SESSION 1: ROCK FILL

Papers:

INVESTIGATIONS INTO THE DEFORMABILITY OF ROCK FILL
A.J. Bowling; vol 1, 1-6

A THEORETICAL INVESTIGATION OF THE CONSTRUCTIONAL BEHAVIOUR OF A ROCK FILL DAM
A.K. Parkin and G.S.N. Adikari; vol 1, 7-12

Paper by A.J. Bowling

Mr J.P. Blakeley asked the reason for putting a bitumen layer between the rockfill and concrete face. In reply Mr Bowling said that the bitumen layer sealed the surface prior to placing the concrete slab, protected the surface and also provided a working construction surface. Mr Blakeley went on to ask, since the paper stated that the rockfill should not be too deformable, what would generally be regarded as acceptable modulus value and what deformation in the dam would be measured for a dam with this modulus? Mr Bowling replied that an acceptable rockfill modulus would be between 30-40 MPa and this would correspond to a deformation somewhere in the region of 150mm-200mm.

Mr B. Chappell commented that rather than an elastic modulus, the modulus of deformation was more apt. The indices used appeared to be disparate and he wondered if there was a way of combining these in relation to the deformation modulus. Also, he gathered that once the modulus was obtained, it was analysed to give the predicted performance. He wondered how this compared with the actual measurements monitored and how the field moduli were determined in practice. Replying, Mr Bowling pointed out that the compression test from which the elastic modulus of a rockfill sample can be determined is merely an index which does not necessarily have to be used to give a prediction of elastic behaviour. Furthermore the results obtained show good correlation between moduli determined in the laboratory and those determined from field tests. The method used to determine the observed and predicted settlements, and hence to predict the moduli, was a two dimensional finite element elastic analysis.

Mr T.A.H. Dodd pointed out the way of quantifying parameters of change of grading by the use of Hudson's 'A' parameter in the segregation of aggregate.

Mr Boyd asked Mr Bowling if his approach was going to be adopted as a design standard. Mr Bowling hoped that standard test procedures could be established but he felt that problems would be encountered in determining the grading of rockfill. The gradings adopted at present are established from the modal grading of a number of rockfills used.

Mr B. Clegg sought information on the importance of the particle shape. He thought that the laboratory jaw crusher might influence the shape and might not give a shape distribution similar to that used in actual rockfill. Mr Bowling pointed out that his experiments related to standard crushed rockfill rather than to river gravel and that no attempt was made to control the shape parameter in the test procedures.

Mr Vutukuri put forward a general question on the prediction of the behaviour of rockfill materials using the methods available to correlate between properties determined from laboratory testing and in situ measurements. Mr Chappell indicated the importance of extensive field work in any such correlation. Mr Bowling elaborated on the importance of dam instrumentation and the maintenance of dam behaviour records which provided a basis for the future design of dams.

Paper by A.K. Parkin and G.S.N. Adikari

Mr C.J. Graham noted that the authors had difficulty in some zones determining a reasonable stress distribution and hence values for the non-linear modulus. He asked whether there was any advantage to be gained by using an averaging or smoothing technique to remove the fluctuations in the stress distribution, and hence in the modulus, where they occurred. Replying, Mr Adikari said that there was no real advantage in using a non-linear model compared with the elastic model, due to the difficulty in determining the parameters.

Mr Clegg queried the influence of particle shape in relation to the laboratory tests with parallel gradings. Dr Parkin, in replying, said that it was difficult to give a definite answer.

Mr Chappell asked what happened to the definition of the elastic modulus in areas of high stress gradients and large deformations? In reply, Mr Adikari - referring to the stress/strain curves which he had obtained from the results of the tests undertaken in the laboratory - pointed out the hyperbolic nature of the relationship in which the Poisson ratio (ν) beyond 8-9% strain deviated from the observed values which resulted in a certain approximation.

Mr A. Hosking said that, while he wished to congratulate all the authors of papers presented at the session, he would like particularly to comment on the matters raised in the paper by Parkin and Adikari.

He was very glad to see this paper as Talbingo was one of the most under-reported dams in history. For some ten years prior to the completion of Dartmouth Dam in 1979 it had been the highest dam in the southern hemisphere - 162m - but had had no substantial paper written about it. The Snowy Mountains people who designed Talbingo, and also Dartmouth - 180m - simply went on to more dams and did not write up their achievements. He had been very happy when the CSIRO and Monash University undertook to study the extensive data on Talbingo Dam and to analyse them in the way they had done in this paper.

Talbingo Dam was designed principally in the period 1965-66 when neither he nor his fellow workers had heard of finite element analyses. Their methods were to carry out a very thorough investigation, to design the dam by the best means known at the time, primitive as we now know them to be, to build it well and faithfully and to instrument it thoroughly so that its performance could be followed throughout construction and in the years of operation, paving the way for the next, and often higher, dams.

In the fifties and sixties, nobody knew much about the behaviour of rockfill, but the instruments they put into dams like Geehi, Jindabyne and Blowering dams, and others, allowed them to design Talbingo, Dartmouth and many more with confidence. Precedent still plays a powerful part in earth-rock dam engineering.

By the time Dartmouth came along they had some facility in finite element analysis and had been glad to adopt it as a major design tool ever since. Even so, they fully instrumented every dam to ensure that performance followed design expectations.

Once, they used to measure only the pore pressures, the settlements in vertical lines through the core, and the surface settlements and deflections on the rockfill shoulders, and their knowledge of the internal stresses and deformations was extremely limited. For the high, 116m, but relatively flat, dams like Eucumbene, the first on the Snowy Mountains Scheme, this hardly mattered. They simply followed the great traditions of the very successful zoned dams of the USBR, like Deer Creek, Green Mountain, and Anderson Ranch. However, once they began to steepen up the faces, strengths and deformations of the rockfill especially, became of the utmost importance. Their embankment instruments had to become much more sophisticated and complete, and they had to develop more suitable testing gear, including a very large triaxial compression cell.

Their new instruments soon told them that the core was not simply consolidating and settling, but was deforming appreciably and pushing out the rockfill zones, sometimes with considerable lateral strain. They also told them about the very important differential settlements between the zones, particularly between 1A and 2A and all the problems this caused because of load transfer and possible hydraulic fracturing. In Balderhead Dam, England, and later Teton Dam core trench in the USA, this factor became super critical.

And now a great change had come over the design of such structures. In this paper on Talbingo Dam, with hindsight, and in other dams with foresight, these things could be discovered analytically. Figures 4 to 9 of the paper showed it all. Where once things were sensed by reason or intuition, and later confirmed by instrument observation, now performance could be predicted very accurately by computation. This was a very great advance.

He had been surprised perhaps in the present analysis that, overall, the elastic methods came closer to the truth than the non-linear methods, but this was no doubt a matter of the input data chosen. Certainly, even rockfill was far from being elastic and earthfill even less so, so that non-linear methods must eventually prevail.

<u>Prof. Endersbee</u> - referring to fig.6, pages <u>1 to 10</u> - commented that the core was hanging on the shoulders from which prediction of pore pressures was made and that this was a major problem with the thin core in rockfill dams. Now with the modern numerical analysis it was possible to estimate the behaviour and to predict hydrostatic jacking. <u>Mr Hosking</u> commented that in the case of <u>Talbingo Dam</u> it was the pore pressures which were higher than those predicted due to change in optimum pore pressure with respect to time. It was the hydrostatic condition in the core rather than the hang up and they were aware of the existence of the problem.

Finally, Mr Adikari presented results of a refined analysis of pore pressures, referring to fig.7(b) which indicated a closer correlation between the measured and predicted values.