USE OF REVERTIBLE BIO-POLYMER SLURRY TO RETROFIT A SAND CHIMNEY DRAIN AT HAYS CREEK DAM

By:

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Abstract:

This paper deals with some of the processes and details that were behind the philosophy to upgrade this zoned embankment dam. The thrust of this paper is with regard to the geotechnical aspects that were dealt in retrofitting a sand chimney drain using a revertible bio-polymer to facilitate construction in this dam. The first of its kind to be successfully completed in an operating dam in this country.

1.0 Background

Hays Creek dam is a rolled earth embankment 27m high at the deepest section and has a crest length of 77m. It is located at the Hunua Gorge, south of Auckland in New Zealand (Map 1). It impounds approximately 1 million cubic meters of water at top water level. The dam and the associated filter station are currently owned and operated by Watercare Services Ltd (WSL) for the water supply of Papakura district.

The reservoir was commissioned in 1967 and operated until 1989 by Papakura City Council (PCC). In 1989 under Local Government Reform the ownership and operational responsibility for the dam and Papakura filter station were transferred to the Auckland Regional Council (ARC) and since 1991 to WSL.

At the time of transfer, the dam and its ancillary structures were in a poorly maintained condition. There were very little monitoring or operational details of the dam. ARC, with the advice of its in-house staff and external consultants, effected emergency repairs to the downstream shoulder of the dam and the downstream spillway channel.

2.0 Investigations

To investigate the overall condition of the dam, Tonkin & Taylor Ltd (Consulting Engineers) were commissioned by the ARC in 1989 to conduct a Safety Evaluation Study (Stage I) followed in 1990 by a commission to Works Consultancy to conduct a (stage II) study. To obtain better information on the performance of the dam, eleven piezometers were installed for the first time on this dam during the Stage II study (Fig 1).

In keeping with Works Consultancy's recommendations of Oct 1991, further analyses of the pore water pressure variations on the dam were conducted by WSL's staff. The results of this study identified that additional piezometers were required at strategic locations to obtain better understanding on the performance of the dam. In Dec 1991 five drill holes were put down and 14 more piezometers were installed. The results of the piezometer readings revealed that the dam in fact operated as a zoned embankment and not as a homogeneous embankment as previously inferred (Fig 2). Fig 2 is a highly idealised cross section of the dam. Investigations showed that while there is a core in the sense that the central part of the dam has lower permeability than the shoulders, there is no well defined boundary between core and shoulder, and no significant filter zones. All that can really be said is that the central section is substantially more clayey than the shoulders, but is certainly not free of random granular zones. Also the data gathered from a limited period of monitoring of the dam showed that there were no symptoms of distress, incipient failures (visible on the face of the dam), or discolouration of seepage water through the dam. However, due to the standards adopted by the designer at that time and the techniques used in the construction the integrity of the dam was in doubt.

3.0 Potential Failure

The Safety Evaluation reports on Hays Creek Dam and subsequent investigations showed that the dam had the following weaknesses that had the potential for a catastrophic failure, especially in the event of a moderate earthquake.

Incompatibility between the core and the downstream shoulder material of the dam could result in the mi-

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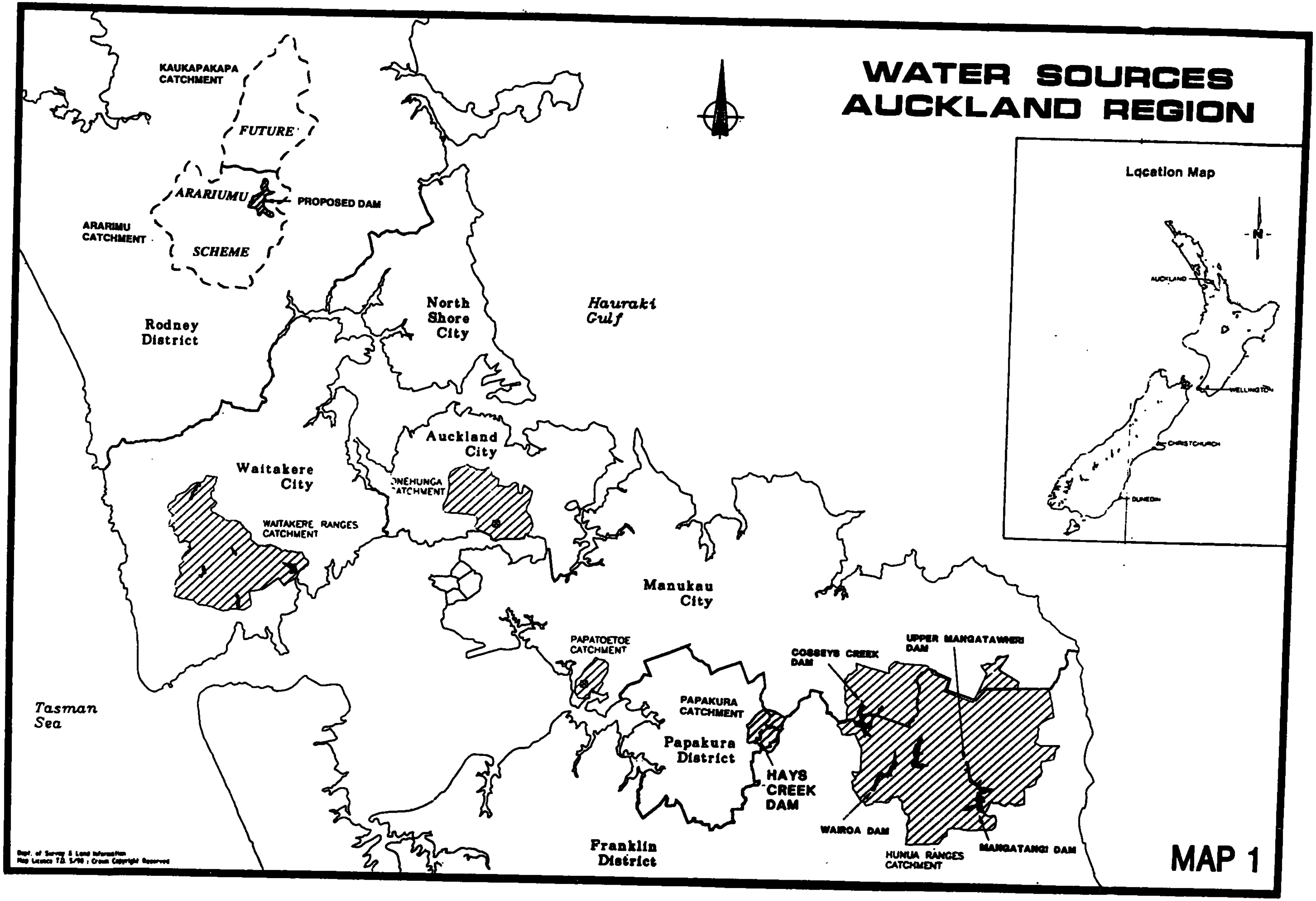
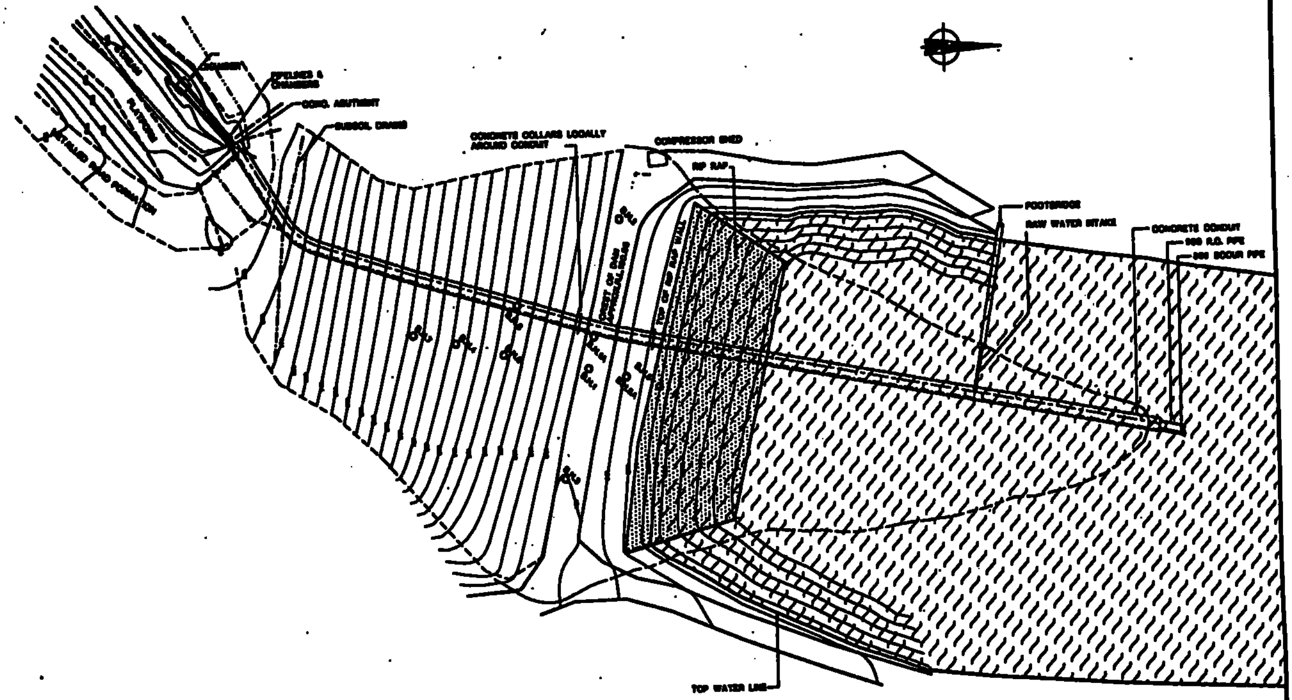
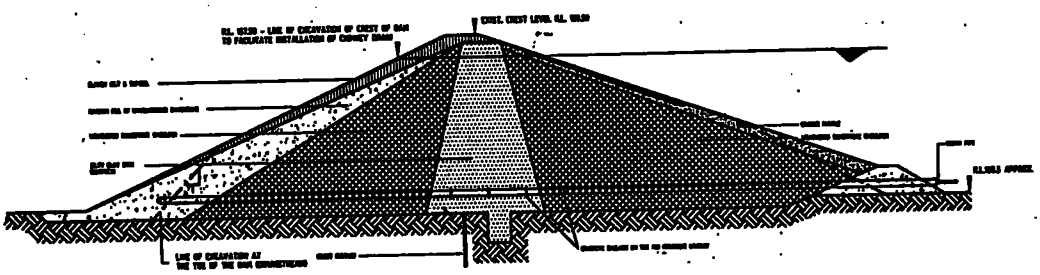

WATER SOURCES
AUCKLAND REGION
Location Map
AUCKLAND
WELLINGTON
CHRISTCHURCH
DUNEDIN
KAUKAPAKAPA CATCHMENT
FUTURE
ARARIUMU
SCHEME
PROPOSED DAM
ARARIMU CATCHMENT
Rodney District
North Shore City
Hauraki Gulf
Auckland City
ONEHUNGA CATCHMENT
Waitakere City
WAITAKERE RANGES CATCHMENT
Manukau City
PAPATOETOE CATCHMENT
PAPAKURA CATCHMENT
Papakura District
HAYS CREEK DAM
COSSEYS CREEK DAM
UPPER MANGATAWHIRI DAM
WAIROA DAM
HUNUA RANGES CATCHMENT
MANGATANGI DAM
Tasman Sea
Franklin District
MAP 1



HAYS CREEK DAM
Papakura, AUCKLAND
DAM LAYOUT (PRIOR TO 1994 UPGRADE)
Scale 1 : 750

NOTE:
ALIGNMENT OF EXISTING CONCRETE CONDUIT INTERPOLATED FROM CONSTRUCTION DRAWINGS OF [illegible]

FIG. 1



HAYS CREEK DAM
Papakura, AUCKLAND
CROSS SECTION THROUGH DAM (PRIOR TO 1994 UPGRADE)
Scale 1 : 750

FIG. 2

gration of fines from the core to the downstream shoulder of the dam. This could eventually lead to an uncontrolled piping failure of the dam.

Poor quality control adopted during construction was evident by the presence of lenses of granular material sandwiched between layers of silty CLAY at various sections of the clay core. It was felt that this situation could lead to an uncontrolled hydraulic fracture of the core and a catastrophic failure of the dam especially due to earthquake.

Raw water from the reservoir to the filter station passed through a 900mm diameter concrete conduit located within the foundations of the dam, as shown in Fig 1 & 2. There were inadequate upstream controls at the raw water intake to the reservoir. The full pressure head from the reservoir acted over the entire length of this conduit, so that in the event of a rupture of the conduit from an earthquake, or ground subsidence, the outcome could be serious. Investigations showed that the pore water pressure reading at a location directly above the conduit was higher than readings at other equivalent locations within the dam, suggesting that there was a direct connection between the lake and the periphery of the conduit.

A dam break study showed that in the event failure of the dam the flood would cover private homes, commercial property, public recreational areas, roads and the main trunk rail line. Most of the inundation would occur within an hour of the failure of the dam.

4.0 Evaluation of Remedial Options:

THE FOLLOWING OPTIONS WERE CONSIDERED ON DAM UPGRADING:-

a) Do nothing but continue the monitoring programme in place

b) Decommission the dam and the filter station

c) Demolish the dam and rebuild

d) Upgrade the dam with a waterproof membrane on the upstream face, and upgrade the conduit and water intakes.

e) Install a plastic "concrete" core to the dam , and upgrade the conduit and water intakes

f) Install a chimney drain and upgrade the dam. (Although this was not considered until later)

THE FOLLOWING CRITERIA WERE USED TO EVALUATE THE BENEFITS OF EACH OPTION:

- All existing water sources should be used to their full capacity consistent with cost before developing any future source.
- Any source left undeveloped for a period of two years would be subjected to a loss of any resource permit issued under the Resource Management Act (RMA).
- Any solution should be acceptable to the ARC Environment & Planning Department and the RMA.
- The possible piping failure of the dam is to be obviated.
- A reliable downstream discharge should be provided.
- The controls for the intake valves should be accessible at all times and under all weather conditions.
- The technology used should be compatible with present day methods of dam construction.
- The solution should make the best use of the available assets.

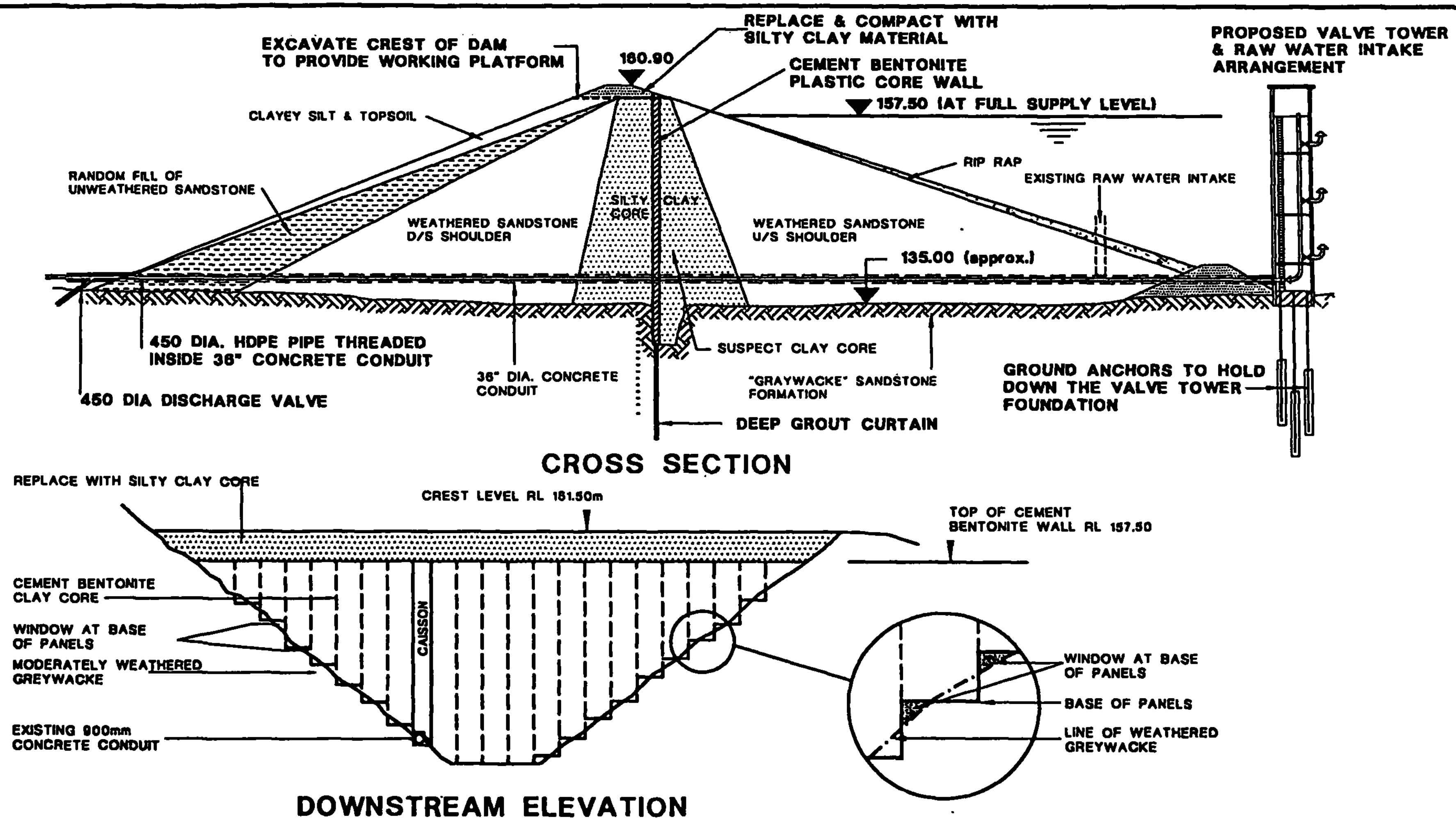
A SUMMARY OF SELECTION OF THE PREFERRED OPTION IS GIVEN BELOW.

- **Do Nothing** was not an acceptable option for the following reasons:-
- Internal erosion could develop with little or no warning, and the consequences could be catastrophic.
- Having identified the problem and the risks, there is a legal requirement that an acceptable solution should be found.

Decommissioning too was not an option as it violated some of the above evaluation criteria.

Among the upgrading options identified the preferred alternative was the introduction of a continuous plastic "concrete" core through the existing core of the dam. This alternative envisaged the following elements:

- To excavate a trench through the existing silty CLAY core , from the crest of dam to the valley floor in bentonite slurry medium, and to replace the bentonite slurry with cement bentonite to form the plastic core (Fig 3).
- To provide a more reliable raw water intake arrangement such as a valve tower with all the control valves within a single dry well.
- To depressurise the 900mm concrete conduit and thread a 350mm HDPE pipe through the concrete conduit and to utilise the HDPE pipe as the raw water supply pipe line from the dam.



HAYS CREEK DAM
Papakura, AUCKLAND
DETAILS OF BENTONITE CORE WALL OPTION
Scale 1 : 600

FIG. 3

- To provide an alternative water supply to Papakura during the construction period . This would serve future requirements for Papakura, and give an additional security of water supply.
- The existing water resource permits to be retained, thus deferring the next future water source.
- Existing silt sediments to be retained in the lake.
- The estimated cost of this option was NZ$6.4 million including the new pipeline.

5.0 Design Concept Review

Expertise in the use of bentonite Cement Slurry walls is limited in New Zealand. For this reason WSL commissioned Gutteridge Haskins and Davey Pty Ltd (GHD) Australia as the external peer review consultant to WSL's in house design team. Following detailed studies, engineers from GHD concluded that keying the plastic core wall approximately 1m into the moderately weathered Greywacke sandstone might prove to be difficult. The consequence of such an ineffective key could lead to the creation of preferential drainage paths or 'windows' between the panels and the valley floor (Fig 3). The result could be an undesirable end product.

In place of a plastic core wall an alternative concept was proposed by GHD which was to provide a properly designed vertical sand chimney filter drain immediately downstream of the core, and the drainage from the sand filter drain to be directed into the depressurised 900mm diameter concrete conduit. This proposal had much to commend it, since the essential aim of any remedial measures was to reduce the risk of internal erosion and piping, rather than to reduce seepage quantity, which was not a problem. It was suggested that the sand filter drain could be introduced by one of the following methods:

To excavate the trench to valley floor using a clam shell in a suitable revertible bio-polymer medium to temporarily support the trench wall and then backfill the trench with graded sand.

or

To install a system of overlapping bored piles backfilled with graded sand.

To construct the outlet from the chimney drain into the concrete conduit it was planned to sink a caisson of sufficient size down to the conduit where manual access would be possible to carry out the necessary work. Details are given later.

Introduction of such a filter system would prevent the migration of fines from the suspect clay core to the downstream embankment and thereby secure the dam against sudden piping failure. Although the filter drain option is a "neat " solution to the problem, case histories of such construction works were not readily available; particularly using revertible polymer mud.

WSL therefore made world wide enquires regarding the installation of deep trenches and discovered that similar works were underway in the USA . These were in the installation of deep drainage trenches and one on a 13m deep embankment levee. The embankment levee was in Phoenix , Arizona. It was the first known such trial on levees or dams in the USA. The trial was conducted by the United States Bureau of Reclamation (USBR) using EZI mud a synthetic bio polymer. WSL's staff visited this site and other similar sites in Taipei , Taiwan. With the valuable information gathered from these site visits the decision was made to proceed with the vertical chimney drain, and minor modifications were made to the preliminary tender documents to obtain the desired outcome for the completed work.

Before commencing with work on the dam itself, the Contractor was required to excavate two trial trenches (side by side) using the proposed bio polymer, and each trench to be not less than 15m deep, 2.8m long and 0.8m wide. The site designated for the trial trenches was close to the spillway and away from the dam site.

6.0 Trial Trench Excavation:

The Contract was let to Tunnel & Civil Ltd, with Bachy / Brian Perry Jv as specialist sub-contractors to carry out the trench excavation. Bachy is a reputable international consortium of contractors who have had experience in bio-polymer slurry drainage installation works. The contract was let in early December '93. The trial trench excavation began in February '94.

EZI-Mud a synthetic bio polymer was made into a slurry that had a viscosity of approximately 43 sec. as measured in a Marsh Funnel viscometer. During the excavation the viscosity of the slurry was maintained at not less than 40 sec. The mechanism of operation of the slurry is that it forms a semi-permeable film on the freshly excavated surface and prevents further loss of slurry in to the ground. Throughout the excavation the slurry was maintained at near surface level and at the prescribed viscosity. At the completion of the excavation the slurry was replaced with graded saturated sand that was fed through a trammie pipe from the top of the trench, thereby displacing the slurry. Experience gathered from the USBR showed that saturated sand passed through this polymer " in lumps" and thereby segregation of sand was controlled. When the trench was completely backfilled with sand, water and sodium hypochlorite as a mixture was circulated through previously installed well points in the sand trench. This sodium hypochlorite mixture 'broke down' the polymer slurry and thereby increased the permeability of water through the sand filter. On completion of this task the sand was compacted using a 'lance vibrator' to achieve the required relative density.

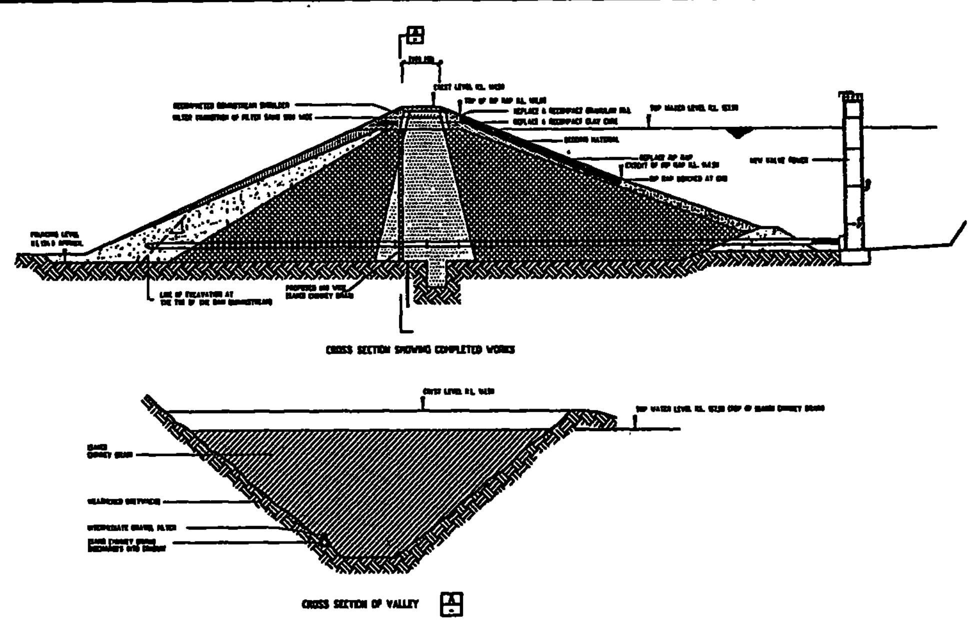
In the trial panel, sand from Tuakau was used as the filter medium. The trench was backfilled and the degraded slurry was flushed out. Relative density (R/D) measurements on the backfilled sand showed that it was too loose and failed to meet the prescribed (R/D) values. Although the selected sand for the trial panel satisfied the specified grading requirements, it contained considerable fines in the form of iron sand. It is believed that the fines may have separated out into lenses of low permeable layers and trapped large volumes of slurry mixed water. Pumping or draining the slurry mixed water proved ineffective. Hence the test site was abandoned. A second trial panel was successfully completed on top of the dam using silica sand from a different source where fines below 150 m were limited to a maximum of 5%.

7.0 Installation of the Central Collector Drain and the Sand Chimney Drain

A 2m diameter hole was drilled from the crest of the dam under bio polymer slurry to intersect the 900mm concrete conduit. On reaching the required depth a 2m diameter steel caisson was lowered into the hole, and the slurry that remained in the caisson was pumped for storage and reuse. The location of the central drain and the detail of the connected works are shown in Fig 4. The contractor sank the caisson at exactly the intended location and no difficulties were experienced in carrying out this work.

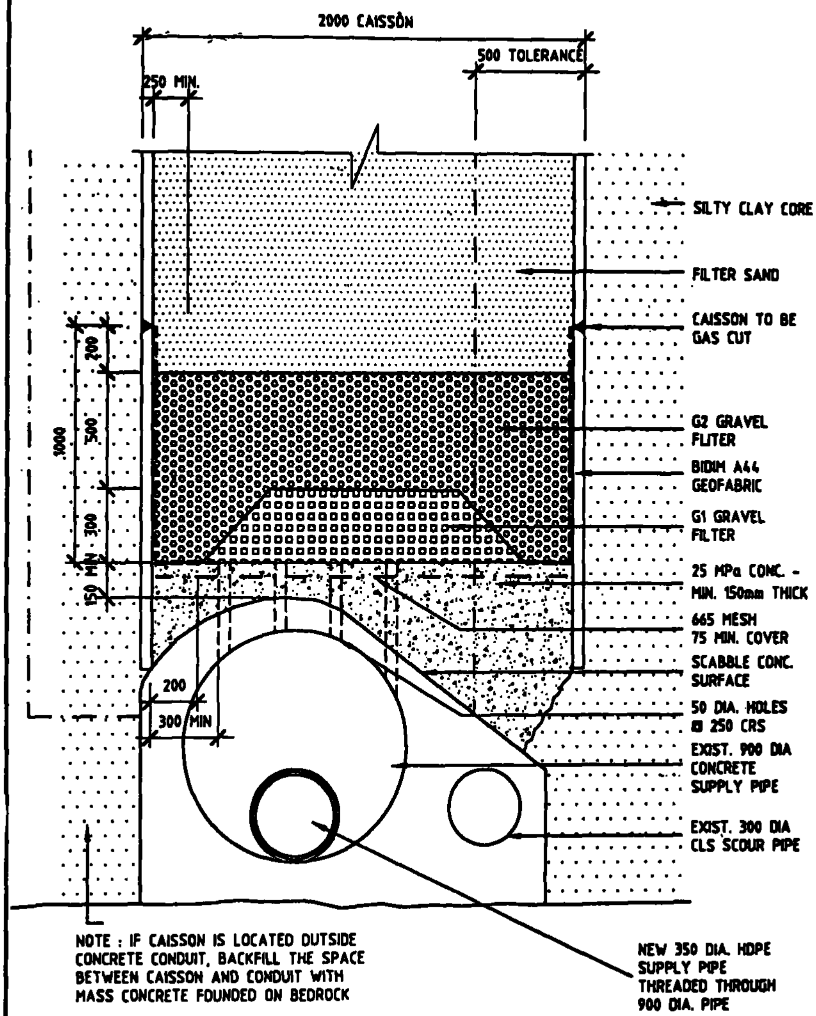
The base of the 2m diameter caisson was carefully cleaned until the 900mm concrete conduit was exposed. A level concrete platform was constructed on top of the exposed pipe. A series of 50mm diameter drainage holes was put through the concrete platform and the 900mm concrete conduit to provide a central drainage path for the chimney drain. Graded gravel filters followed by sand were backfilled to a depth of 1m from the top of the platform of the caisson. The 2m diameter steel caisson was "gas cut" at the top of the sand level i.e 1m from the platform level. The caisson was withdrawn above the gas cut line while sand was backfilled in the caisson. This technique ensured that the central filter arrangement remained intact when the caisson was withdrawn. (Fig 5)

The installation of the chimney drain began with a 2.8m long panel immediately east of the 2m caisson. The excavation of the panel was completed successfully and a 'stop-end' was placed 500mm from the end away from the caisson. The stop-end consisted of two identical I beams of 400 x 800 welded across the flange with a steel plate to provide a 'square box girder'. The stop-end was lowered into the trench with the



HAYS CREEK DAM
Papakura, AUCKLAND
DETAILS OF CHIMNEY DRAIN INSTALLATION
Scale 1 : 750

FIG. 4



HAYS CREEK DAM
Papakura, AUCKLAND
DETAIL OF CHIMNEY DRAIN/CONCRETE CONDUIT INTERFACE
Scale 1 : 20

FIG. 5

webs of the girder parallel to the trench wall. The stop-end was to prevent the flow of sand from the backfilled section into the unfilled 500mm space, so that construction of the adjacent panel could proceed with the sand retained in the completed panel. This arrangement was vital for the continuity of the sand drain.

However the trench walls were uneven because of the presence of granular fill and cobble to boulder sized particles in the silty CLAY core, and a tight seal between the stop-end and the wall of the trench proved impossible. When sand was placed in the 2.3m length of the trench some sand /slurry flowed around the stop end (Fig 6a). This was accentuated by the excavation of the adjoining panel (by the movement of the clam shell in the slurry). The excavation was abandoned when the flow of sand from one trench to the other had detrimental effect on the clam shell operation and possibly on the quality of construction.

The stop-end was removed and the trenches were re-excavated as a single trench of 5.6m length to the foundation level of the dam . The stop-end was placed at a distance of 500mm from the furthest wall and the space between the web of the stop-end and the trench wall was packed with gravel filled geo-fabric sock. The contractor believed that the "gravel-sock" arrangement would control the flow of sand from one trench to the other during the construction procedure (Fig 6b). However this arrangement also failed. Sheet piling the space between the trench wall and the stop end was also tried (Fig 6c), but driving sheet piles through the sand proved unsuccessful and this alternative too was abandoned.

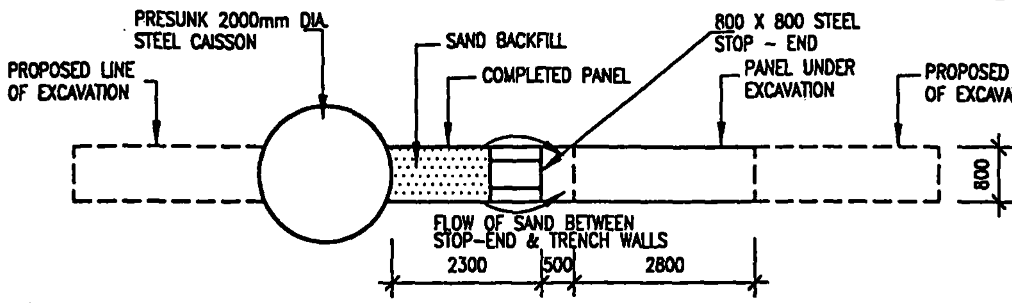


Fig. 6A - Panel Installation with Steel stop - end

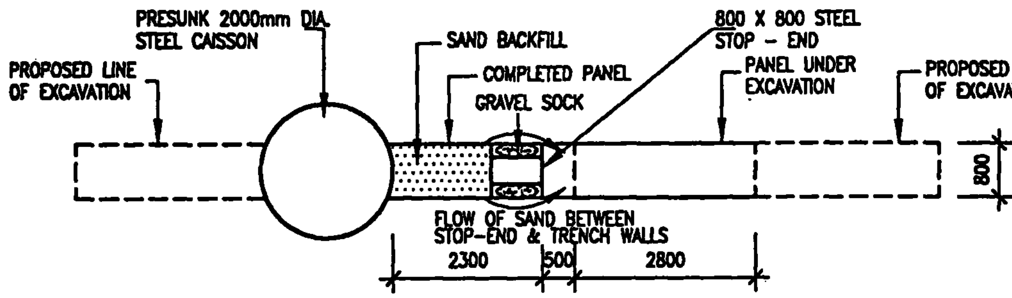


Fig. 6B - Panel Installation with Steel/Gravel sock stop - end

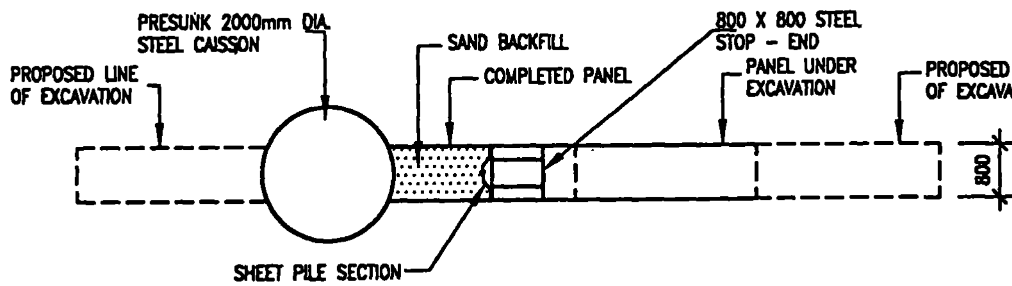


Fig. 6C - Panel Installation with Sheet Pile stop - end

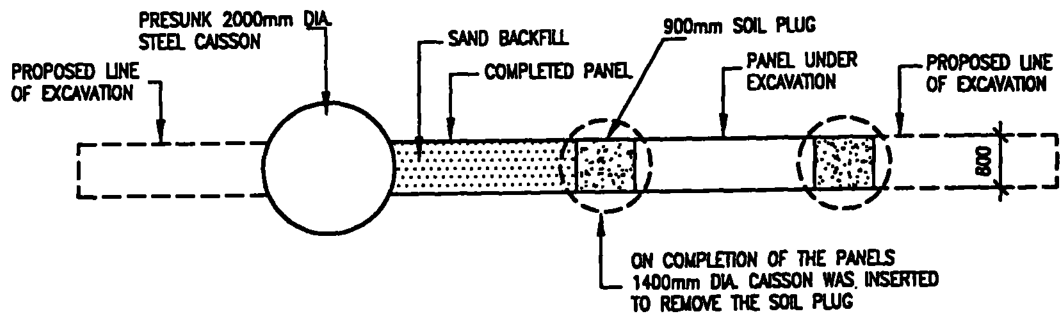


Fig. 6D - Panel Installation with Soil Plug stop - end

HAYS CREEK DAM
Papakura, AUCKLAND
DETAILS OF CHIMNEY DRAIN PANEL INSTALLATION
Scale 1 : 100

FIG. 6

Yet another variation was tried out. Having gained confidence in working with panels of longer than 2.8m, WSL agreed to a longer panel length of 7.8m with a 900 mm "soil-plug" ie the existing soil left in place between excavated panels to act as stop-ends to separate these panels. In all five panels and five "soil-plugs" were created and the panels were successfully backfilled with sand (Fig 7). A caisson of 1400mm diameter was driven vertically with short rotational oscillations to completely encompass the 900mm soil-plug. While the caisson was advanced the soil-plug was excavated by a 'benoto grab' working inside the caisson. When the caisson reached to the foundation levels it was backfilled with sand and withdrawn in stages.

On achieving a continuous sand chimney drain the remaining bio polymer in the sand was degraded by the addition and recirculation of a mixture of sodium hypochlorite and water. This process was terminated and the remaining solution was flushed out when the recirculating solution ceased to have a 'soapy' feeling between fingers - confirming the degradation of the bio-polymer. (Note: If the bio-polymer solution is left unflushed it will be destroyed by soil bacteria and by the flow of seepage water, however the addition of sodium hypochlorite merely accelerated the destruction of the polymer by artificial means).

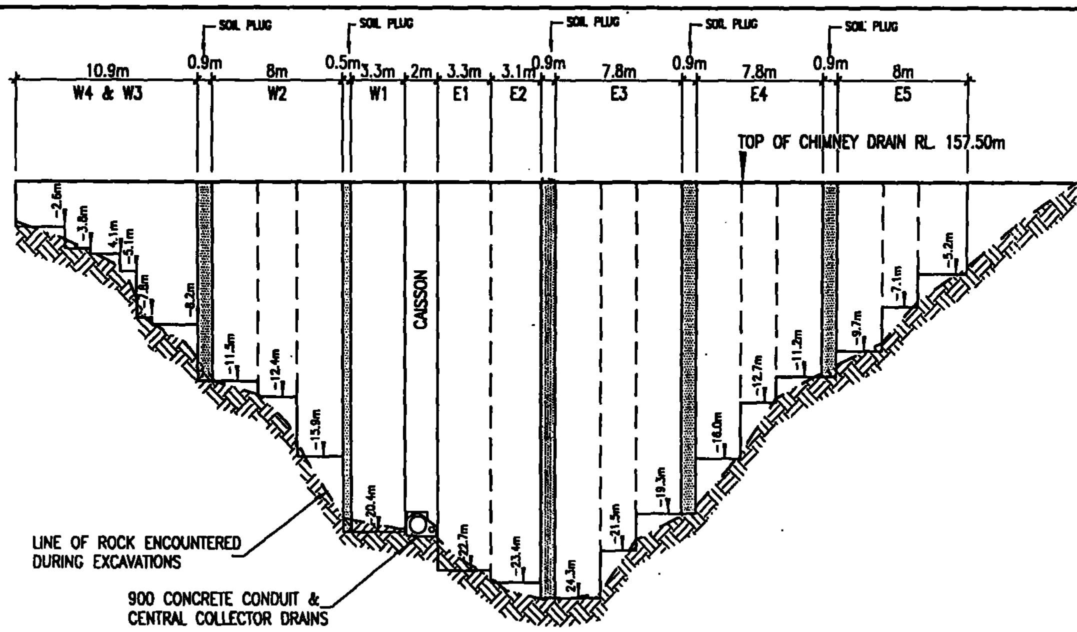
The dam, valve tower, and the concrete conduit were completed and the dam was recommissioned in July '94, to help quench the thirst of Auckland in its 1 in 100 year drought.

8.0 Conclusion

The construction of a vertical chimney drain has been successfully completed in an existing dam by using a polymer slurry trench procedure followed by sand replacement. Some difficulties were experienced during construction with the intended "stop-end" arrangement. These were overcome by replacing the intended steel stop-ends with a column of intact clay core which was later removed and replaced by sand. Such a procedure ensured connection between individual panels to form a continuous graded sand chimney drain. Initial observations following recommissioning of the dam showed that total seepage flows from the drain to be only slightly greater than pre-upgrade seepage rates and the piezometers readings too show no surprises.

9.0 Acknowledgment:

We are grateful to Watercare Services Ltd to have allowed us to carry out successfully this pioneering work on Hays Creek Dam and presentation of this paper.



HAYS CREEK DAM
Papakura, AUCKLAND
ELEVATION OF CHIMNEY DRAIN FROM DOWNSTREAM SIDE
Scale 1 : 250

FIG. 7

10.0 References:

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