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Large Debris Flows in the Townsville Urban Area and Associated Remedial Works.

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Summary: Landslides and Debris Flows have occurred in Townsville, Queensland, during intense tropical rainfall events. This paper describes two recent debris flow events, their effects on infrastructure and the remedial works undertaken.

INTRODUCTION

Large debris flows occurred in the Townsville urban area following intense rainfall associated with Tropical Cyclones *Sid* and *Tessi* in 1998 and 2000 respectively. The Magnetic Island landslides (1998) developed into debris flows, one of which entered a resort. completely or partly demolishing 8 motel style units. In 2000 two debris flows formed from landslides high up on the slopes of Castle Hill in the centre of Townsville, with debris flowing around and into several houses, filling a swimming pool, blocking storm water drains, scouring channels down the hillsides and between two houses, and finally forming alluvial fans down suburban streets.

This paper provides an overall description of these events, with particular emphasis on one of the 2000 events – the Stanton Terrace debris flow. The nature and probable causes of the event are discussed, together with remedial works designed by the authors and implemented by Townsville City Council with disaster relief funding.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The Townsville area is characterised by low-lying, relatively flat plains interspersed with localised ranges of low hills. The hills generally rise abruptly from the plains with slope angles of around 20" to 30" and local rocky outcrops and cliff lines. Magnetic Island is generally comprised of steep boulder covered hill slopes with localised areas of gently sloping and flat land along the coastal strip and in the broader gullies.

Both Castle Hill and Magnetic Island are dominated by granite and granodiorite, with highly variable depths of weathering and soil cover, and extensive areas of bare rock and/or boulder fields. On Castle Hill the granite has weathered to produce steep rock cliffs and broad slabs of bare rock, steep slopes containing scattered boulders, and areas of sandy clay and clayey sand residual soil around 1m to 2m thick. On Magnetic Island boulder fields cover extensive areas. Both locations include deeply eroded drainage gullies that tend to run directly down the slope with little or no meandering.

1998 RAINSTORM EVENT

Cyclone Sid deposited approximately 549mm of rain in Townsville during 24 hours, and significantly heavier rainfall is likely at Magnetic Island, off the coast from Townsville. This event may have been the equivalent to a 1 in 500 year return period rainfall. Two major and a number of minor debris flows occussed on Magnetic Island, together with a number of small slope failures mostly located on small road cuttings.

Both major debris flows on Magnetic Island occurred within the Nelly Bay basin, and flowed down pre-existing gullies. Both contained significant proportions of boulders ranging from 1 m^3 up to 8 m^3. together with sand derived from the weathered granites. Both gullies had changes of direction roughly corresponding to the break in slope and at these points some of the debris continued straight ahead, with smaller rocks and liquidised soil generally continuing along the original streambed alignment. Flow velocities were very fast (estimated at up to 120 km/hr) with super-elevation being clear on the sides of the deeply scoured gullies. Gullies downstream of the initiating event were scoured to bedrock as flows of up to 3000 m^3 occurred.

One of the debris flows occurred in a gully to the rear of an occupied resort. Eight motel style units were completely filled with sand and some boulders, and cars to the rear of the units were crushed. Fortunately no one was injured as the occupants of the units were moved about 2 hours before the debris flow due to flooding of the units.

The two major Magnetic Island failures appear to have been triggered by the collapse of boulders close to the ridgelines, initially causing a cascade effect of boulders into gullies that may have been temporarily dammed. Either the initial collapse by itself, or in combination with the sudden release of a pulse of water when the temporary dam broke, acted as the trigger mechanism for the large boulder rich debris flows.

2000 RAINSTORM EVENT

On the evening of 3 April 2000, two debris flows initiated high up on the slopes of Castle Hill, and debris flowed rapidly down gullies and hill slopes until deposited behind, in and around five houses at Stanton Terrace and along Stuart Street. Locations are shown in Figure 1, and an overall view of the Stanton Tessace debris flow is presented in Figure 2.

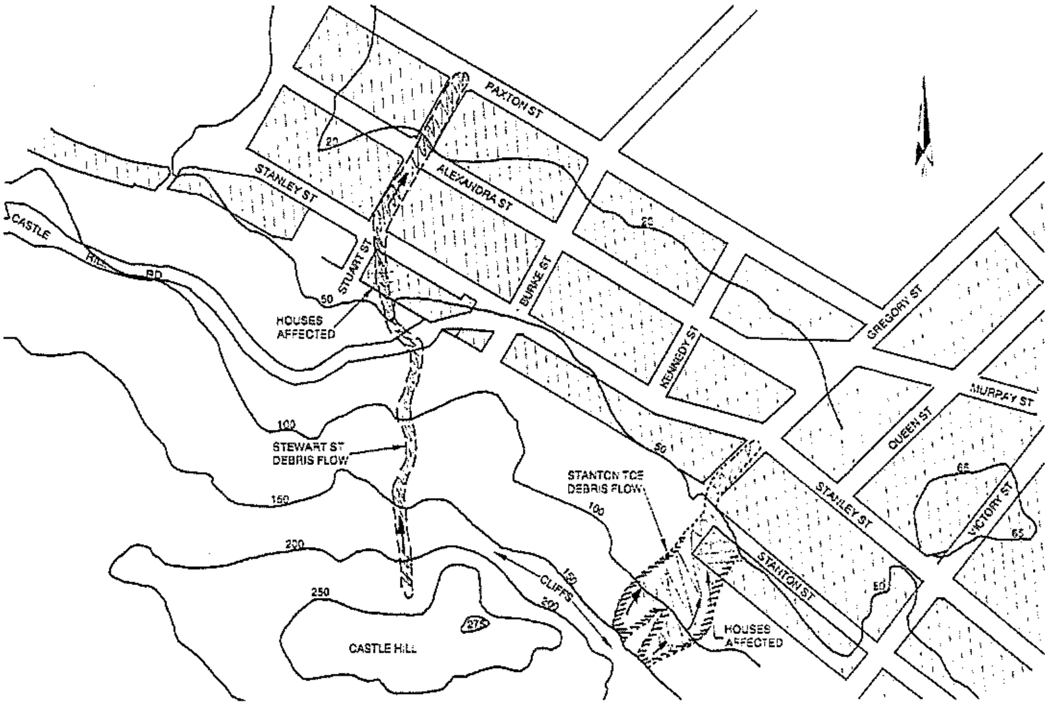


Figure 1, Location of debris flows from Castle Hill

The Townsville area experienced heavy rain associated with tropical cyclone Tessi during the period 2 to 4 April 2000. This followed earlier heavy rain during late Febmary, with approximately 1180 mm falling during January to March inclusive. A total of 467 mm of rain was recorded during the 3 days to 9 am on 4 April, with 430 mm falling during 3 April. Figure 3 shows the cumulative rainfall during the cyclone.

The Stanton Teirace debris flow initiated from three source areas close to the base of the rock cliffs on the northern face of Castle Hill. From newspaper reports and an eyewitness account, it is understood that movement of soil commenced high up above the gully between 36 and 38 Stanton Terrace (two overlapping source areas), immediately followed by rapid movement of debris down the hillside. Movement was accompanied by sound like that of "a 747 taking off'. Boulders moved with the other debris, and did not bounce and roll ahead of the remainder of the flow. Within 20 seconds, similar movement and debris flow occurred in the area uphill from 42 Stanton Tessace (the third source area). The eyewitness's impression was that the entire duration of movement for the flows in this area was approximately 45 seconds, with speed of the flow approximately 60 km/h.

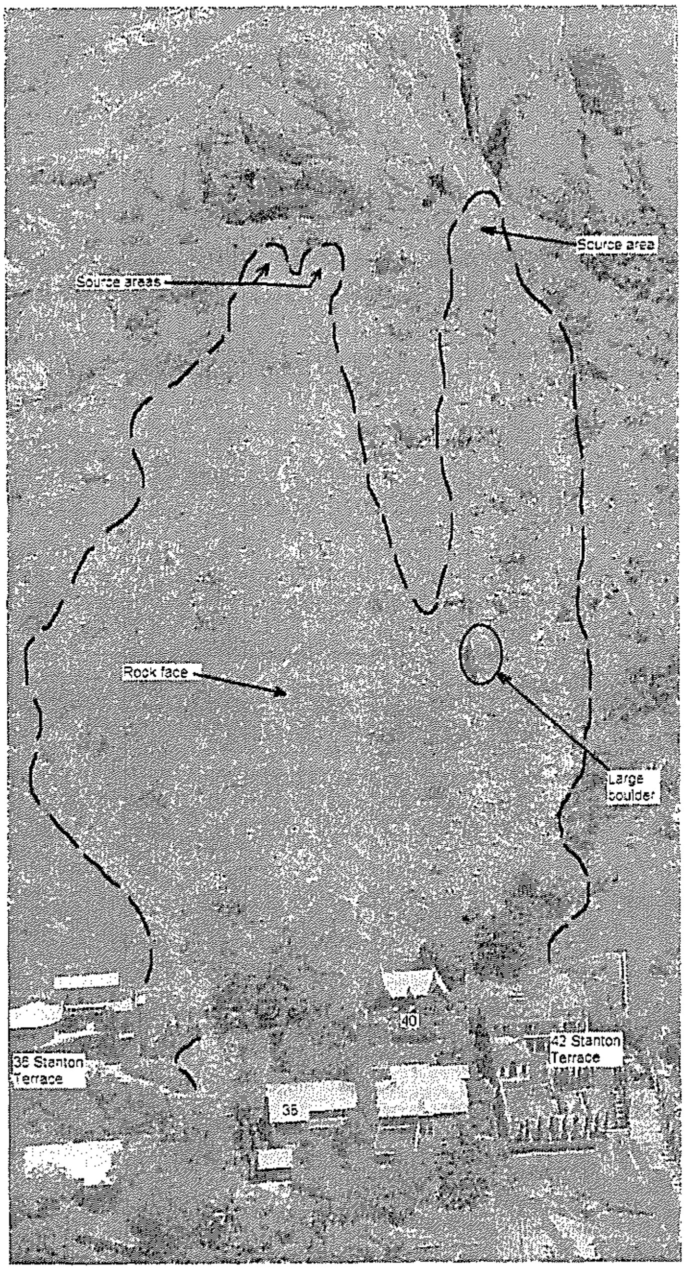


Figure 2, Stanton Terrace Debris Flow

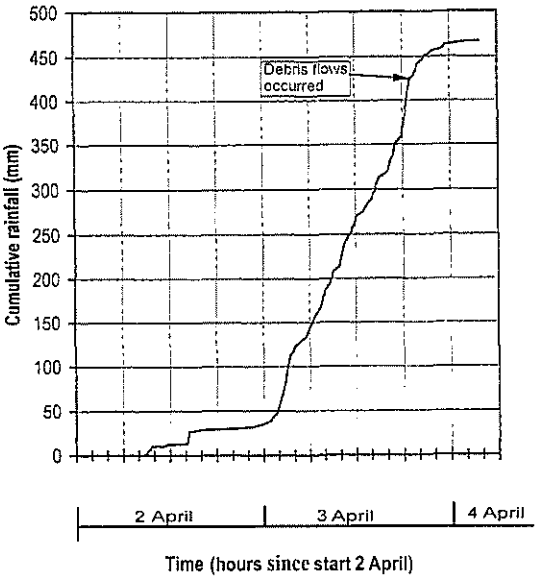


Figure 3, Cumulative rainfall from Cyclone Tessi.

The debris flow above Stuart Street occurred approximately 25 minutes later. This flow was confined to the deeply incised gully running from near the peak of Castle Hill into Stuart Street. A number of other debris flows occurred from the hills around Townsville during the same event but did not impinge on any infrastructure or dwellings.

Following the debris flows and during the following evening, residents from the Stanton Terrace and Stanley Street areas east of Gregory Street were evacuated by the Queensland State Emergency Service. Residents uphill from Paxton Street and between Gregory and Stuart Streets were evacuated during the early hours of 4 April.

Slope Conditions Before Collapse

Prior to the debris flows the slopes were lightly vegetated with some trees. Vegetation had been severely damaged by bushfires during the 1999 dry season. A generalised hillside cross-sections through the Stanton Terrace debris flow is presented in Figure 4. The overall slope of the hillside from approximately 50 metres behind the residential properties to the base of the cliffs is 30" to 35". Isolated small to large boulders were located both within the established gullies and on the open slopes. Similar slopes occur in the headwaters of the Stanley Street debris flow.

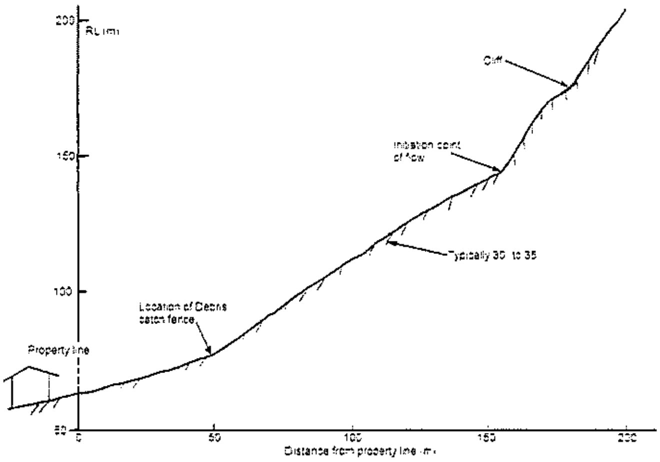


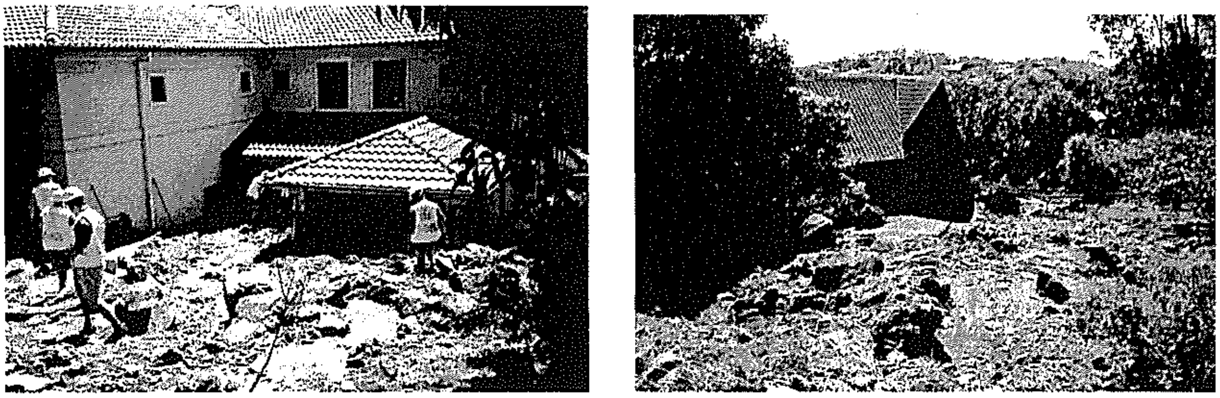
Figure 4, Typical Slope Section through Stanton Terrace Debris Flow

Debris Flow Development and Consequences

The initiating events at Stanton Terrace appear to have been slipping of soil at thsee separate locations. The extent of the two overlapping areas was approximately 25 metres by 20 metres, with the third being approximately 16 metres by 20 metres in area. These failures were surficial in nature, being typically 1 to 2 metres thick with near vertical back and side scarps and bare soil and highly to extremely weathered rock exposed over the stripped areas. In both triggering areas the cliffs above would have concentrated flows into the areas that failed.

Once initiated the moving volume increased dramatically as the flowing debris advanced down the slope, scouring deeper channels and entraining extra material ranging from soil to large boulders. A small volume of debris was deposited on previously grassed slopes immediately downhill from the source areas. Much of the debris flowed into and down previously existing watercourses, scouring deeper gullies. Some sheet flow occurred, including immediately downhill from the sources.

Debris travelled some 200 to 250 metres reaching occupied houses at Stanton Terrace. The debris flowed around and into the house at 42 Stanton Terrace, filling the courtyard with debris up to 2 metres deep (Figure 5). Debris flowed underneath the "A-frame" house at 40 Stanton Terrace, filled the backyard swimming pool at 38 Stanton Terrace, flowed down the driveway at 36 Stanton Terrace (Figure 6), and blocked the drainage pipes beneath 34 Stanton Terrace and down the side of 42 Stanton Terrace. The house numbers are shown on Figure 2. No one was injured in the event.



Figures 5 & 6, Typical debris to rear of Stanton Terrace houses.

The debris varied from mud (silt-clay-sand mixtures) to silty gravelly sand, with frequent cobbles and boulders. Much of the material was saturated, with the consistency of liquid mud in places. Boulders with dimensions up to 4 metres had been transported down the slope and deposited in the area behind the houses and in the pool at 38 Stanton

Terrace. Sand and silt washed down Gregory Street as far as Stanley Street. Water flow continued through the affected area for several days after the event.

A number of boulders remained on the hillside following the debris flow. One particularly large boulder (approximately 6m x 4m x 4m) was located immediately beside a deep scour channel. This boulder was considered to be potentially unstable and life threatening. It was considered likely that hrther heavy rain may lead to widening of the erosion channel so that the boulder would then slide and/or roll down the slope, potentially impacting the houses in its path. Remedial works for this boulder, comprising buttressing, erosion protection and anchoring with wire ropes were therefore carried out on an emergency basis during the following three days.

The "A-frame" house was ultimately demolished and replaced. The other houses were found to be substantially undamaged when the debris was removed.

The failed area contained a number of hazards to workers and houses below the area including:

- A number of small to large boulders in hazardous to potentially unstable conditions,
- The fluidity of the debris (mud) close to the residences,
- Over steepened slopes around the source areas and some debris remaining on the slopes, and
- Severely scoured and over steepened soil slopes downhill from an area of bare rock face.

A surficial soil failure about 20 m below the car park on Castle Hill initiated the Stuart Street debris flow. Most boulders and soil were stripped from the gully, leaving a number of precariously placed boulders on the edges of the newly eroded and deepened gully.

Causes of the debris flows on Castle Hill

The initiating landslides and the resulting debris flows were precipitated by heavy rainfall. In addition to direct rainfall, the source areas were also subjected to concentrated flow from catchments formed by the gullies and rock faces above. The slope of the source areas is quite steep and there was little protection of the natural slope by trees and shrubs. Under saturated conditions calculations show that these areas have marginal stability. This is common for residual weathered soils on steep slopes. Observation of some fmer grained soils during remedial work suggests that some of these are prone to remoulding to slurry when saturated and disturbed.

The slopes containing the source areas faces the windward side of Castle Hill during cyclone "Tessi", with wind directions predominantly from the E and NE, and were therefore subject to more intense rainfall than the western and southern slopes of Castle Hill. Timing of the events in relation to the rainstorm (see Figure 3) suggests that both cumulative rainfall and intensity may have been contributing factors. With marginally stable saturated slopes and gully material the build up to a debris flow is likely.

REMEDIAL WORKS ON CASTLE HILL

Following the failures a large number of boulders remained on the slope, some of which have been moved and/or subjected to scour, locally steeper slopes existed around the perimeters of the source areas, and loosened debris remaining on the steeper part of the slopes could not be removed. Major stabilisation and/or clean up of these areas were not considered feasible in view of the scale of work required and severe access difficulties. The adopted remediation strategy included localised stabilisation of some larger boulders insitu on the slope, and the construction of rock bunds and boulder catch fences on the lower slopes to reduce the exposure of residents and stsuctures downhill to risk from further debris and/or boulder movements. Insitu stabilisation measures included the provision of concrete buttresses, erosion protection and cable staying. Rock filled gabions were constructed below some boulders to provide additional support. A number of boulders were broken up insitu once the boulder catch fence was installed. In some cases, in order to reduce the risk of boulders rolling, cargo nets were placed over the boulders to be broken and tied back to the slope with grouted rock bolts.

A plan showing location of several of these features is presented in Figure 7. A similar approach was adopted for the 1998 Magnetic Island debris flow, and the debris flow at Stuart Street. In each case stabilization of the source area and scoured debris flow path was considered impractical due to severe access difficulties, and remedial works were individually designed to suit local conditions and make use of local materials.

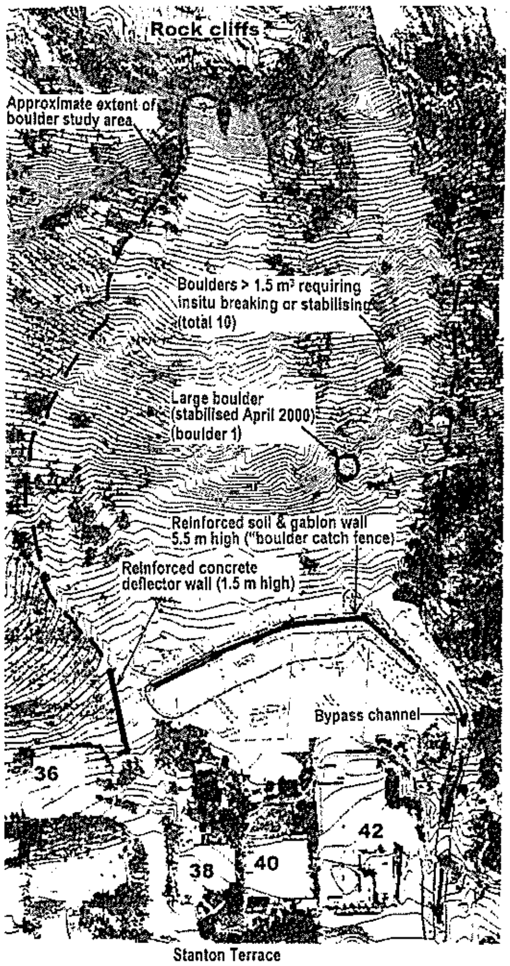


Figure 7, Remedial Works at Stanton Terrace

Boulder Catch Fence

Boulders greater than 1m sizes within the debris flow catchment area were individually assessed to provide input to design of the boulder catch fence. This included field assessment of the size, embedment condition and potential stability of approximately 160 boulders. Based on the distribution of boulder size and stability condition, the catch fence was designed to retain boulders up to approximately 1.5 m size. Ten boulders larger than this size, and that were considered to have an unacceptable likelihood of downhill movement were identified and stabilised or broken insitu following construction of the boulder catch fence.

Analyses of movement (rolling and bouncing) of boulders of various shapes and up to the design size were used to design the height of the wall and its position at the foot of the slope. The rock trajectories were estimated using the Colorado School of Mines CRSP program. Wall heights, to a maximum of 5.5m. were chosen so that of 10,000 boulders analysed, only 1 would travel past the wall. The wall cross-section was designed to absorb the energy of the design boulder travelling at a speed of 24 m/s. as assessed from the boulder movement analyses.

An energy absorbing wall was chosen in preference to energy absorbing fence structures, since the height required was near the upper limit of steel catch fences, costs were favourable, and the stsucture was able to be constsucted using Council's own work force with design and construction advice from Coffey. The wall's plan orientation was chosen to take advantage of natural features, and to deflect potential debris towards the two major gullies at the site. An illustrative cross-section of the reinforced soil and gabion wall is shown in Figure 8. Gabions were used to form the uphill face. The downhill face was reinforced using galvanised and plastic coated wire mesh with the mesh reinforcement anchored to the gabions and wrapped around the face. Conventional plastic geogrids were not used since they may melt if exposed to bushfires. Additional longitudinal reinforcement layers were incorporated to provide energy absorption capacity in the case of boulder impact. The finished structure was grassed on the downhill side, effectively camouflaging the structure when viewed from below.

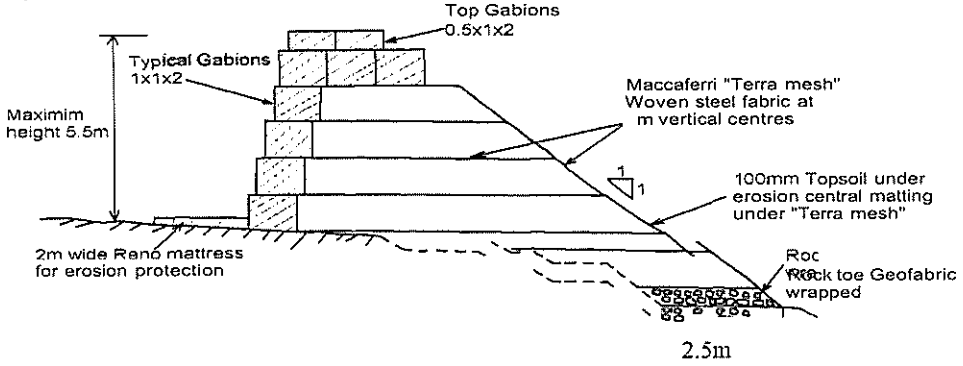


Figure 8, Cross Section of Boulder Catch Structure

FURTHER ACTIONS

Following the 1998 debris flow event Townsville City Council (TCC) has undertaken a study to identify landslip and debris flow hazards, and has incorporated guidelines and development restrictions into their planning processes.

ACKNOWLEGEMENTS

There was considerable input from TCC staff both during the emergency works and in finalising the form of the remedial design. Mr Ian Burns contributed in a major way to construction of the remedial works. A number of Coffey staff in additional to the authors were also involved at various stages in the studies, in particular Greg Hackney. Their contribution is gratefully acknowledged.