PARADISE DAM COMMISSION OF INQUIRY

Commissions of Inquiry Act 1950

STATEMENT OF TIMOTHY NIGEL GRIGGS

Name of witness:	**Timothy Nigel Griggs**
Date of birth:	[redacted]
Current address	[redacted]
Occupation	**Senior Civil Engineer**
Contact details (phone/email):	[redacted]
Statement taken by:	**Shana Webster - Lawyer**

I, **Timothy Nigel Griggs**, state as follows:

1 I am employed as a Senior Civil Engineer within the consulting business of Hydro Electric Corporation (**Hydro Tasmania**).

Qualifications and experience prior to the Paradise Dam Project

2 I hold a Bachelor of Engineering (Civil) (Honours) (University of Tasmania 1995). I also hold a Master of Technology (Deakin University 2001).

3 I commenced employment with Hydro Tasmania in February 1996 as a Graduate Engineer in the civil engineering team of the consulting division of Hydro Tasmania.

4 During the period from February 1996 until February 1998 I undertook consulting work in the field of dam safety, which included inspections, surveillance reviews and safety reviews of a variety of dam types, including conventional concrete gravity dams.

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5 During the period from February 1998 until July 1999 I was seconded to the engineering group of Generation North, another division of Hydro Tasmania, as a field engineer based in north-west Tasmania. During this time I undertook tasks which included project management and contract management as part of Generation North's capital works program, maintenance engineering work, asset management and the provision of technical advice.

6 In July 1999 I returned to the civil engineering team of the consulting business of Hydro Tasmania in Hobart, Tasmania. During the period from July 1999 until May 2003 I undertook two secondments of approximately 6 months each to Hobart Water and Goulburn-Murray Water, during which I undertook project management and contract management for a number of civil projects. During this period I was also involved in a number of civil and dam safety projects, including the design of dam safety upgrades, engineering assessments for Hydro Tasmania's dam portfolio risk assessment, dam inspections and surveillance reviews for a variety of dam types, including conventional concrete gravity dams.

7 A copy of my curriculum vitae is document **HYT.600.003.0001**.

Overview of my role in the Paradise Dam project

8 I initially became involved in the Paradise Dam project during the period from May 2003 until July 2003 as part of the dam design team working on the tender design for the project. At this time I had no prior experience in the design of new dams or with roller compacted concrete (**RCC**) dams.

9 In this role my main task was to undertake the dam stability analysis. I also undertook the design of a number of the individual elements of the dam. I worked under the supervision of Richard Herweynen, who was the Dam Design Team Leader.

10 After our consortium was awarded the project in or around October 2003, I again became involved with the project as part of the dam design team working on the detailed design phase of the project. As with the tender design, I worked under the supervision of Richard Herweynen, the Dam Design Team Leader.

11 In this role I undertook a review of the Thiess / URS Tender Design

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(**DNR.007.1087**). I also undertook further work on the dam stability analysis, as well as the civil / structural design of a number of elements of the dam, including:

(a) the primary and secondary spillway aprons and end walls;

(b) the downstream facing for the primary spillway; and

(c) the primary spillway crest, the secondary spillway crest and the left abutment crest.

12 I remained in this role until March 2004.

13 During the period from March 2004 until July 2005 I undertook the role of site design representative for the project. I was based on the construction site during this period. In this role I worked under the supervision of Richard Herweynen, who at this stage had the title of Dam Design Coordinator. My role included:

(a) collating evidence that the construction works had been carried out in accordance with the design; and

(b) providing a rapid response to design related construction queries.

The tasks I was required to perform in this role are outlined in more detail in a memorandum I received from Richard Herweynen dated 27 February 2004 (**DNR.020.019.2601**) prior to my commencing work on the construction site.

14 In July 2005 I finished up in my role as site design representative and returned to Tasmania. Prior to leaving site I handed over to a replacement site design representative, William Curlewis, another civil engineer from Hydro Tasmania.

15 From this point in time my main role in connection with the Paradise Dam project was to collate the Final Design Report (**DNR.001.0267**). This involved liaising with various members of the design team who provided the inputs for the report. I finalised the report in November 2005.

16 I have set out below my comments in connection with a number of specific issues that have been raised by the Paradise Dam Commission of Inquiry.

Stability Analysis

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Overview

17 A stability analysis is required for a concrete gravity dam in order to show that the dam will remain stable under the loading conditions that the dam may experience over its life.

18 In undertaking the stability analysis for the Paradise Dam my initial task was to prepare a basis of design that set out the loading conditions, material parameters and acceptance criteria that were to be used in the analysis. I undertook this work in collaboration with Richard Herweynen. My work in preparing the basis of design included the following:

(a) Obtaining inputs on the hydraulics, geotechnical and concrete parameters from the relevant members of the design team. The hydraulic inputs were obtained from Michael Wallis of Hydro Tasmania. The geotechnical inputs were obtained from Mike Marley and David Starr from Golders, the geotechnical consultant to the project. The concrete parameters were based on information obtained from Dr Ernest Schrader, the RCC consultant to the project. The hydraulic inputs included the spillway rating curve and the tailwater rating curve that allowed the headwater level (upstream of the dam) and tailwater level (downstream of the dam) to be calculated for selected flood events. The geotechnical inputs included the assessed compressive strength and shear strength of the dam foundation. The concrete parameters included the assessed compressive strength, tensile strength and shear strength of the RCC and the recommended design values. I have discussed a number of these inputs in further detail below.

(b) Selecting load categories and load combinations for use in the analysis. This included consideration of uplift. I have discussed the concept of uplift in further detail below.

(c) Developing stability criteria that provide allowable stresses and minimum acceptable factors of safety based on a review of design guidelines.

19 I then analysed sections of the dam using the Cantilever Method. The results of my analysis included a factor of safety against sliding, and the maximum stresses

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Timothy Nigel Griggs

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at a number of levels in each section of the dam. I compared the results of my analysis to the stability criteria.

20 I documented this work in section 5.5 of the Detail Design Report (**DNR.020.026.0332**). This was reviewed by Richard Herweynen, the Dam Design Team Leader.

Uplift

21 Uplift is the internal water pressure acting on the interface between the dam and its foundation and within the body of the dam (that is, between lift joints).

22 I considered two main uplift assumptions in the stability analysis:

(a) 50% uplift assumption: This assumed 50% of the headwater pressure was applied at the upstream side of a section of the dam. This was considered for all sections where an upstream waterproofing membrane and drainage system is in place; and

(b) 100% uplift assumption: This assumed 100% of the headwater pressure was applied at the upstream side of a section of the dam. This was considered for sections through the dam foundation interface and sections where there is no upstream membrane. It was also uses as a sensitivity check for the case of an upstream membrane failure.

23 I described these uplift assumptions in detail in Section 5.5 of the Detail Design Report (**GHD.002.001** at **GHD.002.0137**).

24 Piezometers were installed within the body of the dam and at the dam foundation interface to monitor uplift and to confirm that the uplift assumptions were being met.

Shear Strength of the RCC

25 The shear strength of the RCC is used to assess the sliding factor of safety of the dam. The sliding factor of safety is a ratio of the forces resisting sliding and the forces causing sliding on the relevant section of the dam. The resultant factor of

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Timothy Nigel Griggs

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safety is compared to the stability criteria to determine whether it is above the minimum acceptable factor of safety.

26 There were two components considered for the shear strength of the interface between two surfaces: friction angle and cohesion. In simple terms, friction angle is a measure of the roughness of the interface between two surfaces, and cohesion is a measure of the bond between two surfaces or how well they are stuck together.

27 The shear strength parameters for the RCC lift joints are dependent on the lift joint quality and whether or not bedding mix is used. Bedding mix is a form of conventional concrete that is applied to the surface of a lift joint in order to bind it with the subsequent lift. Bedding mix increases the shear strength (both friction angle and cohesion) and tensile strength of the lift joint in the area that it is applied.

28 The design value adopted for shear strength of the lift joints was selected based on input from Dr Ernest Schrader, specifically Table 6.3 of the Detail Design Report that he prepared.

29 In an e-mail of 13 November 2013 (**DNR.020.019.2507**) Dr Schrader recommended the following be used:

(a) the design properties for 1 year should be used.

(b) LJQI is usually based on an overall value of '0' for the basis of design.

30 Based on this, the design team adopted values associated with a LJQI of '0', which is defined as 'Good' for the design and proposed that a sensitivity analysis be undertaken for a 'Poor' lift joint.

31 On or around 29 May 2004, Dr Schrader provided an updated table of material properties (**SUN.010.002.0356**). This table is included as Table 6.3 of the Detail Design Report. This table provided 'Probable' values of shear strength at various ages and cement contents. The design team selected the strength based on the 60 kg/m3 mix at 365 days age. The table gave a 'Probable' value of tan ϕ = 1.1 and c'=500 kPa for this case. This table also gave recommended reduction factors to convert the 'Probable' value to a design value for both 'Poor' and 'Excellent' lift

Timothy Nigel Griggs

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joints.

32 I adopted the recommended shear strength value for an 'Excellent' lift joint in accordance with Table 6-3. However, on review, I have noted that I used a more conservative reduction factor of 65% of tan ϕ for a 'Poor' lift joint compared to the recommended reduction value of 80% in Table 6-3. The design basis of 'Good' was obtained by averaging the values for 'Excellent' and 'Poor'.

33 Due to this, the design shear strength values I used in the stability analysis are more conservative than that recommended by Dr Schrader in Table 6.3 of the Detail Design Report.

34 The LJQI was prepared by Dr Ernest Schrader and is defined in Section 11 of the Technical Specification on RCC Dam Construction (**Technical Specification**) (refer to **DNR.003.8385** at page numbers **DNR.003.8440** to **DNR.003.8496**). The LJQI was used to evaluate the acceptability of lift joints and considers a number of factors that influence the quality of a lift joint. A point score is provided to positive and negative factors which affect the quality of a lift joint and an overall score is used to assess a rating for each lift joint. The possible ratings are: 'Excellent', 'Good', 'Fair', 'Poor' and 'Very Bad'.

35 Section 11 of the Technical Specification required that, in general, the LJQI rating should average about '0' for each lift in each monolith block. This is equivalent to a 'Good' lift joint. The Technical Specification also states that no lift joint will be allowed to have a LJQI rating below '-5' which is the lower end of a 'Poor' lift joint rating. The quality of a lift can be improved by the application of bedding mix. Bedding mix was applied to ensure that these minimum requirements were met.

36 I used a Shear Friction Factor (SFF) to assess the factor of safety against sliding. This is defined in the Detail Design Report (**GHD.002.0001** at **GHD.002.0141**) in Section 5.5.5 Stability Criteria:

37 This is the same basic formula as given in Equation 6.1 of the ANCOLD (2013) guidelines. The net resisting shear force is divided by the net applied shear force to calculate a factor of safety.

TNJ.

Timothy Nigel Griggs

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38 I consider that that it is proper to consider that the frictional resistance and cohesion would act at the same time to resist sliding.

39 With respect to the comment that there may be a 'strain incompatibility' that prevents this occurring, attention is drawn to Figure 5.1 (a) of the ANCOLD (2013) guidelines. This clearly shows that in order for the dam to slide any bond strength must be overcome on a lift joint.

40 The other component resisting sliding, that due to friction, is due to the weight of the dam applying a load on the lift surface. This frictional resistance to sliding is always present and must also be overcome in order for the dam to slide. The dam's weight is simply its mass multiplied by the gravitational constant and both of these parameters always exist.

41 I do not consider it possible that the bonded areas of a lift joint can move independently of the unbonded areas. The block is a monolith and it must slide as one combined mass. I have found no literature to support the theory that there is a 'strain incompatibility' that prevents cohesion and frictional resistance acting at the same time. To my knowledge, the same basic formula in Equation 6.1 of ANCOLD (2013) has been used by the dams industry for over 40 years without this issue being raised as a concern.

42 The sensitivity analysis I undertook for lifts assessed as having a 'Poor' LJQI rating concluded that all sections of the dam analysed met the stability criteria with either a 'Good' or a 'Poor' LJQI rating.

Tensile Strength of the RCC

43 In simple terms, tensile strength can be considered as a measure of the load required to pull apart two concrete surfaces.

44 The tensile strength of a RCC lift joint is dependent on the lift joint quality and whether or not bedding mix is used. To be conservative, I based the design tensile strength for the RCC on the design value recommended for a 'Poor' untreated lift joint. In accordance with Table 6.3 of the Detail Design Report (**GHD.002.0001** at **GHD.002.0229**) this was calculated to be approximately 250 kPa. The bedding mix specified at the upstream side of each lift joint gives

TNG.
Timothy Nigel Griggs

Taken by

confidence that this minimum tensile strength was achieved.

45 I used the tensile strength in the stability analysis to determine if cracking would occur at the upstream face of the dam for the load cases considered. Stability criteria provided the allowable tensile stress for each load case.

46 The stability analysis I undertook indicated that the allowable tensile stresses were not exceeded for any load case at any lift joint level in the dam and therefore no cracking analysis was required for the RCC.

Compressive Strength of the RCC

47 In simple terms, compressive strength is a measure of the pressure required to crush concrete.

48 The stability analysis I undertook indicated that the compressive stress applied to the RCC was only in the order of 2MPa, while the actual compressive strength of the RCC was estimated to be in the order of 14MPa. The compressive strength was therefore not a significant consideration in the stability analysis.

Treatment of Cold Lift Joints

49 The material properties adopted for the RCC lift joints assumed they were untreated joints (that is, they did not have bedding mix applied) but that they were not cold joints.

50 A cold joint occurs when the lift has reached a certain maturity which affects the bond with the subsequent lift. Section 11 of the Technical Specification classifies Type I and Type II categories of cold lift joints and specific treatment measures for each type. The treatment measure is to apply a certain width of bedding mix to the cold lift joint.

51 The stability analysis I undertook assumed the material parameters for a 'Good' or 'Poor' lift joint and did not specifically consider whether any bedding mix had been placed to achieve this lift joint quality.

52 There was an inherent assumption that lift joints that were assessed as a lower quality than this would be treated in order to bring them up to an appropriate

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Timothy Nigel Griggs

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standard. The method of treatment was generally to apply bedding mix to the lift joint surface.

53 It was assumed that the bedding mix would provide a bond between the two lift surfaces. This assumption was supported by the design values provided for lift joints with bedding mix given in Table 6-3 of the Detail Design Report. ie. there is a line in the table that provides 'Static Shear Strength (MPa) RCC mass and lift joints with bedding' with quoted values of cohesion much higher than for untreated lift joints.

54 I consider that bedding mix should provide a bond between the lift joints in the areas it is applied. And, as per the discussion above, this bond should be considered in the assessment of the resistance to sliding along a lift joint.

Dam/ Foundation Interface

55 As well as assessing stability at levels within the body of the RCC dam, I also undertook a stability analysis at the dam/ foundation interface for each section of the dam.

56 For the dam/ foundation interface I applied a 100% uplift assumption for all cases.

57 Unlike the RCC lift joints, there were cases where cracking was assessed as likely to occur under certain load conditions. Consequently, I undertook a crack analysis for the affected sections of the dam. However, the outcome was that the stability criteria were still met for all sections considered.

58 As an input to the foundation design, I calculated the minimum foundation parameters for various sections of the dam that would be required to meet the stability criteria. For example, the low height sections of the secondary spillway required significantly less strength than the primary spillway.

59 These minimum foundation parameters were provided to Golders to assess the quality of rock required for the dam foundation.

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Design of the primary spillway apron

60 The primary spillway apron protects the rock located immediately downstream of the dam from erosion and therefore prevents undermining of the dam.

61 I was tasked with the civil/ structural design of the primary spillway apron.

62 I prepared the apron design on the basis of the following aspects of the design which had been decided by other members of the design team:

(a) the apron was to be 20 meters wide (in the upstream to downstream direction) with a 1 meter high step at the downstream end. This was the same width as adopted by Sunwater in their preliminary design and Thiess/ URS in their tender design;

(b) the apron was to be constructed of RCC with a minimum thickness of 2 layers (total 620mm) with the top layer to be reinforced with steel bars.

(c) the RCC mix was to be a greater cement content than the dam RCC mix; and

(d) the end wall was to be made of conventional concrete.

63 My design of the primary spillway apron is outlined in section 5.7.6.1 of the Detail Design Report.

64 It should be noted that due to the undulating nature of the dam foundation, the actual thickness of the primary spillway apron was generally more than 900mm. This is demonstrated in the detail provided on the as built survey drawings which are referred to below.

65 I was not required to assess erosion protection measures downstream of the primary spillway apron. This was a task undertaken by the Geotechnical Consultant, Golder and documented in their Geotechnical Design Report (**DNR.006.1154**). Golder did not recommend any protection measures downstream of the primary spillway apron. However, they did include a recommendation for protection of the left abutment excavation at the toe of the left bank. The recommended protection for the left abutment excavation was included

TNG
Timothy Nigel Griggs

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on the design drawings by another member of the dam design team.

Site Design Representative Role

66 My role as Site Design Representative included frequent inspections of the dam works and other civil works, compiling a systematic photographic record of the dam works and other civil works, the collation of daily, weekly and bi- monthly and/or tri-monthly Quality Assurance (**QA**) reports prepared by the RCC QA Engineers, the preparation of design inspection and test plans, and the provision of responses to design related queries from the construction team.

67 I worked under the supervision of the Design Coordinator, Richard Herweynen, during this period. I was in regular contact with Richard Herweynen by telephone and email, and provided him with regular updates on progress and discussed queries I received from the construction team. Richard Herweynen also attended site on a regular basis (every 1 to 2 months), during which time he and I inspected the works and had detailed discussions about the design requirements and responses to design related queries from the construction team.

<u>Inspection of the Dam Foundation</u>

68 Golder developed detailed flow charts for foundation acceptance. This included the foundation requirements for the various sections of the dam which was based on inputs from the dam stability analysis I undertook and geotechnical assessment by Golder (**SUN.120.001.0045**).

69 I undertook inspections of the dam foundation and took photographs to record that the works were being undertaken in accordance with the Technical Specification. I also witnessed representatives from Golder undertaking inspections and mapping of the dam foundations. These inspections were done as the foundations were exposed.

70 I recall there was significant effort undertaken by the construction team in cleaning the foundations, and ensuring the foundation was clean was a focus of my inspections.

71 Golders provided advice to the construction team on foundation treatment measures. For example, if an area of low strength material was identified, a

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Timothy Nigel Griggs

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Golder representative would provide advice on the excavation and backfill of this feature (refer to (**HYT.600.004.0001**), which is an example of advice which Golder provided to a construction representative on foundation treatment measures).

72 The dam design Drawings show a flat foundation surface under the dam. I recall that the dam/ foundation interface in fact had significant undulations. I can remember forming the view that it would be very unlikely for the dam to fail along such an interface because the undulating nature of the interface meant that shear strength would be significantly higher than what had been assumed in the design (refer to **HYT.600.005.0008**), which is a copy of the as built survey of the dam which shows the undulating nature of the dam/ foundation interface).

73 I prepared a foundation inspection and test plan which was initialled by me and the Golder representative after completion of each our inspection and mapping activities (refer to **SUN.120.001.0102**, which is a copy of the foundation inspection and test plan as at 28 July 2005, which was during my last week on site).

<u>Trial Embankment</u>

74 A trial embankment was constructed at the far right abutment of the dam in June 2004. It was used to trial the RCC placement techniques and allow the construction workers to become familiar with the process of RCC placement and the associated quality control and quality assurance.

75 I recall that a number of lessons were learnt from this trial. There was a report prepared by the RCC QA Engineers which documented the results of the trial and made recommendations for improvements in practice.

76 I also recall that a particular area of focus by the RCC QA Engineers was methods to reduce segregation which was observed on some of the lift surfaces of the trial embankment. The RCC was made with a graded mixture of crushed rock (from large particles up to about 50mm size down to sand sized particles) as well as cement and water. Segregation occurs when the larger particles separate from the smaller particles resulting in a collection of coarser particles in one area. Areas of segregated concrete have lower strength and appropriate treatment measures are required.

TNG.

Timothy Nigel Griggs

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Placement of RCC

77 I undertook frequent inspections of the RCC dam works. However, for a significant period of the construction, the RCC was placed during both a day shift and a night shift and I was therefore not able to inspect all of the RCC placement. I relied on the RCC QA Engineers to supply evidence of the quality control and quality assurance processes which was provided in the form of regular QA reports and memorandums.

78 My recollection is that the QA processes were undertaken in a very diligent and professional manner. My observations at the time were that the RCC QA Engineers appeared to be very knowledgeable about RCC and were focused on completing their work to a high standard. In fact, the standard of QA I witnessed on the Paradise Dam project exceeded the standard that I have witnessed in any project that I have since been involved in.

Cleaning and Curing of the Lift Joints

79 Section 11.10.1 of the Technical Specification provides general requirements for cleaning of the RCC lift surfaces. In particular, this section provides:

> *"Joint surfaces shall be kept clean, uncontaminated, and continuously moist condition until placement of the succeeding concrete.*
>
> *.....*
>
> *Compacted RCC surfaces to receive bedding mix at the upstream face shall be especially clean. RCC surfaces at the upstream half of the dam shall be essentially uncontaminated where the RCC is placed on them. The downstream half of each layer shall also be kept clean and damp, but occasional isolated rocky or small contaminated areas will not be reason to stop placing. The middle third each lift shall also be kept reasonably clean, but this is the least critical area of the lift and the Engineer may occasionally permit placement to continue in this area with lift surfaces that are less than ideal."*

80 I recall a significant amount of effort was put into cleaning the lift surfaces. This included the use of air hoses and vacuum trucks to remove debris on the lift surface. Air and water was also used to remove sediment.

TNG.
Timothy Nigel Griggs

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81 I can also recall the RCC QA Engineers providing a number of recommendations on methods to improve construction practices in order to reduce the amount of cleaning required. This included a greater focus on continual curing of the surface.

82 I can also recall curing being undertaken on the RCC lift surface by workers using a hose to keep the surface moist.

83 The LJQI was used to assess each and every lift and included specific penalties for inadequate curing and/or poor surface condition (as well as a number of other factors). For example, if large areas of the lift surface were allowed to dry in hot weather, a penalty would apply which would affect the assessment of lift joint quality overall. If the lift joint quality was assessed to be too low, then bedding mix would need to be applied to improve it.

Application of Bedding Mix

84 The dam design drawings included the placement of a 600mm wide strip of bedding mix adjacent to the upstream face on all lift joints. This was to provide an area of low permeability immediately downstream of the drainage system and to provide some tensile capacity at the upstream edge of the RCC lift joint.

85 Section 11 of the Technical Specification required bedding mix to be placed as a treatment for cold joints and to improve the lift joint quality when required (for example, on areas of segregation).

86 I can recall observing bedding mix being placed on RCC lift joints, including adjacent to the upstream face and on areas of segregation. However, I can't recall specific details on the widths that were applied or the specific locations.

87 I have been made aware of a memorandum from Dr Ernest Schrader dated 2 August 2004 (**DNR.011.1255**) that suggests that the width of bedding mix placed on cold joints could be reduced. I cannot recall being sent this memorandum during the construction phase of the project.

88 In the course of preparing this affidavit, I located a number of photographs from the construction period that indicated bedding mix being placed on about 15% of the lift surface. This width was estimated based on the known location of the conveyor posts with respect to the upstream face of the dam. An example

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photograph is **HYT.600.003.0001**.

89 In the course of preparing this affidavit, I also located a spreadsheet with a file date of 15 December 2004 that provides a summary of the required width of the bedding mix on each layer of the dam that has been calculated based on 10% and 15% of the total width of each lift surface (**HYT.600.005.0007**). This is consistent with the reduced widths of bedding mix given in Dr Schrader's memorandum of 2 August 2004 (**DNR.011.1255**).

90 I have also briefly reviewed the location of bedding mix with respect to selected drill holes undertaken during the period 2015-2019 and make the following comments:

(a) My brief review is provided in **HYT.600.008.0001**.

(b) My conclusion was that it likely that the drill holes did not intercept bedding mix as they were drilled too far away from the upstream face.

Comment on GHD's stability analysis

91 The main issue I have with the GHD Stability Analysis (**IGE.034.0001**) is that there is no consideration of the likelihood of the input parameters and therefore it does not meet the recommendations of the Queensland Government's *Guidelines on Acceptable Flood Capacity for Water Dams* (December 2019) (**HYT.600.008.0005**).

92 These guidelines recommend that a risk based approach be used to assessing the acceptable flood capacity of all large dams in Queensland, as opposed to the more traditional standards based approach that GHD have put forward in their stability analysis memo.

93 In order to consider the requirements of these guidelines, an appropriate probability distribution for a number of input parameters including the following would need to be estimated:

(a) Uplift pressures

(b) Tensile strength

(c) Shear strength

TNJ.

Timothy Nigel Griggs

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94 For the case of uplift pressures, consideration of the actual readings of the piezometers needs to be made. In the case of Paradise Dam, most piezometers located within the body of the dam are reading zero pressure (refer **DNR.002.3132** Paradise Dam – Dam Safety Review). Only piezometers located with the body of the dam should be considered for this assessment. Currently GHD are also considering piezometers at the dam/foundation interface and this is affecting the assessment of likely uplift pressures within the body of the dam. The likelihood that the uplift pressure assumptions would increase substantially in a range floods needs to be considered.

95 For the case of tensile strength, as discussed earlier, the design assumed a small tensile strength for the RCC lift joints as recommended in Table 6-3 of the Detail Design report for a 'Poor' lift joint. The Drawings included a requirement to place 600mm of bedding mix adjacent to the upstream face on each lift and the Specification included requirements to ensure the upstream third of each lift was particularly clean. The GHD assumption that lift joints have zero tensile strength at the upstream side would have a very low probability and a range of appropriate tensile strengths for the lift joints should be considered.

96 For the case of shear strength parameters:

(a) the likelihood of the lift joints being at residual strength is considered to be zero. This is because, by definition, the lift joints can only be at residual strength if they have experience large displacement. The 2016 Dam Safety Review (**DNR.002.3132**) indicates that the dam has not experienced large displacement therefore the lift joints cannot be at residual strength.

(b) With respect to the comment in ANCOLD (2013) that the difference between residual shear strength and sliding friction strength is only 2 to 3 degrees, based on data from EPRI (1992). The caveat given in the EPRI (1992) report needs to be considered:

The sliding friction strength data are only slightly above residual strength data because, in the multistage test procedure, each lift joint was sheared more than once. Tests performed as part of this study showed that after the initial test, the sliding friction strength was approximately equal to the residual strength. The great majority of the data is essentially residual strength data.

TNG.

Timothy Nigel Griggs

Taken by

(c) For areas of unbonded lift joint a proper assessment of the sliding friction strength needs to be undertaken. The likelihood of having bonding and cohesion on a lift joint also needs to be properly assessed based on all available information including the quality control records on bedding mix.

97 It is my opinion that a risk assessment that considers the likelihood of all these input parameters needs to be undertaken in order to make a proper assessment of the risk of dam failure. Such a risk assessment is required to meet the recommendations of the Queensland Government's *Guidelines on Acceptable Flood Capacity for Water Dams* (December 2019) (**HYT.600.008.0005**).

Friction (only) calculation

98 I have undertaken the friction (only) calculation that was discussed at the Commission hearings on 10-11 March 2020.

99 The assumptions and results of my assessment are provided in **HYT.600.008.0003.** I found that a friction angle of 38° was required to produce a factor of safety of 1 against sliding failure.

100 My assessment shows that the stability assessment is sensitive to the overly conservative input parameters that GHD have adopted.

TNG

Timothy Nigel Griggs

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OATHS ACT 1867 (DECLARATION)

I, Timothy Nigel Griggs, do solemnly and sincerely declare that:

1 This written statement by me dated 12 March 2020 is true to the best of my knowledge and belief; and

2 I make this statement knowing that if it were admitted as evidence, I may be liable to prosecution for stating in it anything I know to be false.

And I make this solemn declaration conscientiously believing the same to be true and by virtue of the provisions of the *Oaths Act 1867*.

TNGriggs Signature

Taken and declared before me at Brisbane this 12th day of March 2020.

Taken by Shana Webster

~~Justice of the Peace / Commissioner for Declarations~~ / Lawyer