioned, the roads adjacent to these properties both had pronounced vertical displacements. Indication of the slip movement within the ground surface was noticeable chiefly around the vicinity of the affected structures, with some relatively fine soil cracks between. Some cracking in the ground surface had extended just across the residential land into the Education Board property to the north. Some ground distortion was evident within the kerbing on the western side of Christie Street below Penrich Street. Structural damage had by this time occurred along the northern side of No. 5 Christie Street.

By 24 July (see Plate 6B) the main tension crack had developed markedly, with a virtually continuous line extending through the residential sections on Edward and Mitchell Streets, the Education Board property and into the Silver Peaks County rural land to the north. The inner edge of this tension zone (combining to form the graben) had not developed significantly at this stage. Some secondary ground cracking was evident across the southern margin of the intersection of Charles and Gordon Streets. Structural damage was occurring to the property situated on the lower west side of Gordon Street as a result of this secondary ground cracking. A strongly defined crack had developed across the roadway of Christie Street at its intersection with Penrich Street. Severe cracking and over-riding of the kerb on the western side of Christie Street, below Penrich Street and above John Street, suggested compression and shearing movement in this area. Significant uplift was evident beneath the northern side of No. 5 Christie Street, and the line of this ground deformation had extended eastward across the section, across the lower slopes of No. 66 Neill Street, and across the north-western corner of the neighbouring soccer field. The uplifted side of this zone of deformation appeared to be a compression roll, particularly on the steeper terrain of No. 66 Neill Street. Similar compression rolls in the ground surface had developed diagonally across the upper quarry floor. Several ground cracks were also evident in the driveway leading up to the Sun Club. By this date (24 July) movement across the tension crack at Mitchell and Edward Streets was reported to us at some 20 mm per day.

As indicated on Plate 6C, a well defined graben (averaging some 12 metres in width) had formed over most of the length of the tension crack by 1 August. Vertical displacement of the graben varied, but an average movement of something like 1 metre had occurred resulting in major destruction to those structures located within its path. The upper (northernmost) extent of the visible ground cracking had curved north-east, towards the terrain bordering the northern portion of the Sun Club. Extensive shearing was evident across Christie Street immediately below Penrich Street, and the crack across the Penrich/Christie Street intersection had enlarged significantly and was requiring daily infilling. The graben, across both Edward and Mitchell Streets, was requiring continuous infilling in order to maintain vehicle access. Secondary cracking within the main block (on lower Gordon Street and Charles Street) had developed markedly, with two vacated houses now seriously distorted. The quarry floor at the upper level had by now a series of compression rolls developing more or less parallel to and along the line of the two lowest bench levels. In addition, other tension cracks had developed more or less transverse to the compression rolls on the outer edge of the quarry's northern embankment. Pronounced ground cracks had developed along the driveway to the Sun Club, beneath the old garage structure, and extended in a discontinuous line northward, then spread as an en-echelon formation more or less in a direct line uphill and in a generally western direction along the northern margin of the former landslip mass. A series of fine crazed cracks appeared on the stripped surface of the lower quarry face in the vicinity of Boring B2 (see plate 2B for boring locations). The seemingly irregular pattern of cracking in the wet sand at this location suggested that the floor of the quarry was commencing to heave. As at 1 August, the rate of movement across the major control points along Edward and Mitchell Streets had increased to some 100 mm per day.

We understand that the rate of movement generally kept increasing steadily up to approximately 290 mm per day, this reading being recorded on the evening/early morning of 7/8 August immediately prior to the major movement.

4.3 Main Movement of August 8, 1979

At about 9 p.m. on 8 August, the large block of land situated to the east of Christie Street underwent a rapid mass movement and was displaced some 50 metres away in a south-easterly direction (see Plates 4 and 6D). The movement of this predominantly intact block took place largely over a period of an hour and appeared to be in the nature of a deep translational slide, with secondary rotational slumping in the area of the headscarp. At the toe of the slide, there was considerable compressional heave.

The majority of residential damage occurred within the zone of widening, bordering the headscarp, where a series of rotational blocks rapidly developed. Generally these rotational slump blocks paralleled the primary tension scarp. Other lesser damage did occur along the fringe areas of the lower compression zone, and within the relatively intact main block where extensive secondary cracking occurred.

4.4 Post Failure Observations

The plane of the slide movement appears to have closely paralleled the top plane of the Abbotsford Formation. The slope of the upper surface of the Abbotsford Formation towards the quarry floor was in the vicinity of 7° (refer Plate B-1). During the course of the build-up in movement and the final main movement, the upper crust of loess and boulder clay colluvial soil remained remarkably intact. The mass of land involved in the slipping was translated some 50 metres in a south-easterly direction towards Miller Park. There appears to have been no significant rotation within the bulk of the upper soil mass. After the failure, levels taken immediately west of the failed block and at the end of Charles Street give a difference in level equating with a movement down a plane inclined (below horizontal) at approximately 7°. Measurements show that the Sun Club area (northern) block moved less distance relative to the main (southern) block, with a minor shear zone of differential movement in between these two blocks.

At the lowest portion of the slip toe (i.e. on the soccer field and southern half of Miller Park), the slip advanced across the near-level ground as an earth flow. This material appeared to comprise fine silty sand with a very high water content. Materials exposed on the ground surface within the former quarry floor comprised principally fine to medium sand. The vertical uplift over the quarry floor varied from some 5 metres over the lower level of Harrisons Pit (south end) to some 20 metres on the upper quarry level. Within the Sun Club property itself, portions of the entrance driveway and other areas located approximately on top of the former slip toe zone, were uplifted by some 10 to 12 metres. The movement within the Sun Club property is very confused and the overall pattern on lower portions of the movement has not, as we understand, yet been completely defined. It would appear that the Clubhouse was rotated but not significantly uplifted. During the process of apparent squeezing out (from beneath the sliding mass) of the sand mass at the quarry floor, the cut faces and intervening benches of the quarry remained remarkably intact. Survey data and photographs suggest that there was a tendency for the quarry face to have rotated with the failure, with the former near level bench lifted and tilted back into the face. Generally the maximum zone of uplift appeared to be near the central portion of the whole slide mass base, i.e. at the northern portion of the quarry entrance way to the Sun Club. In front of the Sun Club entrance, the slip appears to have extended further eastward than at any other location.

On the upper surface of the slide mass, particularly in the vicinity of Charles and Gordon Streets, extensive shear cracks had developed through the ground and these shear cracks had aligned NW-SE, approximately parallel to the southwestern margin of the slide along Christie Street. (These cracks if left untreated and open could continue to be active and may ultimately contribute to partial disintegration of the remnant mass of land. However extensive earthworks in the area have significantly lessened this possibility). Just prior to the main failure and immediately following it, the majority of the houses on the north side of Charles Street were virtually undamaged.

The topography after the subject slip, as at August 15, 1979 is shown on Plate 3, Post - Slide Topography.

Immediately following the major movement on 8 August, earthmoving machinery was brought on-site under the control of Civil Defence. This machinery was used to regrade locally oversteepened areas. The progress of this work as at August 24, 1979, can be seen on Plate 6E.

5.0 REMEDIAL MEASURES CONSIDERED PRIOR TO FAILURE

The investigation into the nature, extent and cause of the developing landslip was the principal task requested of us by the Earthquake & War Damage Commission on June 27, 1979. In addition we were to consider and report upon feasible methods, if any, of stabilising the landslide.

Because of the obvious size and nature of the landslip, as apparent at the time of our taking over the investigation programme from E.R. Garden and Partners in the latter part of July, we advised the Commission in writing (see Appendix C) that adequate engineering investigation of the slip would take some months and that this work would be necessary before any reliable remedial measures could be implemented.

Meanwhile three basic possible remedial measures sometimes pertinent to such situations were considered. These were:-

(1) Replacement of weight at the toe of the hillside in the quarry floor area.

(2) Regrading of the higher land surface.

(3) Reduction of groundwater within the slide mass.

Of the three possible measures considered, number 2 (regrading) was ruled out as being impractical, as it would have required major earthworks in land residentially developed. Measure 3 (dewatering) was considered possible but with virtually no knowledge at that early stage of either piezometric pressures within the block or zones of possible infiltration, this option was considered to be somewhat premature. However, an attempt was made to excavate pumping shafts in the Education Board land, but refusal was repeatedly encountered in excavating holes through the thick overlying boulder layers and precluded this method from being an effective short-term remedy.

Measure 1 (replacing some material back over the quarry floor) was considered in more detail. On the basis of the somewhat sketchy and certainly incomplete information available late in July, a stability analysis of the existing situation was run based upon an inferred section through the slip mass. Assuming that the then-existing terrain had a factor of safety of 1.0, we calculated that the addition of a blanket of 3 metres of filling (approximately 50,000 cubic metres) over the entire surface of both quarry benches could increase the factor of safety by some 4%. This order of increase in safety factor was considered to be of relatively low reliability, having regard to the limited information from which it was deduced. Also, we were not satisfied as to the true effect of providing additional toe weight and there was the further question of the feasibility and difficulty of carrying out such a major earthworks operation in the short term.

As the investigation proceeded, further information was obtained regarding the possible influence of the East Christie St Stream on the slide mass groundwater. On 2 August the piping of the lower portion of the stream above Christie Street was carried out. As discussed above, attempts were made close to the stream bed in the Education Board property to sink a series of shafts down into the underlying Abbotsford Formation. Ideally these shafts were then to have been utilised as pumping wells for removing groundwater. However, difficult ground conditions encountered within the colluvium layer prevented the sinking of these shafts from being a speedy operation. Similar well shafts were attempted in the floor of the quarry, near Boring B2 but due to rapid caving in of saturated sand during boring, these attempts at providing well locations were also abandoned.

As a general conclusion we considered that stabilising the slip mass with quick remedial measures was not feasible in the prevailing circumstances.

6.0 RELEVANT FACTORS

As previously discussed in our progress report dated July 16, 1979, we believe that the landslip must be considered in relation to a number of factors, all of which may have contributed in some degree to the ultimate failure.

These factors are:-

6.1 Geology

Large portions of the general Abbotsford - Green Island area are considered to be geologically unstable terrain. Significant areas of ancient landslip have however been residentially developed as have adjacent areas.

The ridge area (which Christie, Edward, Mitchell, Gordon and Charles Streets occupy), is the remnant of a formerly more extensive land surface. The ridge is bounded on both the east and west sides by former large slips. Ultimately, in the course of natural long-term geologic processes, this ridge would continue to be lowered and redeposited by the adjacent stream system.

We note however that until this recent event, this particular ridge does not appear to have suffered landslip movement.

6.2 Rainfall

We understand there are a number of rain gauges in the vicinity of Abbotsford. The Southern Reservoir station was used by us as being relevant to the upper Christie Street area. Based upon the rainfall records from this station, the months of January, February, March and April 1979 had a relatively low rainfall, being 81%, 56%, 76% and 84% of the monthly normals, respectively. May 1979, had a marked increase to some 159% of the monthly normal. Such an influx of water, after a prolonged period of relatively dry conditions, could have produced a rapid increase in groundwater pressure. Prior to this time, in late 1978 when signs of some movement were evidenced at No. 11 Edward Street and No. 16 Mitchell Street, there had been a preceding 7 month period when the rainfall was well in excess of the mean, but otherwise there is no information correlating ground movement with rainfall.

6.3 Groundwater

The East Christie St stream, appears to form part of the southwestern margin of the slip mass and could also comprise a major source of infiltration for groundwater. The course of the stream above Mitchell Street has been investigated and in places relatively clean sand beds of the Green Island Sand Formation closely underlie its course.

Groundwater may also have been supplemented by direct infiltration from the land above, particularly where the cover of the less permeable loess is very thin or non-existent.

An additional source for ingress of water into the existing natural flow system could possibly be the Dunedin City Corporation water main which extends along the north side of Abbots Hill Road immediately above the slide mass area. We understand that in the past this main has had a number of leaks.

6.4 Quarry

The Harrisons Pit quarry was developed between 1964 and 1969 at the base of the hillside, east of Charles Street and north-west of Armstrong Lane.

Landslipping is often induced by undercutting the toe of a slope. This usually occurs in nature by gnawing away of the hill base by stream, river or sea erosion. The rate of subsequent failure is then largely dependent upon the geomorphological factors such as topography, slope, soil properties and groundwater. Once undercut, the induced change in stress conditions causes strain to develop and over a period of time gradual changes within the landmass occur until ultimately failure occurs, more often than not finally triggered by a significant increase in groundwater pressures; i.e. due to heavy rain, snow melt, etc. After the quarry had been opened up the ground above would have been subjected to stress change and minor adjustments to reinstate equilibrium would occur.

6.5 Seismic Events

Information regarding seismic events which would have been felt in the Abbotsford area since 1965, has been supplied by the Geophysics Division of the D.S.I.R. According to these records the area has been subjected to nineteen shocks, of which only two are likely to have produced an Intensity in excess of MM V within the Abbotsford area (i.e. an intensity at which most people would be awakened from sleep, some windows crack, unstable objects displaced). One event occurred on April 9, 1974 and had an Intensity of MM VII and was followed by several lesser aftershocks, within the following two hours. On May 4, 1976 a shock registering an Intensity of MM V was recorded.

In our opinion, these recorded seismic events prior to the failure in August 1979 would have been felt more or less equally in all Abbotsford and the surrounding areas. It is difficult to determine precisely what effect these earthquakes would have had upon the development of the slide. It is however reasonable to infer that such shocks could have been detrimental to stability in the event of any pre-existing or developing stability problem.

7.0 MECHANISM OF LANDSLIDE AND ANALYSES

The slide occurred along a plane having a slope of about 7 degrees. This is very close to the general dip of the Green Island Sand - Abbotsford Formation interface. The slope is substantiated by examining the displacement vectors of particular points picked on the pre-slide and post-slide topography.

The slope of 7 degrees is a very flat one for a landslide to occur and requires either:-

(a) Low Strength Mechanism

a very weak soil layer existing along the shear plane;

or (b) Water Pressure Mechanism

high water pressures developing which partly "float" the mass down the slope;

or (c) a combination of the above factors.

Before moving on to the site we were aware of the need to identify these factors and our work was principally aimed at recovering undisturbed samples for strength testing to investigate item (a) and installing field piezometers in specific strata to investigate item (b).

The work carried out by us (and we understand all other work carried out so far at the site) has failed to clearly identify the specific combination of factors which caused the slip.

Stability analyses consist of determining the resisting forces which are available because of the inherent soil strength and dividing by the driving forces which are produced by gravity; the resulting ratio being a factor of safety (Fs). This applies to a slope which has not failed. However, when a slope is at the point of failure or, having failed is moving at a constant velocity, then the factor of safety is equal to unity i.e. Fs = 1.

Taking the lowest strength value measured from the recovered samples and the highest measured water table (the worst combination factors) a stability analysis gives a factor of safety of 4.1. For the condition that prevailed at the time of our investigation (i.e. failure at almost constant velocity) this figure must have been 1.0.

In our analyses we have therefore carried out a parametric study in that:-

(i) we have taken the water level as measured and determined the shear strength that the soil would be required to have for Fs = 1.

and (ii) we have taken the minimum measured shear strength and determined the water pressure that would be required for Fs = 1.

It is likely that these represent the two limiting conditions with the actual condition at the time of failure lying somewhere in between. While the further work being carried out at present under the direction of D.S.I.R. and M.W.D. may enable the limits to be further refined, they are hampered by the fact that the slip has now occurred and the pre-slip groundwater conditions can no longer be measured.

Using these derived parameters we have carried out analyses of the effect of fluctuations in water pressure and have examined the relative stability of the slope as it existed in 1962; i.e. prior to the main excavation of the quarry.

7.1 Low Strength Mechanism

If the failure was caused by an as yet unidentified stratum of weak soil, then at some stage the maximum shear strength of this material will have been exceeded. As shear strain develops resisting strength may then tend to reduce to a residual value thus giving a driving force greater than the resisting force, leading to an acceleration of movement. This will continue unless either additional resisting forces are encountered (e.g.

at the toe of the landslip), or driving forces are reduced (e.g. by lowering of the water pressures). Such changes may result in a steadying or stopping of the motion.

7.1.1 Analyses

Analyses based on this mechanism using the method detailed in Appendix B with water levels as measured have given the following results:-

Angle of Shearing Resistance (Ø')	Factor of Safety (based on c' = 0)
7^{o}	1.02
8^{o}	1.14
9^{o}	1.26

Extrapolation of these results gives for a balance of forces (i.e. factor of safety = 1), an average angle of shearing resistance of 6.9^{o}. The above table gives an indication of the sensitivity of the analysis to variations in the angle of shearing resistance.

Using the Ø' angle of 6.9^{o} we have considered the effect of fluctuations in the water table. Results are as follows:-

Water Table Height (m)	Factor of Safety
+ 1 (m)	0.97
As measured	1.00
- 1 (m)	1.04

Using an angle of shearing resistance of 6.9° and a water table as measured we have determined that the factor of safety for the pre-quarry (1962) topography was 1.01.

7.1.2 Factor Favouring Low Strength as the Likely Mechanism

1. Montmorillonitic minerals have been identified from samples taken from the site area. This mineral has an inherent ability to produce low residual shear strength parameters. It has the capacity to swell and absorb water into its basic soil structure and its activity, (which is expressed as a ratio of the Atterberg Plastic Index to the percentage of clay fraction) is significantly higher than other clay minerals such as illite and kaolinite. The magnitude of the shear strength in a montmorillonitic soil is subject however to variation depending on the amount of clay fraction within a sample.

7.1.3 Factors Which Do Not Favour the Low Strength Mechanism

1. No continuous band of fine-grained material has been identified at or close to the depth of the shearing surface by our investigations.

2. Where seen in shafts sunk after the failure it has been reported to us by MWD that the failure surface consists of a highly sheared zone up to 2 metres thick.

3. All test results performed by us gave residual strength values of ϕ' much greater than 6.9° (Refer Plate A-4).

7.2 Water Pressure Mechanism

In this mechanism it is postulated that water infiltrates from a recharge zone into a confined aquifer which is adjacent to (probably slightly below) the potential failure plane. From this zone the water pressure reduces mainly due to head loss through flowing in the porous medium of the aquifer, is not specifically influenced by the ground surface topography, and can exist at pressures which would result in a static head higher than normal hydrostatic pressure indicated by the groundwater table and perhaps even higher than the ground surface level.

The quantity of water needed to obtain high groundwater pressures would not necessarily be great, provided the aquifer is reasonably confined. The most likely source would be from the East Christie St Stream which, above Christie Street, flows close to the level of the Abbotsford Formation. A further possible source is from the conduit formed by alluvium in old buried water courses, either in the relic landscape or in any stream subsequently covered and redirected by landslip movement.

7.2.1 Analyses

In these analyses we have used the lowest measured angle of shearing resistance (Ø') of 30° and have considered a number of hydraulic gradients from the assumed recharge point. The results are as follows:-

Hydraulic Gradient	Factor of Safety
2.5°	1.68
2.2°	1.41
2.0°	1.19

From these results we have extrapolated for a balanced force situation (Fs = 1) a required hydraulic gradient of 1.8^{O}.

Using this hydraulic gradient together with a ϕ' of 30^{O} we have determined that the pre-quarry (1962) topography would have had a factor of safety of 1.37.

7.2.2 Factors Which Favour the High Water Pressure Mechanism

1. With fines contents from 18 to 35 percent, both the Green Island Sand and Abbotsford Formations are generally, relatively impermeable. With the type of drilling used, detection and recovery of thin permeable sand strata were not feasible; however, there is some field evidence to support the assumption that they exist. Pockets of grey sand were noted near the slip plane in boring B1 and caving occurred in the shaft attempted near boring B2.

2. There is some evidence of differential piezometric pressure from the results recorded at B2 where the water level in this boring is 1 to 2 metres above that in adjacent TP2A pit. This is however only indicative, as the water level in the boring was from a standpipe only rather than from a sealed piezometer.

3. There was the sand which in flowing out at the toe of the slip exhibited a liquefaction type behaviour which is related to high water pressure. However this may have been generated as a result of movement and is not necessarily indicative of a high initial water pressure.

7.2.3 Factors Against High Water Pressure Mechanism

In the field measurements taken, no significant water pressure heads were recorded. There was however a particular constraint on the measurements taken in the bore holes located in the slip zone as these were drilled when movement was at the rate of about 100 mm per day and it was thus not feasible to install piezometers below the plane on which shearing was then occurring.

7.3 General

As has been discussed above, for the slip to have occurred parameters other than those measured in our investigation would be required. We consider that our analyses have demonstrated the relative effects of parameter changes at either end of the likely range of possible conditions and that the true behaviour probably lies somewhere within this range.

Because of the early identification of montmorillonitic material in the site soils, we did consider, prior to commencing the fieldwork, the most likely mechanism to be the low strength mechanism. On reviewing available data, it appears that the more likely mechanism involves excess water pressures but with soils having strengths lower than we have been able to measure.

8.0 SUITABILITY OF SITE FOR DEVELOPMENT

The area east of Christie Street has developed sporadically since the early 1940's, with the latest development, generally in the Charles Street area, continuing into 1979. Since the recognition of the developing landslide in June 1979, a number of opinions have been made public upon the suitability of the failed area for residential purposes. Much of the criticism against the area having been developed has been on the basis that geologically the general area of Abbotsford is well known for its instability.

The fact that the Sun Club property contained a large, geologically very young, bowl originating from former land slipping could perhaps have highlighted the presence of some risk of developing in this area. However, such a feature would not necessarily have indicated that adjacent land would be unsuitable for residential development.

Awareness of the former slide at the Sun Club should perhaps have suggested the desirability of a pre-development site investigation, in keeping with the more recently accepted "State of the Art". Nevertheless we believe that it is extremely unlikely that a conventional site investigation for a proposed residential area would have determined the likelihood of the nature and extent of the failure which ultimately occurred. One has only to look at the difficulties and expense of the investigation carried out to date in order to determine the nature and possible cause of the landslip which actually occurred and can be readily defined, in order to understand the difficulty involved in anticipating the possibility of the August 1979 event. We are of the opinion that the forecasting of the likelihood of such an event occurring, based upon conventional site investigation within the bounds of reasonable cost and experience deemed adequate for residential development, would have been virtually impossible. Had the east Christie Street area been proposed as the site for a comprehensive development of high capital value (e.g. a major hospital, an extensive commercial plant, power station, etc) then adequate funds may have been available such that a detailed and exhaustive site investigation may have more accurately predetermined the true risk of large scale landslip.

It is our understanding that prior to June 1979, the only other known problem in this area was at No. 5 Christie Street in 1972. At that time, we understand that the apparent behaviour of the house foundations suggested settlement, rather than landslipping, as being the most likely cause of the damage. Considering the record of apparently stable behaviour for this area generally over the years, we would see no specific reason why conventional residential development should not have been allowed, other than perhaps within close proximity of the large natural failure immediately to the north-east of the subject block (i.e. the Sun Club slide) and of the quarry face.

With respect to the effect of the quarrying operation at Harrisons Pit, apart from the points which arise from stability analyses, we would take this opportunity to make further comment on the suitability of this excavation:

The previous small scale quarry was developed in a large way during the late 1960's. It is our understanding that the opening up of Harrisons Pit quarry was a result of fill requirements for the nearby Motorway construction. At least a portion of the excavation could be considered as a direct response to an emerging stability problem then being encountered on the Motorway - reactivated area of West Abbotsford Landslide.

The quarry face slopes, as finally cut, appear to have remained remarkably stable over the approximate 10 year life since excavation. In fact they remained largely intact even after the main landslip. This would suggest that with respect to localised stability problems, the quarry was adequately designed and constructed.

It could also be claimed that in consideration of former slipping as evidenced by the nearby Sun Club slide, design for local and even moderate sized failures was appropriate at that time. However, conventional investigation would have been unlikely to identify the true risk of a landslide on the scale that finally occurred.

While we do believe that the cutting of the Harrisons Pit Quarry is likely to have had a part in the development of the ultimate landslide of August 1979, it is our opinion that except with the benefit of hindsight the quarrying action cannot be considered as being entirely unreasonable.

9.0 GENERAL

This report presents the results of our investigation into the nature, cause and possible remedial works of the East Abbotsford Landslide, as requested by the Earthquake and War Damage Commission. Field information was obtained principally during the month prior to the main movement of 8 August 1979 and during the emergency period.

Investigation and analysis has continued under the direction of DSIR and MWD. A Commission of Inquiry has been set up to consider and report to Government on the event.

The East Abbotsford Landslide in our opinion may be classified as a translational block slide of a substantial land mass which before movement was an integral part of the natural terrain. As such, it is within the definition of a landslip as defined under the Earthquake and War Damage Act and Regulations.

Remedial measures discussed in the report relate only to items considered or implemented prior to the final movement. Up to that time long term remedies had not been defined and further consideration became of academic interest only and hence was not pursued.

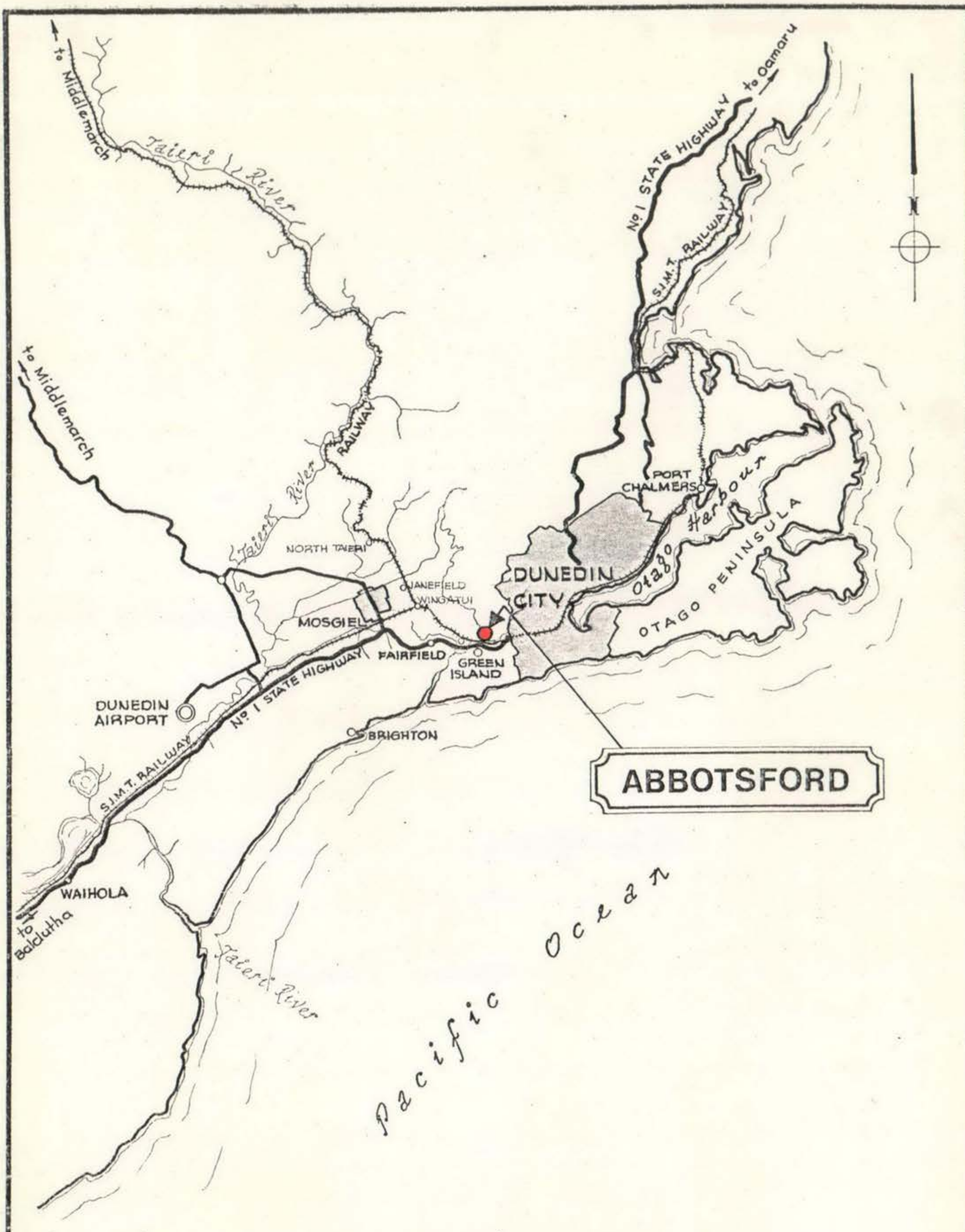
In regard to cause it should be noted that seldom if ever can a landslide be attributed to a single definite factor. The process leading to the development of the slide has its beginning with the formation of the material itself when its basic physical properties are determined. Subsequently a number of contributing factors such as those discussed are likely to be involved prior to some action setting the mass of material in motion. The last action which might make only a very minor contribution cannot be regarded as the only cause, even though it was necessary in the chain of events.

The following plates and appendices are attached to complete this report:-

Plate 1	Locality Plan
Plate 2A	Site Plan - Abbotsford Area
Plate 2B	Site Plan - East Abbotsford
Plate 3	Post-Slide Topography
Plate 4	Displacement Plan
Plate 5	Abbotsford as Developed in 1942
	East Abbotsford Landslip:- Recorded Ground Deformation
Plate 6A	- as at July 4, 1979
Plate 6B	- as at July 24, 1979
Plate 6C	- as at August 1, 1979
Plate 6D	- as at August 9, 1979
Plate 6E	- as regraded on August 24, 1979

Appendix A	Fieldwork and Laboratory Testing
Appendix B	Method of Stability Analysis
Appendix C	Preliminary Reports

BRICKELL, MOSS, RANKINE & HILL
Consulting Engineers



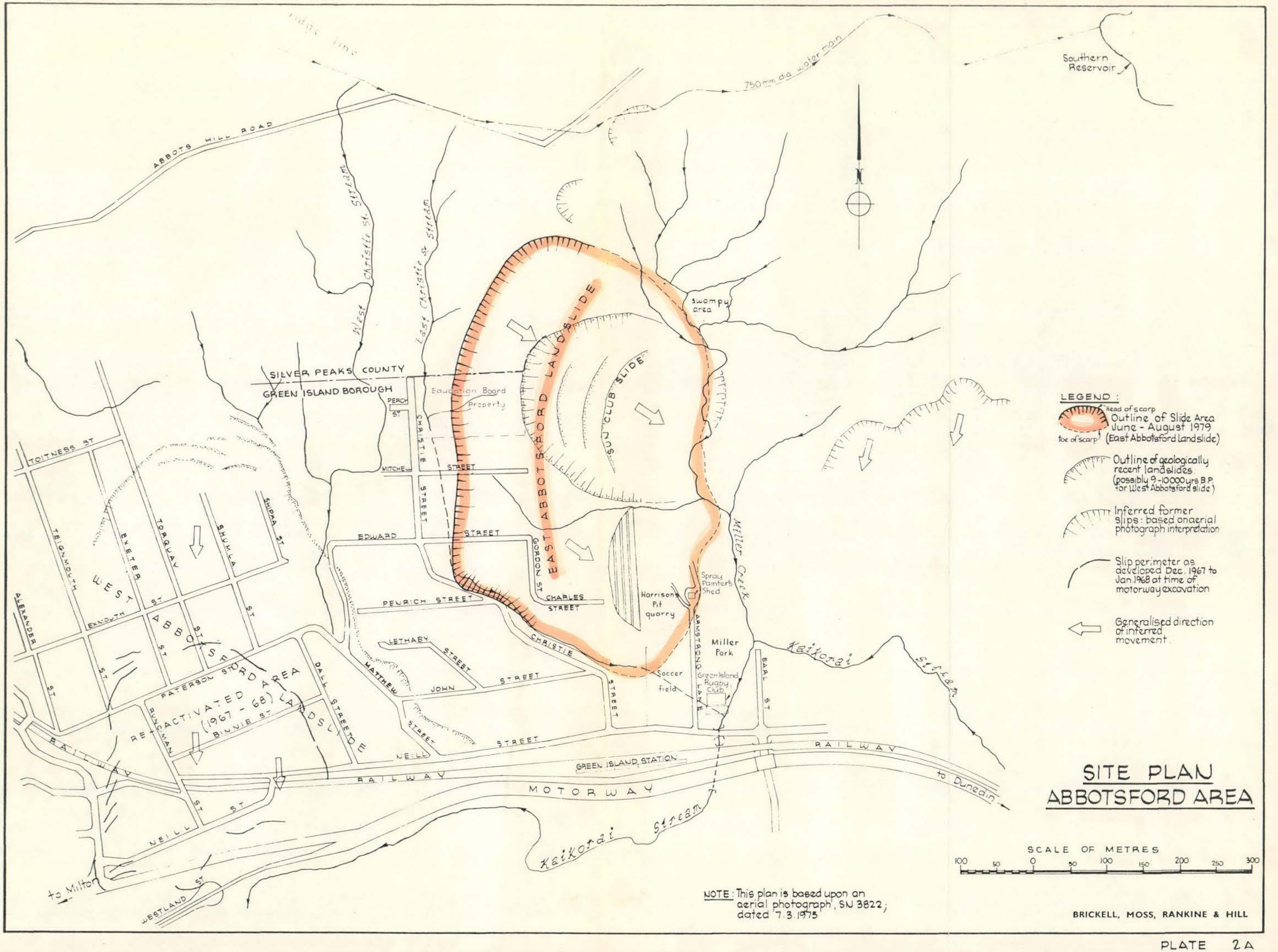
LOCALITY PLAN

SCALE OF KILOMETRES

5 4 3 2 1 0 5 10 15 20 25 30

BRICKELL, MOSS, RANKINE & HILL

PLATE 1

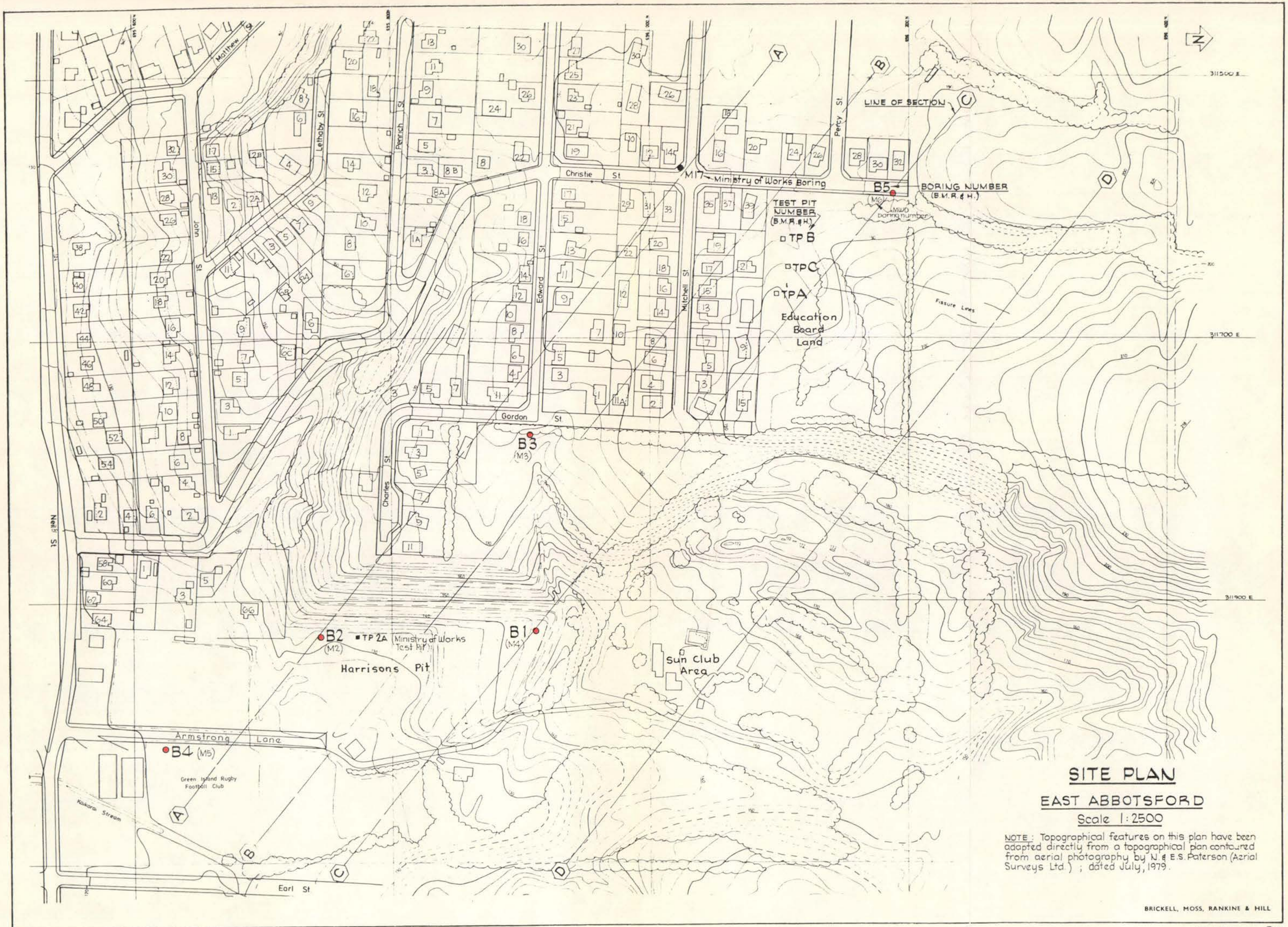


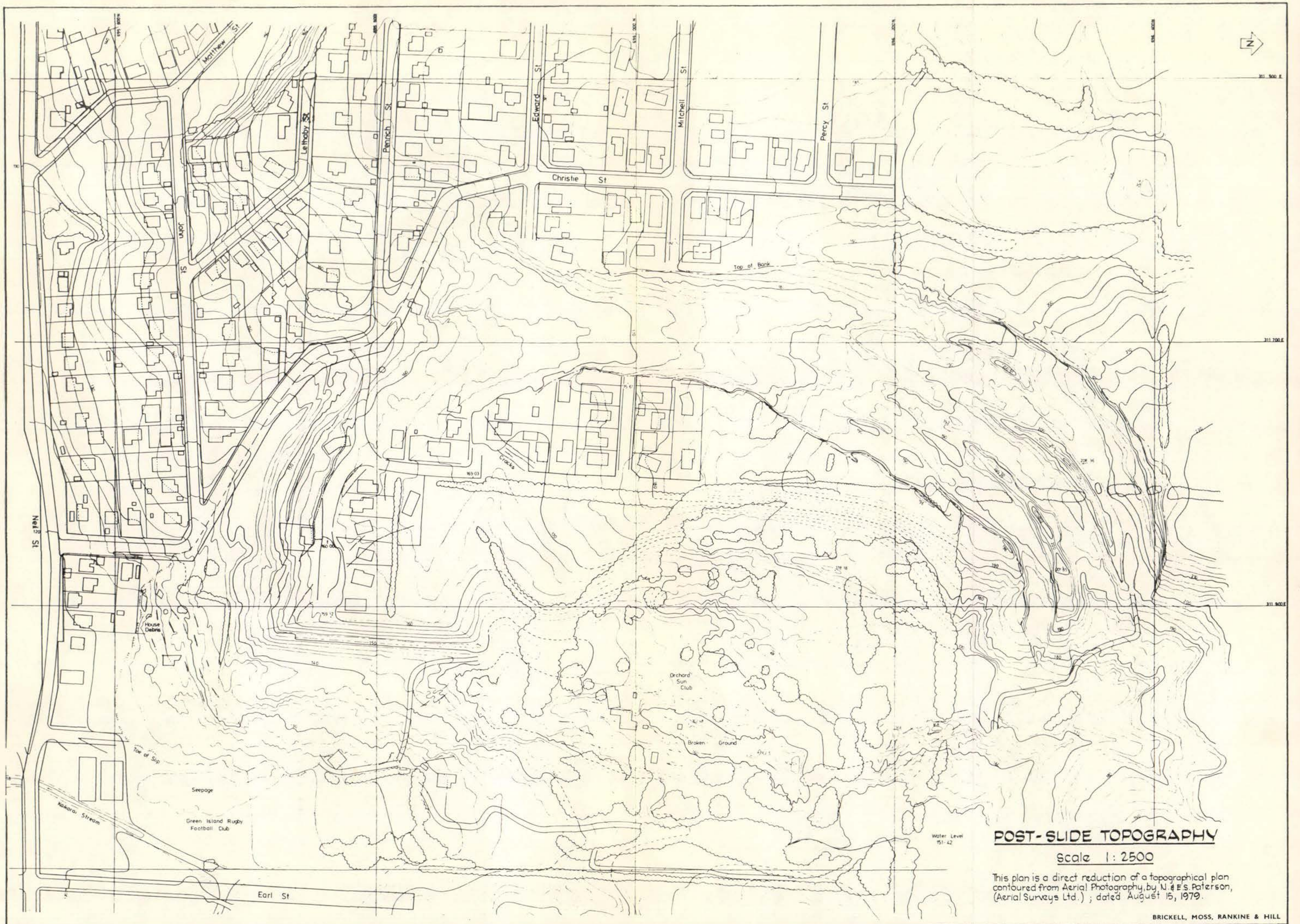
NOTE: This plan is based upon an aerial photograph, SN 3822; dated 7.3.1975

SITE PLAN
ABBOTSFORD AREA

BRICKELL, MOSS, RANKINE & HILL

Job No 51118 . E. & W.D.C. . Abbotsford, Dunedin . AGM . 9.79


SITE PLAN
EAST ABBOTSFORD
Scale 1:2500
NOTE: Topographical features on this plan have been adapted directly from a topographical plan contoured from aerial photography by N. & E.S. Paterson (Aerial Surveys Ltd.) ; dated July, 1979.
LINE OF SECTION
BORING NUMBER (B.M.R.& H.)
TEST PIT NUMBER (B.M.R.& H.)
MWD boring number
M17 Ministry of Works Boring
B1 (M4)
B2 (M2)
B3 (M3)
B4 (M5)
B5 (M6)
TP A
TP B
TP C
TP 2A Ministry of Works Test Pit
Education Board Land
Fissure Lines
Harrisons Pit
Sun Club Area
Green Island Rugby Football Club
Kaikorai Stream
Armstrong Lane
Christie St
Gordon St
Edward St
Mitchell St
Percy St
Charles St
Penrich St
Lethaby St
John St
Matthew St
Neil St
Earl St
311500 E
311700 E
311900 E
BRICKELL, MOSS, RANKINE & HILL



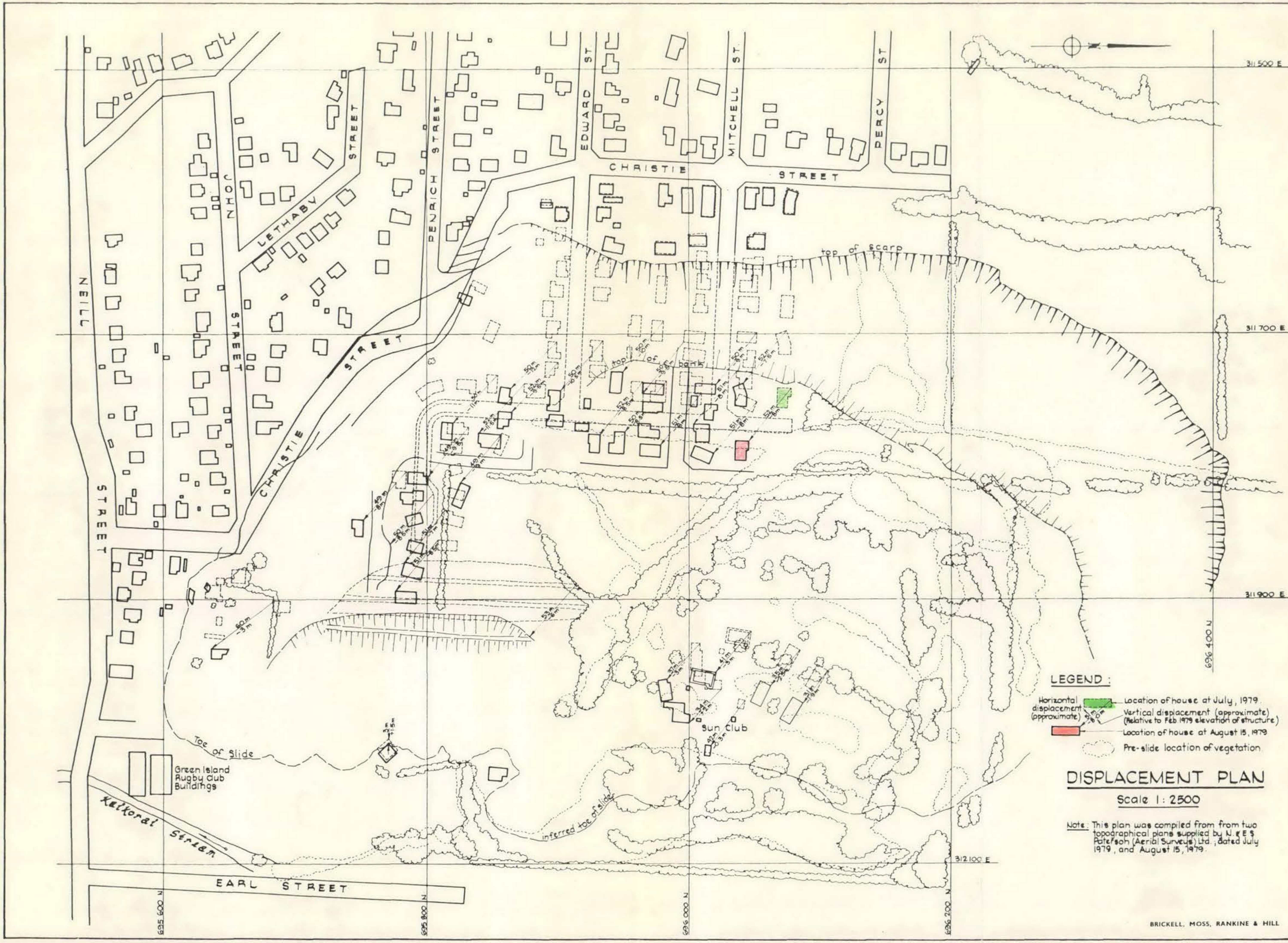
POST-SLIDE TOPOGRAPHY

Scale 1 : 2500

This plan is a direct reduction of a topographical plan contoured from Aerial Photography by N. & E.S. Paterson, (Aerial Surveys Ltd.) ; dated August 15, 1979.

BRICKELL, MOSS, RANKINE & HILL

PLATE 3


LEGEND:
Horizontal displacement (approximate)
Location of house at July, 1979
Vertical displacement (approximate) (Relative to Feb 1979 elevation of structure)
Location of house at August 15, 1979
Pre-slide location of vegetation
DISPLACEMENT PLAN
Scale 1 : 2500
Note: This plan was compiled from from two topographical plans supplied by N. Z. E. S. Paterson (Aerial Surveys) Ltd., dated July 1979, and August 15, 1979.
BRICKELL, MOSS, RANKINE & HILL
NEILL STREET
JOHN STREET
LETHABY STREET
PENRICH STREET
EDWARD ST
MITCHELL ST
PERCY ST
CHRISTIE STREET
EARL STREET
top of scarp
top of bank
Toe of Slide
inferred toe of slide
Sun Club
Green Island Rugby Club Buildings
Kaikorai Stream
311 500 E
311 700 E
311 900 E
312 100 E
695 600 N
695 800 N
696 000 N
696 200 N
696 400 N

EAST ABBOTSFORD LANDSLIP Scale 1:2500 (approx.)

AS REGRADED
ON AUGUST 24, 1979

PLATE 6E

EAST ABBOTSFORD LANDSLIP
Scale 1 : 2500 (approx.)

AS AT AUGUST 9, 1979

PLATE 6D

EAST ABBOTSFORD LANDSLIP
Scale 1: 2500 (approx.)

AS AT AUGUST 1, 1979

PLATE 6c

Job No 51118 · E & WDC · Abbotsford · AGM · 28.9.79

EAST ABBOTSFORD LANDSLIP
Scale 1: 2500 (approx.)

AS AT JULY 24, 1979

PLATE 6B

JOB Nº 51118 · E & WDC · Abbotsford · AGM · 26.9.79

EAST ABBOTSFORD LANDSLIP   Scale 1 : 2500 (Approx.)

RECORDED GROUND DEFORMATION AS AT JULY 4, 1979

✕ marks dislocation of services;   ▬ marks line of surface deformation.

① 16 Mitchell St. : some damage noted October/November 1978. Possibility of some damage in basement prior to 1974.

② 11 Edward St. : minor cracking of garage/basement floor noted in October/November, 1978.

③ 5 Christie St. : movement of ground surface beneath house first recorded in April, 1972.

PLATE 6A

Scale 1: 3000 (approx.)

ABBOTSFORD AS DEVELOPED IN 1942

PLATE 5

APPENDIX B

METHOD OF STABILITY ANALYSIS

B1.0 Analytical Procedure

To determine the factor of safety (Fs) for the failure surface chosen on our cross sections, we have adopted the method of analysis presented by Janbu. This is a modification of the simplified Bishop Method of slices for non-circular slip surfaces. In developing this method, some simplifying assumptions were made regarding inter-slice forces but it has been shown that the values of factor of safety approximate closely to those determined by more rigorous methods.

The governing equation involves an iterative process and accordingly our slope stability studies were performed using a computer programme.

The sections analysed were divided into strips, and pore pressure, geometry and strength parameters at the centre of each strip were determined.

As described in the text following we have had to make a number of assumptions regarding the geometry of the subsurface shape of the failure surface.

We have found that whilst the absolute results obtained may be significantly affected by variations in geometry, the relative results do not change markedly. It is in this context that factors of safety are quoted to three significant figures in order to illustrate the relative effect of specific parameter changes.

We have allowed for three dimensional effects in our analyses as follows:-

- The safety factor for a given set of parameters for all sections has been determined by the method described above.

- A weighted safety factor has then been computed using the ratios of total weight per unit width of the soil for each cross-section multiplied by the corresponding plan areas.

B2.0 Cross Sections Selected for Analysis

For the purpose of our stability analysis we have developed four cross sections, three of which AA, BB and CC were aligned through the main block, and the fourth DD through the Sun Club area.

In order to determine the alignment of the cross sections and hence the most critical shape geometry we considered directional movement of specific features contained within the main block before and after the slip. Accordingly the alignment of our sections corresponds to the general direction of such movements as depicted on Plate 4, Displacement Plan contained in the body of the report.

The locations of the cross sections are shown on Plate 2B, Site Plan also contained in the body of the report. Details of the cross sections are presented on Plate B-1, Inferred Subsurface Sections.

B3.0 Cross Section Topography

The pre-slip surface topography used for the cross sections has been taken from a survey plan supplied by E.R. Garden & Partners, details from which are presented on Plate 2B.

Details of the ground contours subsequent to mass movement of the soil block have been taken from the post-slide topographical survey plan as shown on Plate 3 in the main report.

The pre-quarry ground surface has been determined from a topographic plan based on the 1962 aerial photograph.

B4.0 Subsurface Details

Sections AA, BB and CC have been developed using information gained from early MWD borings and from our borings. The logs used are shown on Plate B-1.

In the present absence of specific subsoil data in the Sun Club area, the profiles for section DD have been extrapolated using the above borings. We have assumed uniform lithology across the bedding planes to the position of section DD. This approach is subject to confirmation by fieldwork currently being carried out by DSIR and MWD.

B5.0 Assumed Failure Plane

B5.1 Principal Slip Surface

Where relevant, the position of the principal shear plane has been based on recorded inferred shearing depths of inclinometer tubes installed by MWD.

BORING NO.	B1	B2	TP2A	B3		B4		B5		TPA	TPC
LOCATION	Near Sun Club	Harrisons Pit	Harrisons Pit 30 m east of B2	Edward Street		Miller Park		North end of Christie Street		In field to east of north end of Christie Street	
SURFACE R.L.	142.6	130.5	131	176.0		120.6		189.2		190	188
BORING DEPTH	14.2 m	15.2 m	7.0 m	32.1 m		28.2 m		17.5 m		9.8 m	7.2 m
REMARKS & DEPTH BELOW GROUND SURFACE	One standpipe to depth: 12.0 m	One standpipe to depth: 12.0 m	One standpipe to depth: 6.0 m	Piezometer tubes to depths: A=28.5m	B=23.8m	Piezometer tubes to depths: A=26.0m	B=7.0m	Piezometer tubes to depth: A =7.0m	B=12.4 m	One stand pipe to depth: 9.8 m	-
SEALED ZONE	-	-	-	26.0 m to 29.0 m	22.0 m to 24.0 m	24.8 m to 27.0 m	5.0 m to 8.5 m	5.0 m to 8.5 m	10.5 m to 13.5 m	-	-
DATE	OBSERVED WATER LEVEL (DEPTH BELOW GROUND SURFACE IN METRES)										
30.7.79	2.0										
31.7.79 a.m.	2.02	0.3									
31.7.79 p.m.	2.02	0.44									7.0
1.8.79	2.01	0.51									
2.8.79	1.98	0.62								8.6	
3.8.79	1.91	0.66									
4.8.79	2.21	0.75	3.08	23.95	23.76					9.6	
5.8.79	2.23	0.72	2.42	24.81	23.93*					9.0	
6.8.79	2.26	0.78	2.23	24.98	23.96*					9.1	
7.8.79	2.38	0.83	2.16	24.97	23.97*	9.09	4.33			9.2	
8.8.79	1.60	1.10	2.30	22.90	21.70	9.15	4.30			9.35	
9.8.79	Blocked	Blocked		4.0 Blocked**	20.0 Blocked***	8.05	4.15		2.50 Δ		
10.8.79						7.0	6.10		2.30 (1)		
11.8.79						8.15	4.00		2.60 (2)		
12.8.79						8.10	4.00		-		
13.8.79						8.10	3.90		2.60 (3)		
14.8.79				**17.2 Blocked	***20.0 Blocked	8.10	3.95		2.60		
15.8.79						8.10	4.00		2.70 (4)		
16.8.79						8.10	4.10		2.70		
17.8.79						8.20	4.10		2.70 (5)		

MAJOR MOVEMENT (between 8.8.79 and 9.8.79)

Notes:

* Spiralling of wire down piezometer tube caused inaccurate readings.

** Blocked at 4m, no water. Blockage apparently cleared possibly caused by flow of water or ground movement or combination of both - subsequent blocked at 17.2 m.

*** Blocked at 20 m, no water.

Δ Two piezometers were installed in B5. Connection between piezometer tube and piezometer lost during installation of the upper piezometer.

(1) Blocked at 12 m

(2) Blocked at 11.7 m

(3) Blocked at 11.4 m

(4) Piezometer tube flushed out water level returned to 2.70 m.

(5) Piezometer tube filled with water, level returned to as measured i.e. 2.70 m.

OBSERVED GROUND WATER LEVELS

BRICKELL, MOSS, RANKINE & HILL

Job No: Client: Location: Date:

DEFINITIONS OF DESCRIPTIVE TERMS

RELATIVE DENSITY OF COHESIONLESS SOILS

	Corrected SPT 'N' value (blows/300 mm)
Very Loose	0 to 4
Loose	4 to 10
Moderately Dense	10 to 30
Dense	30 to 50
Very Dense	> 50

GRAIN SIZE

BOULDERS	> 200 mm
GRAVEL	
Very coarse	200 mm to 60 mm
Coarse	60 mm to 20 mm
Medium	20 mm to 6 mm
Fine	6 mm to 2 mm
SAND	
Coarse	2 mm to .6 mm
Medium	.6 mm to .2 mm
Fine	.2 mm to .06 mm
SILT & CLAY	< .06 mm

GRAIN SHAPE

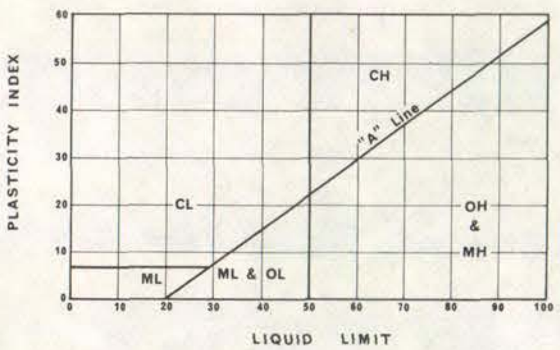
Angular	Showing little or no evidence of wear; edges and corners sharp, secondary edges present.
Subangular	Showing some effect of wear; faces virtually untouched but edges and corners slightly worn.
Subrounded	Showing considerable wear; edges and corners rounded off to smooth curves, original faces considerably reduced.
Rounded	Original faces almost completely destroyed, but some comparatively flat surfaces present. All original corners smoothed off to broad curves.
Well rounded	No original faces, corners or edges left. The entire surface consists of broad curves; flat areas absent - virtually spherical.

CONSISTENCY OF COHESIVE SOILS

Very Soft	-	squeezes between fingers
Soft	-	easily moulded by fingers
Firm	-	moulded by strong finger pressure
Stiff	-	dented " " " "
Very Stiff	-	dented only slightly by finger pressure
Hard	-	dented only slightly by pencil point.

STRUCTURE

Layer	A relatively continuous planar unit of soil, limited by difference in composition, texture or structure.
Lens	A discontinuous unit of soil, usually of limited area and generally less than 300 mm thick.
Bed	One distinct soil unit of sedimentary origin, confined within distinct bedding planes.
Homogeneous	Uniform properties within a soil unit.
Interbedded	Alternate beds of soil within a major soil unit.
Laminated	Distinct, fine layers each generally less than 3 mm thick.
Banded	Alternate layers of soil with distinct colour differences.
Mottled	Irregularly marked with spots or zones of different colours.
Slikenside	Smooth, polished sometimes striated planar structures resulting from insitu movement.



PLASTICITY CHART

MAJOR DIVISIONS			SYMBOL	TYPICAL NAMES
COARSE GRAINED SOILS (More than 1/2 of soil > 0.06 mm)	GRAVELS (More than 1/2 of coarse fraction > 2 mm)		GW	Well graded gravels or gravel-sand mixtures, little or no fines.
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.
			GM	Silty gravels, gravel-sand-silt mixtures.
			GC	Clayey gravels, gravel-sand-clay mixtures.
	SANDS (More than 1/2 of coarse fraction < 2 mm)		SW	Well graded sands or gravelly sands, little or no fines.
			SP	Poorly graded sands or gravelly sands, little or no fines.
			SM	Silty sands, sand-silt mixtures.
			SC	Clayey sands, sand-clay mixtures.
FINE GRAINED SOILS (More than 1/2 of soil < 0.06 mm)	SILTS & CLAYS (LL < 50)		ML	Inorganic silts and very find sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
			OL	Organic silts and organic silty clays of low plasticity.
	SILTS & CLAYS (LL > 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
			CH	Inorganic clays of high plasticity, fat clays.
			OH	Organic clays of medium to high plasticity, organic silty clays, organic silts.
HIGHLY ORGANIC SOIL			Pt	Peat and other highly organic soils.

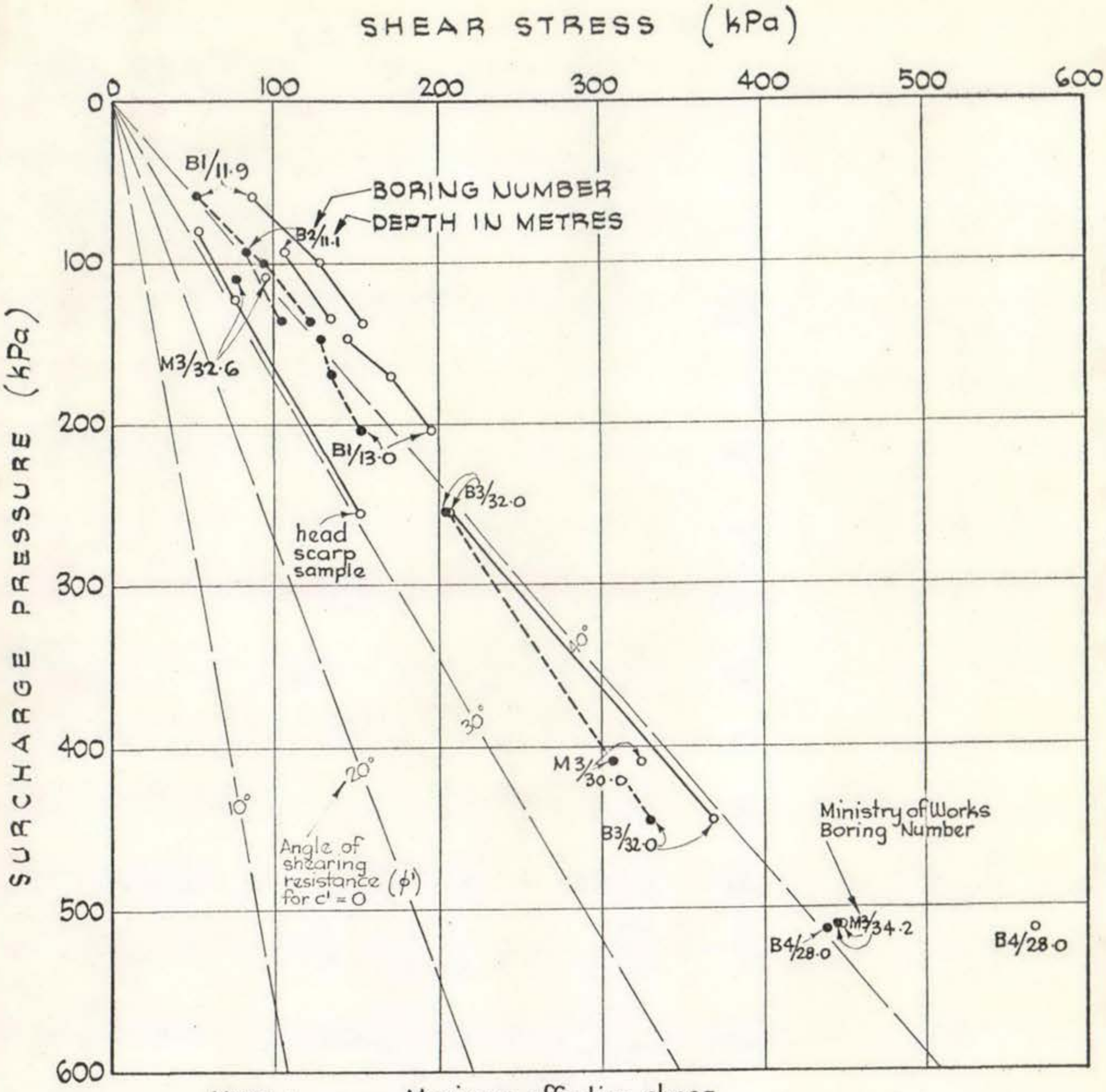
CLASSIFICATION CHART

(Unified Soil Classification System)

METHOD OF SOIL CLASSIFICATION

BRICKELL, MOSS, RANKINE & HILL

PLATE A-2



NOTE : ∘ = Maximum effective stress
• = Residual effective stress

Rates of strain :

M3 samples	: 0.3 mm/min.
Headscarp sample	: 0.0073 mm/min.
All other samples	: 0.024 mm/min.

RESULTS

BORING NUMBER	DEPTH	SURCHARGE PRESSURE (kPa)	MAXIMUM SHEAR STRESS (kPa)	RESIDUAL SHEAR STRESS (kPa)
M3	30.0	409	323	308
	32.6	110	926	72
	34.2	510	449	417
Headscarp		80	52	–
		121	74	–
		256	150	–
Remaining results are shown to the left of the Boring Logs				

STRENGTH TESTS

BRICKELL, MOSS, RANKINE & HILL

Appendix B

METHOD of STABILITY ANALYSIS

APPENDIX A

FIELDWORK AND LABORATORY TESTING

A1.0 FIELDWORK

A1.1 Drilling

Five exploratory borings were drilled at the site with truck-mounted rotary-wash equipment supplied by the MWD, Green Island, drilling unit. All borings were 100 mm diameter, with the exception of boring B5 which was 76 mm diameter. The holes were partially cased and extended to depths varying between 14.0 metres and 32.0 metres below ground level.

This fieldwork was supervised on a full time basis by one of our field engineers who in conjunction with our project engineering geologist and project geotechnical engineer determined the boring locations. The field engineer logged the soils encountered and carried out soils sampling at intervals in the borings.

The locations of the borings are shown on the Site Plan, Plate 2B, contained in the body of the report. Logs of the borings, as recorded in the field and amended where necessary by the results of laboratory testing, are shown on Plates A-1A through A-1F, Boring Logs. An explanation of abbreviations and symbols used on the boring logs is given on Plate A-1A.

The soils have been classified in general accordance with the Unified Soil Classification System, a summary of which is attached as Plate A-2, Method of Soil Classification.

A1.2 Sampling

The field engineer specified procedures for the recovery of undisturbed samples. These samples were, where possible, recovered in a 60 mm internal-diameter, split ring-lined sampling barrel which was advanced by hydraulic pressure in soils having a soft consistency. When firmer more dense soils were encountered, the sampler was advanced under a series of blows delivered by a drop hammer. The number of blows required to advance the sampler a specified distance was recorded and these blowcount records are shown on the attached logs. Dense soils, which were encountered in most borings, were sampled using a thin walled cylinder, again advanced using the drop hammer.

A1.3 Piezometer Installation

Piezometers were installed in borings B3, B4 and B5 and these comprised an 0.6 metre length of 42 mm diameter, perforated plastic tubing protected from contamination and blockage by a double wrap of towelling and an outer sheet of brass gauze. The piezometers were connected to small-bore thin-wall plastic tubing which was sealed at the ground surface by a plastic cap.

The piezometers were located at predetermined depths in the above borings. The surrounding zones were isolated by forming a cement grout plug above and below each piezometer. Two piezometers were installed in each of the holes.

A1.4 Groundwater

As described above, piezometers were installed in bores B3, B4 and B5. In the remaining boreholes B1 and B2 and in test pits TPA and TP2A, open standpipes were inserted. Water level readings were measured, where possible, on a daily basis with the aid of a water level indicator. The measured water levels in the borings and piezometers are tabulated on Plate A-3, "Observed Ground Water Levels".

A2.0 Laboratory Testing

A laboratory testing programme was carried out on representative samples to evaluate their soils engineering characteristics appropriate to this study. These tests can be summarised as follows:-

(a) Water content/dry density tests carried out on undisturbed samples for use in correlation.

(b) Strain controlled, consolidated drained slow direct shear tests performed at selected surcharge pressures to evaluate strength properties. Three of these tests were performed on samples of sandy silt retrieved from the head scarp north of Christie Street, from a level 5 metres below the top of the scarp.

(c) Percent fines (passing 75 mm sieve) tests were performed on representative samples to aid in assessing relative permeabilities.

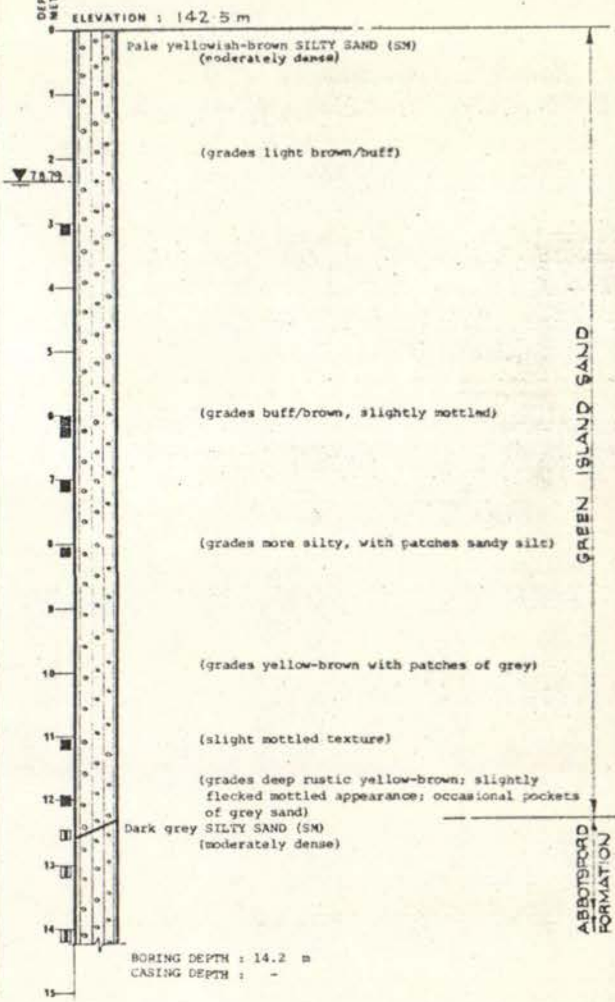
Test results are shown to the left of the boring logs on Plates A-1A through A-1F where appropriate and are also presented graphically on Plate A4, Strength Tests.

The following plates are attached to complete this Appendix:-

Plates A-1A to A-1F	Boring Logs
Plate A-2	Method of Soil Classification
Plate A-3	Observed Ground Water Levels
Plate A-4	Strength Tests

CLASSIFICATION DATA			STRENGTH DATA				MOISTURE-DENSITY DATA		FIELD DATA
% FINES (-Nº 200)	LIQUID LIMIT	PLASTICITY INDEX	TYPE OF STRENGTH TEST	TEST SURCHARGE PRESSURE, kPa	TEST MOISTURE CONTENT, %	SHEAR STRENGTH kPa	NATURAL WATER CONTENT, %	DRY DENSITY, kg/m³	PENETRATION RESISTANCE
									PUSH
							24.8	1565	PUSH
							25.1	1558	
							26.6	1529	PUSH
							26.1	1554	
30							22.1	1588	PUSH
26							21.2	1683	PUSH
26			cd D.S.	59	23.4	84/52	23.4	1651	S = 93
37			cd D.S.	101	24.0	128/91	24.0	1641	
20			cd D.S.	139	23.0	153/120	23.0	1660	S = 11 for 140mm
32							22.1	1695	
24			cd D.S.	149	22.4	144/123	22.4	1667	S = 30 for 200mm
31			cd D.S.	170	22.5	171/135	22.5	1621	
29			cd D.S.	204	24.1	194/154	24.1	1571	
23							19.2	1647	S = 32 for 250mm

BORING 1



BORING AND TEST PIT NOTES, ABBREVIATIONS & SYMBOLS

1. The borings were drilled between 27 July and 7 August 1979 with trailer mounted rotary wash equipment. The test pits were drilled with Caldweld rig (1 metre diameter shaft).

   100 mm size and 76 mm size casing was used in the borings.

2. Undisturbed sample recovered in split barrel, 60 mm I.D. ring lined sampler.

   Undisturbed sample recovered in 60 mm I.D. thin wall Shelby tube (operated off a fixed piston) sampler.

   Undisturbed sample attempted, but missed or disturbed in recovery.

   S — Number of blows to drive sampler 300 mm with SPT hammer.

   PUSH — Sampler driven by hydraulic pressure.

   Core sample obtained in triple tube, rotary core barrel.

   Core sample attempted, but missed in recovery.

   Core length removed for laboratory testing.

   Observed static ground water level.

3. The elevations of the borings have been extrapolated from the pre-slip topographical plan.

4. Indicated depths are in metres below the existing ground surface.

5. cd DS = Strain controlled, consolidated drained, shear test at natural water content;
   Tabulated shear strength values are maximum/residual.

BORING LOGS

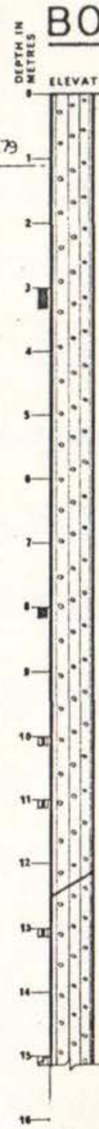
BRICKELL, MOSS, RANKINE & HILL

Job Nº 51118 . F & W.D.C . Abbotsford, Dunedin . RJD . 9.79

CLASSIFICATION DATA			STRENGTH DATA				MOISTURE-DENSITY DATA		FIELD DATA
% FINES (-Nº 200)	LIQUID LIMIT	PLASTICITY INDEX	TYPE OF STRENGTH TEST	TEST SURCHARGE PRESSURE, kPa	TEST MOISTURE CONTENT, %	SHEAR STRENGTH kPa	NATURAL WATER CONTENT, %	DRY DENSITY, kg/m³	PENETRATION RESISTANCE
24							24.0 26.1	1537 1591	PUSH
18							21.8	1598	PUSH
27							20.3	1620	S = 30 for 250 mm
30 26			cd D.S. cd D.S.	94 135	23.9 23.8	104/81 135/103	23.9 23.8	1620 1591	S = 34 for 250mm
20							19.0	1660	S = 60 for 250mm
									S = 61 for 170mm

BORING 2

ELEVATION : 131·5 m



Light grey/buff yellow SILTY SAND (SM)
(moderately dense)

(grades yellowish-brown)

(grades light grey/buff)

(contains isolated patches of yellowish-brown sand, moderately dense to dense)

(grades greyish-buff/yellowish-brown mottled)

Dark grey SILTY SAND (SM)
(dense)

BORING DEPTH : 15. 2 m
CASING DEPTH : -

GREEN ISLAND SAND

ABBOTSFORD FORMATION

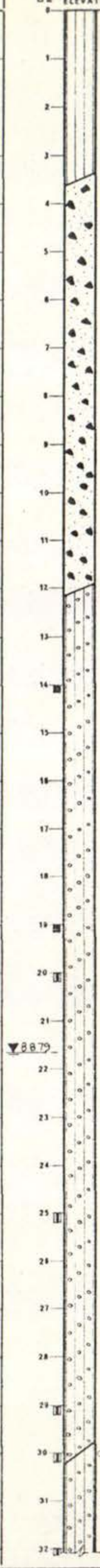
BORING LOGS

BRICKELL, MOSS, RANKINE & HILL

BORING 3

ELEVATION : 176.0m

CLASSIFICATION DATA			STRENGTH DATA				MOISTURE-DENSITY DATA		FIELD DATA
% FINES (-Nº 200)	LIQUID LIMIT	PLASTICITY INDEX	TYPE OF STRENGTH TEST	TEST SURCHARGE PRESSURE, kPa	TEST MOISTURE CONTENT, %	SHEAR STRENGTH kPa	NATURAL WATER CONTENT, %	DRY DENSITY, kg/m³	PENETRATION RESISTANCE
28							22.3	1566	PUSH
21							24.2	1523	PUSH
							17.8	1650	S = 63 for 170mm
13							15.8	1634	S = 57 for 250mm
78							19.9	1688	S = 50 for 240 mm
37 29 53									S = 50 for 160 mm
31			cd DS	256	22.3	207/205	22.3	1637	
34			cd DS	445	24.4	368/331	24.4	1562	S = 57 for 140mm



Yellowish-brown SANDY SILT (ML)
(firm grading stiff)

LOESS

Brown SANDY GRAVELS (GP)
(coarse gravels boulders and cobbles rounded to sub-rounded in brown silty sand matrix)

COLLUVIUM

Light grey/buff yellow SILTY SAND (SM)
(moderately dense)

(grades light yellowish-brown)

(grades dense, rustic yellowish brown, contains random isolated pockets of light grey sandy silt)

(grades light grey, becomes flecked and patchy)

(grades more silty)

(grades yellow brown/light grey and mottled)

GREEN ISLAND SAND

Grey SILTY SAND (SM)
(dense)

BORING DEPTH : 32.1 m
CASING DEPTH : 26.0 m

ABBOTSFORD FORMATION

BORING LOGS

BRICKELL, MOSS, RANKINE & HILL

PLATE A-1C

Job No 5111B E W D C Abbotsford, Dunedin RJD 9.79

BORING 4

CLASSIFICATION DATA			STRENGTH DATA				MOISTURE-DENSITY DATA		FIELD DATA
% FINES (-Nº 200)	LIQUID LIMIT	PLASTICITY INDEX	TYPE OF STRENGTH TEST	TEST SURCHARGE PRESSURE, kPa	TEST MOISTURE CONTENT, %	SHEAR STRENGTH kPa	NATURAL WATER CONTENT, %	DRY DENSITY, kg/m³	PENETRATION RESISTANCE
							26.5	1559	PUSH
							56.2 58.5	1055 1080	PUSH
									PUSH
							22.4	1530	PUSH
							23.6	1555	S = 63 for 160mm
22							26.3	1583	S = 71 for 220 mm
18							25.5	1600	S = 89 for 200 mm
							27.6	1465	S = 71 for 200mm
							25.9	1551	S = 84 for 200mm
							22.7	1666	S = 89 for 220mm
							24.9	1588	S = 107 for 200mm
24							25.6	1980	S = 96 for 210mm
							23.6	1641	S = 89 for 190mm
26							25.5	1574	S = 75 for 170mm
22							24.9	1594	S = 64 for 170mm
27							24.0	1604	S = 66 for 165mm
25							21.1	1701	S = 64 for 165mm
19									S = 63 for 90mm
18							20.0	1574	S = 86 for 160mm
35			cd D.S.	514	26.7	568/437	26.7	1597	S = 125 for 120mm

DEPTH IN METRES

ELEVATION : 120.6 m

FILL

0 — Dark brown slightly gravelly SILT (ML (topsoil)
Dull greyish brown SILT (ML)
(contains some brick rubble)

1 — Dull greyish brown/brown mottled slightly SANDY SILT(ML)
(contains pockets of dark brown sandy silt, grades dull grey, with occasional fragments of decayed wood and other fibrous matter)

2 —

3 —

RECENT ALLUVIUM

Brown SANDY GRAVEL (GP)
(moderately dense)

4 —

▼88.79

Dark brown SILTY SAND (SM)
(moderately dense)

5 —

Light grey buff SILTY SAND (SM)
(moderately dense)
(grades greyish yellow)

6 —

Light grey SAND (SP)
(dense; contains pockets of silty sand also black flecks and faint brown irregular banding)

7 —

8 — (grades greyish green/brown contains occasional irregular bands of brown silty sand and pockets of grey silt).

9 — Light grey/brown SILTY SAND (SM)
(dense)

10 —

(grades brown/yellowish brown)
(grades light buff/pale yellow brown contains black flecks - faintly mottled)

11 —

(grades light grey/yellow brown and mottled)

12 —

(contains pockets of grey silty sand also with lenses of brown friable silty sand)

13 —

14 — (grades light grey with slight faint yellow brown staining; contains occasional pockets of sandy silt)

15 —

(grades very dense)
(grades light/pale yellow brown/light grey and mottled)

16 —

17 — (grades light grey/brown; contains numerous discrete small pockets of rustic brown silt giving a speckled appearance)

18 —

19 —

20 — (grades moderately dense)

21 —

(grades yellowish-brown)

22 —

23 — (occasional inclusions of grey silty sand)

24 —

(grades rustic yellow brown silty SAND (SM)

ABBOTSFORD FORMATION

Dark grey slightly SILTY SAND (SM)
(moderately dense)

25 —

26 —

(occasional fine, discontinuous seams of black carbonous silt)

27 —

28 —

BORING DEPTH : 28.2 m
CASING DEPTH : 6.0 m

29 —

BORING LOGS

BRICKELL, MOSS, RANKINE & HILL

Job No 5111B · E.& W.D.C. · Abbotsford Dunedin · BJD 9.79

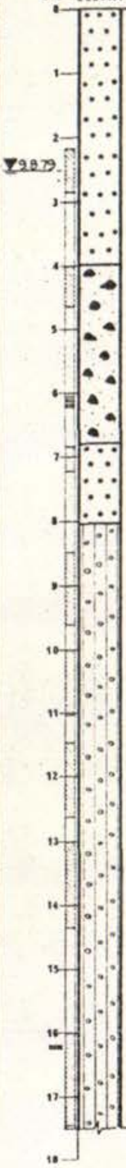
Job No 5118 E & W.D.C. Abbotsford, Dunedin RJD 9.79

CLASSIFICATION DATA			STRENGTH DATA				MOISTURE-DENSITY DATA		FIELD DATA
% FINES (-No 200)	LIQUID LIMIT	PLASTICITY INDEX	TYPE OF STRENGTH TEST	TEST SURCHARGE PRESSURE, kPa	TEST MOISTURE CONTENT, %	SHEAR STRENGTH kPa	NATURAL WATER CONTENT, %	DRY DENSITY, kg/m³	PENETRATION RESISTANCE
22							19.1	1766	

BORING 5

DEPTH IN METRES

ELEVATION : 188.0 m



Dull yellow brown SAND (SP)
(contains occasional black flecks and patches of darker brown sand between 2.2-2.3 m)
(moderately dense)

Brown SANDY GRAVEL (GP)
(large gravel boulders and cobbles in yellow brown sand matrix; contains some dark brown staining on fracture planes)

Yellow brown SAND (SP)
(contains occasional black flecks and some faint bands of dull red brown sand; moderately dense)

Grey SILTY SAND (SM)
(moderately dense)

(contains fine, discontinuous lenses of black carbonous silt - hard and intact at 10.2 m)

(contains fine discontinuous lenses of black carbonous silt)

(contains more black carbonous silt lenses)

LOESS

COLLUVIUM

GREEN ISLAND SAND

ABBOTSFORD FORMATION

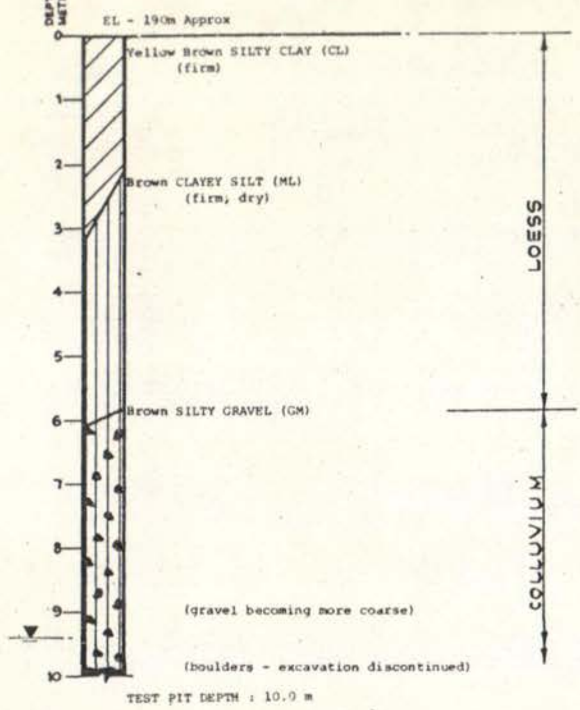
BORING DEPTH : 17.5 m
CASING DEPTH : 8.0 m

BORING LOGS

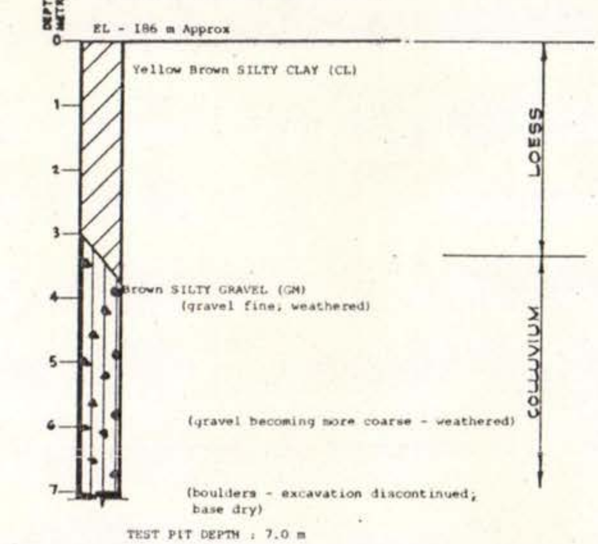
BRICKELL, MOSS, RANKINE & HILL

PLATE A-1E

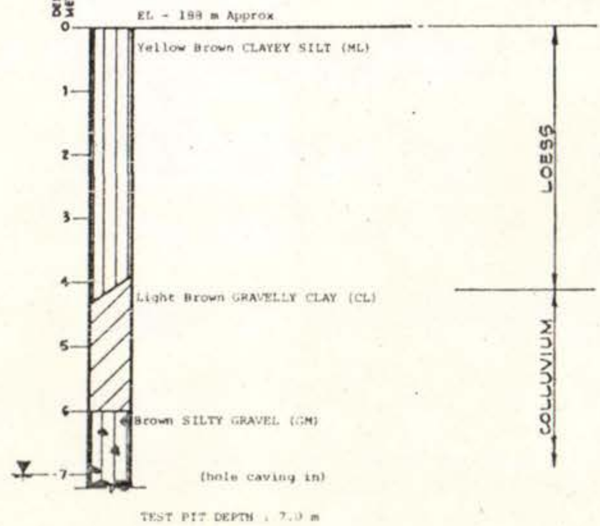
TEST PIT A



TEST PIT B



TEST PIT C



BORING LOGS

BRICKELL, MOSS, RANKINE & HILL

PLATE A-1F

Job No 51118 . E & WDC . Abbotsford Dunedin . AGM . 9.79

Appendix C

PRELIMINARY REPORTS

BRICKELL, MOSS, RANKINE & HILL

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Ian C. Smith ME, DIC, MICE, MNZIE
William D. Champion BE, FICE, FI Struct E, FNZIE
Keith H. Gillespie BE, MNZIE
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Frank N. Blackwell BE, MI Mech E, MIHVE, MNZIE
David G. Cox ME, FNZIE, FIE Aust
Wilson E. Lattey MNZIS
Robert L. Bishop BE, MNZIE MIE Aust

OTAGO SAVINGS BANK BUILDING
106 GEORGE STREET
DUNEDIN

P.O. BOX 5243, MORAY PLACE
TELEPHONE: 773-203
CABLES: 'RANHILL' DUNEDIN

Also at:
WELLINGTON, AUCKLAND, LOWER HUTT
PARAPARAUMU, LEVIN, TAKAPUNA
PALMERSTON NORTH

6 July 1979

79140

The Manager,
Bird & Associates (Otago) Ltd.,
Loss Adjusters,
P.O. Box 564,
DUNEDIN.

Attention: Mr Hillsmith

Dear Sir,

Re: LANDSLIP
ABBOTSFORD-GREEN ISLAND

This confirms our verbal advice of 4 July 1979 that following discussions between our Mr A.G. Mahoney and Mr I. McKellar, of Geological Survey, on-site inspections and discussions on 4 July 1979 of the above area, it is our opinion that this ground movement is definitely a landslip. Consequently, we believe it comes under the E.W.D.C. Act and we recommend that it be defined as such in order that property owners affected can be advised accordingly at the earliest possible time. We recommended that you should clear this with E.W.D.C. in Wellington and take whatever follow-up action is necessary as a matter of priority.

Since we have been engaged by E.W.D.C. we have sent them a copy of this letter direct. We see a clear need to get together with yourselves, E.R. Garden & Partners and ourselves, to clearly define respective positions in this matter, thus avoiding any potential conflict of interest. We suggest this could be done next week, and will contact you to arrange this early in that week.

Yours faithfully,

p.p. BRICKELL, MOSS, RANKINE & HILL

David G. Cox

ASSOCIATES:
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BRICKELL, MOSS, RANKINE & HILL

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Also At
WELLINGTON, AUCKLAND, DUNEDIN
PARAPARAUMU, LEVIN, TAKAPUNA,
PALMERSTON NORTH.

COPY

CONFIDENTIAL
FO[illegible] [illegible]RTH-
[illegible] [illegible]GE
CO[illegible] THEIR LOSS
[illegible] ONLY.

51118

July 16, 1979

The Secretary,
Earthquake & War Damage Commission,
P.O. Box 5038,
WELLINGTON.

Dear Sir,

Progress Report
Landslip
Green Island - Abbotsford
Dunedin

As requested by telephone with our Mr Travers on 27 June the writer has inspected the above site, met and discussed the situation with various parties involved and advises the following:-

1. The ground cracking presently affecting properties in Mitchell and Edward Streets appears to be the tension crack of a very large landslip. The ground deformation and resulting damage to man-made structures within the Patterson property on the lower portion of Christie Street probably defines the lower limit of ground movement.

2. At present, structural damage is apparent on some eight properties but in the long term a substantial increase in this number is a distinct possibility.

3. At the time of inspection, on 3 and 4 July, two houses had incurred sufficient damage that the owners had evacuated them.

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4. Immediately to the northeast of the affected portion of residential land, there is a very extensive bowl shaped depression which has resulted from massive slipping in the very recent geological past. The head scarp of this former landslip is less than 100 metres away from the most northerly point of known ground cracking, presently developed within the Education Board property, to the north of Mitchell Street. Mr I. McKeller of the New Zealand Geological Survey considers that a similarly extensive landslip in the recent geological past has occurred in Abbotsford in the close vicinity and just west of the present site. Since slipping, the area has been residentially developed. The rapidity of such large scale land movements is not known hence any inference upon similarity of likely behaviour to the present slip problem cannot be usefully inferred.

5. After inspection of the area and discussion with Messrs D. Brathwaite (of E.R. Garden & Partners, Consulting Engineers), and I. McKeller it is my opinion that the problem of ground cracking and associated house damage is attributable to a landslip as defined by the Act. In this respect, please see our letter dated 6 July, 1976, addressed to Bird and Associates, Dunedin.

6. The engineering work presently being carried out on the site and instigated by E.R. Garden and Partners in association with Mr McKeller, comprises -

   a) the drilling of three exploratory borings;

   b) a survey control over the affected block of land.

   To date the drilling programme has comprised one relatively shallow hole approximately opposite No.14 Mitchell Street and another in the floor of the former Ministry of Works and Development quarry, immediately below the termination of Charles Street. The third boring is proposed to be drilled in the street at the intersection of Gordon and Edward Streets.

   In addition to the existing survey control which has already been established down Mitchell, Edward, Charles and Penrich Streets, it was suggested that the survey cover should extend over the likely toe zone of the slip i.e. beyond the termination of Charles Street, down the cut batter face and well out over the quarry floor. Likewise further coverage of the presently suspected 'toe zone' between lower Christie Street and the adjacent rugby club grounds is desirable. Messrs Brathwaite and Mahoney discussed the desirability of this extension of the survey cover and agreed upon its implementation by the former. The survey control will be necessary for defining the full extent of the slip and provided it is regularly monitored, will also serve a prime function of showing up any trend such as acceleration in the rate of movement hence possibly act as an early warning device for any further, seriously damaging movement.

7. Based upon information known to date, it appears that signs of movement within structures which we now consider as straddling the tension zone of the slip, e.g. No. 11 Edward Street, were first noted about October/November 1978. Prior to this the only recorded ground disturbance in the general vicinity was in 1972 on the Patterson property situated on the lower slopes of the general area. The ground disturbance at that time may be directly related to the present problem or possibly a more restricted movement, of part only of the apparent present large scale movement.

8. At this point in time, we would not recommend the expenditure of significant orders of insurance monies as making repairs to the affected structures. Because of the scale of potential slip, the chances are that structural repairs at this stage to damaged properties are probably destined to be ultimately useless hence the maximum amount of cover on the properties in the event of future total pay outs should be insured. This aspect can be reconsidered at a later stage if the slip should show definite signs of stabilising.

9. Located immediately east of the subject block of land just out from and below the termination of Charles Street there is a large cut batter face. The average height of the cut face is in the order of some 20 metres, the base of which we understand is now owned by the nearby sports club. This area was formerly the site of quarrying operations carried out by the then Ministry of Works during the late 1960's. The quarry supplied bulk filling during the initial construction of the nearby motorway.

Based upon the results of drilling work carried out to date, it appears that the former quarry face comprises a relatively thin upper natural surface layer of loess (aerially deposited silt) some 1 to 3 metres deep overlying some 4 to 6 metres of firm, bouldery clay deposits (considered to be of colluvial origin). This material in turn overlies a moderately dense silty sand which extends down for some 12 metres to Abbotsford Mudstone. At the quarry location the underlying surface of the mudstone comprises a dark grey, moderately dense silty sandstone facies rather than true mud. The purpose of the initial three exploratory holes, we understand, is to provide some basic understanding of the general lithological nature of the subject site and also to allow the installation of inclinometers in the completed holes. The inclinometers can then be regularly checked along with the survey monitoring and will provide information on future movement direction and depth. The positioning, logging and final depth determination of the holes is being organised by Mr I. McKeller at the request of Mr D. Brathwaite. The holes are being drilled by a Ministry of Works and Development drill rig.

10. The cause of the slip is not yet clear. However at this stage we would suggest the following factors will have had a substantial bearing upon the present situation:-

a) The area of land presently considered to be involved in the slip appears to be substantially similar geologically and topographically to the general surrounding terrain. The surrounding areas show several clear examples of large scale landslipping. Some of these former, identifiable landslip zones have been residentially developed. In addition, during the time of the nearby Green Island-Abbotsford motorway earthworks, some 10-12 years ago a similarly large area of slipping developed but was apparently stabilised by immediate reinstatement of filling at the toe zone.

This general area i.e. Green Island-Abbotsford area is considered as geologically unstable terrain and hence for engineering purposes only of marginal stability at the best.

b) The development of the former quarry between Charles Street and Armstrong Lane effectively removed considerable toe support to a large portion of the land above and hence could be considered as comprising a substantial contributary cause. In this context, it may be significant that the first known ground movements in the immediate vicinity appeared at Pattersons. Movement of the ground at this location seemed to have commenced within several years of the cessation of nearby quarrying operations.

c) The lower portion of the suspected tension zone of the slip mass appears to more or less follow down a natural stream valley from Edward Street southeastward, down through Pattersons property to the neighbouring playing field. Such a valley system may well form a zone of weakness both from the aspect of comprising a defined margin where the overlying stronger, colluvial deposits are probably missing (or at their thinnest) as well as being a general zone of natural waterinfiltration. Above Edward Street the tension crack appears to continue northward independently of the adjacent stream valley.

d) Once gradual movement had been initiated within the block of land, probably at a very slow rate, then any undetected fractured services will have compounded the situation, perhaps to the point of significant aggravation and ultimately, particularly in the case of stormwater and watermain disruption causing a significant acceleration of movement. This may be an explanation for the apparent major movement experienced in early June. We understand that the rainfall for some months immediately prior to this date was not excessive and if anything, less than average.

GENERAL

With respect to the various parties and their respective responsibilities, involved in the landslip, we understand that E.R. Garden & Partners were initially involved in the landslip at the request of Bird and Associates on behalf of the Earthquake and War Damage Commission. In due course however, as the significance of the problem became apparent, the Green Island Borough's involvement in the situation became a necessity, presumably on the basis of responsibility to local ratepayers who were directly affected by the slip problem. Because of E.R. Garden & Partners longstanding relationship as engineers to the Borough, the principal involved, Mr D. Brathwaite preferred that his involvement with respect to the Commission be phased out as early as convenient. You then requested us to become involved. Therefore in order that the changeover of the role of the Commission engineering advisers i.e. E.R. Garden and Partners to Brickell, Moss, Rankine & Hill be facilitated, we suggest the following be implemented:-

- E.R. Garden and Partners carry out the regular survey monitoring, extend the existing survey control as previously discussed and generally complete the compilation of investigation drilling (with the aid of Mr McKeller) up to the completion of the third boring of the current investigation programme. This will include the obtaining of a 1:2000 scale (or thereabouts) aerial photo coverage of the area and a similarly scaled topographic plan. When available, copies of this information should then be made available to us for the evaluation and planning of any future investigations.

- E.R. Garden & Partners should carry on with the survey monitoring and these records plus any related information on the behaviour of the subject land, be made readily available through the Green Island Borough to any genuinely interested parties.

- BMR&H involvement will comprise actioning any request made either directly by the Commission or by Bird and Associates (Otago) Ltd as is appropriate. Presently we would envisage the inspection of any further claims or deterioration of structures as being served by our resident Dunedin Partner, David Cox and any more significant geotechnical aspects, by the writer.

- In general terms, we see the Green Island Borough as being the organisation best situated, and possibly obliged to advise various property owners on aspects of safety. Should the question arise of advice to property owners to remain or evacuate their respective dwellings, the Local Borough and perhaps the associated Civil Defence organisation would be the appropriate organisation.

- In the event that monitoring of the slip suggests an increase in rate of movement and concern is developed upon the interpretation and consequently implementation of the appropriate line of action necessary required, a consensus of informed opinion should be readily available. We foresee that a clear line of communication upon this particular aspect should be set up between Messrs Brathwaite, Cox, Bird and any other local qualified person such as Mr I. McKeller, who has a genuine interest and ability to contribute to resolving the situation.

CONCLUSIONS

The problem already affecting some eight houses in the area is considered to be due to the initial tension crack of a developing large scale landslip. The landslide is definable as a landslip within the meaning of the Act. Ultimately some 30 to 40 sections could be involved. Based upon surrounding examples of large scale slipping involving many metres of horizontal and vertical displacement, ultimate disruption of the whole block of land cannot be entirely ruled out. At this stage any more refined forecasting of likely behaviour is really only guesswork and could well be very misleading. However we would suggest that further disruptive movement over the present winter is to be expected. Further investigation of the nature and properties of the subsoils and groundwater levels involved in the landslip may clarify some of the apsects involved in forecasting further likely behaviour.

Because of the size of the area involved alone, immediate remedial measures required to stabilise the land appear impractical. However, considering the ultimate value of the property and land at risk, some considerable expenditure on relieving the problem will possibly be warranted. While our initial reaction upon the scale of the problem, is that stabilisation measures would be most formidable, such measures will not necessarily be impossible nor impractical. As all landslipping involves water problems to a greater or lesser degree, it may well be considered after future investigation and detailed analysis that deep drainage may be the key to future stabilisation.

RECOMMENDATIONS

The Green Island Borough should keep all records of future ground movements surveyed and act in an advisory capacity to individual owners on matters of safety and general welfare. Obviously the Borough should continue its regular inspection of all street services, particularly in the critical tension zones.

The Commission and its agents should process new claims as they come in and in the event of seeing obvious or likely dangerous situations to advise the appropriate owner and/or local body officer accordingly.

Future soils investigation will be required in order to adequately sample the subsoils and analyse the stability in order to derive any practical means of improving the existing, apparently precarious situation. In order that such an investigation be best organised, all the present information i.e. initial boring logs, topographic and photographic cover and survey records should be completed, compiled and made available to us.

In the event of such a future exploration programme being implemented and practical solutions for increasing stability formulated, we cannot realistically foresee any specific improvement on site stability being made before the coming summer. Consequently the immediate following winter and spring months will prove to be the critical time for the subject land and properties involved. At this juncture it appears that the as yet unaffected property owners within the subject block of land (i.e. southeast of the tension crack) should be advised of the possibility of ultimate disruption to their land and properties in the future. How soon or indeed whether this will happen at all is an unknown, but nevertheless the risk of such should not be kept from them.

We trust this progress report upon the landslip at Green Island covers adequately the respective aspects of current concern to the Commission.

Yours faithfully,
p.p. BRICKELL, MOSS, RANKINE & HILL

A.G. Mahoney

AGM/JHT/reh

c.c. BMRH, Dunedin

BRICKELL, MOSS, RANKINE & HILL

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51118

July 20, 1979

The Secretary,
Earthquake & War Damage Commission,
P.O. Box 5038,
Lambton Quay,
WELLINGTON.

Dear Sir,

Progress Report
Landslip
Green Island - Abbotsford
Dunedin

Further to our progress report dated July 16 and our subsequent meeting on July 18 at your office we wish to clarify the following specific points concerning the above landslip.

1. The ground cracking presently affecting properties in Mitchell and Edward Streets appears to be the tension crack of a very large landslip. The ground deformation and resulting damage to man-made structures within Patterson's property on the lower portion of Christie Street probably defines the lower limit of the present ground movement.

2. Based upon data available to date, the affected block of land appears to be sliding on the upper surface of the Abbotsford Mudstone formation. Since initially recorded in June, the movement appears to have maintained a regular rate of approximately 10 mm per day.

3. Immediately to the northeast of the affected portion of residential land, there is a very extensive bowl shaped depression which has resulted from massive slipping in the very recent

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geological past. The head scarp of this former landslip is less than 100 metres away from the most northerly point of known ground cracking, presently developed within the Education Board property, to the north of Mitchell Street. It is also considered that a similarly extensive landslip in the recent geological past has occurred in Abbotsford in the close vicinity and just west of the present site. Since slipping, this particular area has been residentially developed.

4. Preliminary engineering work prepared and presently being carried out on the site under the sole direction by E.R. Garden and Partners in association with Mr I. McKeller, of the New Zealand Geological Survey, comprises:-

a) the drilling of four initial exploratory borings;

b) a monitoring survey control over the affected block of land.

We understand that the purpose of the initial exploratory holes, is to provide some basic understanding of the general lithological nature of the subject site and also to allow the installation of inclinometers in the completed holes. The inclinometers can then be regularly checked along with the survey monitoring and will provide information on future movement direction and depth. The survey control is being carried out to determine the extent of the slip and provided it is regularly monitored, will also serve a prime function of showing up any trend such as acceleration in the rate of movement.

5. The safety of the residential development on the land involved in the slip, is dependant largely upon the future rate of movement of the slip mass. Because of the size and nature of the slip, as understood to date, further movement can reasonably be anticipated. Any prediction at this time as to the likely rate of movement in the near future will not necessarily be reliable. Based upon historical slips in the locality, movements have generally appeared to be prolonged and slow processes. However, though it is probably reasonable at this time to infer that similar rates of movement are likely to occur on the subject slip, such an inference cannot be entirely relied upon. There is the distinct possibility that a significant increase in movement rate could occur with little or no warning in the event of very heavy prolonged rainfall and/or a ground tremor. If such movement occurs, all the properties within the slip mass and perhaps some of the properties immediately downhill of the landslip area could be endangered.

Until the soil properties, ground water conditions and the geometry of the slip mass is thoroughly investigated, more definitive forecasting of the landslip behaviour is of limited reliability.

6. The cause of the slip is not yet clear. However, at this stage we would suggest the following factors will have had a substantial bearing upon the present situation:-

a) The area of land presently considered to be involved in the slip appears to be substantially similar geologically and topographically to the general surrounding terrain. The surrounding areas show several clear examples of large scale landslipping. Some of these former, identifiable landslip zones have been residentially developed. In addition, during the time of the nearby Green Island-Abbotsford motorway earthworks, some 10-12 years ago, a similarly large area of slipping developed but was apparently stabilised by reinstatement of filling at the toe zone. The Green Island-Abbotsford area is considered as geologically unstable terrain and hence for engineering purposes only of marginal stability at the best.

b) The development of the former quarry between Charles Street and Armstrong Lane may have effectively removed considerable toe support to a large portion of the land above and hence could possible be considered as comprising a contributary cause.

c) The lower portion of the suspected tension zone of the slip mass appears to more or less follow down a natural stream valley from Edward Street southeastward, down through Patterson's property to the neighbouring playing field. Such a valley system may well form a zone of weakness both from the aspect of comprising a defined margin where the overlying stronger, colluvial deposits are probably missing (or at their thinnest) as well as being a general zone of natural water infiltration. Above Edward Street, the tension crack appears to continue northward independently of the adjacent stream valley.

d) Once gradual movement had been initiated within the block of land, probably at a very slow rate, then any undetected fractured services will have compounded the situation, and will ultimately, particularly in the case of stormwater and watermain disruption, cause a significant acceleration of movement. This may be an explanation for the apparent major movement experienced in early June. However, the effect of the preceding very high rainfall in May following a prolonged dry period cannot be discounted.

7. Continuous and regular monitoring of the landslip area is necessary.

8. Adequate investigation of the slip in order to determine what, if any, remedial measures are engineeringly feasible to stabilise the slip will take some months. Alleviation of the problem through a thorough engineering evaluation cannot be expected in the short term.

RECOMMENDATIONS

The Green Island Borough should keep all records of future ground movement surveys and act in an advisory capacity to individual owners on matters of safety and general welfare. The Borough should continue its regular inspection of all street services, particularly in the critical tension zones.

In the event of practical solutions for increasing stability having been formulated, we cannot realistically foresee any specific improvement on site stability being made before the coming summer. At this juncture it appears that the as yet unaffected property owners within the subject block of land (i.e. southeast of the tension crack) and also on the lower portion of Christie Street should be advised of the possibility of disruption to their land and properties in the future. How soon or indeed whether this will happen at all is unknown.

Yours faithfully,
p.p. BRICKELL, MOSS, RANKINE & HILL

R.L. Bishop

A.G. Mahoney

AGM/RLB/reh
c.c. E.R. Garden & Ptrs

BRICKELL, MOSS, RANKINE & HILL

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PALMERSTON NORTH

3 August 1979

79140

The Secretary,
Earthquake & War Damage Commission,
P.O. Box 5038,
WELLINGTON.

Dear Sir,

Re: ABBOTSFORD LANDSLIP:

CERTIFICATION BY CONSULTING ENGINEERS

Further to recent discussions we confirm the wording as agreed in principle with yourself and representatives of the Housing Corporation for certification of individual residences by E.R. Garden & Partners, and our firm jointly as follows:-

Re: NO.X, SMITH STREET, ABBOTSFORD

"In our professional opinion, not to be construed as a guarantee, the residence at the above address is being damaged by the landslip/ is within the landslip area, and is now at risk. Further, in view of the continuing and increasing movement, it is considered probable that the above will be damaged beyond repair, or become unsuitable for use as a residence, in the immediate forseeable future. This professional opinion is furnished to Earthquake & War Damage Commission for its purposes alone, on the express condition that it will not be relied upon by any other person."

We would recommend that no certificates be given to individual house-owners, but that they should be warned of risk by E.R. Garden & Partners acting for Green Island Borough Council, as has been happening to date, and that upon request a certificate as above will be furnished to your Commission as appropriate.

We trust this meets with your approval.

Yours faithfully,
p.p. BRICKELL, MOSS, RANKINE & HILL

DGC

David G. Cox

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In borings M2, M3 and M4, which were immediately adjacent to our bores B2, B3 and B1, respectively, shearing was recorded at depths of 11.9 m, 32.2 m and 12.0 m respectively. The failure is assumed to be defined by straight lines passing through the relevant borings at their appropriate shear depths. This straight line was extrapolated to the position of the toe slope and the head slope.

Inclinometers M2 and M4 indicated shearing at, or very close to, the interface between the Green Island Sand and the Abbotsford Formation whilst M3 showed the shearing to occur some two metres below this interface. Although the shearing coincides with the interface in bores M2 and M4 it seems somewhat anomalous when a study is made of the relevant cores which were taken during the pre-slide movement period. In these cores there is a clearly defined sudden change from Green Island Sand to Abbotsford Formation with no discernible break, fracture zone, or zone of disturbance.

In the absence of more extensive data we have, with the exception of the M3 vicinity, taken the principal shearing surface as coincident with the Green Island Sand - Abbotsford Formation interface.

B5.2 Toe Slope

The toe slopes have been developed from a study of the shape of the post-slip topography in the vicinity of the toe of the main block.

B5.3 Head Scarp

We have used a head scarp with a vertical tension crack to half depth with a slope of ½ to 1 (horizontal to vertical) below this; based on observations immediately subsequent to the main block movement.

B6.0 Parameters

B6.1 Density

For the purpose of our analysis we have adopted average measured values for the bulk density for the Green Island Sand and the Abbotsford Formation and have assumed typical bulk density values for the loess and colluvium soils.

The bulk density values used as the basis for our analyses were as follows:-

Soil Type	Bulk Density (kg/m^3)
Loess	1700
Colluvium	2000
Green Island Sand	1960
Abbotsford Formation	1990

B6.2 Angle of Shearing Resistance (Ø')

The particular Ø' angles used for the principle failure surface are described in the main text. It has been assumed that the effective cohesion is zero (c' = 0).

The Ø' angle for the reverse toe slope, which rises through the Green Island Sand, has been fixed at 30°.

We have assumed that a tension crack existed over the full sloping length and depth of the head scarp, and therefore there is no component for resisting force along this plane of failure immediately prior to the main failure.

B6.3 Ground Water Table

Groundwater was, where possible, monitored on a daily basis subsequent to the completion of our borings. For the purpose of establishing a water level on the cross-sections we have plotted the last measured value recorded prior to the main block movement.

In our analysis we have assumed the water table to be defined by a line passing through the measured values which have been plotted on the section. This line has been extrapolated both in the upslope and downslope direction.

B6.4 Ground Water Pressure

As part of our analysis we have considered the possibility of sub-artesian or artesian groundwater conditions existing, confined to the vicinity of the Green Island Sand - Abbotsford Formation Interface (i.e. in the vicinity of our inferred shear plane surface). This assumption requires that a low permeability capping stratum exists immediately above the excess ground water pressure zone. For the purpose of analysis, we have assumed infiltration occurs where cross-section DD crosses the East Christie Street Stream (refer Plate 2B), and have considered linear variable-angle hydraulic gradient from this point.

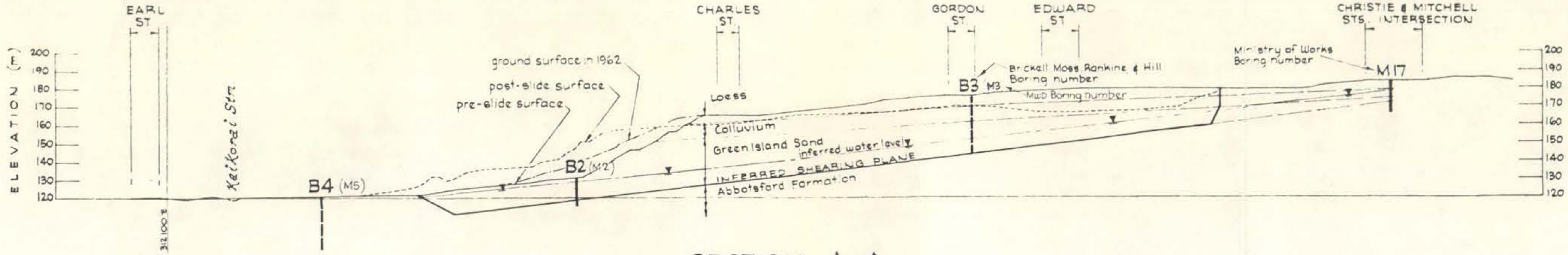
B6.5 Water Pressure at Head Scarp

Where appropriate we have included the effect of hydrostatic pressure acting below the ground water table line in the head scarp tension crack.

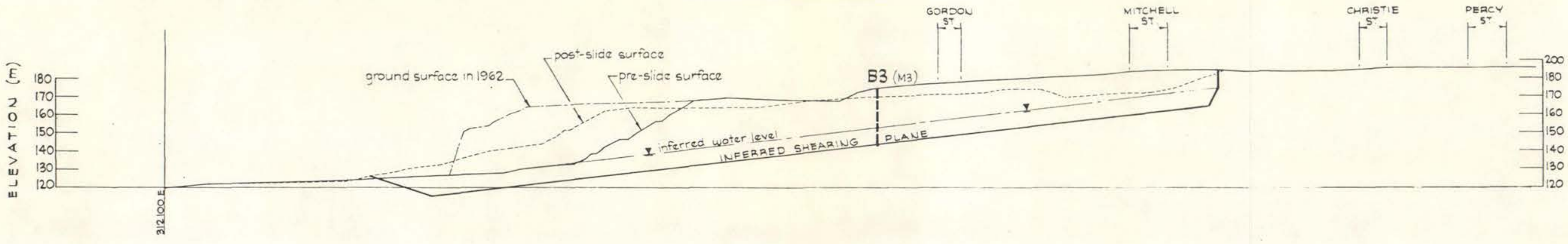
B6.6 Attachments

The following plate is attached to complete this Appendix.

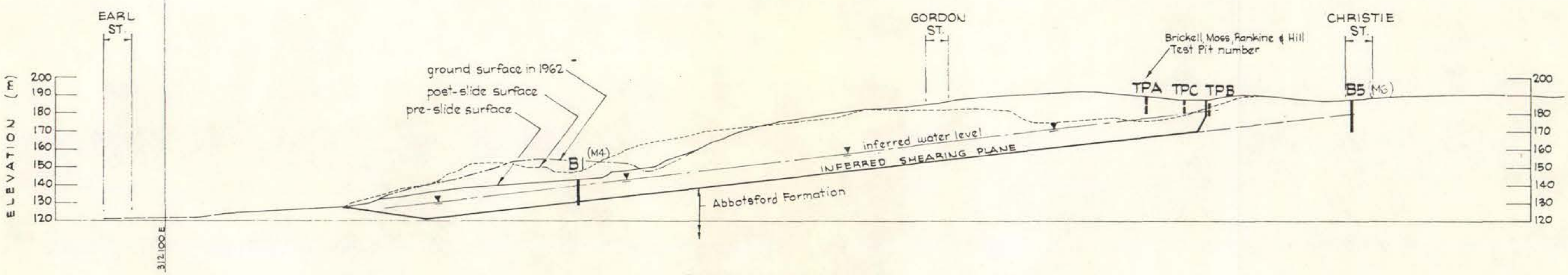
Plate B-1 Inferred Subsurface Sections



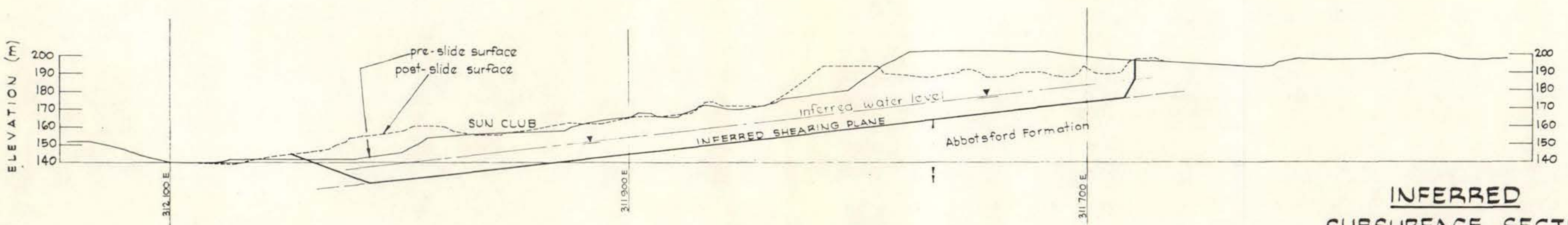
SECTION A-A



SECTION B-B



SECTION C-C

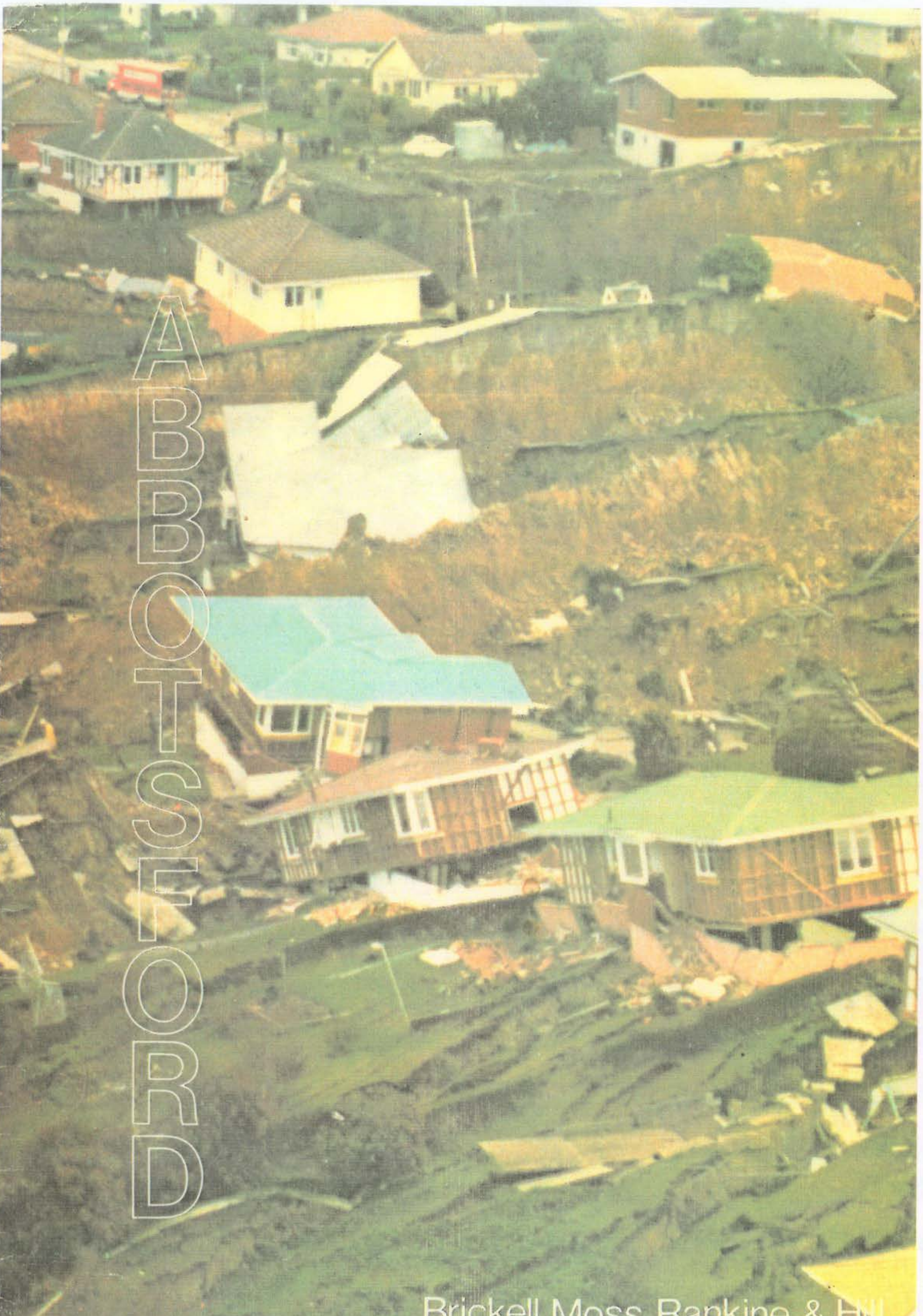


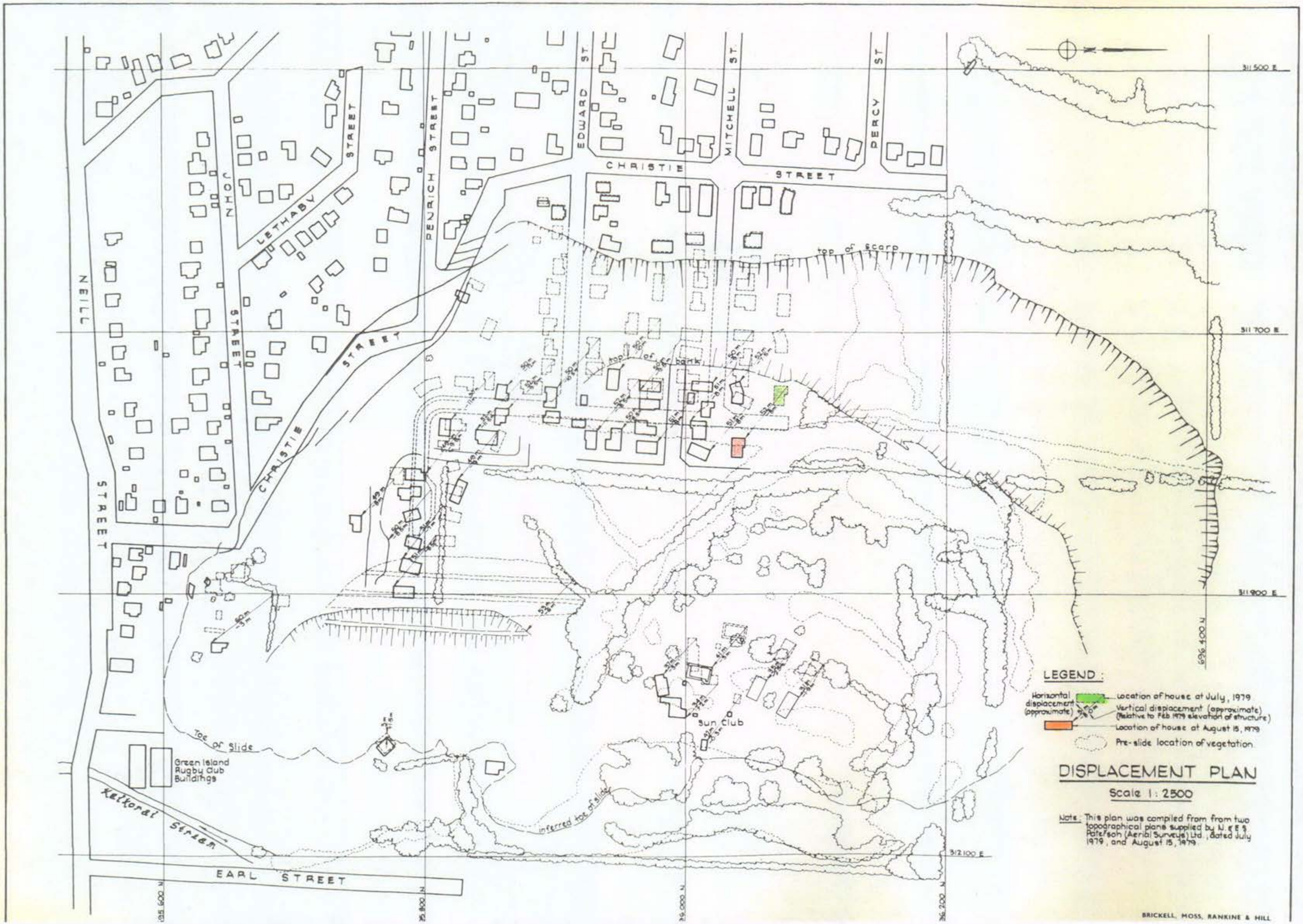
SECTION D-D

INFERRED SUBSURFACE SECTIONS

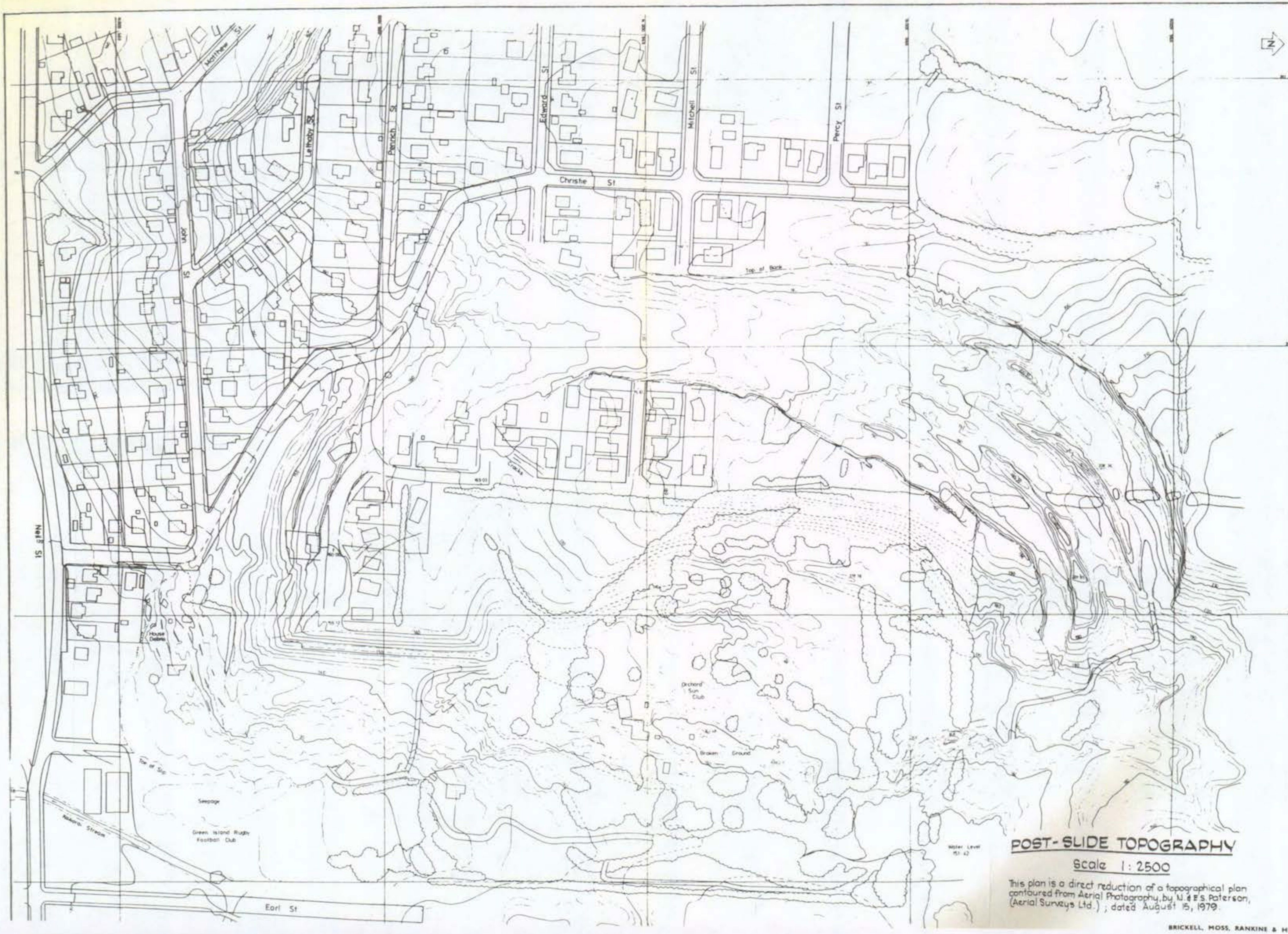
Scale 1:2500

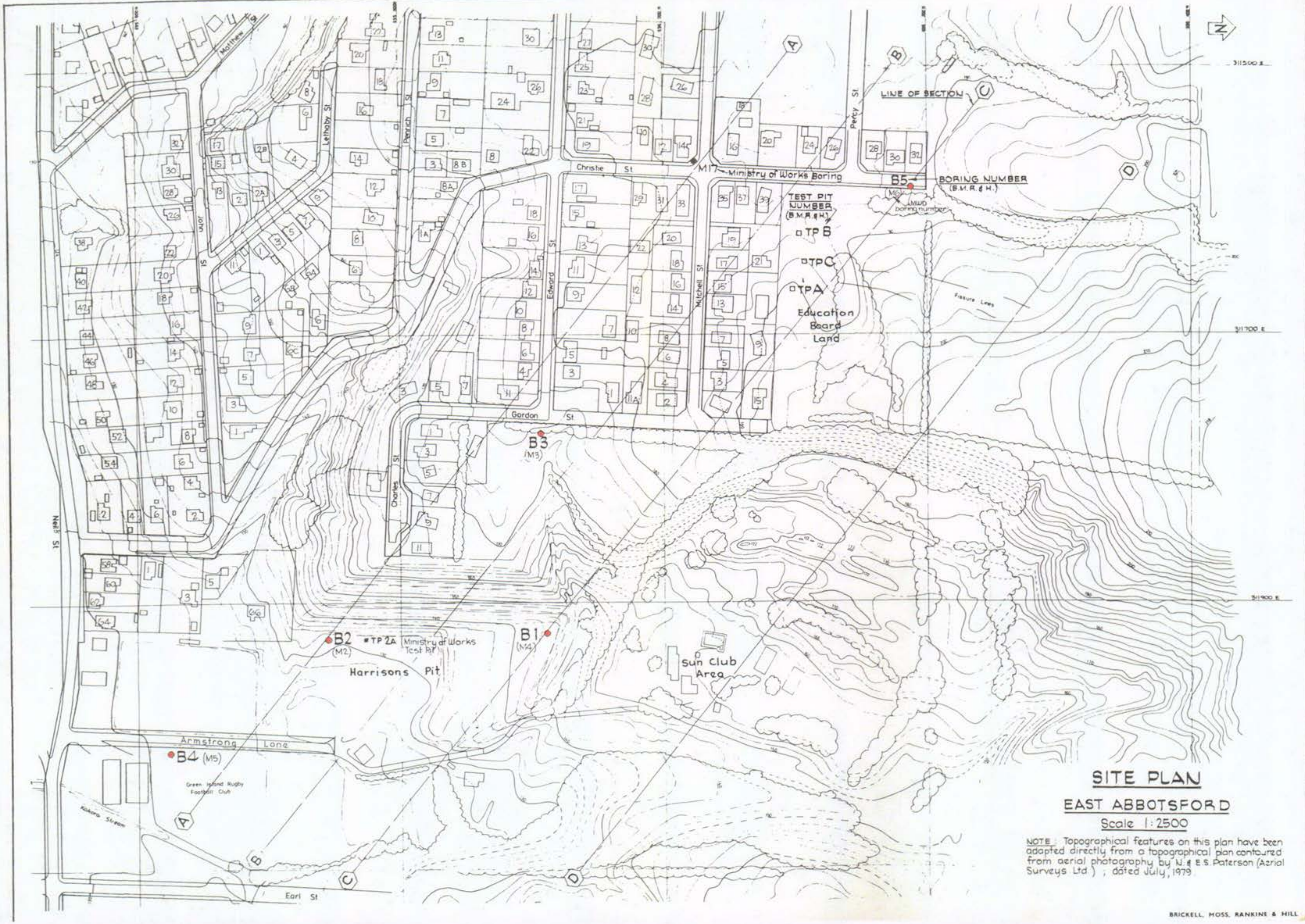
BRICKELL, MOSS, RANKINE & HILL


ABBOTSFORD
Brickell Moss Rankine & Hill



DISPLACEMENT PLAN
Scale 1 : 2500
LEGEND :
Horizontal displacement (approximate)
Location of house at July, 1979
Vertical displacement (approximate) (Relative to Feb 1979 elevation of structure)
Location of house at August 15, 1979
Pre-slide location of vegetation
Note: This plan was compiled from from two topographical plans supplied by N. Z. & S. Paterson (Aerial Surveys) Ltd., dated July 1979, and August 15, 1979.
NEILL STREET
JOHN STREET
LETHABY STREET
PENRICH STREET
EDWARD ST.
MITCHELL ST.
PERCY ST
CHRISTIE STREET
top of scarp
top of bank
Toe of Slide
inferred toe of slide
Sun Club
Green Island Rugby Club Buildings
Kaikorai Stream
EARL STREET
311 500 E
311 700 E
311 900 E
312 100 E
695 600 N
695 800 N
696 000 N
696 200 N
696 400 N
BRICKELL, MOSS, RANKINE & HILL


Matthew St
Lethaby St
Pennich St
Edward St
Mitchell St
Percy St
Christie St
Top of Bank
Neill St
House Debris
Cracks
Orchard Sun Club
Broken Ground
Toe of Slip
Seepage
Green Island Rugby Football Club
Kaikorai Stream
Earl St
Water Level
POST-SLIDE TOPOGRAPHY
Scale 1 : 2500
This plan is a direct reduction of a topographical plan contoured from Aerial Photography, by N. & E.S. Paterson, (Aerial Surveys Ltd.) ; dated August 15, 1979.
BRICKELL, MOSS, RANKINE & HILL



SITE PLAN

EAST ABBOTSFORD

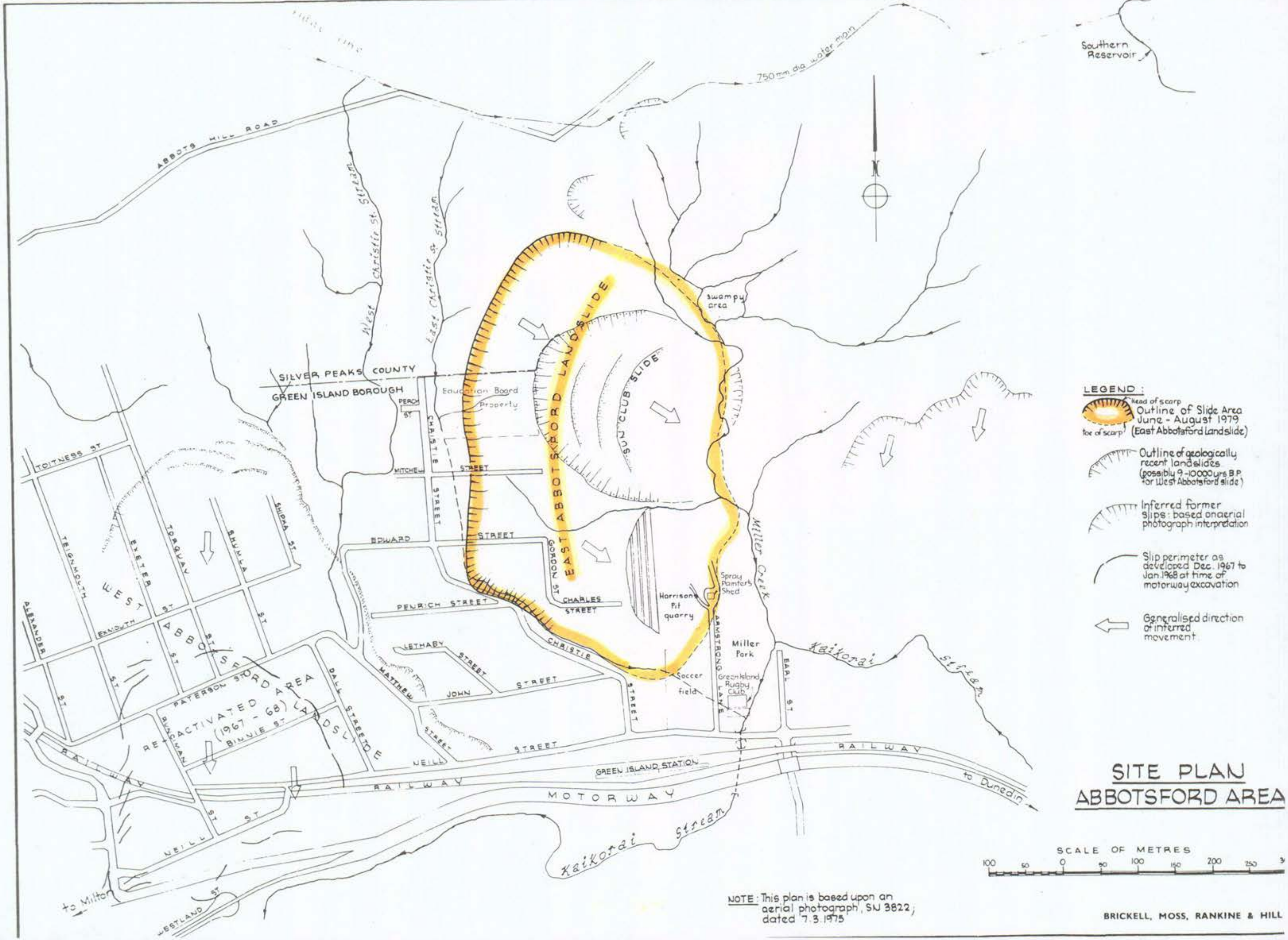
Scale 1:2500

NOTE: Topographical features on this plan have been adapted directly from a topographical plan contoured from aerial photography by N. & E.S. Paterson (Aerial Surveys Ltd.); dated July, 1979

BRICKELL, MOSS, RANKINE & HILL

Appendix A

FIELDWORK and LABORATORY TESTING


SITE PLAN
ABBOTSFORD AREA
LEGEND:
head of scarp
Outline of Slide Area June - August 1979 (East Abbotsford Landslide)
toe of scarp
Outline of geologically recent landslides (possibly 9-10000 yrs B.P. for West Abbotsford slide)
Inferred former slips: based on aerial photograph interpretation
Slip perimeter as developed Dec. 1967 to Jan. 1968 at time of motorway excavation
Generalised direction of inferred movement
SCALE OF METRES
100
50
0
50
100
150
200
250
NOTE: This plan is based upon an aerial photograph, SN 3822, dated 7.3.1975
BRICKELL, MOSS, RANKINE & HILL
Southern Reservoir
750 mm dia water main
ABBOTS HILL ROAD
West Christie St. Stream
East Christie St. Stream
SILVER PEAKS COUNTY
GREEN ISLAND BOROUGH
Education Board Property
EAST ABBOTSFORD LANDSLIDE
SUN CLUB SLIDE
swampy area
Miller Creek
Spray Painter's Shed
Harrisons Pit quarry
Miller Park
Green Island Rugby Club
Soccer field
Kaikorai Stream
WEST ABBOTSFORD AREA
RE-ACTIVATED (1967 - 68) LANDSLIDE
GREEN ISLAND STATION
RAILWAY
MOTORWAY
to Dunedin
to Milton
TOITNESS ST
TEIGNMOUTH
EXETER
TORQUAY
SHUMLA ST
EXMOUTH
ALEXANDER ST
PATERSON ST
BUNGMAN
BINNIE ST
DALE STREET
MATTHEW STREET
NEILL STREET
JOHN STREET
LETHABY STREET
PEURICH STREET
CHARLES STREET
GORDON ST
EDWARD STREET
MITCHELL STREET
CHRISTIE STREET
PERCY ST
ARMSTRONG LANE
EARL ST
WESTLAND ST

EAST ABBOTSFORD LANDSLIP Scale 1:2500 (approx.)

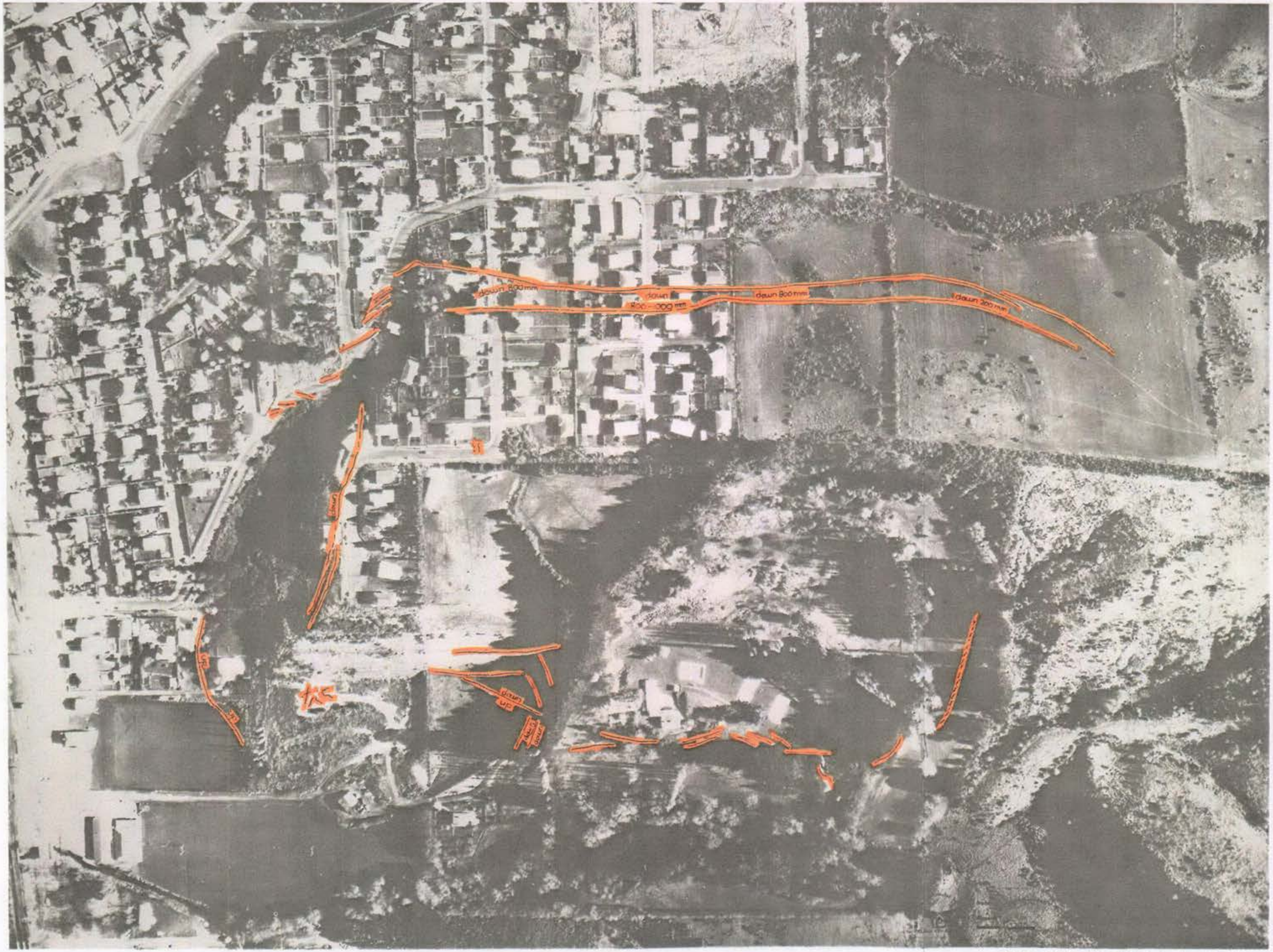
AS REGRADED ON AUGUST 24, 1979

EAST ABBOTSFORD LANDSLIP
Scale 1: 2500 (approx.)

AS AT AUGUST 9, 1979

PLATE 6D

Job No 5118 . E & SSC . Abbotsford . Auth. 20.8.79



EAST ABBOTSFORD LANDSLIP
Scale 1: 2500 (approx.)

AS AT AUGUST 1, 1979

Job Nº 51118 · E & WC · Abbotsford · AGM · 26.9.79

Job Nº 51118 · E & WDC · Abbotsford · AGM · 26.9.79

EAST ABBOTSFORD LANDSLIP

AS AT JULY 24, 1979

EAST ABBOTSFORD LANDSLIP   Scale 1 : 2500 (Approx.)

RECORDED GROUND DEFORMATION AS AT JULY 4, 1979

✕ marks dislocation of services;   ▬ marks line of surface deformation.

① 16 Mitchell St. : some damage noted October/November 1978. Possibility of some damage in basement prior to 1974.

② 11 Edward St. : minor cracking of garage/basement floor noted in October/November, 1978.

③ 5 Christie St. : movement of ground surface beneath house first recorded in April, 1972.

PLATE 6A

Scale 1 : 3000 (approx.)

ABBOTSFORD AS DEVELOPED IN 1942

MAJOR MOVEMENT

BORING NO.	B1	B2	TP2A	B3		B4		B5		TPA	TPC
LOCATION	Near Sun Club	Harrisons Pit	Harrisons Pit 30 m east of B2	Edward Street		Miller Park		North end of Christie Street		In field to east of north end of Christie Street	
SURFACE R.L.	142.6	130.5	131	176.0		120.6		189.2		190	188
BORING DEPTH	14.2 m	15.2 m	7.0 m	32.1 m		28.2 m		17.5 m		9.8 m	7.2 m
REMARKS & DEPTH BELOW GROUND SURFACE	One standpipe to depth: 12.0 m	One standpipe to depth: 12.0 m	One standpipe to depth: 6.0 m	Piezometer tubes to depths: A=28.5m	B=23.8m	Piezometer tubes to depths: A=26.0m	B=7.0m	Piezometer tubes to depth: A =7.0m	B=12.4 m	One stand pipe to depth: 9.8 m	-
SEALED ZONE	-	-	-	26.0 m to 29.0 m	22.0 m to 24.0 m	24.8 m to 27.0 m	5.0 m to 8.5 m	5.0 m to 8.5 m	10.5 m to 13.5 m	-	-
DATE	OBSERVED WATER LEVEL (DEPTH BELOW GROUND SURFACE IN METRES)										
30.7.79	2.0										
31.7.79 a.m.	2.02	0.3									
31.7.79 p.m.	2.02	0.44									7.0
1.8.79	2.01	0.51									
2.8.79	1.98	0.62								8.6	
3.8.79	1.91	0.66									
4.8.79	2.21	0.75	3.08	23.95	23.76					9.6	
5.8.79	2.23	0.72	2.42	24.81	23.93*					9.0	
6.8.79	2.26	0.78	2.23	24.98	23.96*					9.1	
7.8.79	2.38	0.83	2.16	24.97	23.97*	9.09	4.33			9.2	
8.8.79	1.60	1.10	2.30	22.90	21.70	9.15	4.30			9.35	
9.8.79	Blocked	Blocked		4.0 ** Blocked	20.0 *** Blocked	8.05	4.15		2.50 Δ		
10.8.79						7.0	6.10		2.30 (1)		
11.8.79						8.15	4.00		2.60 (2)		
12.8.79						8.10	4.00		-		
13.8.79						8.10	3.90		2.60 (3)		
14.8.79				** 17.2 Blocked	*** 20.0 Blocked	8.10	3.95		2.60		
15.8.79						8.10	4.00		2.70 (4)		
16.8.79						8.10	4.10		2.70		
17.8.79						8.20	4.10		2.70 (5)		

Notes:

* Spiralling of wire down piezometer tube caused inaccurate readings.

** Blocked at 4m, no water. Blockage apparently cleared possibly caused by flow of water or ground movement or combination of both - subsequent blocked at 17.2 m.

*** Blocked at 20 m, no water.

Δ Two piezometers were installed in B5. Connection between piezometer tube and piezometer lost during installation of the upper piezometer.

(1) Blocked at 12 m

(2) Blocked at 11.7 m

(3) Blocked at 11.4 m

(4) Piezometer tube flushed out water level returned to 2.70 m.

(5) Piezometer tube filled with water, level returned to as measured i.e. 2.70 m.

OBSERVED GROUND WATER LEVELS

RELATIVE DENSITY OF COHESIONLESS SOILS

	Corrected SPT 'N' value (blows/300 mm)
Very Loose	0 to 4
Loose	4 to 10
Moderately Dense	10 to 30
Dense	30 to 50
Very Dense	> 50

GRAIN SIZE

BOULDERS		> 200 mm
GRAVEL		
	Very coarse	200 mm to 60 mm
	Coarse	60 mm to 20 mm
	Medium	20 mm to 6 mm
	Fine	6 mm to 2 mm
SAND		
	Coarse	2 mm to .6 mm
	Medium	.6 mm to .2 mm
	Fine	.2 mm to .06 mm
SILT & CLAY		< .06 mm

GRAIN SHAPE

Angular	Showing little or no evidence of wear; edges and corners sharp, secondary edges present.
Subangular	Showing some effect of wear; faces virtually untouched but edges and corners slightly worn.
Subrounded	Showing considerable wear; edges and corners rounded off to smooth curves, original faces considerably reduced.
Rounded	Original faces almost completely destroyed, but some comparatively flat surfaces present. All original corners smoothed off to broad curves.
Well rounded	No original faces, corners or edges left. The entire surface consists of broad curves; flat areas absent - virtually spherical.

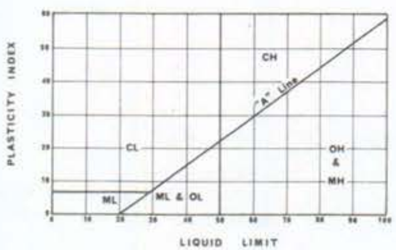
CONSISTENCY OF COHESIVE SOILS

Very Soft	- squeezes between fingers
Soft	- easily moulded by fingers
Firm	- moulded by strong finger pressure
Stiff	- dented " " " "
Very Stiff	- dented only slightly by finger pressure
Hard	- dented only slightly by pencil point.

STRUCTURE

Layer	A relatively continuous planar unit of soil, limited by difference in composition, texture or structure.
Lens	A discontinuous unit of soil, usually of limited area and generally less than 300 mm thick.
Bed	One distinct soil unit of sedimentary origin, confined within distinct bedding planes.
Homogeneous	Uniform properties within a soil unit.
Interbedded	Alternate beds of soil within a major soil unit.
Laminated	Distinct, fine layers each generally less than 3 mm thick.
Banded	Alternate layers of soil with distinct colour differences.
Mottled	Irregularly marked with spots or zones of different colours.
Slikenside	Smooth, polished sometimes striated planar structures resulting from insitu movement.

DEFINITIONS OF DESCRIPTIVE TERMS



PLASTICITY CHART

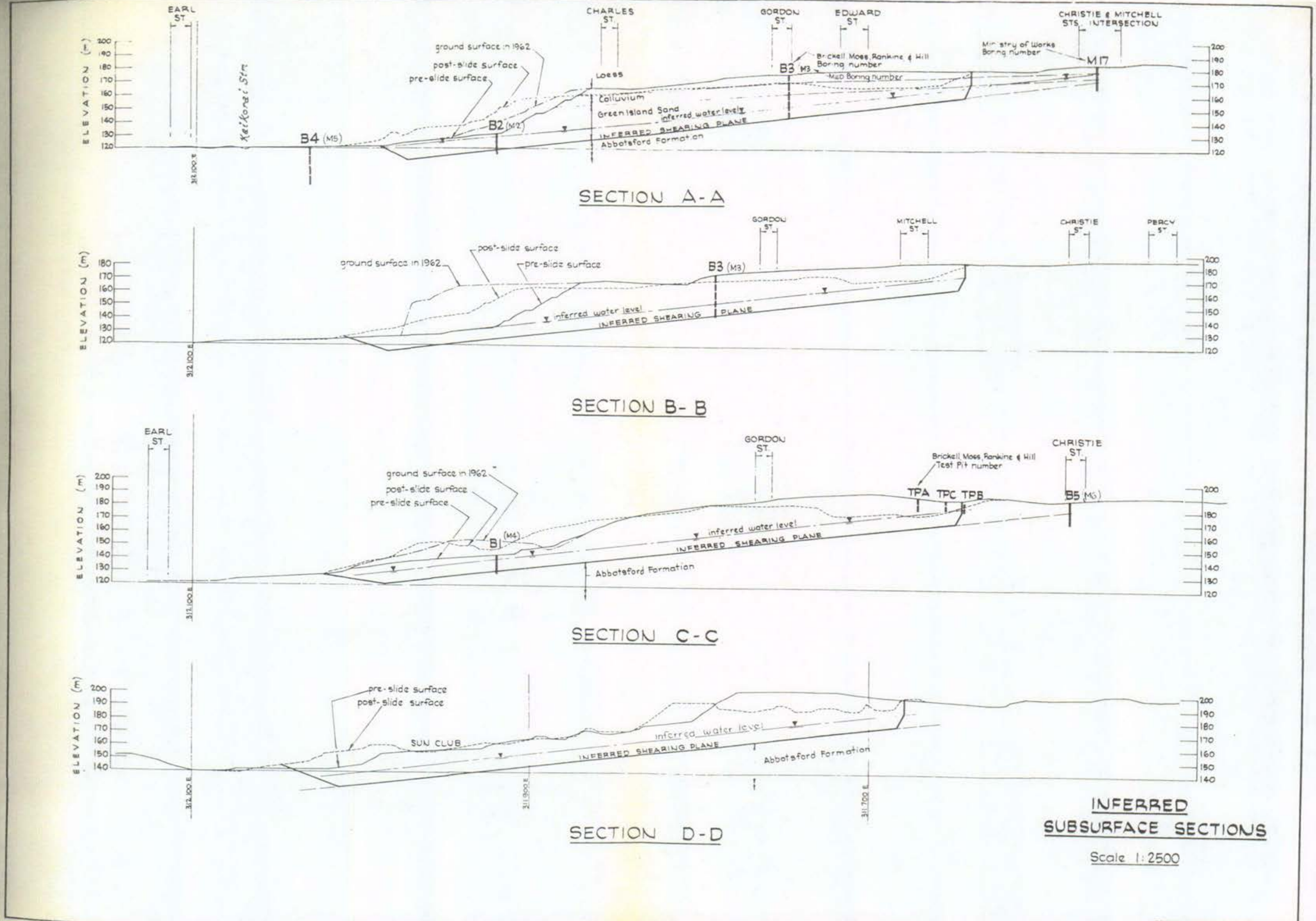
MAJOR DIVISIONS		SYMBOL	TYPICAL NAMES
COARSE GRAINED SOILS (More than 1/2 of soil > 0.06 mm)	GRAVELS (More than 1/2 of coarse fraction > 2 mm)	GW	Well graded gravels or gravel-sand mixtures, little or no fines.
		GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.
		GM	Silty gravels, gravel-sand-silt mixtures.
		GC	Clayey gravels, gravel-sand-clay mixtures.
	SANDS (More than 1/2 of coarse fraction < 2 mm)	SW	Well graded sands or gravelly sands, little or no fines.
		SP	Poorly graded sands or gravelly sands, little or no fines.
		SM	Silty sands, sand-silt mixtures.
		SC	Clayey sands, sand-clay mixtures.
FINE GRAINED SOILS (More than 1/2 of soil < 0.06 mm)	SILTS & CLAYS (LL < 50)	ML	Inorganic silts and very find sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
		OL	Organic silts and organic silty clays of low plasticity.
	SILTS & CLAYS (LL > 50)	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
		CH	Inorganic clays of high plasticity, fat clays.
		OH	Organic clays of medium to high plasticity, organic silty clays, organic silts.
HIGHLY ORGANIC SOIL		Pt	Peat and other highly organic soils.

CLASSIFICATION CHART

(Unified Soil Classification System)

METHOD OF SOIL CLASSIFICATION

BRICKELL, MOSS, RANKINE & HILL



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