DSC Notes on ANCOLD Paper

Oaky River Dam is located in northern NSW and failed by overtopping during a large flood event on 22 February 2013. The attached paper, ***Samios, G. and Gough, S. (2014), "Oaky River Dam Failure", Proceedings, Australian National Committee on Large Dams (ANCOLD) 2014 Conference, Canberra, 21-22 October 2014, ISBN 978-09875022-1-6,*** is reproduced here with the permission of the Australian National Committee on Large Dams. The NSW Dams Safety Committee (DSC) thanks ANCOLD for this permission and acknowledges that the copyright of the Proceedings is vested in ANCOLD. No part of this published paper may be reproduced or transmitted in any form without prior permission from ANCOLD and the authors of the paper. The opinions expressed in the paper remain the responsibility of the authors concerned and do not necessarily reflect those of ANCOLD or the DSC.

See ANCOLD Paper following below

Oaky River Dam Failure

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Oaky River Dam is located east of Armidale in northern NSW and is owned and operated by Essential Energy. It has a gross storage capacity at Full Supply Level of about 2,700 ML and provides water to a hydroelectric power station downstream of the dam. Constructed in 1956, the dam is approximately 18 metres high and comprises a concrete gravity gated overfall section flanked by concrete faced rockfill embankments. Flood waters are controlled by four large steel radial gates in the central section.

Following an extreme flood event late on Friday 22nd February 2013, water overtopped the dam crest leading to total collapse of the dam's right embankment and a span of the nearby intake tower access bridge as well as the cutting of power to the dam gates. The dam's left embankment was also severely damaged. Options considered for remediation of the dam include decommissioning or reinstatement and upgrading to NSW Dams Safety Committee requirements.

Keywords: *dam, flood, overtopping, collapse, remediation*

Introduction

Oaky River Dam is owned and operated by Essential Energy and provides water to a power station located downstream of the dam. The dam is approximately 18 metres high and comprises a gated structure flanked by concrete faced rockfill embankments.

Following an extreme flood event on Friday 22nd February 2013, water overtopped the dam crest leading to total collapse of the right embankment and one span of the nearby intake tower access bridge. The dam's left embankment was also severely damaged. As a consequence of the collapse of the right embankment, the power to the gates was cut, rendering them inoperable.

This report presents observations and assessments made following an inspection of the dam immediately after failure by Essential Energy personnel in company with engineers from NSW Public Works Dams & Civil Technologies. Options considered feasible for post-failure treatment of the dam are also presented.

The Existing Structure

Oaky River Dam was constructed between 1951 and 1956 by the then New England County Council (later Country Energy and now Essential Energy) as part of the Oaky River Hydro-Electric Scheme. The scheme serves to provide power to its constituent areas in the Armidale region.

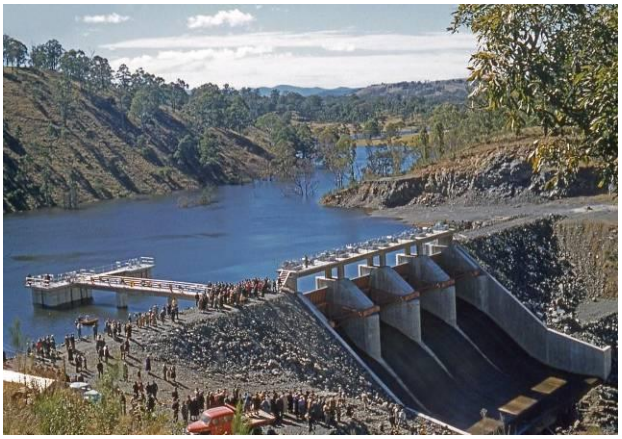
Oaky River Dam is located approximately 50km east of Armidale and is accessible by a good road, the last 10km being gravel. The dam has a gross storage capacity at Full Supply Level (FSL) of about 2,700 ML and a catchment area of 200km². The dam stores water in the Oaky River which is then diverted through a tunnel and steel pipe to a surface power station located approximately 1km downstream of the dam on the right bank of the river.

The dam has a concrete gravity gated overfall section flanked by concrete faced rockfill abutments. The concrete section has a crest length of 43m and a maximum height of 11m. The rockfill abutments have a maximum height of 18m, crest lengths 40m (left) 50 m (right), crest width 10m and side slopes of IV to 1.3H both upstream and downstream. (Note that left and right are designated looking downstream as per usual hydraulics and dams engineering practice).

Flood waters are controlled by four 8.5m wide by 6.7m high steel radial gates which provide a 0.9m freeboard to the crest of the rockfill abutments. The gates are numbered 1 to 4, no.4 being closest to the dam's right bank. Gates 1 and 4 can only be operated manually while gates 2 and 3 can be operated automatically or manually.

Water is drawn through a 0.9m diameter steel pipe for discharge to the power station. There are four 1.2m diameter scour pipes.

For Oaky River Dam, both the Flood Consequence Category and Sunny Day Consequence Category have been assessed as LOW. In accordance with NSW Dams Safety Committee (DSC) guidelines, the dam is required to pass the 1 in 1,000 Annual Exceedance Probability (AEP) flood.



Photograph 1: Oaky River Dam – at opening in 1956

Photograph 2: Oaky River Dam – upstream side, pre-failure (2012)

Relevant Notes from Previous Reports

The 2010 Surveillance Report noted that:

> *The highest flood passed by the spillway occurred on the 9th March 2001 and the storage level was at Full Supply Level RL13.7, 6.7 m above the spillway fixed crest. Gate openings were as follows: Gate 1 – 2.5 m, Gate 2 – 1.5 m, Gate 3 – 1.5 m and Gate 4 – 2.5 m.*

The 2010 Surveillance Report concluded the following:

> *Based on visual inspection, the dam is considered to be in a safe condition. The spillway gates are operational and structurally sound. Winch ropes require replacement asap. Gates require repainting*.

The 2010 Surveillance Report also recommended (amongst other items) that:

> *The gates should be operated over their full operating range every 12 months.*

The issues highlighted by the 2012 Surveillance Report recommendations in regards to dam gate corrosion and winch ropes were under investigation with NSW Public Works in the period leading up to the February 2013 incident with the intention of an RFP/Tender for a fully scoped program of works

Operation of the gates was aligned with two-yearly maintenance regimes, the last of which was July 2011. At that time, all lubricants were changed to synthetics in an effort to overcome moisture ingress; and the gates operated over their full range. All pivots were also lubricated. Care was required to operate the gates during maintenance works due to concerns with the gate seals. These seals and their inspection/replacement were also part of the scope of works being undertaken with NSW Public Works leading up to February 2013.

The 2008 Audit Report recommended (amongst other items) the following:

> *The top of the copper seal embedded in the upstream face slab located nearest to the right abutment had completely corroded and should now be repaired to prevent high storage levels infiltrating the right embankment*

Subsequent to this report, further inspections of these seals were carried out in 2009 both above and below the waterline at the time as well as the seals associated with the main scour valves. No subsequent issues were found during those inspections and no issues were found during the 2010 Surveillance Report.

The 2012 Oaky River Dam Flood Routing study indicated:

> *For all the latest determined 1 in 1,000 AEP design storm durations up to and inclusive of the 4 hour storm event, the routed maximum dam storage flood elevations were found to be under the gate's support wing walls of RL 14.60 mAHD. For the 5 hour event, the flood elevation was routed to be RL 14.85 mAHD and it was found to be RL 14.94 mAHD for the 6 hour event, i.e. the critical (worst) event.*
>
> *Therefore the dam currently would not cater for its Acceptable Flood Capacity (AFC), i.e. the critical 1 in 1,000 AEP flood event, as required by the DSC.*

Flood Studies

As noted, the Acceptable Flood Capacity (AFC) for Oaky River Dam is the 1 in 1,000 AEP flood in accordance with DSC requirements. Updated hydrographs prepared for the dam indicate that the 1 in 1,000 AEP inflow flood is equivalent to 1,556 cumecs (derived from the critical 6 hour storm event).

Routing studies were undertaken by NSW Public Works (2012) to assess the ability of the dam to pass the 1 in 1,000 AEP inflow flood. Results showed that the dam would be overtopped – by about 340mm – even if the gates were completely opened and there was free flow through the spillway.

The dam's crest flood, ie that flood that will just reach the dam's embankment crest without overtopping, was estimated to be 1,505 cumecs.

In summary, a 1 in 1,000 AEP inflow flood to DSC requirements is 1,556 cumecs and It is estimated that, at this point, the dam wall would be overtopped by some 340mm. Without overtopping, the inflow flood level or dam crest capacity is the equivalent of 1,505 cumecs.

Dam Failure Sequence of Events

The sequence of events leading up to and during the overtopping of Oaky River Dam has been documented by Essential Energy's dam operator. The following is a summary.

All reduced levels RLs) quoted are based on **the Oaky River Dam local survey datum**. Note that the dam's gate sill level is at RL7.0m, the top of the gates is at RL13.7m

(FSL) and the embankment crest level is at RL14.6m. Storage levels can be determined remotely by dam operators via a system involving telemetered response to mobile phone call-ins.

Thursday 21st February 2013

5.45 pm	Dam level 6.43m
10.30 pm	Dam level 6.53m

Friday 22nd February 2013

7.45 am	Dam level 7.13m
Midday	Dam level 7.73m
	Agreed to lift Gate No.1 by 8 inches (=205mm)
12.15 pm	Local forecast for Armidale 40mm to 80mm rainfall expected
2.00 pm	Low system observed sitting over Bellingen and Dorrigo
	Only misty rain observed at Oaky River
	On advice, lifted Gate No. 1 by 14 inches (=360mm)
3.15 pm	Dam level 8.20m (Operator returns to Armidale depot shortly afterwards)
7.00 pm	Dam level 9.40m
10.00 pm	Dam level 10.86m (Note that dam automation initiates at 13.7m)
11.30 pm	Call from Essential Energy's Network Operator (based at Port Macquarie), alarm for Oaky River Dam storage level (i.e. >13.6m)
11.45 pm	Operator leaves Armidale to travel to dam and observes rain to be increasing heavily during the eastward bound trip

Saturday 23rd February 2013

12.30 am	Approximate time that dam operator arrives at dam. Failure of dam wall observed
	Network Operator notified who then remotely isolates power to the site
	Other Essential Energy personnel notified.

Photograph 3: Oaky River Dam Post-failure February 2013

Inspection of Dam Failure

An inspection of the dam was undertaken on Wednesday 27th February 2013. Attendees included:

- Steve Gough (then Group Manager Technical Services, Essential Energy)
- John Charlier (Manager Generation, Essential Energy)
- Wayne Frasier (Dam Operator, Essential Energy)
- Eric Cameron (Dam Operator, Essential Energy)
- Steve Hansen (Project Manager, NSW Public Works)
- George Samios (Assistant Principal Engineer Dams, NSW Public Works)
- Peter Noden (Mechanical Engineer Dams, NSW Public Works).

Also in attendance for part of the time was Steve Knight (Executive Engineer, NSW Dams Safety Committee).

The weather was fine and sunny.

Access to the dam was via the right hand side of the river from upstream of the dam. The inspection of the dam was undertaken from the right hand side of the storage. Binoculars were used to observe some features more closely. None of the following could be accessed directly during the inspection:

- Left hand side of the storage
- Left hand side embankment section
- Gate hoist bridge
- Intake tower
- Downstream hydroelectric power station.

Selected photos from the inspection are attached at **Appendix B**.

The following observations were made:

1. The whole of the concrete face and rockfill right embankment section of the dam had collapsed, except for some remnants that remained on the upper reaches of the right bank abutment.
2. The gated central structure of the dam appeared in tact and structurally sound, including the right

side counter-forted concrete wall that had been exposed following the embankment collapse.

3. One span of the access bridge connecting the right hand side embankment to the intake tower had collapsed. The intake tower appeared in tact with flood debris caught in the supporting piers and some debris observed on the upper deck level.
4. The rockfill from the left embankment section had partly washed away appearing to leave a short length of concrete face unsupported.
5. A large amount of concrete debris (including the fallen beam from the tower access bridge collapsed span) remained just below the right hand side embankment failure.
6. The rock foundation of the dam's right abutment and the concrete outlet pipe concrete encasement was exposed.
7. A very small amount of reinforcement was exposed in the broken face slab pieces, but it was noted that the slab appeared to have very little reinforcement in general.
8. Copper waterstop was attached in parts to the right concrete wall of the gated structure and the remaining face slabs on the upper right bank. The copper waterstop was severely damaged.
9. Observation of surface vegetation damage and direction indicated water passage over and around the right abutment of the dam.
10. Cabling from the right bank to the dam's gates was damaged and left hanging across the space of the failed right hand embankment. Power connection had still not been restored due to obvious safety concerns. Cabling was later identified as control cabling. Power cabling had been washed away.
11. The gates were inoperable (due to the lack of power available). The gates were all closed – except that Gate No. 1 was slightly higher than the rest, assumed to be still open by the reported 14 inches (360mm).

Considerations on Dam Failure

The following assessments were made:

1. The storm that had passed over the dam site and catchment was of relatively short duration (say 5 to 6 hours) and seemingly very intense.
2. The flood was one of record height and volume and had passed completely over the right hand side embankment and abutment and the gated spillway and partly over the left hand side embankment. This was apparently due to the tight left turning bend in the river just upstream of the dam which resulted in superelevation of the flood water - aiming the bulk of the flow towards the dam's right abutment, more than to the left.
3. The time difference from when the Network Operator (at Port Macquarie) called to raise the alarm for Oaky River Dam until when the dam failure was first noticed on site was only about 1 hour. From the record of telemetered/mobile phone log of storage levels, it appears that the embankment collapse occurred a relatively short time after the Network Operator alarm call.
4. Due to the very rapid flood occurrence, there was not much time to further attempt to operate the gates. It was felt that power was lost quickly which also inhibited operation of the automatic gates, the loss of the bridge prevented manual operation.
5. Failure of the right embankment section appeared to be caused by a combination of flood water overtopping the concrete faced embankment and flood water circumventing the right abutment – possibly for a depth of 600mm or more (no record available) and at high velocity, resulting in a wash out of the rockfill and subsequent collapse of the concrete face slabs. Wave action during the intense sharp flood surge rise would also have been likely, thus exacerbating the overtopping action towards the right hand side of the dam.

   A potential additional factor in the cause of failure is the probability of water penetration through the right embankment rockfill via the copper seal identified in the 2008 Dam Audit Report. Although this seal was subsequently checked and deemed fit for purpose in 2009, any unidentified issues with this seal under the scenario that has taken place has the potential to wash away some rockfill from behind the concrete face slab initiating instability in the right hand embankment section and contributing to ultimate collapse when combined with overtopping flood water.
6. Water overtopping the left abutment was of a lesser volume resulting in partial wash out of the rockfill. Some of the remaining concrete face slab is considered unstable and would collapse if subject to any further undue loading.
7. The failure of the gates to operate or provide any significant flow capacity initially is considered to have been a major factor in the overtopping of the dam. Had the gates opened, some part of the flood surge would have passed through the spillway, thus reducing the extent of overtopping. However, it is considered that the short time frame associated with the flood, along with the necessary time taken for the settlement of the dam gauge, etc, did not allow enough time for the gates to operate. This would have been made more difficult in light of the fact that power supply to the dam gates, which runs by conduit inside the right hand embankment, was

lost with the initial collapse of the embankment. A diesel back-up power supply also became inoperable when the power cable broke following collapse of the dam's embankment section.

Post failure investigations on site by Essential Energy, with power supplies temporarily restored to the gates, showed all gates to be still fully operational.

8. With respect to the telemetry storage gauge, it is considered that it was unable to react and accurately reflect the flood situation in the short amount of time given. The water level across the length of the river near the dam would have been significantly variable with a travelling wave (superelevation) to the outer right hand bend, striking the right hand wall before travelling across the face of the dam wall structure from right to left. Along with significant wave action from a large inflow surge, overtopping of the right abutment would have already taken place by the time the gauge was consistently registering the highest flood level.

Post-Failure Options

Three options considered for post-failure treatment of the dam include:

- Restoration of the dam to its pre-failure condition,
- Upgrading of the dam to fully comply with NSW Dams Safety Committee (DSC) standards,
- Decommissioning of the dam.

Drawings of the options are attached at **Appendix C.**

The option to restore Oaky River Dam to its pre-failure condition essentially comprises:

- Reconstruction of the right bank rockfill and upstream concrete face slab
- Reconstruction of the concrete bridge walkway
- Replacement of the rockfill in the left embankment
- Restoration of power.

The work does not include upgrade of the gates or any mechanical equipment since these components are assumed to have remained in a similar condition post dam failure as in pre dam failure.

Restoration of the dam is to the same configuration, levels and dimensions as the pre-failure structure.

The option to upgrade Oaky River Dam to current NSW Dams Safety Committee (DSC) requirements (including safe passage of the required 1 in 1,000 AEP flood through the spillway with all gates operable) comprises:

- Reconstruction of the right bank rockfill and upstream concrete face slab
- Replacement of the rockfill in the left embankment
- Reconstruction of the concrete access bridge
- Construction of a concrete parapet wall on the dam crest to RL 15.25m
- Repair of the gates and lifting equipment to make the gates fully operable
- Upgrading of the outlet works
- Installation of flood level monitors which are automatically linked to gate opening
- Restoration of power.

The work includes the installation of telemetry facilities and the linkage between the storage level and automatic gate operation as well as preparation of an updated O&M Manual and Dam Safety Emergency Plan.

For the above dam upgrade options, an upstream cofferdam extending from the western wing wall of the concrete gated gravity structure towards the control towers and then to the western bank is envisaged. Construction of the cofferdam with sheet piling driven into the river bed and supported by rockfill is assumed (considered the most feasible arrangement).

Geological assessment of the dam's right abutment (based on site inspection and examination of geological maps of the area) indicates that there would be sufficient suitable rock available to reconstruct the dam embankment and that establishment of a quarry in the area would be feasible. This is considered to be the most economical means of obtaining rockfill, negating the need to source and transport to site from a distant quarry source.

An on site batching plant is also envisaged to avoid the possibility of affecting concrete during delivery over a long distance (eg. from Armidale),

The option to decommission Oaky River Dam essentially comprises:

- Demolition of the dam's left embankment and foundation clean up
- Demolition of the dam's right embankment and foundation clean up
- Removal of all gates and mechanical equipment
- Removal of all mechanical equipment from the control towers
- Sealing off outlet and scour pipework
- Removal of bridge over the spillway
- Removal of access bridge to control towers including piers
- Demolition of the control towers
- Cessation of power to the dam
- Construction of rock protection and rehabilitation of river banks.

For all options, the most convenient method for waste rock and concrete disposal is to use it as river bank scour protection in the vicinity of the dam, or to fill the quarry.

Cost estimates for the above dam options have been prepared and are based on available survey data from WAE drawings of the dam as well as observations from site inspection and preliminary design. A summary of the estimate is indicated in the Table below.

Dam Option	Direct Cost (ex GST)	Total Cost Estimate (ex GST)
Restoration of dam to pre-failure condition	$4.09M	$6.13M
Upgrade of dam to DSC standards	$5.96M	$8.95M
Decommissioning of dam	$2.08M	$3.33M

The estimates do not include the cost of environmental remediation upstream and downstream of the dam.

Future Work

It is considered that the next phase of the project would be to confirm the above estimates and to proceed to more detailed analyses. To this end, the following additional scope of work is proposed:

- Selection of the preferred option,
- A concept stage geotechnical investigation which will confirm the rock source and its suitability (for the upgrade options)
- Environmental assessment of the preferred option
- A survey of the site which will establish more correct dam dimensions and confirm quantities.

Conclusion

Oaky River Dam has a gross storage capacity at Full Supply Level of about 2,700 ML and provides water to a hydroelectric power station downstream of the dam.

The dam comprises a concrete gravity gated overfall section flanked by concrete faced rockfill embankments. Flood waters are controlled by four steel radial gates, the outer gates are controlled manually, while the inner gates are operated automatically.

Following an extreme flood event on Friday 22nd February 2013, water overtopped the dam crest leading to total collapse of the dam's right embankment and a span of the nearby intake tower access bridge as well as the cutting of power to the dam gates. The dam's left embankment was also severely damaged.

Factors that have been considered as contributing to the failure of the dam include:

1. The short duration of the intense storm. This did not allow enough time for flood emergency procedures to be implemented
2. The inability of the gates to open. Although the gates have not operated at more than partially open, collapse of the right embankment prevented any concerted attempt to manually operate the gates while the cut off of electric power to the dam during the storm precluded any automatic operation
3. The potential for infiltration of water through any damaged concrete face joints of the right abutment in conjunction with the flood overtopping the dam crest. This potential factor would contribute to the wash out of the downstream rockfill and the ultimate collapse of the concrete face.

Options for future treatment of the dam include decommissioning as well as restoration to pre-failure condition and upgrading to full NSW Dams Safety Committee requirements.

References

Work-As-Executed (WAE) drawings of the dam construction.

Essential Energy, Oaky River Dam Operating and Maintenance Instructions (part).

Essential Energy, Raising and Lowering of Gates 1 and 4 (Operating Instructions).

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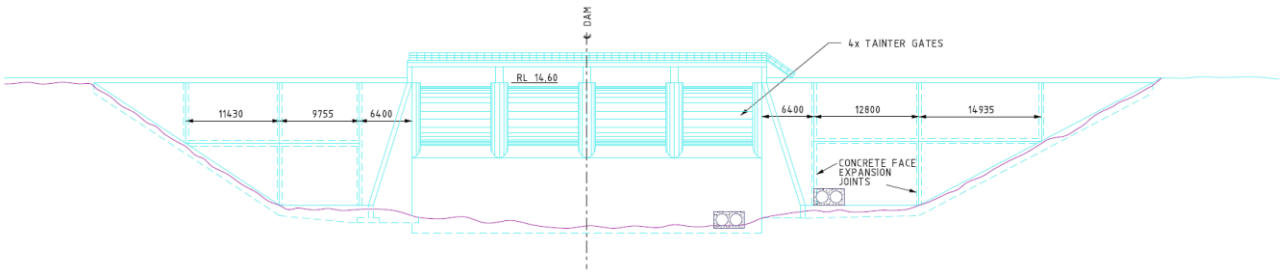
Essential Energy, February 2013. Oaky Dam Wall Failure – Sequence of Events.

NSW Public Works, May 2013. Oaky River Dam Report on Inspection of Dam Failure.

Essential Energy, 6th May 2013. Email correspondence to NSW Public Works outlining tests conducted post failure on the Oaky River Dam spillway gates.

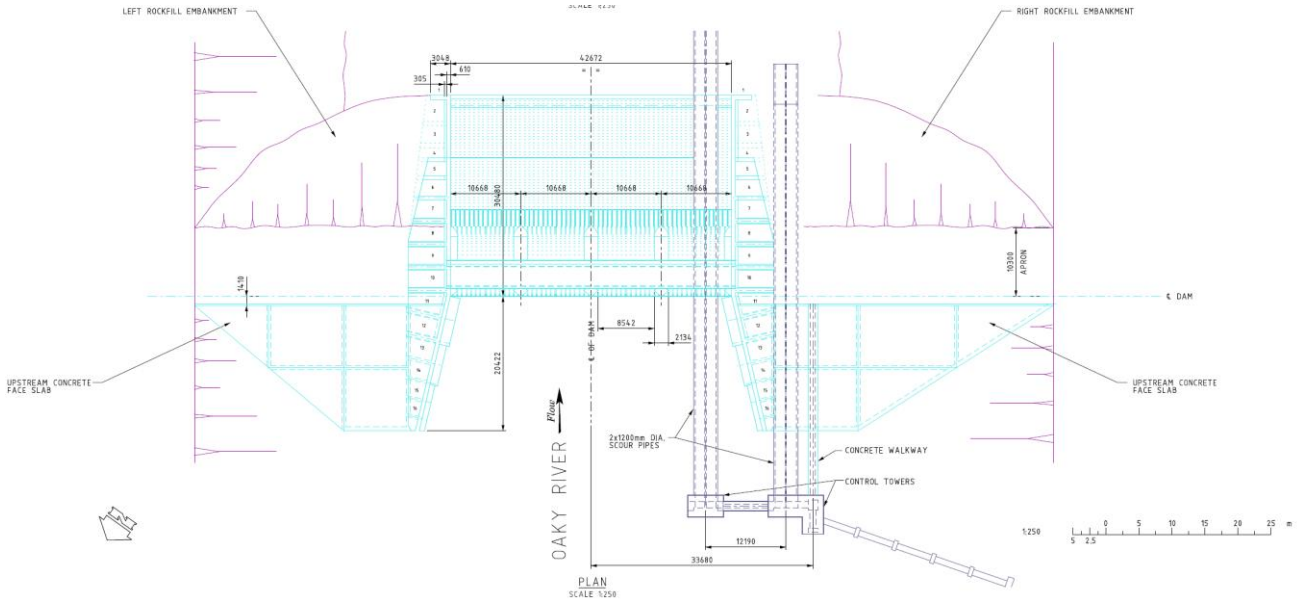
NSW Public Works, September 2013. Oaky River Dam Remediation Final Options Study.

Appendix A Drawings of Existing Dam (prior to failure)



ELEVATION OF UPSTREAM FACE

AS BUILT
PLAN AND ELEVATION



PLAN
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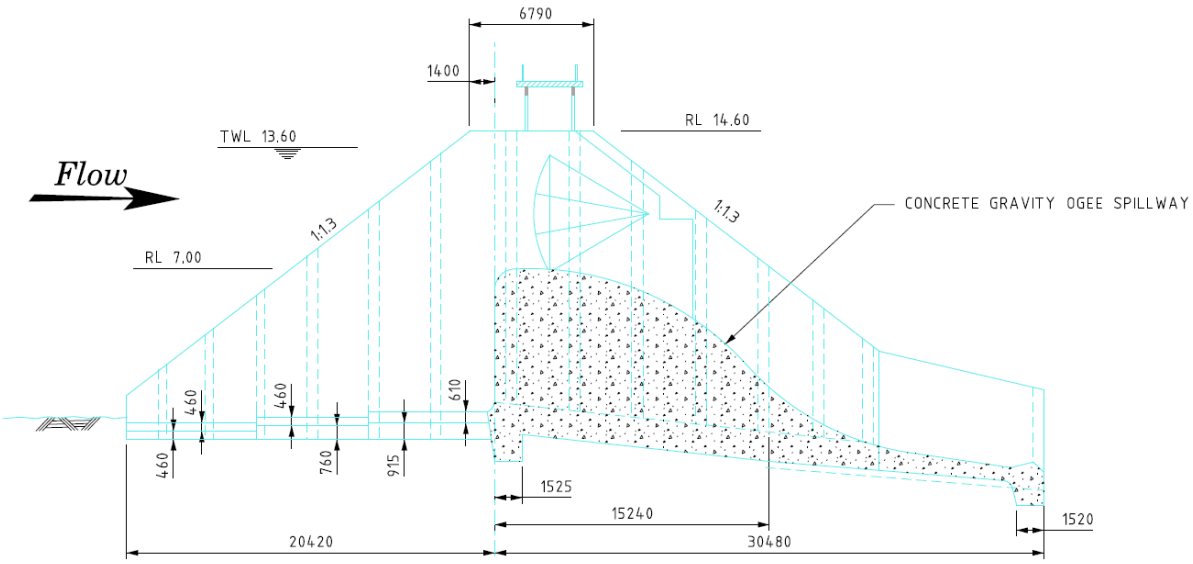

SECTION NEAR EAST ABUTMENT

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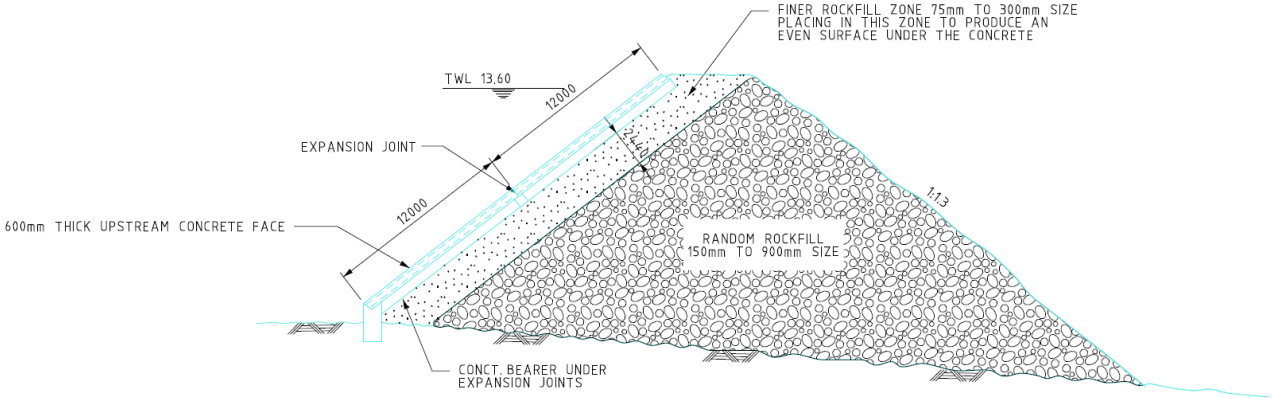
AS BUILT SECTIONS



TYPICAL ROCKFILL SECTION

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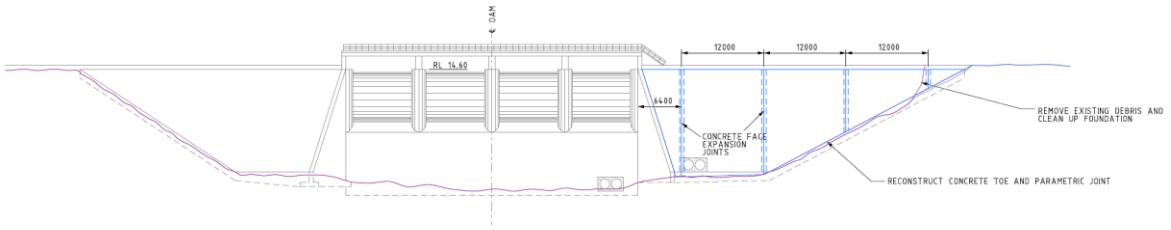
Appendix B Selected Photos from Inspection of Dam Failure

Appendix C Drawings of Post-Failure Options



ELEVATION OF UPSTREAM FACE
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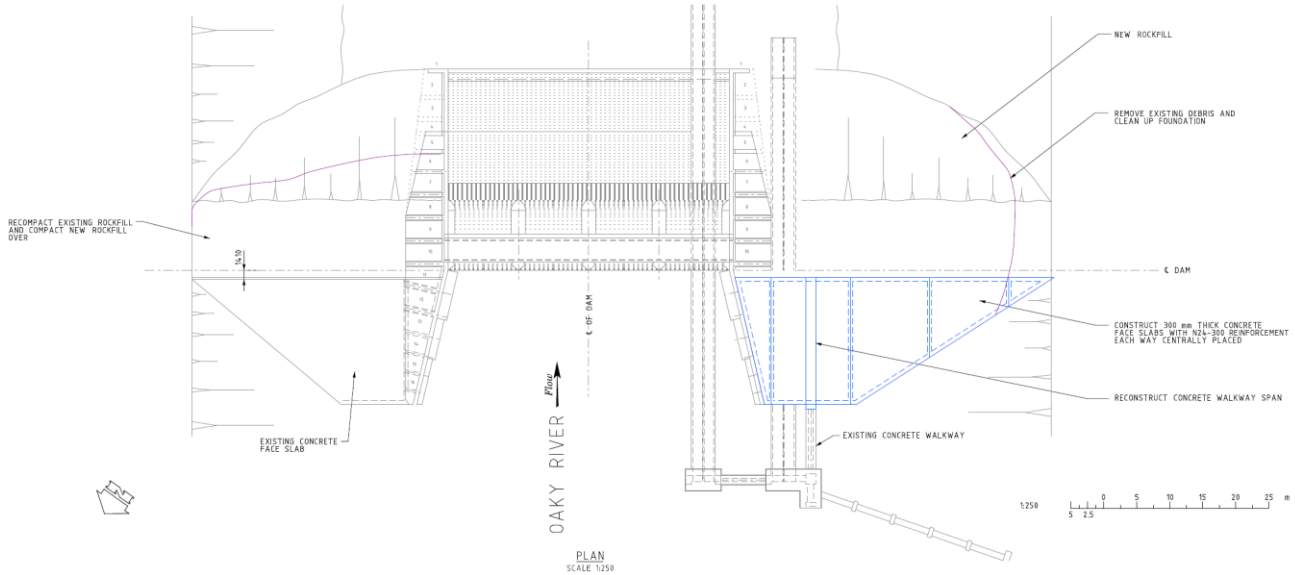
RESTORATION TO PRE-FAILURE CONDITION PLAN AND ELEVATION



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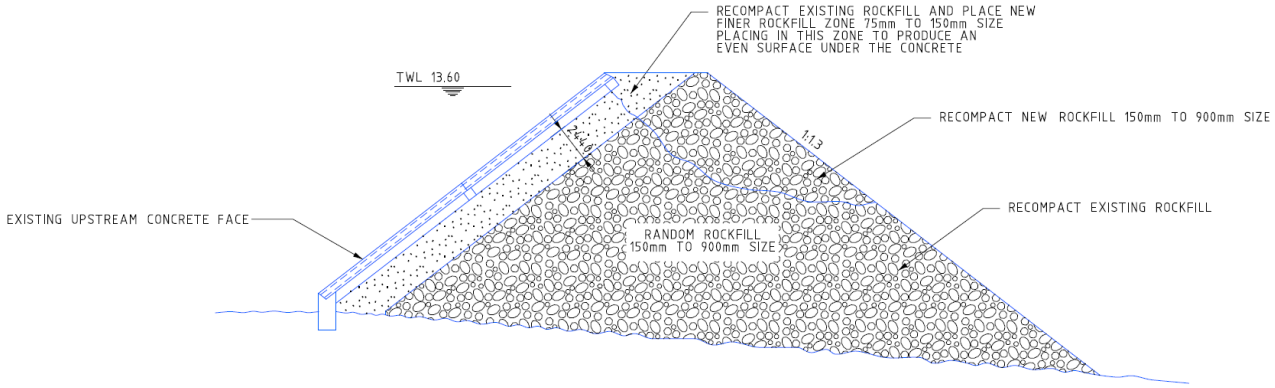
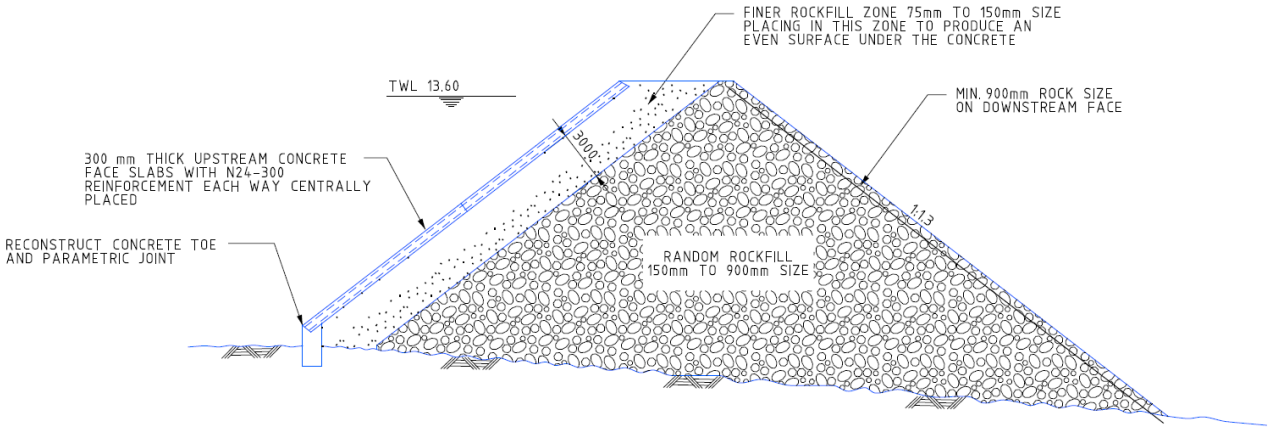


LEFT EMBANKMENT ROCKFILL SECTION

SCALE 1:150

RESTORATION TO PRE-FAILURE CONDITION SECTIONS



RIGHT EMBANKMENT ROCKFILL SECTION

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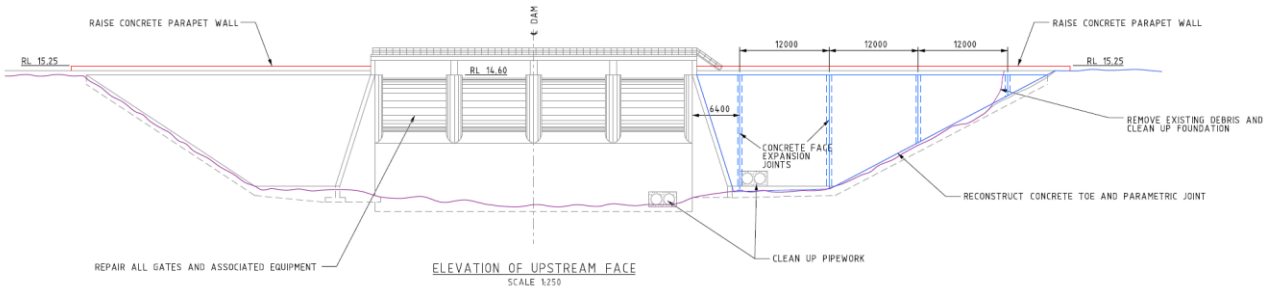
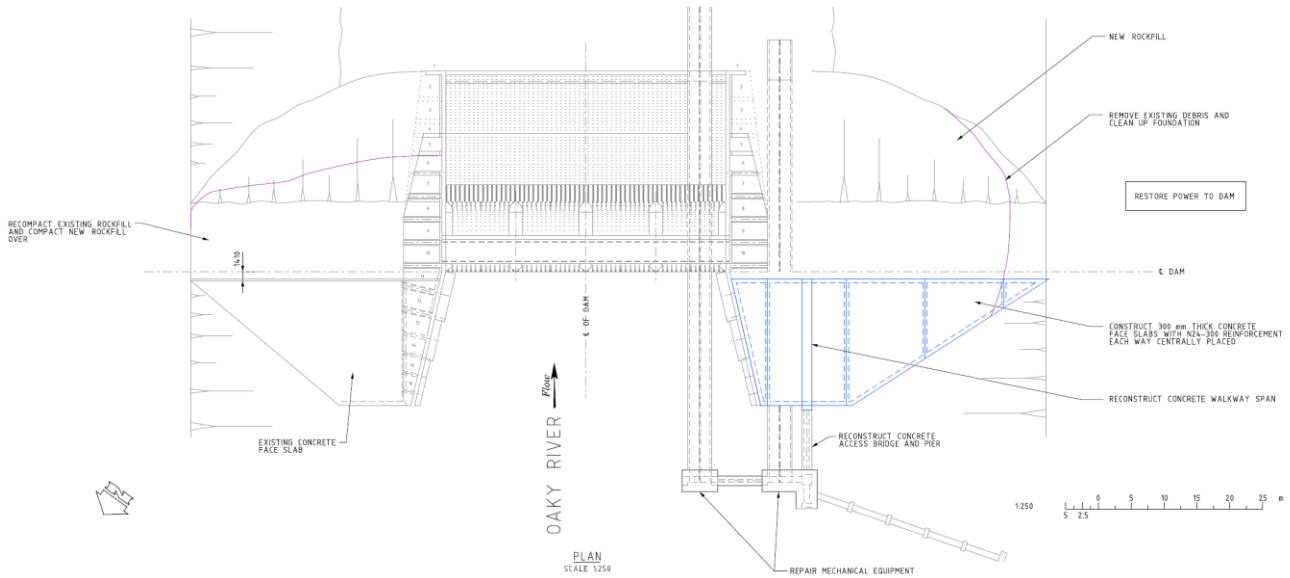
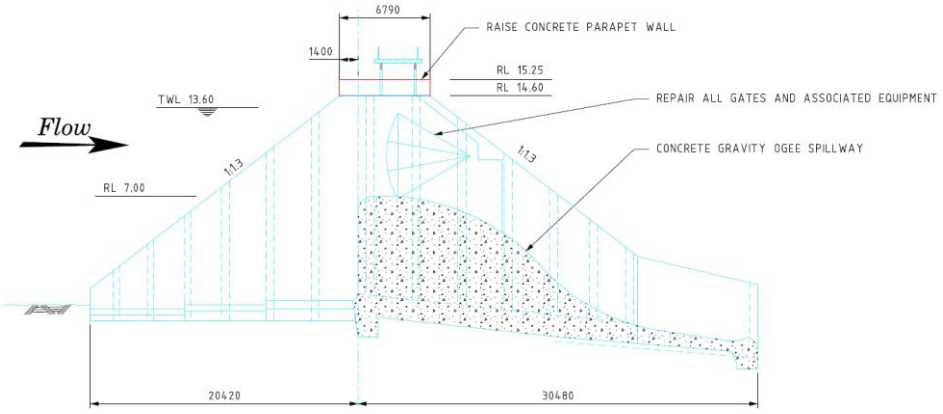


UPGRADE TO NSW DAMS SAFETY COMMITTEE STANDARDS PLAN AND ELEVATION





SECTION NEAR EAST ABUTMENT
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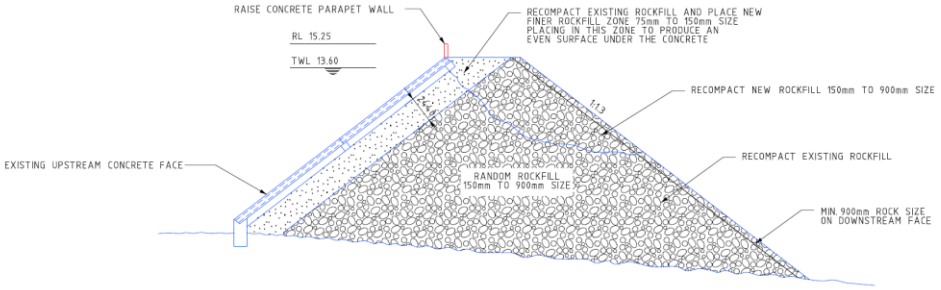
UPGRADE TO NSW DAMS SAFETY COMMITTEE STANDARDS SPILLWAY SECTION



LEFT EMBANKMENT ROCKFILL SECTION
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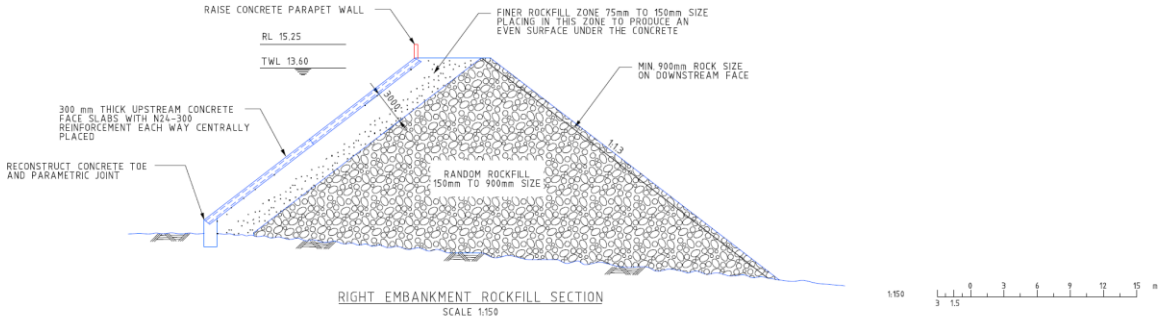
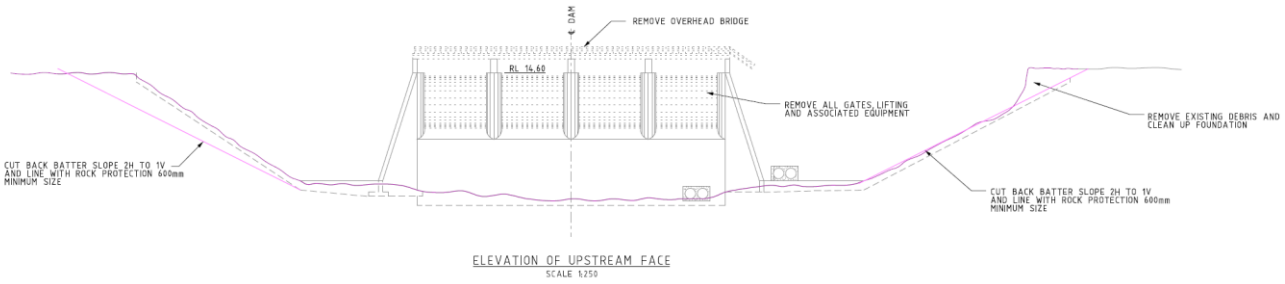


RIGHT EMBANKMENT ROCKFILL SECTION
SCALE 1:150

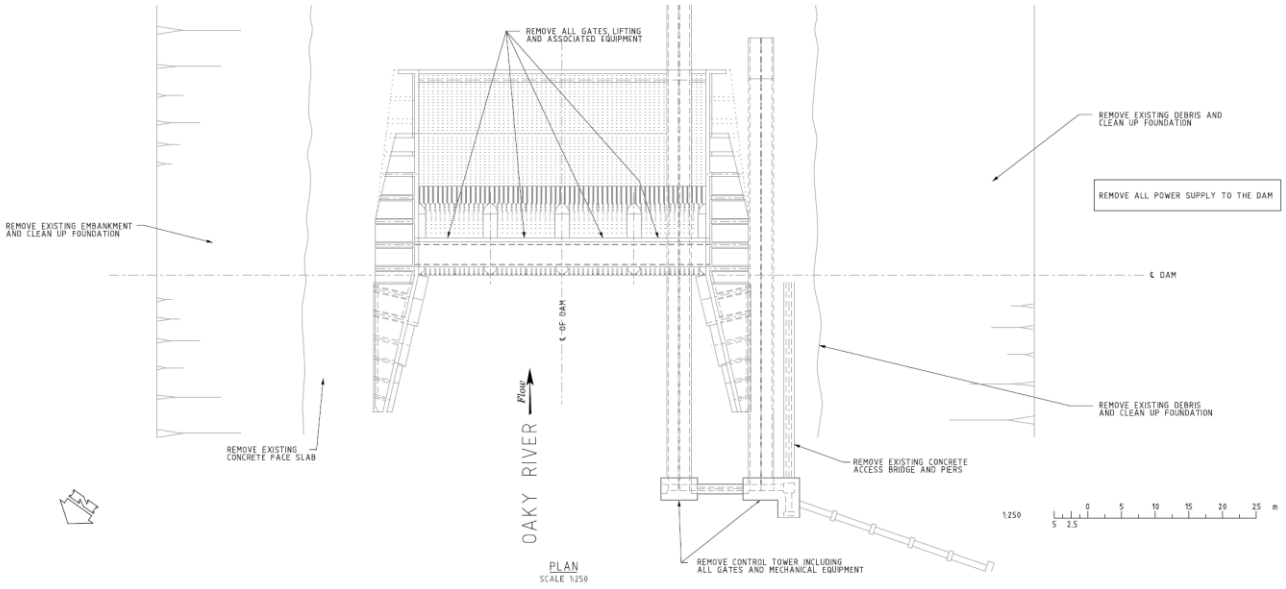
UPGRADE TO NSW DAMS SAFETY COMMITTEE STANDARDS EMBANKMENT SECTIONS



ELEVATION OF UPSTREAM FACE

SCALE 1:250

DAM DECOMMISSIONING



PLAN

SCALE 1:250