Landslide Hazard Assessment Along a Major Communication Routeway in Trinidad

by Stanley Wharton*

Abstract

Communication networks within the Caribbean small island states usually serve as important routeways that link communities located in hilly areas to main market centres elsewhere. The routeway location and design for major roads, like the North Coast Road, traverse exposed areas on hillslopes with varied and adverse geological conditions including weathered low-grade metamorphic rock, parallelism of schistocity planes, joint orientation and cut-slope orientation. The impact of other phenomena, such as climate (especially rainfall from storms and hurricanes) and human activities on the hillslopes that result in deforestation, severely affect the routeway temporarily, and result in varied kinds of landslide activity. These activities frequently render the roads impassable during major rainfall events like storms and hurricanes and pose a major recurrent hazard to the travelling public. To analyse the magnitude and potential danger of these hazards with regard to actual disaster events, statistical techniques have been applied to parameters of the failed slopes, and other data, for hazard assessment. These statistical tests include Discriminant Analysis and Cluster Analysis, Correlation Analysis and Linear Regression. Stereographic Analysis has also been used for analysis of schistocity and slope orientation. The results from the tests indicate that: (1) The most hazard-prone areas along the road is confined to the weathered metamorphosed Maracas Formation. At many localities, the majority of failures occur at truncated ridges where the slope height is greater. The higher the truncated ridge, the larger the landslide indicating that slide size can be predicted using slope height/slope angle relationships. (2) Two landslide size groups can be predicted by using Discriminant Analysis and Cluster Analysis and the results used for planning rehabilitation works after slope failure activity. (3) Slope failures are dominated by large debris slides in weathered phyllites and schists, occasionally with interbedded unconsolidated sandstones at some localities. Schistocity, joint and slope orientation show parallelism at these failed slope locations. (4) The findings can be incorporated within a disaster management framework for landslide prediction and planning after major disaster events. The study allows for better planning in the maintenance of communication routeways within a disaster management framework.

Introduction

Communication networks in many countries in the Caribbean have served as important routeways for human communities, and their design and construction have been subjected to many engineering challenges. These challenges include the nature of the geological structure, the climatic conditions and also the incessant human activities on the hillslopes. The communication networks form integral relief routeways for the safe rescue of people and the safe transport of machinery, foodstuffs and materials especially after disaster events. However, the topography of the islands in the Caribbean, which is normally dictated by the geology of the exposed rock, has constrained the location and design of roads to areas of unfavourable geology and slope conditions. The result is a high incidence of landslide activity along roads after major disaster events.

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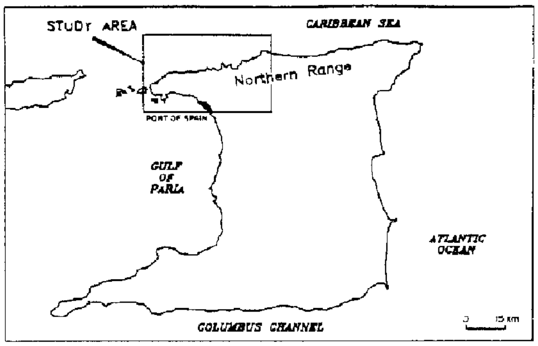
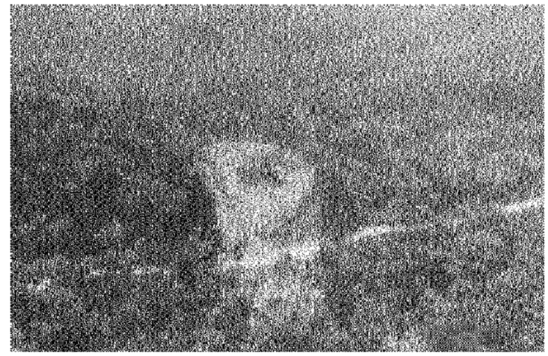
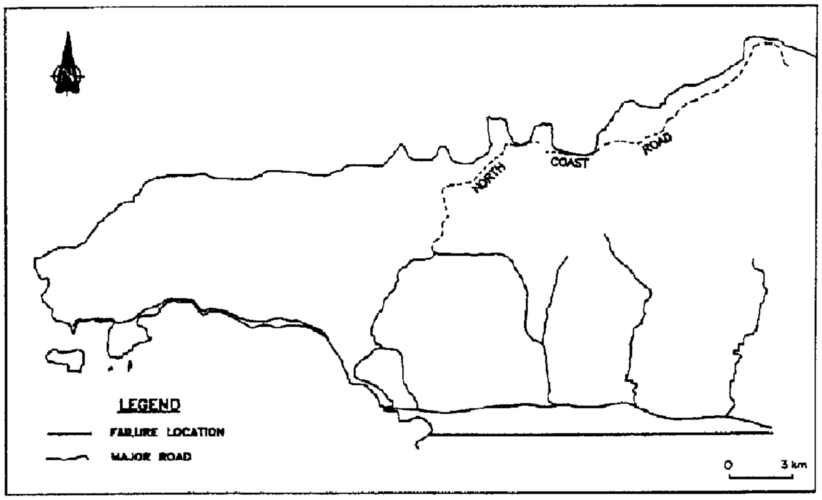
Figure 1A (Right) Locality Map and Figure 1B (Below): Inset of Locality Map.

Figure 2 (Far Right): Oblique aerial photograph of large wedge failure.







The North Coast Road (Figure 1) experiences some of the largest landslides found in the Northern Range of Trinidad[2] and is subjected to repeated failures. These failures pose a danger to road communication and also to the lives of the travelling public as there are no established warning systems (Figures 1 and 2). In order to institute any proper management practice to mitigate against these failures after climatic-related disasters, the mechanism of formation of the landslides and an understanding of the factors that control these failures are considered necessary. Statistical techniques have been used successfully in hazard management in various parts of the world as was similarly used to analyse slope failures in the Northern Range.[3] The purpose of this study however, is to determine the factors contributing to slope failure hazards for prediction and mitigation within a disaster management framework.

Location

The North Coast Road (approximately 25km) runs along the North Coast of the Northern Range, where the hills slope towards the Caribbean Sea (Figure 1). At several localities along the roadway, however, the road passes along major ridges (watershed divides) that define large catchments oriented both to the south and north. The roadway traverses steep hillslopes with approximately 72 per cent of the roadway length accounting for slopes greater than 25°.

The rocks exposed along the North Coast Road consist of varying types of low-grade metamorphosed rocks represented by phyllites, schists, sandstones and quartzites from three rock Formations, the Maracas, the Rio Seco and the Grande Riviere Formations.[4] The Maracas Formation, however, is exposed along a greater area of the roadway and accounts for the largest and more frequent landslides.

A database of 32 landslides was generated using data from dimensions of a failed slope unit that were recorded from field data sheets.[5] These datasets were further subjected to basic statistical tests and advanced tests using Discriminant Analysis and Cluster Analysis for hierarchical classification to define size ranges of landslide volumes. These results were compared with failed slope dimensions and stereographic analysis of rock schistocity planes to determine optimum failed slope conditions.

Results

The main landslide types identified in the study area were debris slides which represent some of the major landlsides in the Northern Range. These landslides occurred both at truncated ridge locations and on the flanks of ridges. Landslides occurring at truncated ridge locations were mainly large single landslides (Figures 2 and 4), which were controlled by the dimensions of the truncated ridge at the road cut. Landslides occurring on the flanks of ridges were mainly compound landslides which collectively affected a larger unit per square area, but which were generally smaller in individual dimensions (Figure 5). The majority of these landslides were associated with upslope deforestation of the hillslope.

Debris slides were generated within selected sections of the weathering profile (Figure 6) within both phyllitic and schistose rocks. The most frequent and smaller landslides (shallow failures) occurred within the residual soil layer (Figure 6) and at the interface with the more competent blue-grey phyllites by gravitational effects. In most cases failures incorporated both deep seated and shallow slide types in the residual soil layer and the underlying Zone 2 layer[6] with the internal rock structure controlling the style and mechanism of failure.

Plots of schistocity, joint, and slope orientations were generated for the landslides along the road using a lower hemisphere Schmidt Net projection (Figure 7). The plots of schistocity, joint and slope orientation indicate a parallelism of the structures that contribute to slope failures. The main failure mechanism is by planar failure where the weathered less competent phyllites and schists glide along both schistocity planes and joints towards the roadbend. These show a bi-directional dip within the slopes and show good comparison with the orientation of the cut slopes A distinct preferred orientation of both north-west-facing and south-facing slope failures also exist along the road

Plots of the schistocity planes show a preferred orientation to the south-east typical of most planar failure mechanisms These orientations show similarities to that for the Northern Range where there is a dominant orientation of schistocity planes to the south-east.

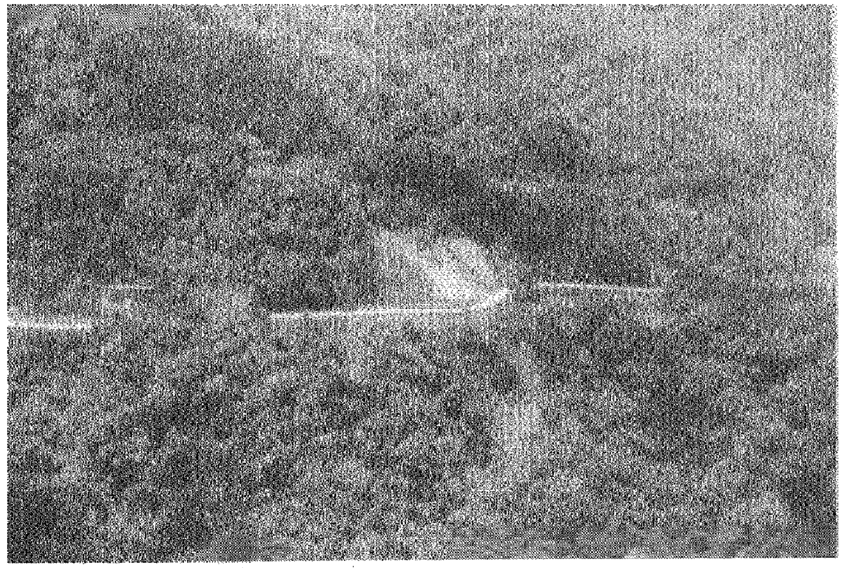
Landslide Volumes

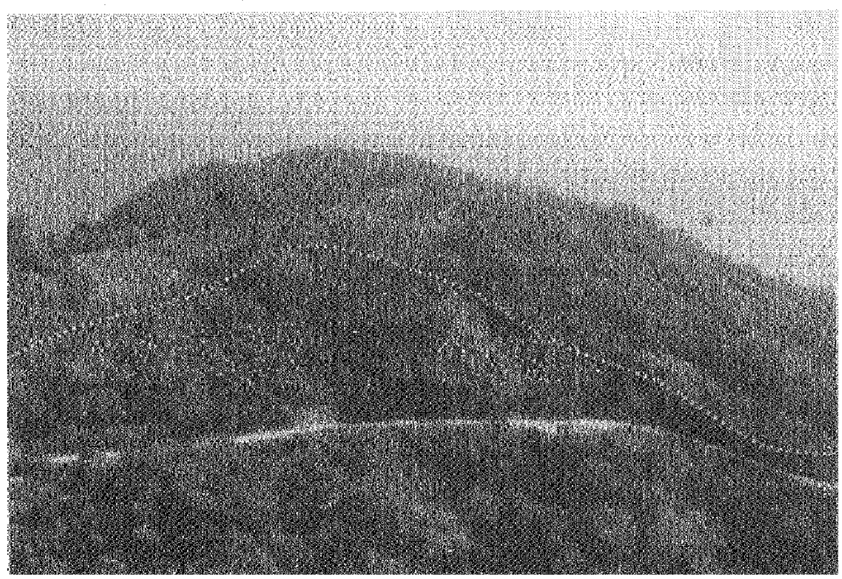
Histogram analysis of estimated landslide volumes along the North Coast Road revealed a large range of sizes among the different failed slopes. In order to analyse these slope failures within the framework of hazard potential and severity, two statistical tests – discriminant analysis and cluster analysis – were applied to define trends in the data. The data indicate that two landslide groups can be identified along the road with each group having different centroid values These two groups refer to landslide volume classes 0-15,000 cubic metres and 15,001-40,000 cubic metres respectively (Table 1)

The 0 to 15,000 cubic metres group corresponds to most of the residual soil slides that were generated within the residual soil layer and also some of the smaller deep seated slides. Slides within this 0 to 15,000 cubic metres category accounted for 66 per cent of all slides along the road, indicating a higher frequency for smaller slides. This higher frequency provides sufficient information for planning clean-up operations after heavy rainfall events for any given section along the road

The angle and length from toe to crown, the road bed length of slope failure, and the failed slope height were used as the discriminating variables for these tests. The percentage of grouped cases correctly classified was 98.88 per cent, reflecting a high predictability for the two group memberships (Table 1).

The cluster analysis test was used to corroborate with the discriminant analysis test results using the two landslide size groups identified from the discriminant analysis test. Using a hierarchical cluster analysis with squared Euclidean measure, the results indicate that two groups 0-15,000 cubic metres and 15,001-40,000 cubic metres can be identified among the estimated landslide volume population (Figure 8) This data can be useful in planning clean-up operations based on knowledge of the frequency of these different size events along the road.





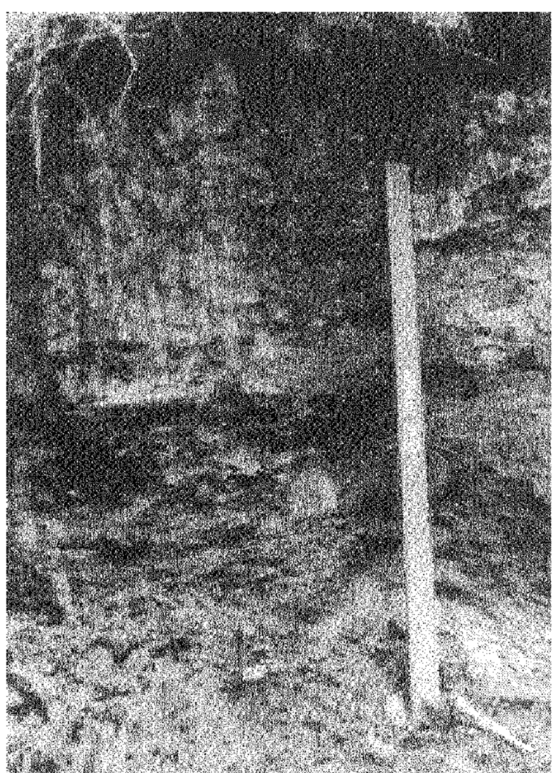


Figure 4 (Top). Oblique aerial photograph of a landslide at a truncated ridge.

Figure 5 (Middle): Oblique aerial photograph of a compound landslide.

Figure 6 (Left): Vertical weathering profile at landslide scarp