CHAPTER 1

1. BACKGROUND, INTRODUCTION, METHODOLOGY & OBJECTIVES

1.1. INTRODUCTION

In this Chapter, the author discusses the background and motivation for the work addressed in this PhD thesis. In addition, the approach to the investigations and analysis and the structure of the thesis document are outlined.

The title of the work presented is "A New Understanding of the Early Behaviour of Roller Compacted Concrete in Large Dams" and the behaviour in question is the effective volume reduction that occurs as a consequence of shrinkage and creep during the period that the concrete temperature is elevated by hydration heat. While the impact of this volume change may only become evident once the hydration heat has dissipated, which can take several years in the case of a large dam, the majority of the associated shrinkage and creep will probably occur within the first month, or two of placement.

1.2. BACKGROUND & MOTIVATION

1.2.1. BACKGROUND

Much has been published addressing the design and the thermal analysis of RCC dams, but no work has been published in the public domain to date to quantitatively compare the predicted early behaviour of RCC with the actual performance on a prototype structure. The scale and cost of any verification work of this nature are obvious and it must always be borne in mind that it is very difficult to motivate expenditure on the investigation of something that is in fact functioning quite satisfactorily and quite possibly even better than anticipated. Furthermore, the period over which performance data must be collected on a large prototype structure, with a hydration heat dissipation period of many years, or even decades, significantly complicates the achievement of a conclusive investigation.

As will be discussed in Chapter 3, the "Traditional" materials model and the "Conventional" analysis techniques generally applied to date have assumed that RCC behaves in the same manner as conventional mass concrete (CVC) during the hydration heating and cooling cycle, with consequential shrinkage and creep resulting in a net reduction in volume compared to placement typically in the range of 125 to 200 microstrain. In the case of a gravity dam, applying these assumptions is conservative, consequently adding an unquantified factor of safety into the design process. In respect of an arch dam, however, adopting such an approach may not necessarily be conservative (*see Chapter 7*), while it may also unnecessarily compromise the technical feasibility of such dam types. With only a small proportion of the world's RCC dams constructed to date being arch, or arch/gravity dam types, this issue has not been of particular significance in the past.

Furthermore, the construction of very high RCC dams (> 150 m) is something of a recent development and accordingly, a conservative approach of favouring gravity-type dams on this scale has so far generally been applied. It must of course be borne in mind that most of these large RCC structures remain decades away from reaching a condition of thermal equilibrium. However, with very high quality concrete now being generally produced by roller compaction, arch-type RCC dams are seen, with increasing frequency, to be the favoured solution at numerous sites and consequently the need for a more precise knowledge of the early behaviour of RCC is becoming critical.

1.2.2. MOTIVATION

The experience of the author has repeatedly suggested that high-paste RCC does not suffer to the same extent as CVC from early shrinkage and creep effects during the hydration cycle. Without quantitative investigation and analysis, however, these subjective observations are of no material value and the consequential need for a detailed investigation was obvious.

Experience in South Africa[3 & 4] and China[5] has demonstrated that the construction of arch dams in RCC is both possible and economically advantageous. For a topographically and geotechnically suitable site, where simplicity and access allow efficient construction, an RCC arch dam type will represent a highly efficient solution. With the production of high quality concrete through roller compaction now widely acknowledged, the application of RCC in arch dams is accordingly likely to become more prevalent.

Many issues related to the construction of arch dams in RCC have been resolved through construction experience and development. Adequate inter-layer bond can be achieved with the correct RCC mix, placement approach and layer surface treatment, while the inducing and directing of joints can now consistently be achieved with confidence. Although the realities of installing effective systems for induced joint grouting are not generally acknowledged, or understood, appropriate solutions have been developed and these will undoubtedly continue to undergo ongoing improvement through future application.

In order to ensure that arch dams can be confidently and efficiently designed and constructed in RCC, however, certain inter-related issues of particular importance must be given specific attention. These can be summarized as follows:

- The early behaviour of RCC under thermal loads.
- The management of hydration heat and joint grouting.
- The ongoing development of efficient induced joint grouting systems.

To facilitate the effective design of hydration heat management and induced joint grouting, it is of fundamental importance that the early behaviour of particularly high-paste RCC, in respect of shrinkage and creep, be better understood.

For a dam designer, the findings presented subsequently in this thesis are of very significant impact. It is not realistically possible to design an RCC arch dam for a shrinkage strain from placement of 200 microstrain. Such a dam would have to cool and be grouted before loading, as is the case for a conventional concrete dam. Otherwise, the stresses would be so high as to be at a level of potential failure. In the case of an RCC arch, the requirement for post-cooling and/or the necessity to delay loading would give rise to the loss of many of the benefits otherwise associated with RCC construction, particularly in the case of a large dam.

If the net shrinkage strain is limited to approximately 50 microstrain, however, it is quite possible to design a dam that can be loaded before it cools. In the case of large gravity dams, the findings imply a reduced sensitivity to cracking parallel to the dam axis and/or a reduced requirement for RCC pre-cooling and restrictive placement temperature specifications.

The foregoing implies that this work makes a very meaningful contribution to the state of the art of RCC dam engineering and will result in real cost savings on large dam construction. With a proven ability to design RCC mixes for significantly reduced shrinkage and creep during the hydration cycle, a complete change in approach and mix testing requirements for the design of RCC arch dams will result.

1.3. RESEARCH OBJECTIVES

1.3.1. Thesis Objectives

The purpose of this study is to demonstrate that high-paste RCC in large dams does not necessarily behave in the same manner as CVC, or need not behave in the same manner if appropriately designed, under the early hydration heating and cooling cycle. On the basis of observation, interpreted and evaluated by modelling, the investigation provides evidence of the actual manner in which the behaviour of RCC differs from the assumptions traditionally applied for dam design and attempts to establish the associated reasons behind these differences.

1.3.2. Key Research Questions

The traditional "early behaviour model" for RCC dam design assumes the same materials properties and behaviour characteristics as conventional mass concrete in respect of shrinkage and creep. The associated design approach equates the consequential reduction in volume from placement to a thermal shrinkage, approximately equivalent to the adiabatic hydration temperature rise, or typically 125 to 200 microstrain. Recorded behaviour from several dams suggests that this approach is not appropriate and significantly overstates the total "shrinkage" experienced in high-paste RCC. The key research question addressed in this work can accordingly be stated as; "Is the traditional design approach that accounts for early shrinkage and creep in concrete dams valid in the case of high-paste RCC dams?"

1.3.3. Research Approach and Focus

The above objectives should be seen in the light of certain realities related to the scale and nature of a dam that will frustrate the absolute accuracy of the comparative analyses. For example, as a consequence of the indeterminate degree of restraint and the variability of the elastic and inelastic properties of concrete and the materials of a foundation rockmass, an evaluation of the stresses induced in mass concrete structures by temperature changes can be considered an estimation at best(2). Consequently, a parametric approach is required in a process of homing in on the set of behaviour characteristics for the RCC in question that most closely represents its actual performance within the prototype dam.

The study uses measured data from prototype structures to evaluate and quantify the observed early behaviour of high-paste RCC in large dams. By simulating the measured performance of a prototype structure through FE modelling, the study seeks to develop a meaningful picture of the actual behaviour of the constituent RCC, on the scale applicable within a large dam, during the process of hydration and subsequent cooling.

While thermal analyses for RCC dams have generally applied a high level of assumption in respect of the shrinkage and creep performance characteristics of the material, the work addressed in this study stands apart in presenting a meaningful comparison of assumed behaviour and actual measured performance.

1.3.4. Value of Research Findings

In comparing the actual structural behaviour of a high quality, high-paste RCC mix, in the context of a prototype dam, with a number of possible behaviour models, a new, and quite different picture of the early behaviour of RCC in large dams emerges. The introduction of this new understanding of the materials behaviour of high quality RCC will add another dimension into the design of large RCC dams and most particularly RCC arch-type dams.

1.4. SCOPE OF STUDY

The investigation presented herein evaluates the instrumentation data for four large prototype RCC dams and discusses preliminary construction instrumentation data from a fifth dam. On the basis of the observations made through measurement, the study goes on to review the associated behaviour of the RCC in each dam. To enable a quantitative evaluation of the behaviour of RCC, FE models are subsequently developed and analysed in an effort to reproduce, as accurately as possible, measured behaviour on a prototype structure.

Combining the temperature, strain and deformation data available for Wolwedans Dam over a period of over 15 years with the fact that the structure functions threedimensionally provided a unique opportunity to quantitatively investigate the early behaviour of the constituent RCC, specifically in respect of the total apparent volume reduction assumed to be associated with autogenous shrinkage and creep.

Having demonstrated the assumptions in respect of autogenous shrinkage and creep traditionally applied for RCC dam design to be exaggerated in the case of a high-paste RCC, the associated reasons are explored.

A new understanding for the early behaviour of high-paste RCC is consequently proposed and the implications of this materials model on the future design of both gravity and arch-type RCC structures are discussed.

Due to the fact that the hydration heat will take several decades to be fully dissipated from a very large dam, the availability of data in respect of the performance of RCC under long-term temperature load in large dams is limited. Wolwedans and Knellpoort Dams in South Africa have been in operation for almost 2 decades and, as a result of their relatively modest size, all of the hydration heat has long since been dissipated, allowing analysis of the long-term thermal effects. In the case of Çine Dam in Turkey, its large size implies that very little of the hydration heat has yet been lost, while Wadi Dayqah Dam in Oman was only very recently completed. As a consequence, it is not yet possible to review the performance of the latter two dams during the heat dissipation cycle phase.

Due to the fact that only strain, and not stress, can realistically be measured in RCC, it is very difficult to establish when creep is occurring under stress. Furthermore, dam instruments do not always function particularly predictably; one gauge might indicate one reading in a particular location, while another might indicate something quite different, despite the fact that conditions are similar.

There are also many factors of influence to assimilate when reviewing dam instrumentation data. Poorly installed, or located instruments and incomplete data will often result in the emergence of a complex picture, which requires detailed consideration in order to identify meaningful trends. Dams are complex, three-dimensional structures constructed on rockmasses with divergent and variable properties and the evaluation of instrument measurements can often involve resolving conflicting data and the development of explanations for identified anomalies.

1.5. LITERATURE & PUBLICATIONS IN DAM ENGINEERING

1.5.1. General

Dam engineering is unlike other forms of engineering in that many decisions on important aspects are left to the judgement of the dam engineer. For this reason, many countries require that the experience and competence of practitioners be reviewed before they may be approved for work on dams of a certain size and importance. In South Africa, before an engineer may take responsibility for a certain task of work on a particular dam, his experience and qualifications for that task must be reviewed by a sub-committee of the Engineering Council and a recommendation made to the Minister of Water Affairs, in terms of Government notice R.1560 of 1986.

Furthermore, the state of the art of technology in dam engineering is maintained by ICOLD, the International Committee on Large Dams, and its national member committees, such as SANCOLD. The triennial Congress on Large Dams is recognised as the forum at which new developments in dam engineering are discussed and endorsed and the volumes of papers published at that forum are regarded as validated technology. Through its sub-committees and national committees, ICOLD also publishes bulletins on specific aspects of dam engineering. These, again, are considered to present the accepted state of the art in relation to any particular technology. The last bulletin on RCC, Bulletin 126, was published in 2003.

In view of the fact that RCC dam technology remains in the process of development, the Chinese and Spanish national committees of ICOLD organise a four-yearly Symposium at which the latest developments and trends in the technology are presented and discussed. Again, this forum is considered to record the state of the art in RCC dam technology. An early paper by the author on the subject of this thesis was considered of such importance that it was selected for presentation as one of the Keynote lectures for the RCC Symposium of November 2007, while Wolwedans Dam was recognised as one of the ten RCC milestone dams on the same occasion.

For a number of years, the United States Army Corps of Engineers (USACE) has published engineering manuals and technical letters on all manner of issues in engineering and their publications on dam engineering are recognised as the leading guidelines in respect of the design and analysis of dams. While regular peer review throughout the duration of a project, in the form of an external panel of experts, has become a matter of course in respect of large dams, probably the most used form of reference in such reviews would be the USACE publications.

Specialist journals that routinely cover dam engineering topics are realistically limited to the following publications:

- The International Journal of Hydropower & Dams. Aqua-Media International Ltd. (Wallington, UK);
- International Water Power & dam Construction. Progressive Media Markets Ltd (Sidcup, UK);
- Hydroworld - HRW. HCI Publications. (Kansas, USA).
- Dam Engineering. British Institution of Civil Engineers. (London, UK).

1.5.2. Available References

As a consequence of the above, the available references with specific relevance to the investigations addressed in this study are generally guidelines issued by the USACE and papers published at ICOLD congresses and the RCC Symposia. Furthermore, as a consequence of the nature of the work addressed, the period over which data needs to be recovered from a prototype structure, the complications of scale in respect of testing, the specialist nature of the problem in question, the stage of development of RCC technology and the developing relevance of the subject in question, very little work of a similar nature exists for reference and comparison. A review and evaluation of the available literature relating to the investigations in question is presented in Chapter 3 of this Thesis.

1.6. INVESTIGATION METHODOLOGIES

1.6.1. General

The investigations presented in this study are the work of a practising RCC dam engineer, with extensive experience in the design and construction of RCC dams and the use of Finite Element structural analysis techniques. The investigations start from the point of macro-scale observation, move through an analytical process of comparing and analysing modelled and prototype performance by Finite Element analysis and finally hypothesise and motivate the cause of the apparent behavioural differences of high paste RCC and CVC.

With data from four prototype RCC dams being analysed and evaluated, the apparent behaviour is repeatedly compared with what might have been anticipated on the basis of conventionally assumed behaviour. When induced joints do not open to the extent predicted, however, the installed instrumentation is generally not adequate to allow the cause of such behaviour to be isolated with certainty. The level of residual stress across un-opened induced joints and between the induced joints, for example, cannot be known, while the impact of the foundation restraint and various other factors cannot be definitively ascertained.

1.6.2. Modelling & Analysis

Simulating measured induced joint openings and crest displacements on a three-dimensional structure through FE modelling allows as real a picture of actual prototype performance and constituent materials behaviour as is ever likely to be possible on a structure with as many factors of influence as a large dam. Applying RCC behaviour characteristics that do not correspond with reality will quickly be demonstrated to cause the modelled structure to behave significantly differently to the prototype. Isolating the actual materials behaviour, it should be possible to simulate the prototype performance with a reasonable level of accuracy.

Essentially two specific performance characteristics of the prototype structure are used for comparison with the FE model; the joint opening at approximately mid-dam height and the crest displacements. The relative simplicity of the model and the applied materials properties with which it was possible to demonstrate that the traditional assumptions in respect of RCC behaviour are flawed is considered as important as the nature of the materials behaviour model itself.

The COSMOS FE analysis software was used for all structural and thermal modelling, with ten-noded solid tetrahedral elements in a high-density mesh. The model simulated the dam and a large section of the foundation, with each radial dam block between induced joints being developed as a separate part, joined to the adjacent blocks with Gap elements, which simply associated adjacent nodes with a friction factor when in contact. For analyses in which induced joints were not allowed to open, replicating the fact that these joints had not opened on the prototype, the Gap elements were simply omitted.

To simulate the effective reduction in concrete volume caused by a range of autogenous shrinkages and creep, which may have occurred during the hydration cycle, equivalent temperature drop loads were applied to the dam structure, using a linear thermal shrinkage/expansion coefficient. Initially, it was foreseen that it would be necessary to apply complex, non-linear materials properties for the dam structure, but the initial analyses, which used elastic properties for both the dam concrete and the foundation, proved quite adequate to accurately reproduce the actual performance measured on the prototype and consequently, all analyses were completed using linear-elastic materials properties.

1.6.3. NEW MODEL APPLICATION

In order to illustrate the impact and importance of the new materials understanding for the early behaviour of high paste RCC, various aspects of the design of the 105 m Changuinola 1 RCC arch/gravity Dam are presented by way of an example. Using the COSMOS FE software, a comparison is made of an appropriate joint spacing design on the basis of the traditional RCC behaviour assumptions and the proposed new understanding. Similarly, the significant impact of the new understanding on the arch design of the same dam is discussed and illustrated.

1.7. RCC DAMS & THE NEED FOR RESEARCH

1.7.1. GENERAL

Over the past two decades the construction of concrete dams by roller compaction has advanced significantly and it is now possible to produce a broad range of concrete qualities by roller compaction. While lower strength, lower deformation modulus and higher permeability RCC is applied for smaller gravity dams (< 100 kg/m^3 cementitious materials), generally in conjunction with an impermeable, upstream face PVC membrane, the preferred approach for most RCC dam construction now applies higher cementitious materials contents (> 150 kg/m^3 cementitious materials) to produce dense, impermeable, high strength mass concrete, as demonstrated by the continuous, bonded concrete cores routinely extracted during quality control testing.

Plate 1.1: Çine RCC

Roller Compacted Concrete (RCC) was first used in dam construction in South Africa in 1984 and at the time, the country was recognized as one of the pioneers of the technology. After the completion of just two significant gravity dams, South Africa's Department of Water Affairs felt sufficiently confident to apply RCC for the construction of arch dams and the design of the 70 m high Wolwedans and the 50 m high Knellpoort dams was initiated. Although Knellpoort is recorded as the first RCC arch/gravity dam in the world, arch action is only incurred during unusual and extreme loading. In the case of Wolwedans Dam, however, arching is initiated once the impounded water exceeds approximately 70% of full capacity.

1.7.2. RCC ARCH DAMS & EARLY RCC BEHAVIOUR

To date, the accommodation of early temperature loads in RCC dams has effectively been limited to the inclusion of induced transverse joints, while the approach to design has generally assumed that RCC behaves in a similar manner to conventional mass concrete (CVC) under hydration temperature rise and post-hydration cooling[6].

Although the above approach has been quite adequate for RCC gravity dam structures, the situation in respect of dams that rely on three-dimensional arching for stability is quite different.

In CVC arch dams, construction in vertical monolithic blocks with groutable joints in between (see **Plate 1.2**) and the inclusion of cooling pipes to remove hydration heat and cool the concrete to a suitable temperature for joint grouting together facilitate the management of the otherwise structurally problematic temperature impacts. Grouting the joints at a suitably depressed temperature consequently effectively eliminates significant temperature drop shrinkage as a loading condition. This approach essentially accommodates all of the volume reduction in the concrete that is experienced after placement, i.e. autogenous shrinkage, drying shrinkage, stress relaxation creep and thermal shrinkage.

Plate 1.2: Typical Large CVC Arch Dam Construction(7)

In the case of RCC, however, vertical joints must be induced, while the installation of an extensive network of embedded cooling pipes is realistically impractical. Consequently, long-term shrinkage becomes an issue of greater significance in the case of an RCC arch dam and a comprehensive understanding of the behaviour of RCC under applicable early thermal loading takes on a particular importance.

1.7.3. The Need for Research

In view of the relatively untested status of RCC technology at the time at which construction at Wolwedans Dam was initiated, it was considered appropriate to install a very comprehensive system of monitoring instrumentation, as described in Chapter 2.

During the course of ongoing monitoring of the installed instrumentation at Wolwedans Dam, a picture started to emerge that demonstrated lower levels of displacement and smaller induced joint openings than had been anticipated in the dam design. In view of the fact that these observations suggested better than expected performance, however, no specific efforts were made to investigate the causative RCC behaviour.

Evaluating the possible origins of this anomalous behaviour, it appeared that significantly less creep than typically occurs in large-scale mass concrete (CVC) during the process of hydration heat development and dissipation might in fact have occurred in the RCC at Wolwedans. This would contradict conventional wisdom, which assumes that RCC behaves in a similar manner to CVC in respect of early shrinkage and creep. Undertaking a quantitative evaluation of this hypothesis, however, was not a straightforward matter, particularly as a consequence of the fact that the dam structure was under load before the effects of the hydration heat had been fully dissipated, the fact that it is not realistically possible to measure stress within RCC and the fact that the three dimensional structural action caused it to be impossible to isolate temperature-specific joint openings.

With instrumentation in later RCC dams suggesting similar patterns of behaviour, it has been the author's long held ambition to undertake an appropriate programme of research, modelling and analysis, with the objective of investigating more thoroughly the actual shrinkage and creep behaviour of high quality RCC under early hydration temperature development and dissipation.

1.8. ORGANISATION OF THE REPORT

CHAPTER 1: INTRODUCTION

Chapter 1 describes the background, motivation and objectives of the investigations undertaken. The approach, scope and structure of the work presented are also discussed.

CHAPTER 2: RCC DAMS INSTRUMENTED, RCC CONSTRUCTION ISSUES AND APPLIED INSTRUMENTATION

In Chapter 2, the dams that form the basis of this thesis are introduced and a brief description of the respective instrumentation installed is provided. In addition, RCC dam construction is described, with particular reference to the methods applied to induce joints and how these influence deformation and strain measurement. The instruments installed to measure strain and joint opening are described and comments are made on respective reliability and accuracy.

CHAPTER 3: LITERATURE AND REFERENCE: THE TRADITIONAL APPROACH TO DAM DESIGN IN RESPECT OF EARLY CONCRETE BEHAVIOUR AND TEMPERATURE LOADS AND THE ASSOCIATED APPLICATION FOR RCC DAMS

In Chapter 3, the state of the art in respect of the early behaviour of concrete in dams is explored through reference, with particular attention to shrinkage and creep and the methods applied to address these issues in dam design. The associated design approach generally applied for RCC is discussed and the compositional differences between RCC and CVC in dams are explored.

CHAPTER 4: STUDYING THE INSTRUMENTATION DATA FOR WOLWEDANS, KNELLPOORT, ÇINE, WADI DAYQAH & CHANGUINOLA 1 DAMS

In Chapter 4, the author presents instrumentation data from the Wolwedans and Knellpoort Dams in South Africa, Çine Dam in Turkey, Wadi Dayqah Dam in Oman and Changuinola 1 Dam in Panama. The indicated performance and behaviour are reviewed and discussed and indications that suggest a possible different behaviour pattern for RCC compared to CVC under hydration heat development and subsequent cooling are highlighted.

CHAPTER 5: SIMULATING PROTOTYPE MATERIALS BEHAVIOUR THROUGH FINITE ELEMENT MODELLING FOR WOLWEDANS DAM

In Chapter 5, the comparative evaluation of the behaviour of the constituent RCC of Wolwedans Dam is described through a series of parametric Finite Element Analyses. In addition, preliminary observations of early RCC behaviour at Changuinola 1 Dam are compared with predictions derived from the Thermal analysis.

The Chapter comprises four sections; the first three addressing a progressive development of the Wolwedans FE analysis. The first analysis seeks to develop a better understanding of the surprisingly small induced joint openings at mid-height, while the second reviews the joint opening profile and the differential temperature drop variations and loads across the dam section and the third reproduces measured joint openings and crest displacements in an effort to establish the order of total shrinkage experienced. The fourth section of Chapter 5 describes briefly the Thermal Analysis for Changuinola 1 Dam and compares the predicted performance with observations and measurements to provide indications of the apparent early RCC behaviour.

CHAPTER 6: DEVELOPING A NEW UNDERSTANDING OF THE EARLY BEHAVIOUR OF RCC IN LARGE DAMS

In Chapter 6, the indicated behaviour demonstrated through the earlier analyses is reviewed and discussed and conclusions are presented. Applying typical Elastic modulus development models and creep models, the creep levels that might be expected to have been evident in the RCC at Wolwedans Dam are compared with the values apparent from the analyses.

In view of the fact that these conclusions suggest that the total shrinkage and creep experienced in the RCC of Wolwedans during the time that the temperature was elevated by hydration heat were substantially lower than would have been expected for CVC, or a low quality RCC, the associated reasons and potential behaviour mechanisms are discussed.

CHAPTER 7: THE INFLUENCE OF THE BENEFICIAL BEHAVIOUR OF HIGH-PASTE RCC ON DAM DESIGN

In Chapter 7, the impact of the better early behaviour of high-paste RCC on dam design is illustrated through the induced joint spacing design, the thermal study, the maximum allowable RCC placement temperature and the arch performance of the 105 m Changuinola 1 arch/gravity dam currently under construction in Panama.

The most significant relevance of a better early behaviour of high-paste RCC will relate to the design of RCC arch dams and the consequential differences in design approach compared to conventionally assumed behaviour are discussed in this Chapter.

CHAPTER 8: STUDY SUMMARY & CONCLUSIONS

In the concluding Chapter, the work presented is summarized, the application of the study findings is discussed and the need for ongoing industry involvement and contribution is highlighted. A summary of the New Understanding of the Early Behaviour of RCC in Large Dams is presented and the methodology for its application in the design of RCC dams is motivated.

1.9. ACKNOWLEDGEMENTS

1.9.1. Wolwedans & Knellpoort Dams

For its diligent efforts in monitoring instrumentation and their assistance in making data available for Wolwedans and Knellpoort Dams, the South African Department of Water Affairs is gratefully acknowledged.

1.9.2. Çine Dam

The Turkish State Hydraulic Works (DSI) is thanked for its permission to use instrumentation data measured at Çine Dam.

1.9.3. Wadi Dayqah Dam

The Ministry of Regional Municipalities, Environment and Water Resources of the Sultanate of Oman is thanked for its permission to use instrumentation data measured at Wadi Dayqah Dam.

1.9.4. Changuinola 1 Dam

CCWJV of Changuinola of Panama is thanked for its permission for the author to refer to the structural and thermal analyses for Changuinola 1 Dam.

1.10. REFERENCES

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