BETWEEN A ROCK AND A HARD PLACE: SUMNER ROAD STORMWATER REBUILD

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ABSTRACT

Sumner Road is a 2.6 km road in Christchurch's Port Hills connecting Sumner and Lyttelton. This important transport link and popular scenic route for drivers and cyclists was damaged in the Canterbury Earthquakes and has been closed since 2011. Perched on a narrow ledge above Lyttelton Harbour, much of the road was damaged by rockfall from the steep cliffs above. The loess soils are also highly erodible, as demonstrated in the 2014 floods which mobilised a number of debris flows, causing further damage to the road.

Scheduled for a much-anticipated re-opening in March 2019, the repair of Sumner Road has been a complex multidisciplinary project, in a unique and challenging environment. Sumner Road is a Christchurch City Council project jointly funded by NZTA and the works have been carried out by McConnell Dowell and its specialist sub-contractors, with Beca as the contractor's designer.

The project includes rockfall risk mitigation works, repair and rebuild of 29 retaining walls, road pavement repairs and stormwater drainage; all within a tight existing road corridor. This required a collaborative multidisciplinary approach and innovative design.

This paper details some of the key challenges and successes of the stormwater design whilst working as part of a wider multidisciplinary team. The stormwater challenges included large concentrated flows, requirements to mimic the pre-earthquake flow patterns, steep slopes, highly erodible soils, as well as ensuring all new drainage assets within the road corridor are cycle safe and trafficable. Stormwater assets, especially those in rockfall risk areas, were required to need no or minimal maintenance.

A key success of the project was the design and implementation of a high capacity, narrow, trafficable pipe inlet structure. This was designed due to the range of inlet structures (catchpits/sumps) on the current market not meeting all of the particular constraints of the site. Other successes included the design of four open flumes to convey flows down highly erodible slopes and two types of energy dissipation structure to mitigate the high discharge velocities.

KEYWORDS

Drainage, stormwater, multidisciplinary, complex, collaboration, erosion, rockfall.

PRESENTER PROFILE

Angela Pratt is a Senior Environmental Engineer at Beca with 15 years' experience in design and consenting of stormwater conveyance, attenuation and treatment systems for roading, industrial, residential and various other projects. Angela has previously been involved in the design of other major roading projects including the Manukau Harbour Crossing in Auckland and Christchurch Southern Motorway Stage 1. Angela is a competitive mountain-biker and road cyclist and she regularly rode Sumner Road prior to its closure in 2011.

1 INTRODUCTION

Sumner Road is a 2.6 km road in Christchurch's Port Hills connecting Sumner and Lyttelton. This important transport link and popular scenic route for drivers and cyclists was damaged in the Canterbury Earthquakes and has been closed since June 2011. Perched on a narrow ledge above Lyttelton Harbour, much of the road was damaged by rockfall from the steep cliffs above (see Figure 1 for an example). The loess soils are also highly erodible, as demonstrated in the 2014 floods which mobilised a number of debris flows which caused further damage to the road.

Figure 1: View of rockfall damage to Sumner Road (early 2016)

The Sumner Road project has involved mitigation of geotechnical risks (primarily rockfall) as well as the repair/rebuild of the road pavement, drainage systems and retaining walls. A new road safety barrier has also been installed along the full length of the road to comply with current safety standards.

The complex and challenging environment of Sumner Road has meant that the design of the drainage elements had to step outside of conventional design methods. Many aspects of the design required detailed multidisciplinary collaboration across drainage, geotechnical, pavements and roading design, and required a balance to be reached between each discipline's drivers and design criteria. These challenges have resulted in a number of bespoke design elements including the following which are described in this paper:

- Design of drainage for a rockfall catch bench
- Design of a high capacity pipe inlet structure/catchpit
- Design of four above ground flumes to convey flows over erodible ground
- Design of two types of energy dissipation structure for at the end of the flumes

2 SUMNER ROAD PROJECT BACKGROUND

2.1 SITE DESCRIPTION

The Sumner Road project site extended approximately 2.6 km from the Reserve Terrace (Lyttelton) intersection with Sumner Road in the south-west, to Evans Pass in the North-east. Refer to Figure 2.

The road initially traverses above Lyttelton Port before taking an almost 90-degree bend at Windy Point, a popular stopping point from which tourists can view the harbour. The road then winds its way up around two major gullies (F and G gullies) above the Lyttelton Port coal yard. The upper part of the road continues to wind through a number of smaller gullies. Below this part of the road is Old Sumner Road which was originally built in the 1850's but is now used by Lyttelton Port Company (LPC) to access their Gollans Bay Quarry located to the east of Evans Pass.

Figure 2: Sumner Road General and Specific Location (Road shown in red).

A feature of the site which was a major driver in the stormwater design is the presence of highly erodible loess soils. Loess originates from Southern Alps greywacke which has been ground by glacial action and then entrained by strong north-westerly winds. The Port Hills (where Sumner Road is located) loess soils are predominantly made up of silts (<30%) and sand (<20%) with the bulk of particles being between 20 and 60×10^{-6}m in size. Erodibility of loess is due to their low permeability and dispersive characteristics with rills, gullies and tunnel gullies frequently seen in exposed soils (McMurtrie et al, 2017).

2.2 PROJECT OVERVIEW

During the 2010/2011 Canterbury Earthquake Sequence, Sumner Road suffered substantial damage due to rockfall, cliff collapse and mass movement hazards and has since been closed. In addition to the risk to road users, instability of the bluffs and slopes upslope of the road further threatened the structural integrity of the road. The stormwater drainage systems servicing the road also suffered substantial damage.

The reopening of Sumner Road will be a major milestone in the city's earthquake recovery. This vital transport route being open, will allow safer movements of dangerous goods and oversized vehicles which needed special closures to allow their movement through the Lyttelton tunnel. The alternative route over Gebbies Pass added a significant distance to the travel to and from the Port of Lyttlelton.

The reopening is also of major significance to the Canterbury cycling community, local tourism and the Lyttelton Community, being a critical component of several frequently used cycle and tourist drive routes.

The Sumner Road rehabilitation project has been undertaken in two key parts; firstly, mitigation of the rockfall risk to the road and secondly, repair and rebuild of the road itself. Design of stormwater drainage systems were required for both stages of the project.

Beca was engaged by McConnell Dowell (MCD), the main contractor, as their designers for the project.

2.3 CLIENT AND STAKEHOLDERS

Sumner Road is owned and maintained by Christchurch City Council (CCC), however given the importance of the road for regional transport, NZTA have funded a significant portion of the rebuild cost, alongside CCC.

CCC project team included members from the CCC transport project management, road maintenance, drainage, and traffic safety and technical services teams. Jacobs acted as CCC's engineering advisors during the project.

A key stakeholder for the project was Lyttelton Port Company (LPC), who owns the land below the road, down to the sea. As all stormwater flows discharge onto/across LPC land, engagement with LPC formed an important part of the project.

2.4 PROCUREMENT AND DESIGN PROCESS

In 2015, Beca Ltd (Beca) was engaged by MCD to act as designer for their design build tender of the Sumner Road Geotech Risk Mitigation Project. After the award of the contract to the MCD team, the project team sought and gained approval to expand scope from the tender design of geotech risk mitigation (primarily rockfall risk) only, to also include the repair /rebuilding of the road. This involved retaining walls, pavement, road geometrics and safety, and stormwater drainage.

MCD also engaged a number of specialist sub-contractors including Doug Hood Mining, Geovert, Civil Construction Ltd, Fulton Hogan and Rock Control.

2.5 STAGE 1: GEOTECH RISK MITIGATION

The objective of the first stage of the project was to reduce the rockfall risk to the road and its users because of instabilities upslope of the road. The most significant mitigation measure was the construction of a 400 m long catch bench under the high cliffs in the upper part of the road. This catch bench was designed to catch the rocks that fall from the cliffs above, with rockfall simulation modelling showing that the catch bench will catch 95% of the rocks falling from the bluffs.

The stage 1 works which were focused on the upper part of the road included:

- The repair of three existing retaining walls to enable heavy machinery to access the catch bench site. In three places the road was too narrow due to the existing road width and damage to these walls, such that there was not sufficient lane width for heavy machinery to pass safely. Whilst being constructed to enable the existing road to be used as a haul road, these walls are also a permanent feature of the project. They were later retrofitted with drainage, barriers and pavement.
- Catch bench (see Figure 3) – approximately 100,000 m^3 of rock was blasted and excavated to construct a 400 m long 8-13 m wide bench with a solid rock bund on the outside edge. The rock which was removed during constructing of the bench was hauled by truck to the top of the road at Evans Pass, where it was tipped onto a stockpile in part of the Gollans Bay Quarry. This rock was reused in other CCC projects before LPC resumed operation of the quarry. See Figure 8.
- Sediment control - a 750 m^3 sediment control pond with associated channels and discharge structures was designed to mitigate the effects of sediment expected from the area where the catch bench waste rock was stockpiled.
- Rockfall Interception Bund construction– a 7 m high 55 m long embankment was constructed in one of the gullies (F Gully) half way along the road. Refer
- Figure 4.

Figure 3: Catch Bench Construction

Figure 4: Rockfall Interception Bund in F Gully Prior to Revegetation (Source: MCD)

Key drainage components of these stage one works included:

- Erosion and sediment control as described earlier.
- Drainage of the catch bench. This included the construction of porous subsoil trenches at several locations along the catch bench to discharge water.
- Construction of a cattlestop/drainage channel to discharge stormwater from the downstream end of the catch bench onto the road.
- Construction of a stormwater conveyance channel around the rockfall interception bund in F Gully, as well as a culvert and associated inlet structure to convey flows under the road (into a flume constructed as part of later works).

2.6 STAGE 2: ROAD REHABILITATION

For the purposes of design and construction, the 2.6 km of road was split into two sections with the lower section being constructed first. Key aspects of the road rehabilitation included:

- Repair or rebuild of 29 retaining walls including two additional walls that were uncovered during the construction process;
- Installation of subsoil drains to resolve a number of slumps;
- Substantial pavement works (either complete rebuild or patch repairs);

- Major earthworks to move the road back into the slope away from collapsed ground and retaining walls at Windy Point.

Drainage works required included:

- The drainage elements of the retaining walls;
- Replacement of damaged stormwater pipes;
- Replacement of the drainage channel for the full length of the uphill side of the road;
- Replacement of three flumes including one of these in a new location;
- Installation of four new high capacity pipe inlet structures and pipes in the upper part of the road to cater for design flows.

2.7 PRINCIPAL’S REQUIREMENTS (STORMWATER)

The design of all elements of the project, including drainage, needed to meet the Principal’s Requirements (PRs). The key drainage requirements were:

- Primary flows – channels, culverts and flumes to be designed to a minimum 20% Annual Exceedance Probability (AEP) storm event
- Secondary Flows – system capacity and management of erosion and instability (overland flow paths) up to the 1% AEP storm event
- Utilise and retain historical drainage paths where possible and where they are assessed to have performed satisfactorily.
- Consider broader drainage requirements when considering retaining wall and roading design
- Assess and mitigate impacts on the LPC proposed haul road and drainage design
- Consider Council preference for naturalised conveyance methods for drainage
- Design systems that need only infrequent maintenance

2.8 EXISTING STORMWATER SYSTEM

The existing Sumner Road was serviced by a range of drainage components including:

- A number of conventional concrete pipes discharging either directly onto the slopes below or into one of three flumes.
- Three CCC hillside sumps connecting to corrugated Aluflo culverts under the road, discharging into (PE or galvanised) flumes supported by a basic waratah support structure (F and G gullies).
- An old square stone box culvert connecting to a damaged (pre-earthquake) earthenware pipe (CH680).
- A hand formed channel of varying capacity along much of the uphill side of the road.

The varying capacity of the roadside channels meant that higher than capacity flows would cross the road where super-elevation changed. This had traffic safety implications.

In addition, an old rock wall (see Figure 5). on the outside of the road, for much of the upper part of the road and parts of lower section, acted to contain flows and concentrate discharge over the edge

Figure 5: Typical view of the upper part of the road with cliff and hand formed channel on the left and rockwall on right (sea side). (Source: Google Streetview).

3 EARTHQUAKE DAMAGE

3.1 GENERAL

The upper half of Sumner Road traverses very steep terrain. Most of the road is formed in rock cut, with smaller areas of fill formed by retaining structures. The cut areas generally performed well, however many of the fill areas and retaining walls deformed or partially collapsed during the earthquakes.

Rockfall was significant and widespread across the site but mainly concentrated in the upper part of the road. Rockfall sources were both from the cut faces immediately adjacent to the road and from rock outcrops above the road, in particular the bluffs area.

The bottom half of Sumner Road traverses a mixture of steep rocky terrain (Windy Point) and slightly flatter loess covered slopes. Rockfall damage to the road was less frequent in this section but damage to the numerous retaining walls was widespread (see Figure 6).

Figure 6: Damage to the road near Windy Point due to a slip removing a retaining wall below the road

Whilst some of the existing rock walls were damaged/collapsed pre-earthquake, these suffered significant damage during the earthquakes.

3.2 FURTHER DAMAGE

After the road was closed in June 2011, further damage occurred to the road, including:

- Post-earthquake, rockfall damage continued to occur both during later earthquakes and after rainfall, as it always had pre-earthquake.
- Early rockfall mitigation works including scaling (abseiling off the cliffs and dislodging loose rock) the steeper cliff areas of the project. The size of the scaled rocks was managed but significant quantities were added to the earthquake damaged road pavement below.
- During investigation and the removal of excessive vegetation uphill of Windy Point, two additional retaining walls were discovered that were not previously visible. These two walls needed to be rebuilt due to the damage incurred during the earthquake.
- In 2014, Christchurch experienced a series of extreme rainfall events including Lyttelton receiving 160 mm of rainfall in one 24-hour period. This equated to a larger than a 1 in 100-year storm event. Whilst debris flows have been known to occur along Sumner Road, this event caused significant debris flows/slips in a number of locations along the road, some requiring new retaining walls.

3.3 STORMWATER SYSTEM DAMAGE

During the early part of the project, detailed stormwater system damage assessments were carried out including site walkovers and CCTV inspections to determine the extent of damage to the pipe infrastructure along the road. A range of damage was found including:

- Collapse of an old stone box culvert where it joined with a newer concrete pipe.
- Various damage to all other concrete pipes including joint separation, cracking, exposed reinforcing.
- Minor joint separation and corrosion damage was seen in the existing corrugated aluminium culverts in G gully.
- Various damage to the hand formed channel along much of the uphill side of the road including cracking and displacement.
- Twisting and rockfall damage to all of the existing galvanised steel flumes in F and G gullies.

4 KEY STORMWATER CHALLENGES

All projects present engineers with a range of challenges to manage and it is the combination of challenges that make a project interesting. Sumner Road is a prime example of this. With most stormwater design projects, managing client and stakeholder expectations, ground conditions as well as managing primary and secondary flows, water quality and flood risk are common. With the addition of the following challenges on this project, detailed thought and close collaboration with all design disciplines was required in order to solve:

- **Large concentrated flows in several places**– these flows and associated debris needed to be managed.
- **The need to mimic pre-earthquake flow patterns** as per the PRs– with a regionally important landowner/stakeholder below the road, the impacts of discharges of stormwater on Lyttelton Port Company operations were a major consideration. LPC were also undertaking their own major works below Sumner Road during construction, for which they needed certainty as to discharge locations from the road above.

- **Steep slopes** - with the road grade at an average of 1 in 20 and general ground slopes up to 1 in 0.5 along with the road traversing the slope, construction of outlet structures on steep slopes was a challenge.
- **Highly erodible loess soils** - the loess soils of the Port Hills are highly erodible especially when subjected to concentrated flows.
- **Managing cycle safety** - with the road being on locally very important cycle routes, "long" and "short bays", consideration of cyclist as well as vehicular safety requirements were at the forefront of any design.
- **No or minimal maintenance** – with large areas of the site subject to ongoing rockfall risk, designing stormwater management systems that required no or minimal maintenance was a key driver for CCC. No access to the catch bench for maintenance of stormwater systems was a requirement.
- **Minimal space** – with much of the road being within a very narrow corridor between cliffs and steep slopes below, the road really is stuck "between a rock and a hard place". Significant costs of potentially very high retaining structures also restricted the ability to widen the road. In addition, much of the existing road lane widths were below modern standards therefore fitting in appropriate drainage management was a major challenge.
- **Retaining walls** – with 29 retaining walls, working the drainage elements around these was a frequent challenge. A large number of the retaining walls had up to 5 m long rock anchors at various angles into the road behind.

In regard to mimicking existing flow patterns, one of the major challenges, particularly in the upper part of the road, related to the detail required along the downhill side of the road.

The form of the road is such that there are sections with crossfall to both sides, and some sections of superelevation which switches direction as the road passes in and out of gullies. In rebuilding the road, safety barrier installation required removal of the existing rockwalls along much of the road (part of existing drainage system) and install a traffic safety barrier. In making these changes, it meant it was not possible to simply contain flows in a kerb and discharge where it did before, as a kerb would not have had as much capacity as the rockwall provided. As a result, methods for controlling the flows and discharge points were considered in detail.

Due to the range of constraints, three main methods of discharge were utilised:

- Concentrated discharges via pipes where deemed appropriate to do so or in the locations of existing pipes;
- Discharge via castellated kerbs (narrow gaps through a kerb to distribute the flow where concentrated discharge was not appropriate);
- Free discharge over the edge where the soils could handle this i.e. less erosion prone soil types or directly onto rock.

The selection of appropriate locations for discharge required detailed collaboration with other disciplines. Initially a geotechnical assessment was carried out to determine what soils were present along the downhill side of the road. From there, consideration of the safety barrier construction requirements was also required. Depending on the space at the edge of the road, decisions were made as to whether barrier support posts could be driven directly into the ground or if they needed a reinforced concrete ground beam (small retaining wall) to support the posts. There were seven variations of ground beams which included variations in beam width, the presence or not of kerb, castellations or the top-level flush with the road. Beams with castellations also needed to be designed to have kerb slots with sufficient width to discharge flow, but yet not to contend with longitudinal reinforcing in the beam.

The form of the castellations was a major consideration with the proposed design to have the kerb cuts perpendicular to the kerb. The potentially more logical way of doing this would be to have the cuts on an angle to increase the efficiency of the discharge. The driver behind the use of castellations was to distribute flow over a wider area rather than concentrating it. Increasing the efficiency of the discharge via an angled kerb cut was therefore the opposite of what was wanted, rather we wanted a small flow to discharge through each.

5 KEY STORMWATER DESIGN ELEMENTS

5.1 INTRODUCTION

The design of the repair and rebuild of the stormwater management system has occurred over multiple stages related to the phases of construction. The following section provides descriptions of the more challenging aspects of the design whereby site constraints required non-standard designs, so that they functioned within the unique and challenging environment of Sumner Road.

5.2 CATCH BENCH DRAINAGE

With substantial stormwater flows likely to be generated by the catch bench catchment, the design of a drainage system which would distribute the flows onto the slopes below (as they did pre-earthquake), was preferred over managing a significant concentrated flow where it discharged onto Sumner Road at the end of the catch bench. Various methods of distributing flows were investigated, including surface channels and more conventional pipes with inlet structures, however three main design criteria were difficult to meet with these designs:

- No maintenance due to rockfall risk;
- Design elements needed to avoid the risk of blockage;
- The outer bund needed to remain intact so that the rockfall mitigation remained effective.

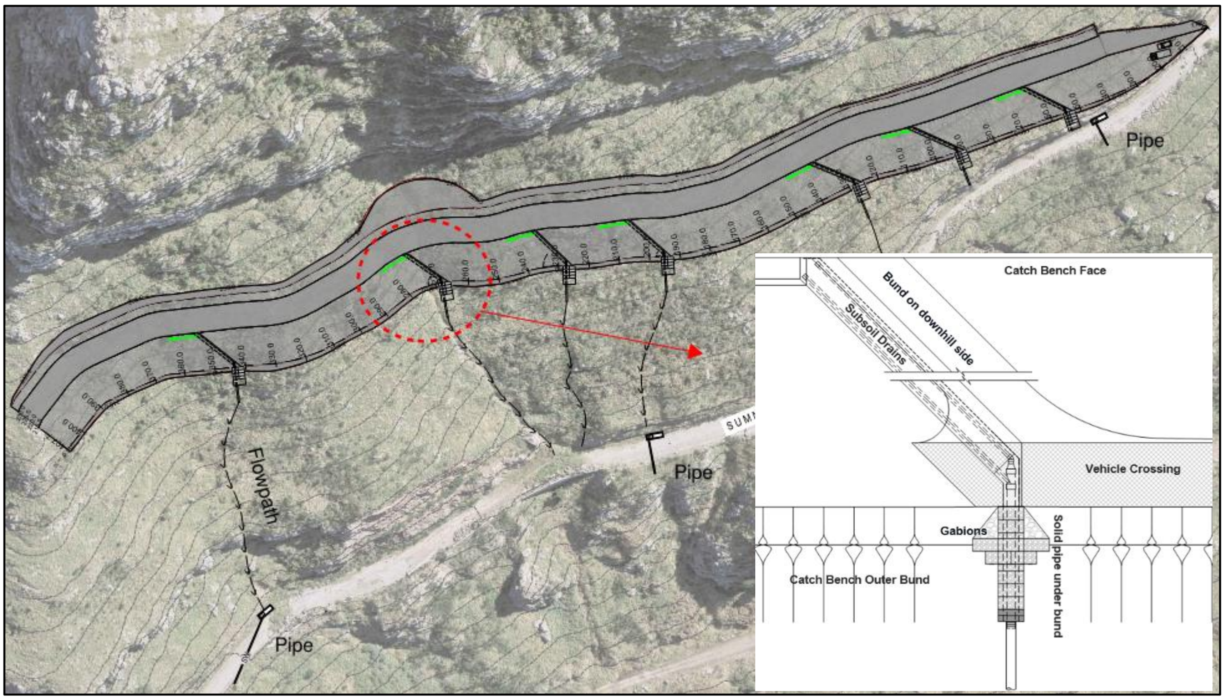
The constructed design included a series of porous subsoil trenches across the bench, passing under the outer bund and discharging onto the slopes below. The design relies on surface flow through the porous gravel and down into a subsoil pipe, hence avoiding the need for an inlet structure which would likely be prone to blocking due to falling rocks and hence would need maintenance to function. Each trench contains two subsoil pipes to provide redundancy and both are sufficiently long enough to provide more than adequate inlet capacity through the perforations in the pipe. See Figure 7.

With the outer bund needing to be intact from a rockfall perspective, the pipe trench needed to be reinstated, this was done using gabion baskets in a stacked arrangement.

Other features of the design included:

- A bund on the downhill side of the trench to increase the ponding depth before water would bypass and flow down to the next trench.
- Lining the trench and bund with Concrete Canvas to prevent leakage and reduce erosion risk on the slopes below.

Figure 7: Catch bench Drainage



5.3 GOLLANS BAY EROSION AND SEDIMENT CONTROL

During the construction of the catch bench, waste rock was transported up Sumner Road to Evans Pass where it was tipped over the side into Gollans Bay Quarry (see Figure 8). This waste rock dump had the potential to be a significant source of sediment and could be discharged into Lyttelton Harbour. CCC's consents for the project required erosion and sediment control practices be implemented. A conveyance channel was constructed below the area where waste rock was to be dumped, with water collected being conveyed to a sediment control pond in the base of the quarry. This discharges into an existing watercourse into Lyttelton Harbour.

Figure 8: Gollans Bay/Evans Pass Tiphead Prior to Rehabilitation (Source: Doug Hood Mining)

5.4 ROCKFALL INTERCEPTION BUND AT F GULLY

Stormwater which previously would have discharged directly onto Sumner Road from F Gully, is now prevented from doing so by the rock interception bund. A stormwater conveyance channel was constructed behind the bund and passing around the end of the bund before discharging into a culvert under Sumner Road. Flows higher than the culvert capacity discharge into the kerb on the uphill side of the road, which was coupled with a wider shoulder to increase capacity. Collaboration between traffic safety, roading and stormwater disciplines was required in order to achieve a cross-section that was safe for both cars and cyclists and that provided adequate conveyance and fitted in the space available. Any flows over and above this cross the road and are discharged via castellations (kerb cuts) in a retaining wall capping beam.

5.5 HIGH CAPACITY PIPE INLET STRUCTURES

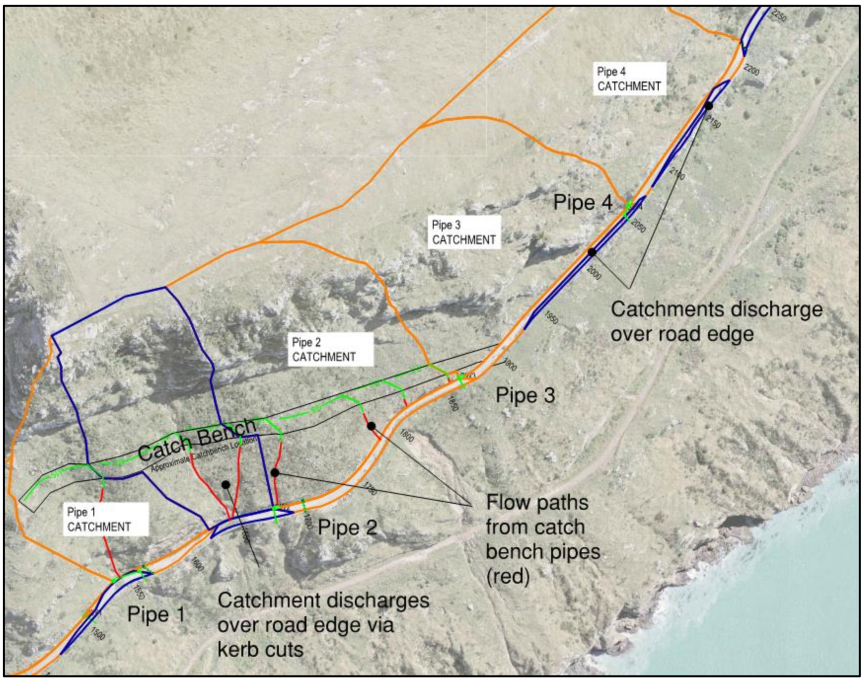
5.5.1 INTRODUCTION

In the upper part of the road, the main existing discharge methods were via 300 mm concrete pipes with basic inlet sumps as well as flow directly over the edge of the road (where rock walls didn't contain flows). To not impact land below, discharge into the same locations as pre-earthquake was necessary.

In designing replacement pipes, the primary flows were found to be significantly higher than standard sump capacities and also required an increase in pipe size (to 450 mm). This required consideration of what sort of inlet structure/sump would be appropriate for the location and the flows. With large steep catchments discharging onto the road, management of the rock, sediment and high flows expected to be conveyed off the hills above needed to be designed for as well as other criteria (see below).

Whilst the design of the inlet structure itself is the focus here, selection of locations for pipes and the inlet structures was also a challenge. The need to pick up flows from the multiple discharge points from the catch bench above, to not overload one or more of the pipes, not create clashes with retaining walls and their associated rock anchors and to discharge into the same location as previous, proved difficult. This criterion was therefore challenged in order to allow different discharge locations to existing. The chosen locations did however result in water reaching Old Sumner Road in generally the same locations as previous. Figure 9 shows the flow paths in the area and the pipe/inlet structure locations.

Figure 9: Pipe locations and contributing catchments.



5.5.2 DESIGN CRITERIA

In designing catchpit/pipe inlet structure for this project, the design needed to meet the following design criteria:

- High inlet capacity (approximately 210 L/s in 20% AEP flow);
- Cycle safe grates;
- Heavy vehicle trafficable – NZTA HN-HO-72 load capacity;
- Narrow – the full width of the structure needed to fit in the 600 mm wide shoulder as the road is very narrow in this location;
- Shallow – to avoid expensive and difficult rock blasting and excavation;
- Needed to accommodate the 450 mm pipes;
- Debris management –debris needed to pass through the inlet rather than be captured on the road.

5.5.3 PROPRIETARY INLET STRUCTURES

There are a large number of catchpits on the New Zealand market sold by a number of suppliers. These include combinations of single or multiple grates as well as back entries of various lengths and varying throat widths. Many councils also have their own specific type of sump and grates. Suppliers of these sumps often provide inlet capacity information however, this is often theoretical and site-specific conditions (e.g. road crossfall and longfall) can mean these capacities may not always be achieved. For example, the maximum capacity is normally for a sag position which can be much higher than a continually grading road, as is the design situation at Sumner Road.

At Sumner Road, a number of these off the shelf units had the theoretical inlet capacity required (eg. the Hynds Megapit) however it was very difficult to find one that met all the design criteria noted above. A bespoke structure which could fit all four proposed structure locations was therefore needed, requiring detailed hydraulic analysis as well as structural design input.

5.5.4 INLET STRUCTURE DESIGN

OVERVIEW

In order to simplify construction, a single inlet structure design has been applied to all four pipe inlets, with the final design being the worst-case (longest) required of all four sites. This meant that the four units could be pre-cast off-site, resulting in a faster onsite construction time in an already very constrained site with multiple contractors working alongside. Having a single design did however mean that the unit had to be rotated onsite to suit the particular road longitudinal grade at each site. Benching of the lower section of the structure prevents ponding.

HEC-22, which our design was based on, provides guidance on the hydraulic design of a range of urban drainage systems including sump grates and back entries. The design guidance in HEC-22 is based on testing of a range of configurations of grates, grate types, and kerb/road configurations.

With the design involving both a grate and a back entry, each component was sized separately in order to intercept the full design flow using methods described in HEC-22. This was considered conservative but does allow for blockage of both components. Whilst it would be possible to vary a number of elements of the design to change the overall inlet capacity, with road longitudinal fall and crossfall being set by the roading designers, as well as width constraints, the final design was decided on by varying the length of the structure in order to intercept the full flow.

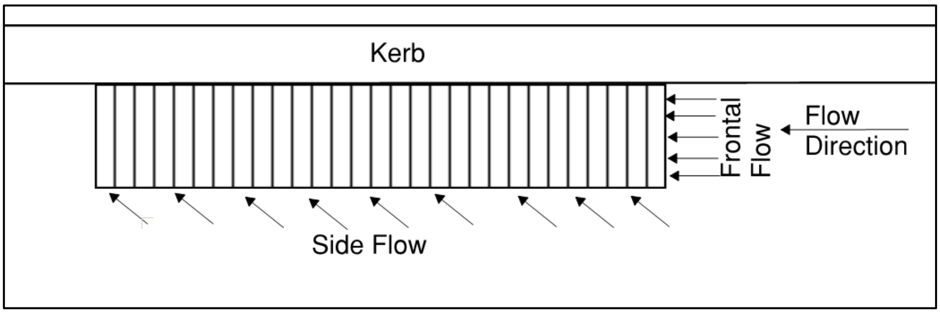
GRATE DESIGN

The capacity of sump grates in a sag position (low point in kerb line) are generally based on a combination of weir flow and orifice flow, with weir flow at the perimeter of the grate up to a certain head and then based on orifice flow through the openings for higher head. For sumps on grade, as is the case for Sumner Road, this does not always apply due to higher velocities causing water to splash over the grate, reducing the efficiency (HEC-22).

As described in HEC-22, the capacity of drainage grates is dependent on the velocity (function of longitudinal road grade), flow depth at the kerb, crossfall of the grate/kerb, the road profile (crossfall) and the grate type (bar spacing, angle etc).

The capacity of the grate has two components, firstly what can be taken in at the upstream edge of the grate (frontal flow (HEC-22)) and then that flowing in from the side of the grate (side flow) (refer Figure 10). HEC-22 provides charts of flow intercepted based on the velocity and the grate length, as well as formulae and charts for determining side flow interception.

Figure 10: Grate Design Terminology



BACK ENTRY DESIGN/DEBRIS MANAGEMENT

The capacity of the back entry relates to the length of the back entry, as well as the flow, longitudinal fall and cross fall.

In regard to debris management, there was much debate in the wider project team about the merits of including a back entry versus not. A back entry on a sump provides higher inlet capacity but can also increases the size of the debris that can pass into the pipes. It is normal practice to try and keep debris out of pipes to prevent blockage over time. Contrary to this, it was decided that preventing debris accumulation on the road (with associated traffic safety impacts) outweighed the potential issues related to removing debris from the pipe.

FINAL DESIGN

As shown in Figure 11 and Figure 12, the final design consists of a 5 m long by 600 mm wide grate. The structure has a shallower first section with the invert then dropping down at the outlet pipe end in order to provide sufficient cover (minimum for a Class 4 pipe) over the pipe. Proprietary galvanized steel grates were also selected to minimise fabrication time. The design also required structural design of the concrete and grate support structure to meet loading requirements.

Figure 11: Bespoke High Capacity Pipe Inlet Structure

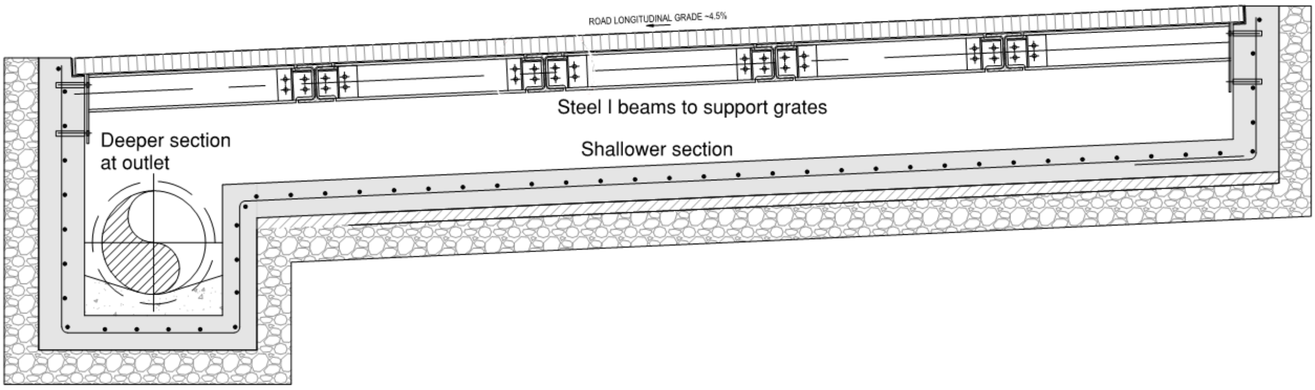
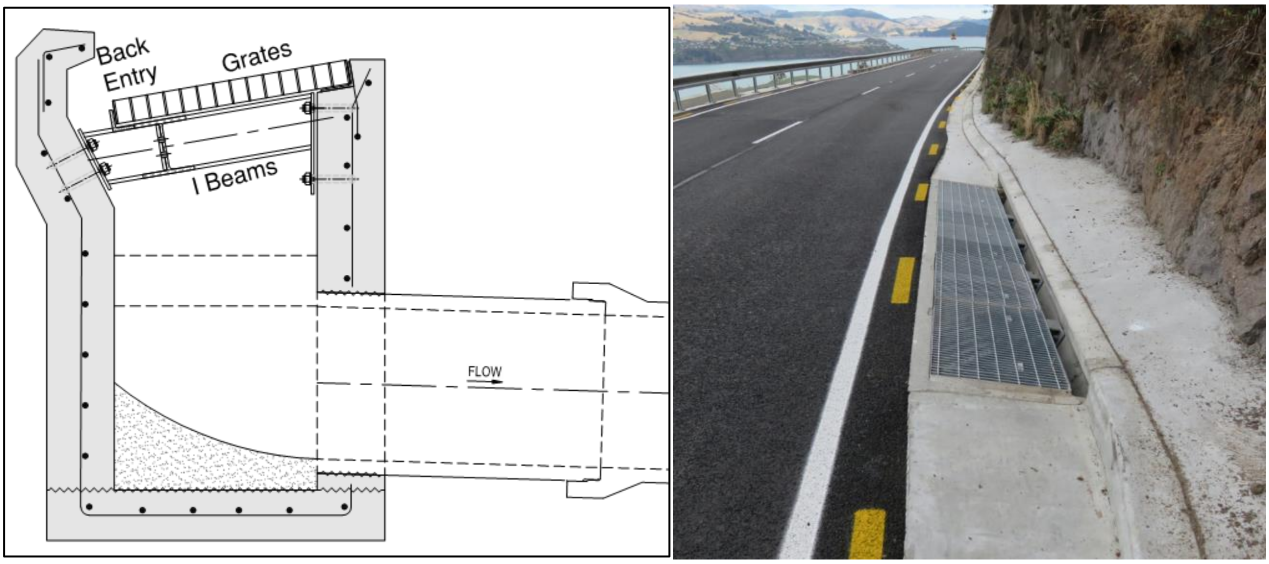


Figure 12: Pipe Inlet Structure Section (at deeper section) and Photo



5.6 FLUME DESIGN

5.6.1 INTRODUCTION

In the F and G Gullies, half way up Sumner Road, stormwater was previously managed by conventional kerb and channel and sumps discharging into flumes. The existing flumes were constructed of corrugated fluming supported by steel waratahs with the flumes sitting directly on the ground. These performed poorly during the earthquakes with various sections of flume twisting as well as suffering from rock damage. Significant erosion occurred under one of the existing flumes. It was unclear as to the exact cause, but this was possibly due to overdesign events, earthquake damage or local surface water flows tracking along the flume where it sat on the ground.

5.6.2 DESIGN CRITERIA

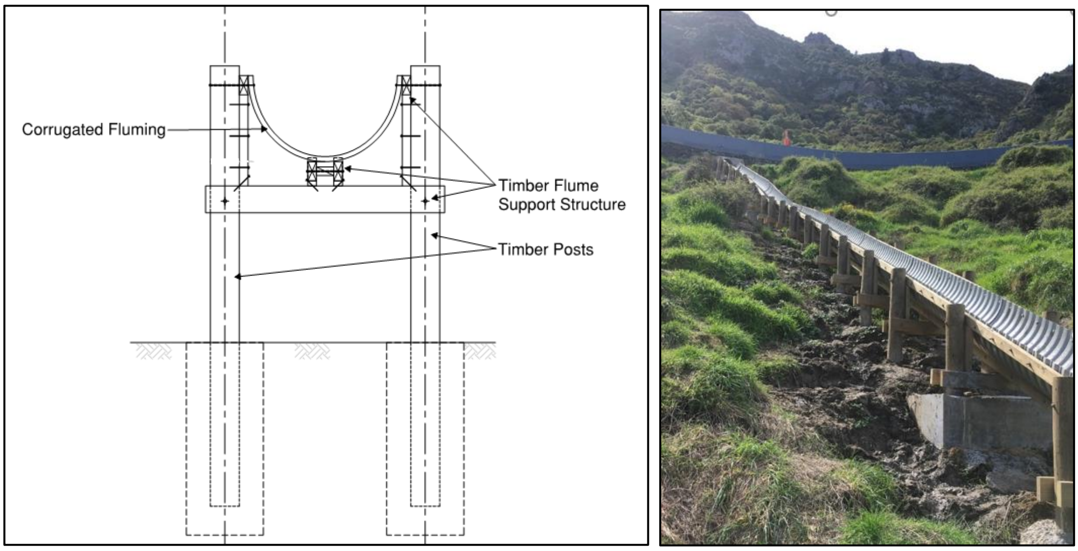
The key design drivers were:

- Open fluming so that maintenance staff can inspect and see blockages more easily, including from the road;
- Earthquake resilience including having a rigid structure that would not warp with earthquake movement;
- Ability for the grade to be as consistent as possible to avoid overflows;
- An above ground structure to avoid water tracking between the ground and the fluming.

5.6.3 FINAL STRUCTURE

A primarily timber structure was designed with 150 mm posts every 1.5 m, on either side of the flume augured 800 mm into the ground. During construction, clashes with large rocks meant that alternative concrete foundations were required on some posts. Cross-bracing between the two posts supports the weight of the flume when flowing at design flow. Refer Figure 13.

Figure 13: Flume Support Structure and Gully G flume during construction.



5.6.4 FLUME MATERIALS

SUPPORT STRUCTURE

Timber was specified for most of the support structure as requested by the Client.

FLUME

In designing the flumes, pipe material selection was an important consideration. Corrugated fluming was considered the most appropriate fluming type hydraulically in order to increase roughness and reduce flow velocities compared to smooth bore fluming.

The two main types of corrugated fluming available on the market are galvanized steel (refer Figure 13) and PE. Whilst both materials were considered, as a rigid structure was necessary to create an earthquake resistant structure, PE pipe was not considered appropriate due to it having a linear thermal expansion coefficient 15 times that of galvanized steel (based on the expected temperature variation at the site). This high level of thermal expansion and contraction would not have been able to be accommodated.

5.7 ENERGY DISSIPATION STRUCTURES

5.7.1 INTRODUCTION

The existing F and G gully flumes discharge into a shallow channel on the side of Old Sumner Road (See Figure 2). The channel then conveys flows to one of two existing culverts under Old Sumner Road which in turn convey flows further down the hill. At Chainage 680 it was proposed to also replace the existing damaged earthenware pipe with a flume of similar nature.

With the proposed 600 mm wide flume carrying almost 600 L/s in a 20% AEP event, and more in a 100-year event, energy dissipation at the discharge point required a reasonably substantial structure. A substantial structure was required given the risks associated with erosion of the loess soils and the potential impact on Old Sumner Road (Gully flumes) and the LPC benches (CH680). In design flows, it was expected that the flow velocity in the flumes would be up to 7 m/s.

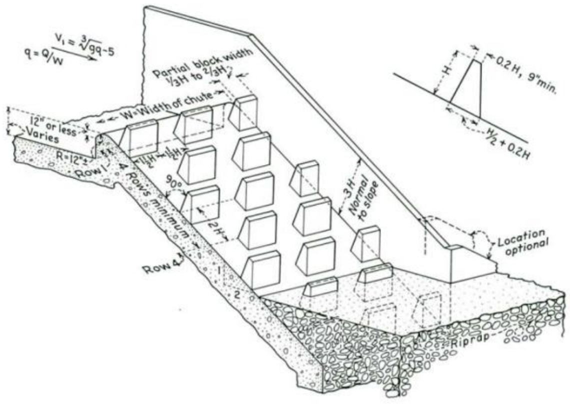
5.7.2 CONVENTIONAL ENERGY DISSIPATION STRUCTURES

The selection of an energy dissipation structure type is often based on the Froude number with various guideline documents (e.g., Auckland Councils TR 2013/018 and FHWA’s HEC 14) providing recommendations on structure types based on Froude Number.

In considering what type of energy dissipation structure to use at the end of each flume, various conventional energy dissipation methods were considered including the following:

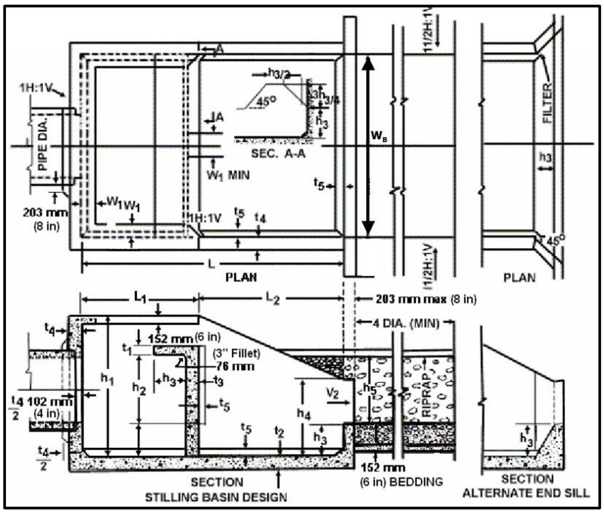
- **Rip rap protection** – the placement of appropriately sized rock at the discharge point is regularly used around New Zealand to prevent erosion, especially in river systems. With high flow velocities and a Froude number greater than 3, rip rap was not considered sufficient for this purpose (refer HEC 14 and AC, 2013). Space constraints also meant this option was not workable.
- **Baffle Blocks** (see Figure 14) – this involves the placement of concrete rock bunds in the flow path with appropriately selected size, number and spacing. Froude number less than 1 is normally required.

Figure 14: Baffle Block Structure. Source HEC 14



- **Stilling/Impact Basins** – Suitable for where Froude Number is greater than 6 (HEC-14). Refer Figure 15.

Figure 15: USBR Type VI Stilling Basin (Source HEC 14)



With Froude Numbers in the range of 4 to 6 for the four structures, neither a rip rap or baffle block structure was considered sufficient hence requiring a stilling basin type structure.

5.7.3 DESIGN CRITERIA

In designing the energy dissipation structure, the following criteria needed to be met:

- Three of the structures needed to convey flows from the channel to the base of slope (Gully's F and G flumes) **Error! Reference source not found.**(see Figure 16);
- Structures needed to maintain access along Old Sumner Road and the LPC bench (Chainage 680) past the structures requiring a narrow width;
- Flow needed to discharge at 90-degree angle to incoming flows.

One of the most important factors governing the design was the need to convey flows along the channel in which it sat, meaning that the water needed to discharge at 90 degrees from the incoming flow. With a conventional stilling basin structure discharging in the same direction as the incoming flow, a modified structure design was required. With potentially complex reinforcing details and hence potentially difficult construction required for a standard USBR stilling basin, we considered that this sort of structure was not justified for the relatively small flow (compared to normal situations where such devices are used).

5.7.4 FINAL DESIGN

A more simplistic, easier and faster to construct structure was designed using two standard box culverts (orientated parallel to Old Sumner Road) and a section of concrete pipe passing through the sidewall (and secured by way of a corbel) into which the end flume was placed. This required structural input in designing the corbel as well as jointing of the two culverts together.

The use of standard box culverts meant that the structure had a "lid" which acted to contain flows and stop splashing onto Old Sumner Road, potentially causing erosion.

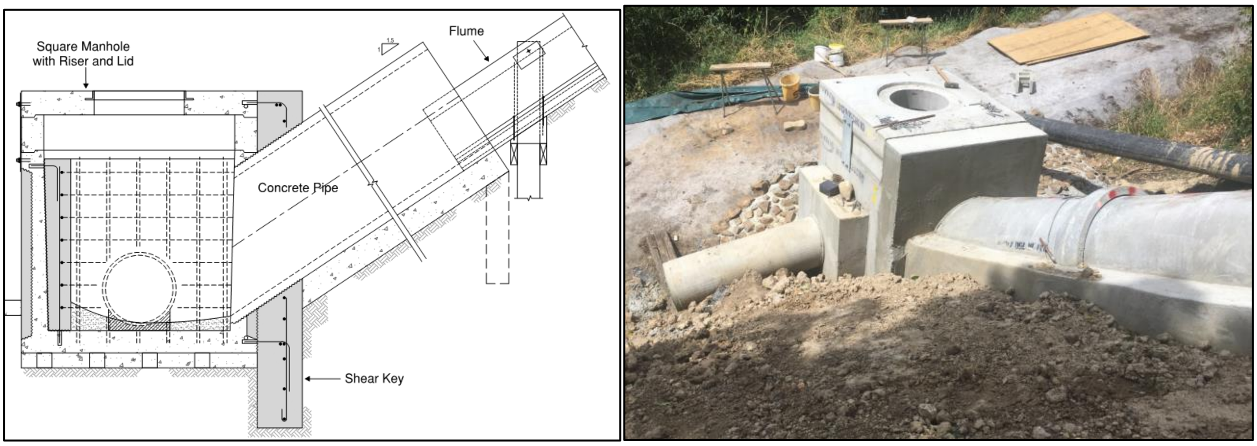
Figure 16: Gullies Energy Dissipation Structure

5.7.5 CH 680 FLUME/ENERGY DISSIPATION STRUCTURE

The energy dissipation structure in this location needed to be different to those in the gullies (See Figure 17). As the discharge was onto LPC land, they requested that the structure be enclosed such that head could build up in it to drive flow into a flexible flume. This flexible flume (fitted by LPC) would convey the flows further down the hill. The main differences between the gullies structures and here include:

- A longer pipe stub on the inlet stub with concrete pipe support underneath it;
- The use of a square manhole instead of a culvert so that a lid could be fitted (with soft spots filled);
- Plates to hold the riser and manhole top in place;
- Bolt down and sealable manhole lid so that it would not pop off when the structure was pressurised;
- A channel around the structure given flow in the LPC channel could not pass through the structure as it does with the previous design.

Figure 17: Chainage 680 Energy Dissipation Structure Drawing and Photo.



6 CONCLUSIONS

The long-awaited opening of Sumner Road in March 2019 will represent the culmination of many years of effort by a huge team of engineers, contractors and Council staff. The severely damaged and rockfall risk affected road has been transformed back into an important asset for the Council and public.

The design of the geotechnical risk mitigation components and road rebuild have required detailed collaboration between the various disciplines to balance numerous design criteria and drivers. The need for this balance in a highly complex and constrained environment has driven the need for a number of bespoke and site-specific stormwater management features. These features have considered the risks of erosion, debris management, space constraints and the risk of future earthquakes and rock fall.

Sumner Road is a stunning piece of road brought back to life for the people of Christchurch.

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