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Ground Engineering – Technology, Common Sense and Good Value?

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ABSTRACT

In 1985 it took the author a month to run 30 Bishop's Simplified limit equilibrium slope stability analyses on a personal computer to support the design of remedial works on a large embankment dam. Today such an effort would probably be criticised as grossly inadequate – verging on the negligent - since it is not uncommon to execute 300, or more, similar calculations using far more sophisticated and accurate algorithms in less than a minute. The paper considers the development and application of technology and advanced analytical tools over the last 25 years and whether they are being put to good use by adding value to our clients, improving our levels of service or reducing geotechnical risk.

Keywords: geotechnical design, analysis, modelling, risk.

1 INTRODUCTION

Over the last 25 years there have been many technological advances that have made a big difference to the work of consulting geotechnical engineers. Communication links have improved by orders of magnitude. As a graduate engineer working in a Scottish design office with one telex machine and no mobile phones being sent for a three week field trip to do some investigations and manage a survey of some dam sites in the remote Orkney Islands was an adventure and a big responsibility. A daily phone call back to the Lead Engineer in Edinburgh to update on progress and discuss any problems was the only contact possible. The ultimate responsibility for capturing the right information in sufficient detail to satisfy the needs of the design team and any contractors tendering on the proposed works was very much left with those in the field.

Today the young graduate can be sent out with a telephone that will capture on camera and video all the site activities. They can use the telephone to instantly download images from site and the investigation findings as work proceeds. They can be in constant contact with the Lead Engineer from anywhere in the world and at any time of day. Twenty five years ago such concepts were science fiction.

With respect to advances in analytical techniques and design office activities similar changes have taken place. This paper presents an overview of the work undertaken in 1985 on the investigation, analysis and design of a medium size, earth dam. The paper discusses the relative costs of executing a similar scope of work in the modern consulting engineers office and compares the relative rigour of the original project study with the scope of work and analyses that might be executed on a similar project in 2012.

In the conclusions the author considers the advances made in our profession and technological progress against three critical, qualitative criteria:-

- Cost
- Service Value
- Risk

2 COD BECK DAM

Cod Beck Dam is a 25m high zoned earth fill embankment with a puddle clay core (Figure 1). The dam was completed in 1953 and stores just over 100,000m3 of raw water for Yorkshire Water

Authority (YWA). The dam is located on the edge of the North Yorkshire Moors near the market town Northallerton.

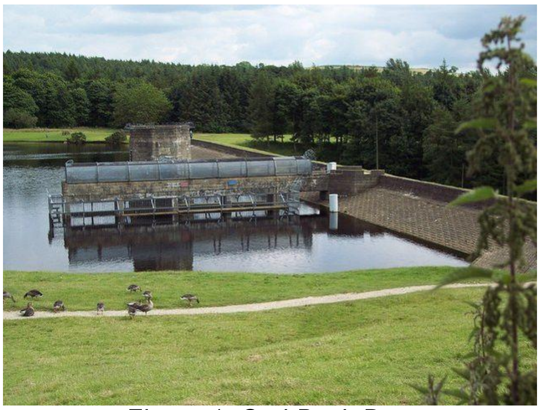

Figure 1: Cod Beck Dam

For comparison, given the location, size, storage, population immediately downstream and associated environmental & commercial effects, in the author's opinion, the potential incremental consequences of failure of the Cod Beck Dam would be classified as "Medium PIC" if not "High PIC" according to the NZ Dam Safety Guidelines, 2000.

2.1 Background

During routine dam surveillance by the Reservoir Engineer from Robert H Cuthbertson & Partners in Edinburgh seepage was observed on the downstream shoulder and right flank / abutment at approximately mid height of the dam. The dam crest showed signs of deformation and it was recommended that urgent investigations into the stability and security of the dam were implemented.

2.2 Investigations

Investigations comprised a series of machine drilled boreholes through the dam crest, the downstream shoulder and dam abutments. Standpipe piezometers were installed in all the boreholes, multi-level piezometers were installed at locations of specific interest. Samples recovered from the shoulder and dam core were tested in a certified soils laboratory for material classification and strength.

Routine (daily) monitoring of the standpipes was undertaken by local YWA staff and weekly data sets were posted to the Reservoir Engineer.

2.3 Interpretation and analysis

Using the site survey plan and original drawings a series of cross sections through the dam and abutments were developed with the investigation data superimposed to provide a visual representation of the dam construction.

The standpipe data was processed by hand and a pore pressure with time graph was plotted by the author to see if there was any response to the pore pressures in the embankment and estimated phreatic surface with changing reservoir water levels. The period over which monitoring had taken place was one full calendar year so seasonal cycles in water level could be identified. In the first of many career limiting observations the author did not leave a good first impression with the Senior Partner when he expressed the opinion that this task was a bit boring in response to the polite request about how he was enjoying his first two weeks of employment as a Graduate Engineer.

Based on the marked-up drawings, the dam slope profiles, embankment zone properties and the pore pressure information an assessment was made of the most critical cross sections and these were simplified into 2-D drawings with X-Y coordinates to define all the surfaces. Over a period of one month the author would make daily return trips to the University of Edinburgh where one of the Civil Engineering Department academics was in possession of a personal computer that could drive a limit equilibrium slope stability software program using Bishop's Simplified algorithm.

The limitations of the computer's processing capacity and the time required to input individual cross section geometries meant that only one section, with one set of soil and pore pressure characteristics could be analysed every 24-hours. The academic would take the afternoon to input the section to be analysed and the PC would be left to run overnight with the results output in the morning to be picked up by the author.

The results of the overnight analysis would be studied during the day in the design office and, if necessary, a revised set of characteristics would be developed to analyse the impact or influence of a varying phreatic surface or upper and lower bound characteristic material properties for embankment fill zones, foundations and abutments.

Given the cost and time associated with analysing each section a great deal of effort was expended on the detailed assessment of each individual analytical run in order to determine what changes to the input data might best serve to provide a greater insight into the dam stability or behaviour. There is no doubt that this long and drawn out process enabled the author to gain a sound and thorough understanding or insight into the limitations and the mechanics of slope stability analysis.

2.4 Design programme and fees

Given that the author was a young graduate involved in the design process but had no awareness of the terms and conditions of the consulting engineer's engagement, the following assumptions regarding the programme and costs associated with the development of the remedial works contract documents are speculative and based entirely on the author's memory of the delivery timeframes.

For comparison, typical time charge unit rates for equivalent NZ based staff have been used to provide an estimate of the project fees in current terms.

Table 1: Fee Estimate for Cod Beck Dam Remedial Stabilisation Design

Activity	Resource	Rate	Est. Hrs	Fee
Stability assessment & reporting	Senior Partner	$325	8	$2,600
	Associate	$240	64	$15,360
	Graduate Engineer	$120	240	$28,800
	Sub-consultant (academic)	$240	80	$19,200
	Drafting	$90	40	$3,600
	Admin / Typing	$70	24	$1,680
Sub-Total				**$71,240**
Drainage design	Senior Partner	$325	8	$2,600
	Associate	$240	40	$9,600
	Graduate Engineer	$120	80	$9,600
Sub-Total				**$21,800**
Tender drawings[1]	Senior Partner	$325	4	$1,300
	Associate	$240	16	$3,840
	Graduate Engineer	$120	60	$7,200
	Drafting	$90	240	$21,600
Sub-Total				**$33,940**
Contract documents[2]	Senior Partner	$325	8	$2,600
	Associate	$240	16	$3,840
	Graduate Engineer	$120	40	$4,800
	Admin / Typing	$70	24	$1,680
Sub-Total				**$12,920**
TOTAL				**$139,900**

[1] Tender drawings were prepared for remedial stabilisation measures incorporating gallery drains, French Drains, dam abutment channel drain and associated safety works. Approximately 15 tender drawings were prepared.
[2] Contract documents were based on ICE 5th Edition Conditions of Contract and issued to five pre-qualified tenderers.

As an interesting comparison it is the author's recollection that the successful tender for the remedial works contract was in the order of £125,000 in 1985. Allowing for UK inflation since 1985 (total inflation 153%) and the current NZ / GBP exchange rate (1.97) this is equivalent to a NZ 2012 contract value of approximately NZ$600,000.

3 "COD BECK" DAM 2012

It would be ideal if there were another near identical project that was completed recently that could be used as a direct and relevant comparison. Unfortunately, that is not the case. However, it is possible to envisage how similar tasks and scope of work could be implemented in the event that there was a similar project to be undertaken on one of Auckland's medium sized water supply facilities.

3.1 Background

If we were to assume that Watercare had identified some visual evidence during their routine dam surveillance operations that one of their water supply dams was experiencing some distress, then it would be reasonable to expect them to engage with appropriately qualified and experienced dam engineers to investigate and advise on appropriate remedial treatment.

3.2 Investigations

Based on the assumption that the surveillance issues raised by Watercare's inspections on their dam were similar to those identified in the early 1980's then it is reasonable to assume a very similar scope of investigations would be executed. It is highly likely that machine drilled boreholes using continuous coring techniques would be put down to identify the characteristic material properties of the different zones of embankment fill. High quality samples would be selected from the core and tested using very similar procedures and laboratory equipment to that employed 25 years ago.

The instrumentation plan would be largely similar to that installed in the early '80's. However, it is now likely that more sophisticated instrumentation and data monitoring equipment would replace the standpipe piezometers. Today it is likely that vibrating wire piezometers would be installed and connected to a data logger that would export real time pore pressure readings over a wireless network to the consulting engineer's office on a daily basis. Instead of a graduate engineer spending two weeks plotting "boring" graphs of manually recorded individual standpipe dipmeter readings there would be a data base and associated spreadsheet graphing tool continuously updating and producing the same records in minutes.

3.3 Interpretation and analysis

Another area of significant difference between the tasks undertaken in 1985 and those completed for a similar project in 2012 will relate to the analysis of embankment stability. Whilst there is still the need to process geotechnical investigation data, determine material characteristic properties, geological and groundwater profiles, once a basic design model and appropriate cross sections have been developed the volume of detailed analysis that can be executed has multiplied by orders of magnitude.

From a cost and time perspective there is simply no comparison. Multiple cross sections can be analysed in a short space of time to identify the most critical. Geological layers and boundaries can be altered to reflect any uncertainty associated with interpolation between borehole locations. Material properties can be varied to afford an insight into the influence of upper and lower bound characteristic strengths.

There have also been some significant changes in the type or analysis that might be undertaken for the stability assessment of an earth dam. Nearly every commercially available limit equilibrium stability software package will now include multiple stability analysis models of varying sophistication that represent a significant advancement in the modelling of slopes. It is now possible to consider more complex non-circular instability mechanisms and more accurate or rigorous mathematical algorithms than the very basic software that was developed in the early '80's that relied on the theory of Bishop's Simplified Method.

Beyond the limit equilibrium approach that would still be routinely applied in design offices around NZ today there are some consultants that would also look to model the dam and embankment using FE software. These even more sophisticated and accurate computer models can couple the soil strength and stiffness characteristics to represent the true behaviour of complex, inter-acting, deforming, soil mass materials rather than the grossly simplified mechanics of forces acting on free-bodies in traditional limit equilibrium software.

Given the power and simplicity of the tools available it is possible for staff with limited experience to execute these analyses. It is also common place for the analyses to be undertaken within constrained timeframes that provide little opportunity for the consideration of the mechanics or limitations and assumptions sitting within the software and the models being applied.

3.4 Design programme and fees

In order to create a contemporary comparison with the original studies on Cod Beck Dam we have created a scenario whereby Watercare have identified a seepage and stability issue on an existing water storage embankment dam. Table 2 represents the resource and budget estimate prepared by an Auckland professional services company to complete the scope of work described in the Watercare Request for Proposal on the interpretation, analysis and design of remedial options for stabilisation measures on the dam.

Table 2: Fee Estimate for Cod Beck Dam Remedial Stabilisation Design (2012)

Activity	Resource	Rate	Est. Hrs	Fee
Stability assessment & reporting	Practice Leader Team Leader Graduate Engineer Sub-consultant[1] Drafting Admin / Typing[2]	$325 $240 $120 $240 $90 $70	2 8 40 0 8 0	$650 $1,920 $3,600 $0 $720 $0
Sub-Total				**$6,890**
Drainage design	Practice Leader Team Leader Graduate Engineer	$325 $240 $120	8 40 80	$2,600 $9,600 $9,600
Sub-Total				**$21,800**
Tender drawings[3]	Practice Leader Team Leader Graduate Engineer Drafting	$325 $240 $120 $90	4 16 40 120	$1,300 $3,840 $4,800 $10,800
Sub-Total				**$20,740**
Contract documents	Practice Leader Team Leader Graduate Engineer Admin / Typing	$325 $240 $120 $70	8 16 40 0	$2,600 $3,840 $4,800 $0
Sub-Total				**$11,240**
TOTAL				**$60,670**

[1] The use of a specialist sub-consultant or academic for the computer analysis and modelling of routine slope stability calculations is no longer necessary for any experienced professional services company.
[2] There are few, if any administration staff or typists engaged to prepare design reports in modern design offices. Engineers will now routinely prepare their own reports.
[3] Estimates for the tender drawings have been revised to reflect the advantages of preparing drawings using CAD tools.

It is interesting to note that in a scale fee comparison the fee estimate for the work scope using 2012 design office technology and procedures is a far more sensible ratio than the cost estimate for the same work undertaken in mid-‘80’s ($60k : $600k approx. 10% cf, $140k : $600k approx. 25%).

4 CONCLUSIONS - COST, SERVICE AND RISK

From Tables 1 & 2 it is very apparent that over the last 25+ years the time related consulting engineering fees for completing a typical stability assessment and remedial works design have significantly reduced. The advances in technology with respect to the analysis of embankment stability enable the modern design office to execute a detailed assessment in a fraction of the time of our predecessors.

The benefit of reduced costs for our clients is enhanced by the more rapid turnaround of reporting and design production. In 1985 the stability study and subsequent design / tendering process took not less than six months to complete. It would now be hard to justify much more than a six week programme for the same project in 2012.

It must also be assumed that the use and application of more advanced analytical tools in the modern design office will have improved the level of rigour in the assessment of dam stability. The opportunity to check for a multitude of mechanisms and characteristic material properties using the most accurate of mathematical algorithms must reduce the risk that the most critical mechanism has not been identified. The ability to apply and consider computer generated models of the dam's response to various load, drawdown and seepage scenarios must result in a higher level of confidence in the design and project outcomes with respect to long term serviceability.

From the client's perspective all the above must be considered good news. From the consulting engineer's perspective we can be proud of the advances our profession has made and the improved levels of service we now provide to our clients. We can perhaps look back fondly at the time when fees were better and the time available to deliver projects was more relaxed, but we must recognise that technology has significantly changed our business.

At least we might think that until we consider; how much care, attention and critical thinking has been applied in the execution of the stability analyses? With appropriate management and supervision from senior staff we can probably conclude this might be adequate – but are we confident that the graduate pushing the buttons on the computer keyboard has had the same learning experience of their 1985 counterpart? The author has significant reservations that this would be the case.

It should also be noted that in this time capsule comparison we have also assumed that our ultimate deliverable has remained largely unchanged. We have assumed that the remedial stabilising design produced for Cod Beck Dam in 1985 was the right solution to the problem identified at that time and, for our parallel project a quarter of a century later, the design recommendations would, in all likelihood, be exactly the same.

This observation opens an interesting debate on the standard of care for professional services and associated liability. It is conceivable that today's experienced consulting geotechnical / dam engineer could complete the same analysis of the original stability of Cod Beck Dam in an afternoon and then they could immediately embark on the design of those same remedial stabilisation measures. Would we consider this to be an acceptable approach?

Put another way, have the technological advances of the last 25 years only provided the profession with a set of mandatory tools that must be used to validate our thinking before we can safely proceed to design and construction? Perhaps more importantly we should also be asking if these tools are actually being used in a manner that does enhance our understanding and insight into the mechanics and limitations of slope stability analysis and the real behaviour of dams. Or, are they being used simply because they are available?

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