WAIMATA RIVER LEFT BANK

PROPOSED HAZARD ZONE

TUKURA ROAD TO HINAKI STREET

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1.0 INTRODUCTION

About 200 metre length of the left bank of Waimata River (from Stn.2965 to 3170) near Tukura Road has slumped frequently during the last 12-15 years. The river has a sharp bend in this reach and the slumped slope is on the outer side of the bend.

This study was undertaken to delineate hazard areas in a 285 metre long reach of the river bank near Tukura Road.

Three meetings were held on May 18, June 29 and Dec. 17, 1992 with the residents to explain the zoning proposals and further investigations were also carried out based on the decisions arrived at these meetings.

2.0 THE AREA UNDER STUDY

The area under study located on the left bank of Waimata river extending about 285 metres downstream from the Hinaki Street (from 2910 m to 3195 m along the river) is a well developed residential area. There is no land reserve adjoining the river bank in this reach and the houses have been constructed close to the edge of the slope.

The slope of the river bank varies from about 1 in 1.5 to 1in 3 and the height varies from 10 to 12 metres. The slope and the berm are covered with some small to medium sized trees, naturally accumulated debris and dumped rubbish.

Examination of the cross sections of the river bank shows that the river bank is in various stages of slumping and the bank at certain sections appeared to have attained a stable slope after continuous slumping.

3.0 SOIL STRATA AND PROPERTIES

Soil investigations carried out in 1991 and 1992 have shown that the main bank consists of silty clays lying on blue/grey marine clay occurring near river bed. The locations of bore holes are shown in Fig. 6 and typical bore hole logs are given in appendix 1. The lower berm at the rivers edge consists of a 1 to 1.6 m thick layer of silt. The shear strength of the soils measured at the site using shear vane during July/August 1991 varies from 28 to 86 kpa with most of the results lying with in the range of 30-40 kpa. indicating the low strength of the materials. Subsequent investigations carried out near the Hinaki street end of the reach and down stream of Tukura Road indicated similar soil profiles.

Investigations have also shown that the water table of the lower berm is almost coinciding with the high tide level of the river. Three metre deep Auger holes done on the slope during Feb. 1991 have not indicated the presence of any water.

Field investigations have also shown the presence of cracks on certain houses located close to the top edge of the bank.

4.0 SLOPE FAILURE

The river bank slope failure usually occurs along a curved surface which can be approximated to a cylindrical surface. The failure occurs when the forces causing the failure (weight) exceeds the resisting forces mobilized by the soil.

The shear strength mobilized along a rupture surface can be expressed as

$$T = C + (\sigma - u)\tan\phi$$

where
T = Shear strength
C = Cohesion
σ = Normal Stress
u = Pore Water Pressure
ϕ = Angle of Shearing Resistance

During heavy rains slopes will get saturated increasing pore water pressure on a possible rupture surface and reducing the shear strength. A river bank stable in dry conditions may fail when saturated. Deep cracks occurring in the silty clays will also accelerate the failure during saturation.

During heavy rains the water level in the river may rise to a peak and continue there for some time and falls soon causing conditions similar to a "Rapid draw down" in a reservoir with pore water pressures remaining similar to those prevailing before the draw down for a short period of time. This condition will cause failure of otherwise stable slopes.

Application of surface loads, earthquakes and river forming processes such as erosion on bends and bed degradation may also cause failure of river banks.

This study is limited to failure of slopes due to saturation, cracks and surface loads. Allowance was also made for bank erosion when delineating Hazard Zones. The slope stability analysis was carried out using the computer program "Slope".

5.0 METHODOLOGY

The river bank was modelled using the Bishop's simplified method available under the "Slope" program. The soil properties for each soil type were established by analysing an apparently stable section. It was assumed that the stable slope was in a state of equilibrium just after the "Bola" peak flood with a Factor of Safety approximately equal to one.

A typical unstable slope was analysed using the soil properties determined as above. This slope was further analysed with probable slumped surfaces. The analysis was also carried out for slopes with hypothetical slopes of 1 in 3 and 1 in 3.5 with different levels of saturation and loading.

The existing stable slope was further analysed by imposing shrinkage cracks at various distances from the edge of the slope and with different saturation conditions.

6.0 RESULTS OF STABILITY ANALYSIS

The soil properties established using the stable slope cross section at station 2995 are given below.

Soil Type	Bulk Unit Weight		Cohesion	Angle of Shearing Resistance deg.
	Below GWL Kn/m^3	Above GWL Kn/m^3	Kn/m^2	
Silty Clay	21	20	8	22
Silt	19	18	5	24
Silty Clay (Sat.)	21	21	4	22
Marine Clay (Sat.)	21	21	4	22

Variation of safety factor with the water table is shown below.

Water Table m R.L.	Factor of Safety
4.3	1.066
5.3 (Bola)	1.013
6.3	0.966
11.2	0.848

Ground level on the top of the slope is about 11.8 m R.L. When a surface load of 35 kn/m2 was added vertically at the edge of the slope with the water table at 5.3 m R.L. the safety factor was 0.995.

The circle with the minimum factor of safety is shown in Fig. 1.

The apparently unstable slope at Stn. 2965 when analysed with the water table at 5.3 m R.L. and above soil properties indicated a Factor of Safety of 0.877 (Fig. 2). Factors of Safety determined for the same section with two probable ground profiles after slumping are given below.

After 1st Slip FS = 0.967
After 2nd Slip FS = 0.992

The ground profiles are shown in Fig. 3.

For a hypothetical slope of 1 in 3 the most dangerous slip circle is on the slope and the Factor of Safety was 1.091.

Variation of the Factor of safety with water table for a circle passing through the top of the slope is shown below.

Hypothetical Slope 1 in 3

Water Table	Factor of Safety
0.6 m below top surface	0.919
At 5.3 m R.L. (6.8 m below)	1.141

Details are shown in Fig. 4.

The most dangerous slip circle for a hypothetical slope of 1 in 3.5 is on the surface of the sloping section of the bank and the details are given below.

Hypothetical 1 in 3.5 Slope

Water Table	Factor of Safety
At 5.3 m R.L.	1.249
0.6 m below surface	1.085

One metre deep cracks were introduced to the stable section at Stn. 2995 and the Factors of Safety were calculated for different elevations of the water table. The results are shown below.

Location of the Crack From the edge of the bank	Factor of safety
3 m	1.017
6 m (1 in 3 Slope)	1.056
10.5 m(1 in 3.5 Slope)	1.147
10.5 m (Water Table 1 m below Surface)	0.966

Water table was maintained at 5.3 m R.L. in the first 3 cases.

7.0 EROSION OF RIVER BANK

Comparison of the surveys done on the river bank during the years 1900, 1947 and 1988 shows that the net movement of the river bank towards the land in this reach is about 4 metres during the period 1900 to 1947. The survey done after Bola in 1988 indicate a river bank movement towards the river in part of the reach due to slumping. The slumped materials will be carried away by the river during minor floods and the bank will continue to move outwards due to erosive actions of the river.

The erosion at the toe of the bank will affect the stability of the slope and a quantitative assessment of the erosion is required when determining the unstable areas. The future erosion of the river bank cannot be predicted accurately but in this case it can be assumed that the bank will get eroded up to a width of 4 metres during the next 50 years. The erosion of the toe can vary widely along the reach of the bank considered and may exceed 4 metres in certain locations.

The effect of this movement on the stability of the slope generally depend on the width of the lower berm. If the erosion continue past the width of the lower berm the stability of the bank will be affected and such conditions were considered when delineating the unstable areas.

The steep slope of the river bank also becomes unstable due to the erosion caused by storm water discharged on to the banks. This can be remedied to certain extent by diverting the roof water away from the slope or carrying the roof water in 100 mm diameter flexible pipes, to the river. No allowance had been made for such erosion when deciding on the extents of the Hazard Zones.

8.0 CONCLUSIONS

8.1 The areas in the river bank with slopes steeper than 1 in 2.5 are unstable and may slump when wet or loaded.

8.2 The area between the hypothetical 1 in 2.5 and 1 in 3.5 slopes is liable to slump under severe conditions such as cracking and saturation.

8.3 Erosion on the outer side of the bend in the river and the bed degradation during large floods may also cause the progressive failure of otherwise stable slopes.

8.4 Constructions on either river bank shall not project in to the river so as to cause irregularities in the flow pattern during large floods.

8.5 The stability of the river bank can be improved by tree planting.

8.6 Special maintenance works shall be carried out in this reach of the river regularly to ensure the removal of any obstructions that may accelerate erosion on left bank.

9.0 HAZARD ZONES

The line on which the hypothetical 1 in 3.5 slope line intersects the top of the bank was drawn on a 1:1000 scale map and then this line was adjusted to allow for bank erosion. The edge of the river channel drawn using 1:1000 scale aerial photographs was used as the reference line. The area of the river bank from the edge of the river to the above line is unstable and slumping is possible.

Any slope failure in this area may cause disturbances in the adjoining land due to presence of permanent buildings extending across the area and large trees. The adjoining land may also get disturbed due to other reasons such as differential settlement caused by the rapid fluctuation of the water table. The average erosion at the toe of the bank is assumed to be 4 metres in 50 years and it can go up to 8 metres in 100 years. A 15 metre wide Fringe Zone is proposed outside the hazard zone to allow for these uncertainties.

The Hazard Zones are shown from Hinaki Street to the boundary of No. 24 Tukura Road. The hypothetical 1 in 3.5 slope when drawn at sections taken further downstream intersected the top of the bank generally at the front of the existing buildings. The river is straight in this reach and there is little evidence of slope failure and therefore the Hazard Zones were not continued downstream of NO. 24 Tukura Rd.

9.1 Hazard Zone

The area extending from the River's edge to the above slope line is classified as the hazard zone.

Suggested Restrictions

(i) This area is unstable and No new permanent dwellings shall be allowed in this zone. Only minor extensions to existing buildings should be allowed.

(ii) Ancillary buildings subject to conditional approval.

(iii) Any bank protection works in this zone shall not cause irregularities in the flow patterns during large floods, nor cause adverse effects upstream or down stream.

(iv) Any activity that may steepen the slope or that may add load on the surface shall not be allowed with out adequate protection to the slope against slumping.

9.2 Fringe Zone

A 15 metre wide strip of land parallel to the hazard zone is classified as a fringe zone.

This area is liable to become disturbed by the slope failures in the hazard zone.

Suggested Restrictions

(i) Re-locatable* dwellings (designed to accommodate differential settlement) only in this zone.

(ii) Ancillary buildings can be sited in this zone, subject to conditional approval.

* The definition of the word re-locatable shall be strictly applied in all cases.

Hazard Zones are shown on Fig. 6.→