TOWN PLANNING SCHEME REGULATIONS

"controlled area" means any area demarcated upon the map by the overprinting of a red honeycomb pattern, where, by reasons of the topography, the unsuitability or instability of the soil or other like reasons, development or building may be prohibited, restricted, or permitted upon such conditions as may be specified having regard to the nature of the said area;

10. LIMITATIONS UPON DEVELOPMENT DUE TO LACK OF SERVICES, UNSUITABILITY OF LAND AND OTHER CAUSES.

(1) Subject to the provisions of Section 47(2) of the Ordinance, the Council may prohibit the erection of any building on land situated in any undeveloped part or parts of the area of this Scheme pending the extension thereto of road, sewer, water supply, light or other necessary public services.

(2) (a) No person shall within a controlled area (as defined in Clause 1) develop any land, or excavate or level any site, or remove any natural vegetation from, or erect any structure of any nature whatsoever or carry out any work upon such site without having obtained the prior approval of the Council in terms of this subclause.

(b) No such approval shall be given unless the City Engineer, after due examination, and subject to such conditions as he may specify, is satisfied that any such development, erection or other work referred to in paragraph (a) hereof can be carried out without danger to the site, or any adjoining site or any building thereon.

(c) For the purpose of any examination referred to in paragraph (b), the applicant shall, where required by the City Engineer, submit such plans or other information as the City Engineer may require. Without affecting the generality of the aforegoing, such plans may be required by the City Engineer:-

(i) to be certified by a Land Surveyor or Consulting Engineer as being correct;

(ii) to show sections through the site over the area to be developed down the line of greatest slope, accurate to 50 millimetres and to scale of 1 : 100;

(iii) to show sections at intervals not exceeding 10 metres across the site or at such closer intervals as the City Engineer may require.

(d) The conditions referred to in paragraph (b) hereof may be such as to:-

(i) restrict the form or nature of the building or structure;

(ii) limit the size and/or shape of the building or structure;

(iii) prescribe the form of foundations for the building or structure;

(iv) prescribe or restrict the materials of which the building or structure is to be constructed;

(v) determine the siting of any building or structure and of any soakpits or other drainage works;

(vi) prohibit or control any excavation on the site, the construction of any roadways, paths and other garden features;

(vii) prohibit or control the removal of any natural vegetation;

(viii) control any other aspects which the City Engineer considers to be desirable.

(e) Notwithstanding anything contained in this sub-clause the Council shall not be liable for any loss or damage which may occur to any building, structure or any property whether within a controlled area or otherwise arising out of any action by the Council or the City Engineer in terms of this sub-clause.

(3) The Council may in relation to the erection, alteration or extension of any building or use of land, impose such conditions as are in its opinion necessary having regard to the low-lying nature of the area.

SPECIAL BY-LAWS RELATING TO THE DEVELOPMENT ON BLUFF SLOPES

(Unstable Areas only)

1. **Structures**

1a No structure shall be permitted on slopes greater than 30° or within 4 metres of the top of such slopes.

1b Structures on slopes greater than 22° must be supported as follows:-

(i) on bored piles founded at such depth that the minimum distance from the base of the pile to the face of the slope exceeds the estimated depth of sliding as set out in Table 1.

Table 1

Angle of Slope	Depth of sliding "D" measured at right angles to slope
22° and flatter	0,00 metres
23°	0,75 metres
24°	1,50 metres
25°	2,25 metres
26°	3,00 metres
27°	3,75 metres
28°	4,50 metres
29°	5,25 metres
30° and steeper	6,00 metres

(ii) on a basement or semi-basement such that the weight of soil which is excavated and removed from the slope is at least equal to the total weight of the structure.

1c Where structures are proposed to be built in proximity to slopes exceeding 22° the criterion for depth of founding of all foundations shall be that no foundations shall be based above a line determined in accordance with the assumed depth of sliding from Table 1 for the major angle of slope. Where the major angle of slopes exceeds 30° both the depth and angle of sliding shall be based on a 30° slope.

1d Plans submitted to the City Engineer for approval are required:-

(i) to be certified by a Consulting Engineer as being correct;

(ii) to show sections through the site over the area to be developed down the line of greatest slope, accurate to 50 millimetres and to a scale of 1:100;

(iii) to show sections at intervals not exceeding 10 metres across the site or at such closer intervals as the City Engineer may require.

2. **Construction of Septic Tanks**

2a In order to prevent concentration of water near the faces of slopes steeper than 22°, septic tank outlets should be placed as far back from the face of the slope as possible and, where conventional soakpits cannot be located behind or below the slip plane, septic tank outlets should be taken down to a minimum depth of 3 metres and not less than 0,6 metres below the estimated slip plane.

3. **Disposal of Stormwater from Buildings**

3a Wherever possible, stormwater from roofs should be taken into stormwater drains. Where this is not possible, such stormwater must be led to soakpits constructed entirely behind and below the slip plane as determined, or taken directly to the bottom of the slope in open channels which should be well keyed into the ground. Great care must be taken to maintain such channels in good repair.

4. **Development of Terraces and Gardening**

4a Terracing or site levelling must be carried out in such a way that it results in a reduction in the weight on the slope. Excess material must not be dumped anywhere on the slopes.

4b The removal of any natural vegetation from slopes steeper than 22° is prohibited without the prior approval of the City Engineer.

4c In planning a garden, every effort must be made to ensure dispersion and not concentration of stormwater.

5. **Construction of Private Access Roads and Steps**

5a Road development on slopes exceeding 30° shall be prohibited.

5b Private Access Roads cutting across the natural slopes steeper than 22° must be entirely cut in and all banks so formed retained by walls of adequate design. Excess cut material must not be dumped anywhere on the slopes.

5c Pedestrian steps must be excavated into and running directly down the line of the slope.

6. **Function of Conditions**

6a The conditions referred to in paragraphs 1 to 5 hereof may be such as to:-

(i) restrict the form or nature of the building or structure;

(ii) limit the size and/or shape of the building or structure;

(iii) prescribe the form of foundations for the building or structure;

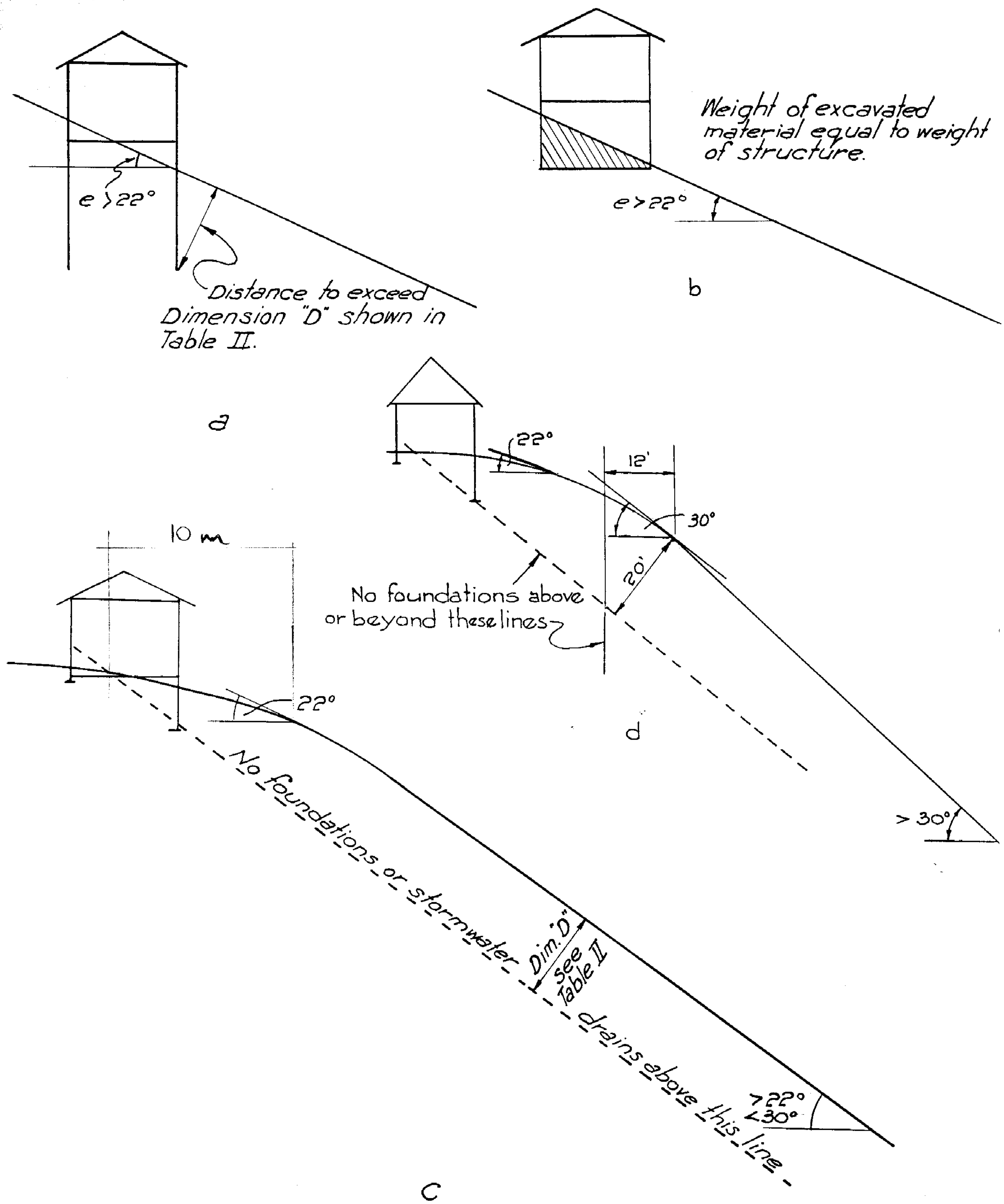
(iv) prescribe or restrict the materials of which the building or structure is to be constructed;

(v) determine the siting of any building or structure and of any soakpits or other drainage works;

(vi) prohibit or control any excavations on the site, the construction of any roadways, paths and other garden features;

(vii) control any other aspects which the City Engineer considers to be desirable.

6b Notwithstanding anything contained in this sub-clause the Council shall not be liable for any loss or damage which may occur to any building, structure or any property, whether within the controlled area or otherwise, arising out of any action by the Council or the City Engineer in terms of this sub-clause.



PROPOSED BUILDING REGULATIONS FOR BLUFF SLOPES

FIG. NO. 2

"controlled area" means any area demarcated upon the map by the overprinting of a red honeycomb pattern, where, by reasons of the topography, the unsuitability or instability of the soil or other like reasons, development or building may be prohibited, restricted, or permitted upon such conditions as may be specified having regard to the nature of the said area;

10. LIMITATIONS UPON DEVELOPMENT DUE TO LACK OF SERVICES, UNSUITABILITY OF LAND AND OTHER CAUSES.

(1) Subject to the provisions of Section 47(2) of the Ordinance, the Council may prohibit the erection of any building on land situated in any undeveloped part or parts of the area of this Scheme pending the extension thereto of road, sewer, water supply, light or other necessary public services.

(2) (a) No person shall within a controlled area (as defined in Clause 1) develop any land, or excavate or level any site, or remove any natural vegetation from, or erect any structure of any nature whatsoever or carry out any work upon such site without having obtained the prior approval of the Council in terms of this subclause.

(b) No such approval shall be given unless the City Engineer, after due examination, and subject to such conditions as he may specify, is satisfied that any such development, erection or other work referred to in paragraph (a) hereof can be carried out without danger to the site, or any adjoining site or any building thereon.

(c) For the purpose of any examination referred to in paragraph (b), the applicant shall, where required by the City Engineer, submit such plans or other information as the City Engineer may require. Without affecting the generality of the aforegoing, such plans may be required by the City Engineer:-

(i) to be certified by a Land Surveyor or Consulting Engineer as being correct;

(ii) to show sections through the site over the area to be developed down the line of greatest slope, accurate to 50 millimetres and to scale of 1 : 100;

(iii) to show sections at intervals not exceeding 10 metres across the site or at such closer intervals as the City Engineer may require.

(d) The conditions referred to in paragraph (b) hereof may be such as to:-

(i) restrict the form or nature of the building or structure;

(ii) limit the size and/or shape of the building or structure;

(iii) prescribe the form of foundations for the building or structure;

(iv) prescribe or restrict the materials of which the building or structure is to be constructed;

(v) determine the siting of any building or structure and of any soakpits or other drainage works;

(vi) prohibit or control any excavation on the site, the construction of any roadways, paths and other garden features;

(vii) prohibit or control the removal of any natural vegetation;

(viii) control any other aspects which the City Engineer considers to be desirable.

(e) Notwithstanding anything contained in this sub-clause the Council shall not be liable for any loss or damage which may occur to any building, structure or any property whether within a controlled area or otherwise arising out of any action by the Council or the City Engineer in terms of this sub-clause.

(3) The Council may in relation to the erection, alteration or extension of any building or use of land, impose such conditions as are in its opinion necessary having regard to the low-lying nature of the area.

REPORT TO

THE CITY ENGINEER, DURBAN

ON

AN INVESTIGATION INTO THE STABILITY

OF THE SEAWARD SLOPES OF THE DURBAN BLUFF

Kentey, von Geusau & Partners
Consulting Civil Engineers & Geologists
Atkinson House
Cape Town

REPORT ON AN INVESTIGATION INTO THE STABILITY OF THE BLUFF SLOPES, DURBAN

1. Terms of Reference:

In terms of letter ref. 34/2 & 3/1/39 dated 1 July 1957, it was requested that an investigation of the Durban Bluff seaward slopes be undertaken in order to determine those areas in which new buildings should perhaps be prohibited altogether, and those were special precautions should be taken. It was later requested verbally that special attention should be devoted to the problem of the three houses affected by the recent slip at Netford Road. Specific attention was drawn to the possible legal implications of total prohibition of buildings as this might involve the Council in expropriation costs of the plots on which buildings would be prohibited.

2. Information Supplied:

In order to assist in the investigation, various large scale contour plans, prepared from aerial surveys, aerial photographs, photographs of the slide at Netford Road and rainfall data requested by ourselves, was supplied. Appropriate extracts from this data supplied are referred to in the text of this report.

3. Field Investigations:

Figure 1 attached is a site plan of the extent of the Bluff investigated. Various hand augar holes were put down at the positions shown, in order to obtain information on the variation in soil profile along and across the Bluff. These borings were put down to depths limited by the efficacy of the equipment used; however, it was considered that, in view of the slides that had occurred and the geology of the Bluff, the depths achieved were sufficient for the purposes of this report. Various disturbed samples were extracted from these borings and submitted to our laboratories for testing.

At Netford Road, Test pits were put down to limited depth and undisturbed samples extracted from these test pits, and submitted to our laboratories for testing.

In addition, detailed visual examination of the Bluff was carried out in order to determine the nature of the various slides that have occurred and to form some opinion on the type and cause of those slides.

2./....

4. <u>Laboratory Investigations:</u>

Grading analyses of the various undisturbed samples submitted to our laboratories was carried out in order to determine the variability of material encountered in the borings. The results of these tests are given on Figure 4 attached.

Permeability tests were carried out on selected materials from the samples submitted to our laboratories and the results of these are given on Table 1 attached.

Triaxial Shear Tests were carried out on the undisturbed samples submitted to our laboratories and the results of these tests are given on Figure 5 attached.

5. <u>Geology of the Durban Bluff:</u>

The bluff consists of sand, partially cemented into Bluff sandstone, underlain by Cretaceous and Karroo sediments.

The sand is of Pleistocene age and is known to be contemporaneous with red Berea sands, and with similar formations along the east coast, e.g. at the mouth of the Umtamvuna River and at Lourenco Margues. The presence of cross-bedding in some horizons and horizontal laminations in others indicate that the sand is partly wind-blown in origin and partly lagoon sediment. Below sea level, and in some parts up to as much as 20 feet above M.S.L., the sand has become cemented into hard sandstone by the precipitation of calcium carbonate and other salts from brak waters.

6. <u>Interpretation of Soil Profiles:</u>

Soil Profiles obtained from the Hand-augur borings are recorded in Figure 2 attached, and a descriptive stratigraphical legend is given on Figure 3.

Stratum A is the leached topsoil which occurs at the surface through-out the length of the Bluff. Stratum B, light reddish brown sand, is an oxidised material which occurs at higher levels; Stratum B′ is similar to B, occurs at the same stratigraphical horizon, but is distinguished by a higher percentage of fine material. Stratum C is the unoxidised yellow sand occurring at lower levels and grading into Stratum D, the cemented sand or Bluff sandstone. The general soil profile is therefore, leached grey topsoil; reddish oxidised sand; yellow oxidised sand; Bluff Sandstone.

3./....

Examination of the various soil profiles shows that the leached topsoil layer is present in all cases, but that the underlying sands do not always show an oxidised layer. It seems probable that the zone of oxidisation is a function of height as it will be noted that this zone is absent only above R.L. 220 and below R.L. 120. As shown later in this report, the degree of oxidation of the sands does not affect the main stability problem and it is therefore considered that, for practical purposes, the profile may be assumed as consisting of topsoil, sands and sandstone.

The underlying sandstones are found at variable depths ranging from only 2 feet below ground level in BH 6 to greater than 42 feet in BH 7. No discernable pattern can be traced governing its depth or occurrence and consequently, its high strength must be ignored and the problem considered as one of the stability of the upper sands only. Within these limitations, and for practical purposes, therefore, the Bluff may be considered as uniform both along and across its slope. Any variation from the above assumption will then only improve the factor of safety.

7. Interpretation of Laboratory Investigations:

a) Grading Analysis: Figure 4 attached shows the results of grading analyses on samples extracted from the various borings. These results are shown in the form of an envelope as the gradings were found to be extremely uniform. The variation in grading between A, B and C strata are scarcely noticeable, except in the finer fraction of the materials and typical examples of the various strata are given. Even in the finer fraction, the variation is almost within the range of practical error for the type of test and consequently, all the sandy materials may be considered, for practical purposes, as being reasonably uniform in grading.

b) Permeability Tests: It was not found possible to extract suitable undisturbed samples for permeability tests in sands of the type forming the Bluff. The method therefore adopted was to compact disturbed samples of the three basic sand strata, A, B and C to Proctor density, measure its permeability at this density, and, using Slichter's tables, adjust the permeability to the actual measured field density. Using this method, the permeabilities of Table 1 were found and it can be seen that the permeability increases with descending strata. While it is not considered that these interpolated permeabilities are extremely accurate, it is considered that the field permeabilities will be higher and consequently that any calculations based on the given figures will be on the safe side. The main object however, was to ascertain the order of variation in permeability of the different strata encountered.

4./....

c) <u>Shear Tests:</u> Saturated consolidated undrained triaxial shear tests were carried out on samples extracted from the testpits at Netford Road, being representative of the three main Strata A, B and C. The results of these tests are given on figure 5 attached and it can be seen that the results are typical of cohesionless materials with value of the angle of internal friction ranging from 32½° in the top soil, through 34° in the oxidised sands to 31° in the basic yellow sands of which the bulk of the Bluff is composed. It is therefore considered that, in any consideration of the theoretical stability of the Bluff slopes, the lower value of 31° for the angle of internal friction should be adopted throughout.

8. <u>General Analysis of Stability of Bluff Slopes:</u>

Taylor in "Fundamentals of Soil Mechanics" defines an infinite slope as a constant slope of unlimited extent which has constant conditions and constant soil properties at any given distance below the surface of the slope. He also shows that, in granular soils, an infinite slope subject to no seepage forces, will be stable if the angle of the slope is less than the angle of internal friction, ϕ, of the material.

It is evident from both the field and laboratory investigations, that the Bluff is composed essentially of granular material overlaying sandstone. It has been shown above that, for all practical purposes, the Bluff sands may be considered as reasonably homogenous both along and across the Bluff as well as in depth. Figure 6 shows some typical cross-sections of the Bluff and it can be seen that, at any specific location, a reasonably constant slope exists over the bulk of the height. Despite the variation in depth to sandstone, it is therefore considered that, for practical purposes, and in order to treat the problem as determinate, the Bluff slopes may be considered as infinite slopes within Taylors definition. The results of the shear tests show that the value of ϕ for the Bluff sands, varies from 31° to 34° and it could therefore be expected that, for stable conditions, the theoretical slopes of the Bluff should be less than 34°.

The site plan of Figure 1 attached shows that the range of slope angles as measured off the contour plans supplied. examination of this drawing shows that the bulk of the Bluff slopes have slopes equal to or greater than 34°. In theory therefore, these slopes should fail and it is apparent that other factors must contribute to the stability of the slopes.

5./....

It may be postulated that, when the Bluff was formed, and prior to the establishment of plant growth on these slopes, the slopes were at a slope approximately 31° to 34°. A fundamental consideration of the stability of all slopes is that mass movement will tend to continue until a topographic bottom is reached and the earths terrain is levelled out. With a stable gradual slope, subject to external disturbances, this levelling process would consist of a gradual movement of surface grains of material towards the topographic bottom. With the establishment of plant growth on the Bluff slopes, this growth would slow down or arrest such movement and could result in a steepening of the slope as these sand grains are piled up against the plant growth. Since this process would be extremely gradual and since root action and possibly a certain amount of natural cementation of the upper layers, would gradually increase the strength of the surface layers of the slope, this steepening would be parallel by an increase in overall strength which would tend to ensure that the slope remains in a state of equilibrium. Over the period of centuries since the Bluff was formed, this process would, by a process of natural trial and error, have eventually resulted in a state of equilibrium as found today.

That this is a reasonable assumption is evidenced by the variable slopes found today, many of which are steeper than the theoretical possible. A further factor to be taken into consideration is that the slides which have taken place within recent years can, as far as has been ascertained, all be associated with man-made interference. The numerous additional factors which have lead to the existence of slopes steeper than the theoretical stable are completely interdeterminate, and one is therefore forced into a consideration of the existing state of affairs and the probable effect of any interference with these existing conditions.

It is evident that the undisturbed slopes of the Bluff are stable and must therefore have a factor of safety against sliding of at least, but probably in excess of 1.0. Numerous buildings are found along the Bluff and, in many cases, the gardens of these buildings are fairly extensively terraced. Many footpaths too exist running from the top of the Bluff to the beach and, as far as can be ascertained, no more than minor local movements have occurred in some instances. Each and every one of the above factors will have some minor affect on the forces tending to cause failure, either by the increase in disturbing form due to the addition of weight at the top of the slope or by the reduction in restoring forces due to slight undercutting at the foot-paths. Despite this comparatively large scale interference with natural conditions, the incidence of major slides is rare and this must support contention that the factor of safety of the existing slope is in excess of unity.

6./....

One major factor contributing towards the continued stability of these slopes is the fact that the top of the Bluff is rounded off and consequently that all such building operations have taken place on less steep portions of the Bluff than applies to the general slopes. This would also imply that the effective weight may be applied where it may not have any serious affect on the potential surface or sliding. Figure 7 attached shows a typical slope and depicts various methods of site treatment. These are subdivided into good and bad practice in which those methods depicted as good practice result in a reduction of weight on the slope while those depicted as bad practice result in an increase in weight on the existing slope. Visual examination of the various structures along the Bluff have revealed many examples of similar types of treatment which, while note coinciding exactly with those depicted, are representative of intermediate methods. Yet, with the exception of the recent slide at Netford Road, no major slides have as yet resulted from these building operations.

Accepting a value of 31° as the friction angle of the Bluff sands and using a factor of safety of 1.5 would imply a working slope of 20½°. The work involved in reducing the existing slopes of the Bluff to a value of 20½° would be enormous and it must therefore be evident that a consideration of the problem from a purely practical basis will be impractical. It is our considered opinion therefore that the only logical method of approach to the problem is to accept the status quo which implies that all existing slopes are reasonably stable with a factor of safety in excess of 1.0 and lay down criteria for future building operations which will not reduce and preferably increase the factor of safety.

9. <u>Consideration of Affect of Rainfall:</u>

Water is present as a contributing factor in almost all earth movements and its damaging action is mostly apparent in the weight added to the soil mass, the reduction in shear characteristics of the soil, the lubricating action on the sliding plane and seepage forces. With material of the type forming the Bluff slopes, both the reduction in shearing characteristics and the lubricating affects can be neglected and the two factors that should be considered are increase in weight and seepage forces.

Just as in the consideration of the general stability of the Bluff slopes it has been shown that, over the period of years since the formation of the Bluff, natural phenomena have led to the establishment of stable slopes, so it can be argued that, over the same period of formation, the disturbing forces which can be attributed to rainfall will have achieved their full affect in the determination of the present stable slopes.

In fact, hydrological considerations must imply that, over the period of the Bluff history, compared with the period of building development on the Bluff, the probabilities are extremely high that greater intensities of rainfall have occurred prior to this building development. It is therefore logical to consider that, on natural slopes, the affect of rainfall and the associated seepage forces will already have played their part in the establishment of stable slopes.

The attached figure 8 shows the monthly rainfall figures over a period of 20 years. The most recent significant slide at Netford Road occurred on 25 May 1957 and an examination of the curves of Figure 8 show that the rainfall during April 1957 was much higher than the average for the month. However, far higher figures were recorded during the months of March 1927, June 1935 and February 1947 while comparable figures were recorded during several monthly periods of which the most recent are February 1939 and February 1949. As far as can be ascertained, no significant slides can be associated with any of the above periods of comparable or higher rainfall. On the other hand, a slide occurred at Strand Road in June 1945 during which month only 6.45 ins of rain was recorded, while in the previous month, only 1.82 ins fell.

Of even more significance is a study of Figure 9 which records the daily rainfall for a period of 90 days prior to the slide at Netford Road.

It can be seen that the major rainfall in this period fell some 27 days prior to the occurrence of the slide and the rainfall between that date and the date on which the slide took place, was negligible. The permeability figures of Table 1, give values of permeability of from 1 to 3 ins per day, and it is evident that the heavy rains would have infiltrated and seeped away in its entirety well before the slide took place. It seems apparent therefore that high intensities of rainfall in itself cannot be a prime factor in the creation of sliding tendencies on the Bluff slopes.

This argument can, however, only be applied to natural slopes. Where man made structures have been placed on these slopes, various other factors must now be considered. If, in any specific area, the rainfall is concentrated and led to one specific point due to such causes as the collection of rainwater off a roof, paved area or road, the concentration, of such rainfall at this location may result in the natural seepage rate being exceeded, resulting in excessive seepage forces and possible piping which may seriously disturb the equilibrium of the slope. This may set off an immediate slide or may so reduce the factor of safety of the slope as to put it into a state of unstable equilibrium, requiring only a small additional factor to trigger off the slide.

8./....

Rainfall may also however, play a contributory part in a further aspect. In the built up areas, gardens have been cultivated and the addition of manure, fertilizers, humus or other factors associated with gardening may result in the upper layers being more water retentive than previously. This implies an unnatural addition in weight at the top of the slope where it is least required and, in certain instances, may be the final factor that triggers off a slide.

It is apparent therefore that, in any consideration of the Bluff stability, rainfall in itself may be ignored by the affect of any interference with the natural infiltration and run-off must be seriously considered.

10. <u>Consideration of Septic Tank Installations:</u>

It was notice at the Netford Road slide that the outlets from Septic tanks are piped down the slope some considerable distance and that these pipes are buried some 2 to 3 feet below ground level. While the amount of water flowing out of a septic tank in itself will not be sufficient to cause a slide, it is considered that a possible hidden break in the outflow pipe may result in severe piping and hence reduction in restoring forces, at and below the break, of a sufficient nature to cause a slide. While there is no direct evidence to show that a broken pipe has caused a slide, the available factors of safety, as shown above, are so slender that it is considered that all possible sources of danger should be eliminated. It is therefore our opinion that all future septic tank outlets should be treated in the manner shown on Figure 10 attached and further, that such tanks should be placed as far back from the face of the slope as the plots will permit.

11. <u>Anticipated Form of Slope Failure:</u>

Both theoretical and practical consideration point to a shallow type of slope failure, similar to Taylor's failure of an infinite slope, in which the plane of sliding is essentially parallel to the surface of the slope as shown on Figure 11. Both the slide at Netford Road and that at Strand Road appeared to have followed this pattern but it is possible that the picture at the Strand Road slide may have been distorted by time and by the presence of the Sandstones at comparatively shallow depth. In general, it is considered that the presence of sandstone at shallow depth may improve the stability of the slope by reducing the disturbing forces and increasing the length of the sliding plane as shown on Figure 11. However, the overall picture must be based on the average conditions where no sandstone occurs and it is our opinion that the adoption of a probable depth of sliding of 20 feet will be a safe assumption and will amply cover the conditions at the two slides examined.

9./....

It is therefore considered that, in laying down criteria for future development such criteria should be cased on the probability of sliding occurring to a depth of 20 feet, measured at right angles to the slope. It has been shown, however, that the theoretical safe slope will be of the order of 31° to 34°. All slopes flatter than this range must therefore have a theoretical factor of safety of greater than unity. The normal factor of safety for slope stability problems is 1.5 implying a working slope of 20½° to 22½° and consequently, it is considered that the final assumption of depth sliding should be based on the following table:

Table 11

Angle of Slope	Depth of sliding measured at right angles to the slope.
Steeper than 30°	20 ft - 6m
27½° to 30°	15 ft - 4,5m
25° to 27½°	10 ft - 3m
22½° to 25°	5 ft
Flatter than 22½°	0 ft

12. Proposed Preventative Measures:

It has been stated above that the purely theoretical approach to the problem will result in completely impractical answers and that the logical approach will be to accept the natural stability of the existing slopes and lay down criteria for future development which will not reduce but will tend to improve the existing factor of safety. It has also been shown that the major factor tending to create sliding conditions is man made interference with natural conditions. The factors that can create this interference are the following:

a) Construction of Buildings
b) Construction of Gardens
c) Construction of Roads and Drainage
d) Disposal of Stormwater from Buildings.
e) Construction of Septic Tanks.
f) Construction of Access to the Beach

Each of these factors will be dealt with separately but, in all cases the basic criteria to be adopted will be that the depths given in Table 11 above will apply and that the safe working slope of the Bluff is that of 22½°.

a) <u>Construction of Buildings:</u> All buildings, except these embodying basements or semi-basements, in which the weight of soil excavated equals the load of the structure, must impose a loading on the soil. In general the loading of an average dwelling house will be of the order of 200lbs/sq. ft of area covered. This is only the equivalent of about 2 feet of soil and as such may have negligible affect on the stability of the slope. However, this loading is usually concentrated on foundations at specific points and it is considered that, with the low factors of safety present in the existing slopes, full account must be taken of such loading. It is therefore recommended that the following criteria be adopted.

In general no structure shall be permitted on slopes greater than 22½°. Where, however, it is considered that other factors make it desirable to permit structures on steeper slopes, such structures shall either be supported on bored piles, founded such that the minimum distance from the base of the pile to the face of the slope is 20 feet or shall contain a basement or semibasement such that the weight of soil excavated is at lease equal to the total weight of the structure. c.f. Figure 12 a and 12 b.

Where structures are built on slopes flatter than 22½°, the criteria for depth of founding of all foundations shall be that no foundations shall be placed above a line determined in accordance with the assumed depth of sliding of Table 11. Such depth of sliding to be based on the major angle of slope. c.f. figure 12.c.

b) <u>Construction of Gardens:</u> The minimum requirements for gardens is that they shall at least conform to the natural existing slope. Where terracing is required, such terracing shall result in a reduction in weight on the slope as depicted in figures 7 d, e and f. In general it is preferred that the method shown on Figure 7 f should be adopted but it is realised that this may be a somewhat rigid requirement.

c) <u>Construction of Roads and Drainage:</u> Since the construction of roads and drainage must lead to concentration of stormwater run-off, particular attention should be paid to the collection and disposal of such storm water. It is considered that the probability of hidden breaks or leaks in stormwater pipes should be taken into account where such pipes occur too near the edges of the Bluff as they may result in piping and hence lack of stability. It is therefore considered that no stormwater pipes should be laid within the zone laid down for no foundations in Figure 12c and further that, where stormwater is taken down the Bluff slopes, it should be taken in the form of open channels running directly down the Bluff.

d) Disposal of Stormwater from Buildings: Where possible, stormwater from roofs and paved areas should be taken into stormwater drains but where this is not possible, such stormwater should be taken down the slope in the form of open channels. Particular attention should be paid to the prevention of concentration of stormwater on the slopes so as to prevent a build up of seepage forces.

e) Construction of Septic Tanks: In order to prevent concentration of water at specific points within the slopes, septic tank outlets should be placed as far back from the face of the slope as possible and taken down to a minimum depth of 20 feet, as shown on Figure 10 attached.

f) Construction of Access to the Beach: The main danger in providing access down the Bluff to the beach lies in the fact that, with the steep slopes of the Bluff, any form of vehicular access to the beach must angle across the slope. Footpaths are comparatively simple as these can be constructed in the form of steps running directly down the slope. Vehicular access must however cut across the slope and this can only be achieved by one of the methods shown on Figure 13 attached. Methods A and B, although possible, are not recommended. Not only will both these methods be expensive but in addition, method B results in the construction of a steeper slope than the natural slope. The necessary retaining walls will be extremely massive and difficult to construct with safety. Method C, while resulting in a reduction in weight, again entails the construction of a massive retaining wall. Method D, on the other hand provides the ideal answer and could be constructed with comparatively little interference with natural conditions.

A further method that might be considered but may prove to costly, is that of chemical consolidation of portion of the slope to be traversed by roadway. The affect of this would be to form an artificial sandstone in which the roadway could be constructed.

13. Slide at Netford Road:

Detailed examination of the slide at Netford Road revealed no specific factor or factors which could have caused the slide. The type of slide that occurred was apparently of the type shown on Figure 11b and it seems probable that the slide was caused by a number of contributory factors, each of which played its part in upsetting the comparatively delicate balance of the existing slope.

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Examination of photographs of one of the houses taken before the slide occurred seemed to indicate that the garden area was built up above previously existing slope thus probably adding some additional weight at the top of the slope; the houses themselves are placed somewhat close to the top of the slope which appeared to be less rounded off in this vicinity than elsewhere; the outlet pipes from the septic tanks were not in a very good condition and may possibly have leaked prior to the slide, causing piping and hence reducing the restoring forces; paved areas in front of the houses appeared to discharge stormwater directly into the top of the slope which, with the water-retentiveness of the garden soil, may have been an added factor. None of the above factors can be stated with confidence to have been present prior to the slide but are mentioned as being probable contributory causes based on observations made some months after the slide occurred.

It is not considered that the footpath running diagonally down the slope below Netford Road could have resulted in sufficient undercutting to cause the slide. Visual examination did not show that the zone of sliding had penetrated as far as this footpath and it seems probable that had the footpath been the major factor, that sliding would have occurred further north where this footpath cuts across the higher portions of the slope.

Remedial measures at the site of the above slide represent a difficult problem. It will be possible to render the houses themselves safe from future slides by underpinning these houses on bored piles carried down 20 to 25 feet. The possibility exists however that further sliding may occur which will then leave these houses suspended fully or partly in the air, dependent on the extent of the slide. Carrying out full remedial measures of a sufficient nature to render the houses safe and restore at least portion of the front gardens will be a costly procedure. This may be achieved either by the construction of a sheet piling wall driven parallel to Netford Road and some given distance in front of the buildings affected with back filling behind this wall to provide some reasonable sized front garden, or alternatively, the sands beneath and in front of the houses could be chemically solidified. Thereafter, careful terracing could provide additional garden space to that which is still standing. Both the above methods will be extremely costs and, at the first estimate are liable to cost between £10,000 and £15,000.

14. <u>Conclusion:</u>

As shown in this report, the theoretical analysis of the Bluff Stability is an indeterminate problem since the inherent stability of the Bluff materials is masked by indeterminate factors such as root action, minor cementation etc. Much of the Bluff is standing at far steeper slopes than is theoretically possible and many structures are standing safely on these slopes. It is therefore considered that the only logical approach is to accept the status quo which implies that such slopes have a factor of safety in excess of unity and to ensure that all future operations on the Bluff do not worsen but preferably improve the existing factor of safety.

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