RISK vs COST – PROTECTING HUTT CITY COUNCIL'S VITAL WASTEWATER RIVER CROSSING

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ABSTRACT

The Hutt City Council is responsible for the conveyance of wastewater from Upper Hutt to Lower Hutt through a 24km gravity network. This includes a section of pipeline crossing the Hutt River near Silverstream. This section of pipeline is encased in a reinforced concrete structure which is anchored to the Hutt River bedrock.

During some maintenance work on the reinforced concrete structure a large scour hole was observed developing in the river bed approximately 15m downstream from the pipeline structure. There was a risk the scour hole would in time undermine the pipeline structure. If the structure were to fail, it could lead to sewage discharging into the Hutt River.

Optioneering quickly discounted re-routing of the pipeline due to cost and time constraints and so, with consideration of the whole of life financial impacts, the design focussed towards an 'in river' solution.

The solution needed to prevent further bed degradation, counteract the river's energy and allow movement from the earthquake fault running underneath the river. Through the optioneering and design process a 'rock ramp' structure was selected as the preferred solution.

This paper will outline some of the design issues and discuss some construction features of the rock protection and illustrate durability post construction.

KEYWORDS

Risk, cost, wastewater, protection, riprap, rock, river, environmental.

1. INTRODUCTION

The sewerage pipeline crossing the Hutt River at Silverstream in Wellington takes sewage from Upper Hutt's 42,000 population and conveys it to Lower Hutt's Seaview Wastewater Treatment Plant via 24km of pipeline. While routine maintenance was being carried out on the reinforced concrete pipeline structure (RCPS) in 2010 a deep scour hole was identified downstream of the RCPS. Hutt City Council's Asset Manager requested MWH New Zealand Ltd (MWH) to investigate the scour hole and assess the risk the RCPS being undermined by scour, which if it failed would lead to sewage discharging into the Hutt River.

The project scope was to investigate the scour hole and evaluate the risk of damage to the RCPS, and then assess high level options. This led to design and construction of a solution that would allow continued service of the bulk wastewater pipeline. The design life of the proposed solution needed to account for the fact that the RCPS may be considered for rerouting due to future potential upgrade. Also, budget constraints meant that any solution depending on cost may have to be staged.

This paper will focus on Stage 1 which was completed in 2012, Stage 2 (which is the scour protection of the true right side of the river) has recently been completed using the same design philosophy. The paper briefly outlines the constraints of the site, summarises the options considered, and discusses design issues in relation to: cost, long-term pipeline future, maintenance and time constraints.

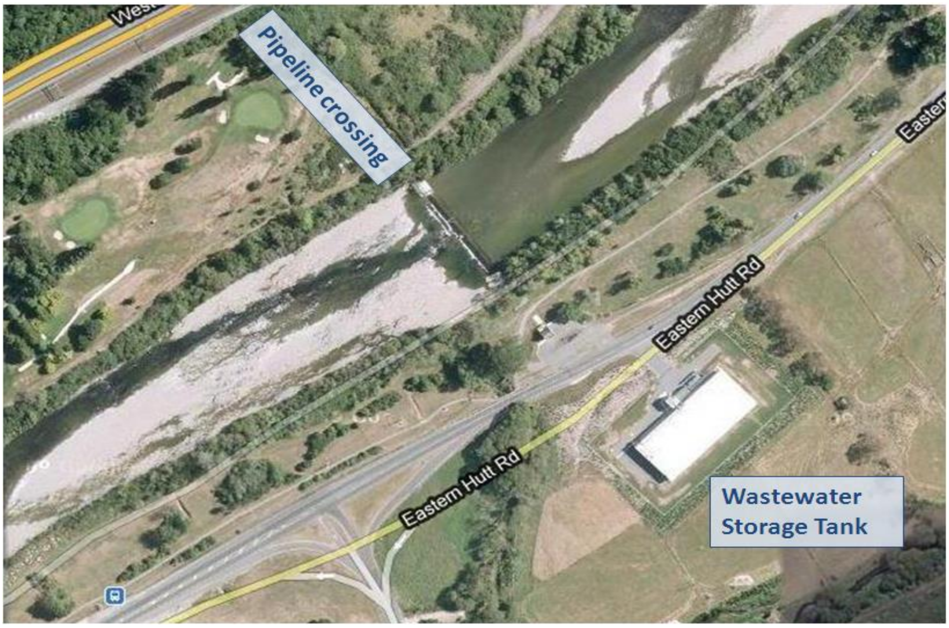
The paper will also outline some interesting construction aspects and finally comment on how Stage 1 of the structure is performing some years after construction as well as discuss the success in relation to ongoing risk mitigation and cost with Stage 2 which has recently been completed.

2. SILVERSTREAM SEWERAGE PIPELINE CROSSING PROTECTION

2.1 WHY PROTECT THE SEWERAGE PIPELINE CROSSING?

The RCPS is located on the Hutt River by Silverstream just south of Upper Hutt in the Wellington region. The RCPS is shown in the aerial photo (Photograph 2-1) below, adjacent to the Silverstream storage tank on the Eastern Hutt Rd. The river currently shows the RCPS as a broad weir across the river bed with wider water flow channel held upstream and narrower flow channel downstream. For the purposes of this paper the terms 'weir' and 'RCPS' are used interchangeably.

Photograph 2-1: Aerial photo of the site



In addition to conveying wastewater from Upper Hutt to the wastewater treatment plant at Seaview, in Lower Hutt, the RCPS also has a secondary function in discharging overflows from the Silverstream storage tank into the centre of the Hutt River during abnormal wet weather events.

The RCPS consists of two trunk sewers and an overflow pipeline encased in concrete with a downstream concrete apron for scour protection, known as the 'rock garden'.

If this structure were to fail it would allow sewage from Upper Hutt to freely discharge into the Hutt River and be extremely difficult to repair in a timely manner.

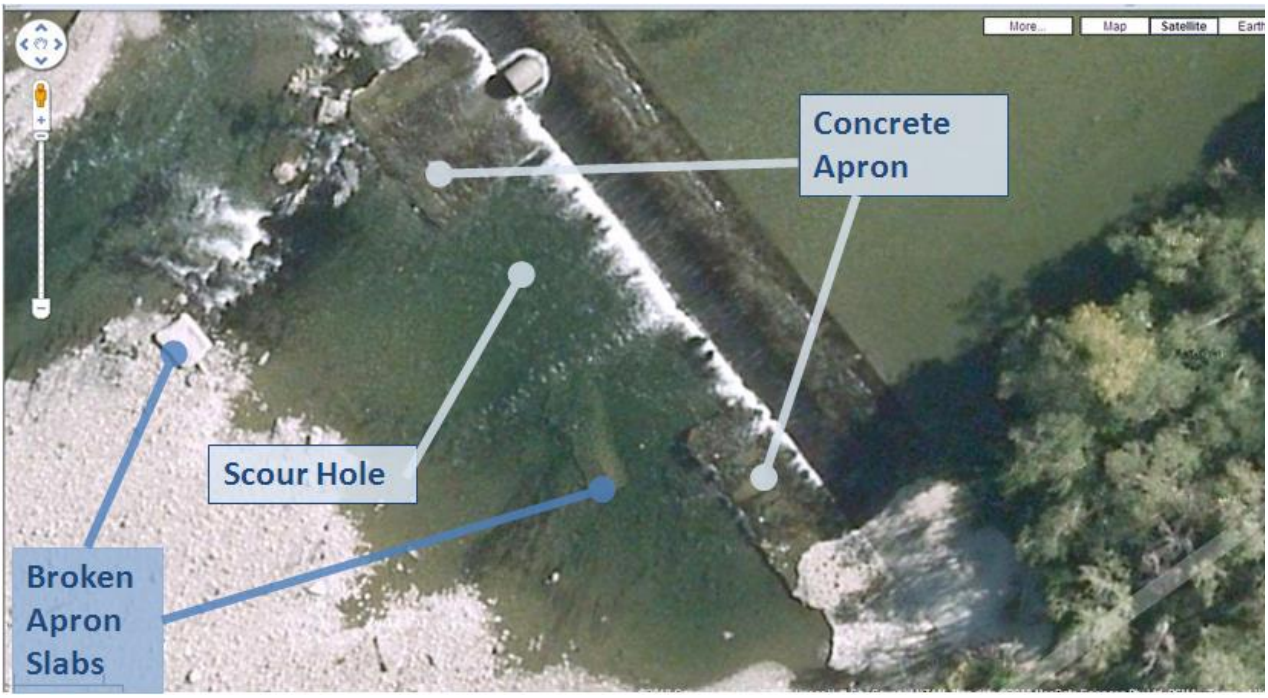
2.2 SCOPE OF WORK

While maintenance work was being carried out on the RCPS it was found that a large part of the 'rock garden' currently protecting the weir structure had been washed away and a scour hole was developing as shown in Photograph 2-2.

The photograph shows that part of the original 'rock garden' immediately downstream of the RCPS had been dislodged from its original position, and remnants are visible in the image. The gap in the 'rock garden' is over 20m along the structure and has broken away from a construction joint with the section of 'rock garden' that surrounds the overflow pipe discharge seen centrally in Photograph 2-2. The 'rock garden' apron otherwise extends across the rest of the pipeline crossing to the right bank. The 'rock garden' is noticeably undermined along most of its length. On the true right of the overflow pipeline approximately 15m downstream is the 'incised' river channel as shown on Figure 2-2.

Hutt City Council (HCC) requested an investigation into the extent of scour and risk to the RCPS's integrity. Once the risk was established HCC requested MWH to assess options, design the preferred solution and monitor its construction.

Photograph 2-2 : Aerial photo of the RCPS (Google image circa February 2008)



2.3 INVESTIGATION

Investigation into the scour included the analysis of cross sectional survey information from the Greater Wellington Regional Council (GWRC), a topographical survey, an analysis of existing river flows and a high level look at options with respect to risk and cost.

2.3.1 Survey

MWH carried out a topographical survey of the site during October/November 2010 when flows were approximately 8m3/s so that levels within the deep 'incised' channel area and scour hole by the RCPS could be obtained in order to establish the extent of scour. From the initial cross sectional information it was believed that the deep channel on the true right of the overflow became shallower as the river moved away from the weir. Hence, for the purposes of getting some detailed information of the scour area MWH concentrated on levels within 100m downstream of the RCPS.

2.3.2 Analysis of Existing Flows

In order to design an appropriate rock size and the structure's extent the critical eroding flows were required to be established. Critical eroding flows were believed to be those events that interact with the existing channel geomorphology to produce strong eddies that can de-stabilise and wash away fractured material. These flows corresponded in general to the confined full 'incised' channel flows, not full overall channel flow. The topographical survey was used to establish actual depths and develop design cross sectional areas. This information together with the information about flows at the closest point to the RCPS as shown in Table 2-1 below, allowed an estimation of the critical eroding flow return period.

Table 2-1 : Design flow estimates from the flow record at Taita Gorge, Hutt River

Returned Period	Flow (m3/s)
1 week	117
4 weeks	276
8 weeks	396
0.5 year	693
1 year	760
2 year	860
5 year	1089
10 year	1296
20 year	1494
50 year	1751
100 year	1944

It was important to ascertain flows for very small return periods as it is often the case that critical eroding flows do not necessarily correspond to the larger events.

Using the Manning's equation and a cross section approximately of 20m from the RCPS where scour appears to be the deepest within the constricted channel it was found that the channel has a maximum flow of approximately 77m3/s using a Manning's n=0.05 (Chow, Open Channel Hydraulics, 1959) and a top water level of about RL29. This indicated that at least on a weekly basis the 'incised' narrow channel is likely to flow full and causing scouring of the bed. This outcome was checked against actual river behaviour.

2.3.3 River Behaviour and Scour

If, as mentioned in Section 2.3.2, the flows causing channel erosion are reached regularly it was important to try and determine what geomorphologic features are contributing to the rapid degrading. To find out more about the Hutt Rivers behaviour MWH we met with the GWRC in September 2010 to outline the scour problem (as shown in Photograph 2-3) and identify any possible contributing factors. GWRC indicated that they believed the river was in a general 'degrading phase' and there was evidence of this kind of scouring at some other locations along the river.

Photograph 2-3: Photo of the RCPS showing undermining and scour

GWRC's monitoring cross sections along the entire Hutt River's length found that a deep 'incised' channel was being formed in the existing bedrock approximately 15m just downstream of the RCPS. This investigation revealed that the 'incised' channel has formed very quickly between 2003 and 2008 as shown in Figure 2-1, and the concern around undermining of the RCPS was real. Visual inspections of the river bed in the area showed that the channel bed did not have any gravels but was formed from highly fractured and weak rock that appeared to be vulnerable to abrasion and river flows.

Cross Section 1350 (5m downstream)

Figure 2-1: Cross sections of river bed 5m downstream of RCPS

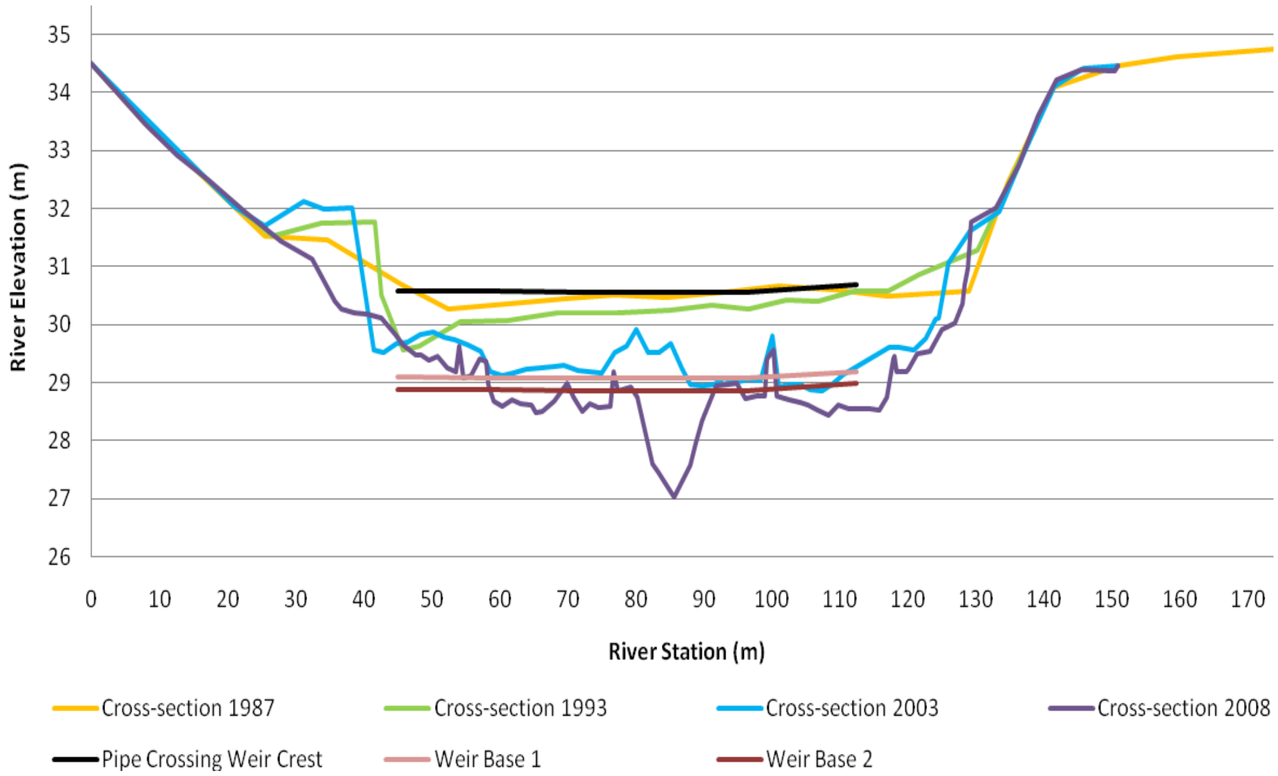


Figure 2-1 shows that the river bed is between RL29-30m centrally in 2003 and this drops to approximately RL 27m in 2008. GWRC was able to provide information on their gravel extraction practice summarised in a report called 'Hutt River Floodplain Management Plan' dated June 2010 which outlines the locations gravel has been and will be extracted within the Hutt River. This report indicated that around the Silverstream area where the RCPS is located, the river is still in a degrading phase which ties in with the present information and survey levels obtained.

2.4 HIGH LEVEL OPTION CONSIDERATION

The investigation results raised concerns about the river bed stability in this location. It was believed if the bed could degrade up to 3m in 5 years then there was a real concern that the RCPS could be undermined in a matter of a few years. At this stage of the project a 'brainstorming' high level optioneering exercise was undertaken between the client's representatives and designers which looked at high level 'order of magnitude' cost comparisons, budgets, timeframes to construct and also the associated risks. The following table indicates the main outcomes of the analysis.

Table 2-2: Summary of High Level Optioneering Outcomes

No	Option	Cost Relativity (1- Greatest cost, 5-least cost)	Risks	Comments
1	Pump station and re-route pipeline over Rail Bridge just north of the site	1	-Bridge life unknown to be able to take a new pipeline. -Current bridge too low for a new pipeline. -Agreements required from a number of stakeholders e.g. multiple TA, KiwiRail, NZTA for a new pipeline in this area	-Highest capital cost -High maintenance requirement -High maintenance cost for pumping station -Longest time to get option built
2	Re Route pipeline under river	2	-Unknown ground conditions -Seismic fault could affect pipeline integrity -Construction method may limit feasibility	-High capital cost -Long time to get option built
3	'Hard' engineering-concrete filling of holes and place rock on top	3	- Need to key into solid rock which is difficult to find -Seismic movement likely to undermine concrete structure -Extent of concrete difficult to define	-Concrete structures in rivers not environmentally friendly -Difficult to maintain integrity -Difficult to repair as scour will attack the next 'softest' spot
4	Rock riprap protection of scour holes	4	-Rock will get washed away - Flow will erode next 'softest' spots	-Difficult to key in rock and place to obtain interlocking rock structure -High monitoring and maintenance requirement -Will provide energy dissipation and allow for ground movement
5	Excavation of downstream bedrock to increase main channel width	4	-Excavating bedrock downstream may not increase channel width - Increasing channel width just downstream may not resolve scour issue which is believed to be fragmented bed material	- The site has issues of aggradation already as seen by beaches -Protection of the scour hole would still be required
6	Do nothing	5	-RCPS likely to be undermined within the next few years	-If nothing is done and RCPS fails this will result in sewage discharging directly into the Hutt River.

Considering the rate at which scour has been/is occurring, the fact that HCC had a limited budget, and the requirements for a flexible energy absorbing solution due to seismic and flow conditions, a rock riprap structure (Option 4) was agreed to be the most appropriate solution.

2.5 DESIGN ISSUES

In the design of a rock riprap structure there are two main variables that need to be determined, rock size and placement.

2.5.1 Rock Sizing

Sizing and choice of the rock consisted of looking at a number of variables including:

- obtaining flow information for a variety of return periods and consideration of the critical flow situation as discussed in Section 2.3.2
- Establishment of ‘effective’ velocity
- Cost of rock
- Rock availability
- Rock structure/durability

In sizing the rock, there are two scenarios: the scour hole immediately downstream of the RCPS approximately 3m deep; and the scour of the ‘incised’ channel just downstream of the scour hole.

A geotechnical assessment was carried out of the bed material and concluded that once the bed material is protected with a layer of rip-rap material it is likely that the erosion processes will be reduced significantly.

As discussed in Section 2.3.2 and 2.3.3, the weekly flow would provide the majority of scouring on the basis that velocities are highest at the surface. Hence, flows within the ‘incised’ main channel would therefore be critical for scour. To allow for a margin of error and be able to resist debris flow rock was sized for the larger events e.g. 100 year Annual Rainfall Intensity (ARI).

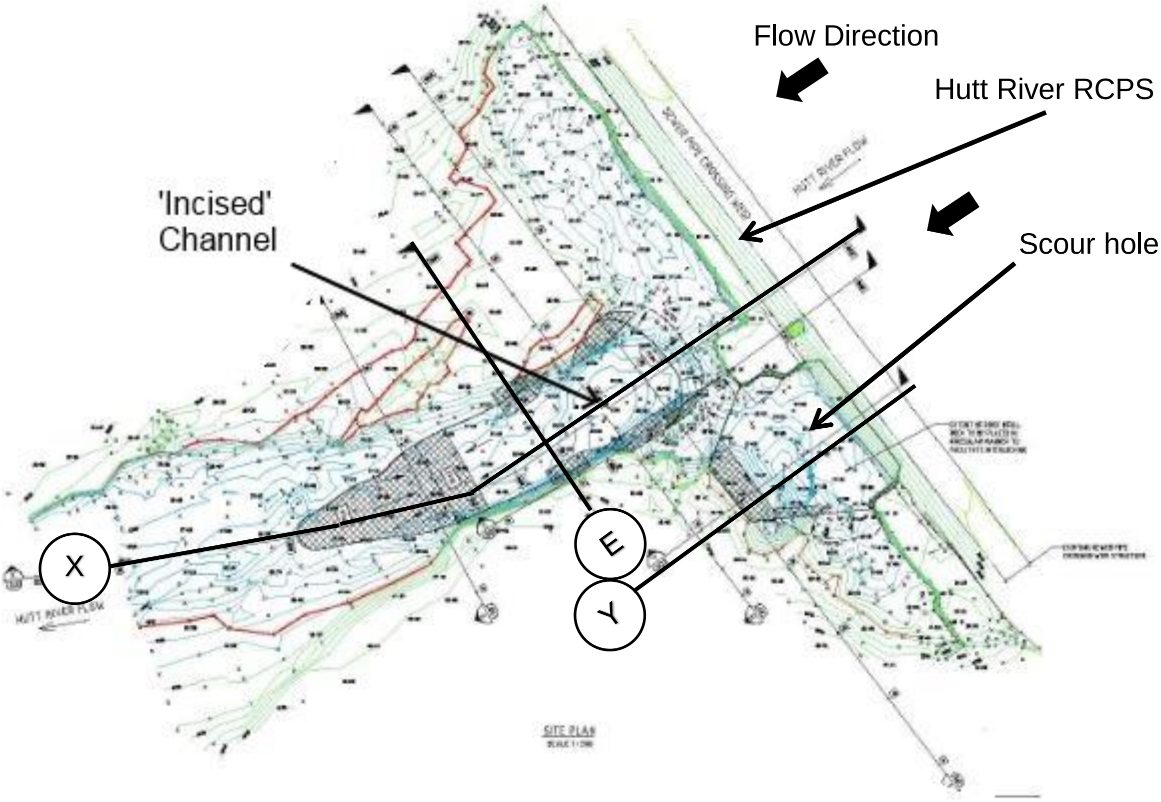
From the HCC Mike 11 model of the Hutt River, a water level in 1993 was extrapolated and then reduced to 2010 levels. For rock sizing of the scour hole immediately downstream of the RCPS and from the Manning’s equation with a Manning’s n=0.05 a mean velocity of 3.44m/s was calculated. This would give an ‘effective’ velocity (Consultants Williams E. & G) of approximately 5m/s for design. From empirical rock riprap equations a D_{50} of approximately 0.8m equivalent diameter was calculated.

Similarly, for rock within the ‘incised’ channel it was believed that velocity at the centre of the main channel would be greatest and therefore rock should be sized for the 100 year event also. A similar analysis to the above was carried out which gave a D_{50} of approximately 1m.

2.5.2 Rock Placement

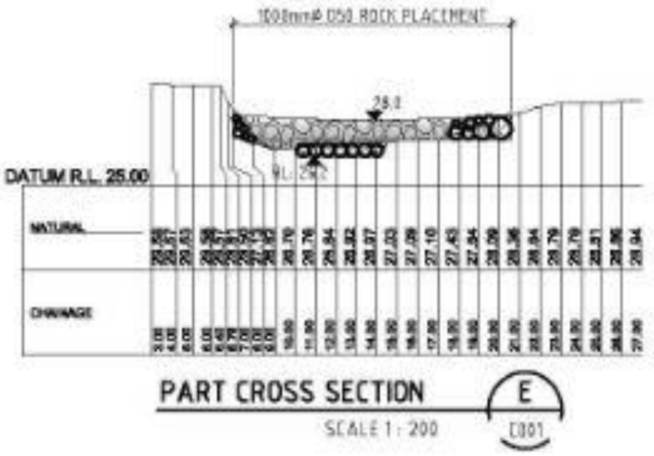
For the rock to provide a durable interlocking structure, rock would need to be keyed into the existing bedrock where possible. As shown in Figure 2-2 it was proposed that excavation of the bed be carried out as indicated by cross hatching to provide ‘keys’ that would provide resistance to the flow.

Figure 2-2: Plan of Stage 1 of Rock Protection Structure



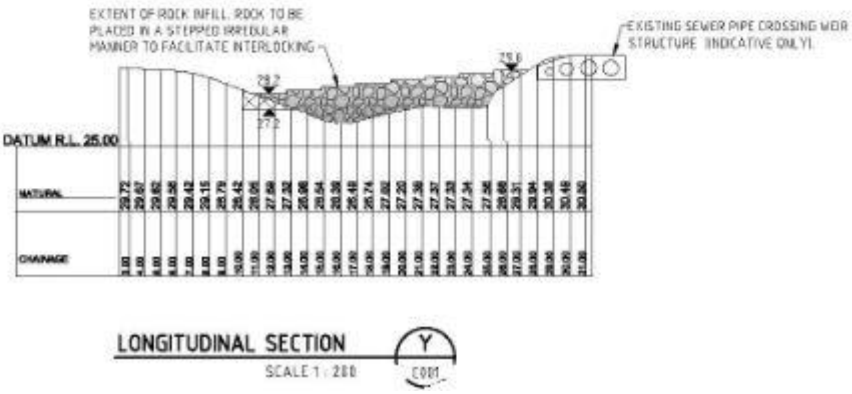
With regard to the placement of rock within the 'incised' main channel it was proposed that rock be placed in steps of 300mm x 5m in length approximately 30m from the RCPS. The 30m length appears from the survey to correspond to the narrowest channel width and it is proposed that excavation of keys on both sides of the channel and at the base would provide the placed rock with some resistance to flow. An example of the proposed keys to be constructed is shown on Figure 2-3. The other reason for the choice of this location is that this was the point where the bed begins to rise again which would indicate the end of the scour hole. The maximum height of the rock placement was proposed to be at the height of the surrounding beach, approximately 29m RL which was the 2003 river bed level.

Figure 2-3: Cross Section of Rock Protection Structure in 'incised' channel showing keys



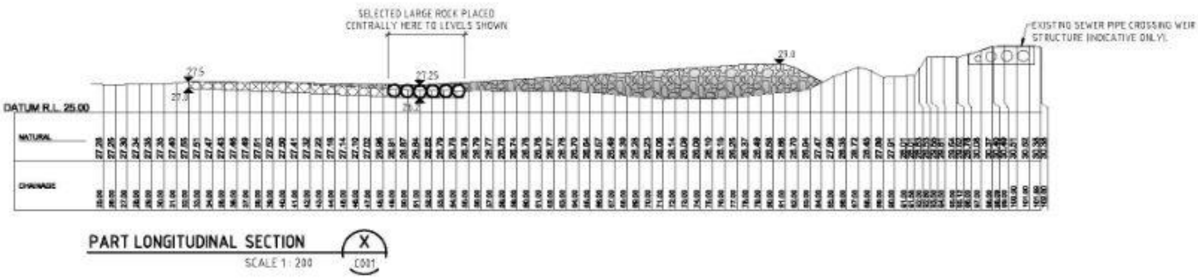
For the scour hole by the RCPS a similar structure was proposed as shown in Figure 2-2 and 2-4 with the height at the weir being the lip level of the RCPS i.e. 29.5m RL. This level would extend some 2m to the extent of the previous rock garden and would drop to 29m RL which would match into the downstream beach level and the natural rock weir level towards the centre of the channel.

Figure 2-4: Long section of rock protection in scour hole by RCPS



An external peer review of the rock sizing and proposed rock placement was obtained. The peer reviewer, using the 'CHUTE' procedure concluded that it would be prudent to use a rock size of D_{50} = 1m equivalent diameter throughout the entire area, and rather than a stepped structure in the 'incised' channel form a 'rock ramp'. The reviewer also recommended to increase the length of scour protection with an upturn at the end to dissipate any final remnants of energy to prevent further downstream scour which can be seen in Figures 2-2 and Figure 2-5.

Figure 2-5: Long section of Stage 1 of Rock Protection Structure in 'incised' channel



2.6 CONSTRUCTION ISSUES

The construction of Stage 1 of the rock riprap structure(s) shown in Figure 2-2, had a number of interesting construction aspects, some of which are outlined below.

2.6.1 Rock Supply and Grading

Prior to advertising the tender for this work MWH carried out discussions with GWRC in relation to rock sourcing of the size and quantity that was required for this project. It was understood that rock was available from three quarries, Linton in the Manawatu region, Taipo Quarry in the Wairarapa and Solly Contractors Ltd in Takaka.

Solly Contractors Ltd was chosen by the Contractor as the rock supplier. Rock was Limestone Rock with a density of 2640kg/m3. The rock was shipped to the Seaview Marina by barge over the Cook Strait. A graded stockpile was then produced by the Engineer at the Marina to allow the Contractor to transport graded stockpiles to site ready for placement.

Photograph 2-4: Rocks arriving at Seaview by barge from Takaka

Photograph 2-5: Sample graded stockpile at Seaview Marina with D50 sizes marked

2.6.2 Health & Safety

Working with large heavy rock within a substantial river presents significant hazards in terms of managing temporary diversions, coping with flash floods, moving very large rocks, working with major plant and working in difficult terrain. The tender process focussed on obtaining a Contractor who understood the hazards around rock placement within major rivers, and had appropriate experience in working with Regional Councils with regard to reporting and awareness of river and climate behaviour. Within the contract document procedures there were specified protocols that required the Contractor to liaise daily with the GWRC flood protection team as well as maintain regular contact with staff off site. Having the right Contractor for this type of work was vital to the project's success. As it turned out the project experienced some major flood events through the contract period which if not managed correctly could have resulted in harm. Photograph 2-6 shows the power of the river washing out a section of the diversion bund built to temporarily divert the river.

Photograph 2-6: View upstream looking at partially washed out diversion bund after heavy rain event

2.6.3 Diversion Bund

To construct Stage 1 of the rock riprap structure a temporary diversion of the Hutt River was built to facilitate construction. The construction of the temporary diversion was carried out by moving beached gravels from just upstream of the site as shown in Photograph 2-7.

Photograph 2-7: On top of the temporary river diversion bund looking upstream

The result of the temporary diversion bund was that it pushed river flow to the true right allowing excavation and rock rip rap placement at the true left as shown in Photograph 2-8.

Photograph 2-8: Diverted River looking at scour under RCPS

2.6.4 New Channel Formation

An unexpected result of the diversion bund was the forming of a new 'incised' channel on the true right as a result of some of the large events (i.e. greater than a Q2 ARI) during construction of Stage 1. The surprise was the speed at which erosion of the bed took place, i.e. over a 2 month period, showing how weak the bed material is in this area.

Photograph 2-9: New 'incised' channel formed on true right

2.6.5 Final Result

The following are some photographs showing the final placement of the rock ramp. The photographs below were taken in March 2012.

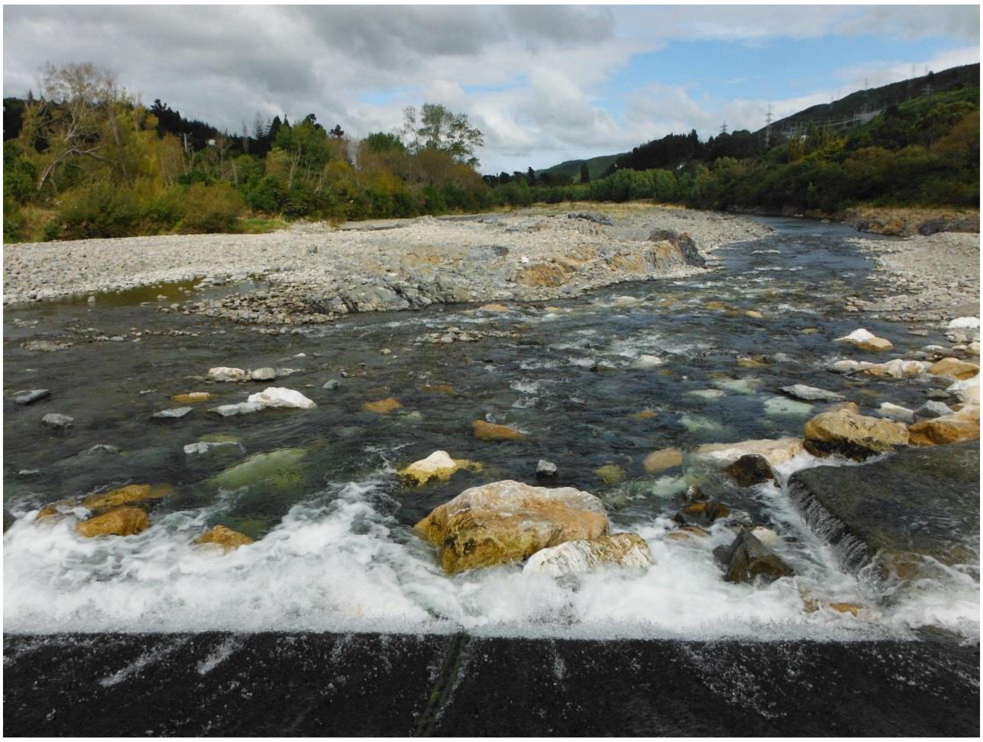
Photograph 2-10: Final rock placement in scour hole by RCPS complete

Photograph 2-11: Rock placement within incised channel looking downstream towards end of rock ramp

2.6.6 Performance After Construction Completed

The cost of Stage 1 of the works was just over $500,000. As with all rock structures maintenance and ongoing monitoring is required as well as annual 'topping up'. For HCC yearly inspections have been carried out since placement at the start of 2012. Inspections are carried out at a time when river levels are low, this is typically during January-March. The following photographs were taken around mid-March 2013 and show that rock is generally in place with a little top up required around the lip of the RCPS.

Photograph 2-12: Looking from the RCPS on true left toward 'incised' channel



Photograph 2-13: Looking from the true right embankment toward the area where rock was placed

The following photograph was taken mid-March 2015 with no top up. However it can be seen that the rock protection structure has resulted in the river eroding the weaker argillite material next to the rock protection structure which has begun wearing another channel.

Photograph 2-14: Looking from the true left embankment at intact rock structure showing new channel forming just downstream

Since Stage 1 was completed in 2012, Stage 2 was completed in early 2016 at a total cost of approximately \$600,000. The river is now more balanced due to bed levels off the RCPS now being the same on both sides of the river and so providing a more even flow distribution over the cross section of the river. A major advantage of this in-place structure is its flexibility during ground movement in earthquakes which allows rocks to move within the interlocking structure. Normal low flows are no longer concentrated into an incised channel leading to scour progression near to the RCPS. The total cost of the rock protection work has been approximately \$1.2M.

3. CONCLUSIONS

The Stage 1 rock protection solution has now been in place for more than 4 years with less than \$10K spent on maintaining the structure over that time. As the placed rock structure is protecting the bed there has been no further degradation of the river bed around the site of the RCPS and therefore the risk of undermining of the RCPS is reduced. As outlined above a major advantage of this type of structure is its ability to both absorb flow energy from the river and ground energy from earthquakes. A possible disadvantage with this type of structure is that it cannot be inspected after large events due to high water levels. With this and other options there is always an element of ongoing protection due to other 'softer' areas become susceptible to scour however this is an ongoing river management issue and not solely related to this project. Overall the design has proved a success for a relatively inexpensive and expedient solution. The newly scoured channels/areas if they do not threaten the integrity of the RCPS need only be monitored with the possibility of future remedial work.

The overall result for HCC is:

1. A flexible form of protection that dissipates flow energy from the river
2. A structure that can move in an earthquake without failing
3. A solution that could be designed and built relatively quickly
4. A relatively inexpensive solution compared to relocating the pipe and/or pumping
5. To date the rock protection structure is functioning as designed and as long as regular inspections identify loss of rock and weak points for repair then there is no reason this structure cannot be maintained for the foreseeable future
6. A good option with regard to minimising the risk of the RCPS being undermined relative to the cost and speed of construction.

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