CHAPTER 6

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

6.1. INTRODUCTION

On the basis of the reviews, evaluations and analyses presented in earlier chapters, it is clear that the traditional assumptions in respect of the early behaviour of high-paste RCC in large dams are not generally valid. In this Chapter, the origins of the apparent reduced shrinkage and creep experienced in high-paste RCC, compared to CVC, are explored, reasoned and motivated.

Plate 6.1: Wadi Dayqah Dam, Quriyat, Oman – August 2009

6.2. THE FINDINGS OF THE INVESTIGATIONS AND ANALYSES

6.2.1. DEFINITIVE FINDINGS

The structural modelling completed as part of the investigations addressed herein suggested that the RCC of Wolwedans Dam could not have been impacted by any significant shrinkage or creep during the hydration heating and cooling cycle. There can be no doubt that should the level of shrinkage and creep conventionally assumed for dam design have in fact occurred, very different structural behaviour to that recorded on the installed instrumentation would have been evident.

The measured un-restrained thermal expansion of the RCC in the core zones of both Çine Dam and Changuinola 1 Dam is considered extremely significant and strongly indicative of the mechanisms that cause RCC to be more creep-resilient than CVC. In mass concrete (CVC) in the core of a dam structure, it would typically be assumed that internal restraint would cause most of the theoretical thermal expansion due to the hydration temperature rise to be lost to creep in the immature concrete. The fact that the thermal analysis of an observed crack in the RCC at Changuinola 1 Dam demonstrated that no significant creep could have occurred is considered to further increase the confidence levels in the observed linear thermal expansion.

While the instrumentation data indicated that some creep or shrinkage undoubtedly did occur in the RCC at Wadi Dayqah Dam, this was a lean mix RCC containing a high quantity of non-cementitious fines and lower quality coarse aggregates. Considering the analyses presented, the instrumentation data evaluated and information available from earlier publications, it would seem that the reduced shrinkage/creep behaviour very specifically relates to higher strength, high quality, high-paste RCC.

On the basis of the above, it can be stated with confidence that it is no longer necessary to assume in dam design that a high-paste RCC acts in the same manner as CVC in respect of the development of shrinkage and creep during the hydration cycle.

6.2.2. REMAINING QUESTIONS & DISCUSSION

Realistically, it will never be possible to model the behaviour of a large prototype dam structure with complete accuracy. Too many indeterminate factors can influence the final behaviour and consequently, although the analysis results for Wolwedans Dam suggest no creep, or shrinkage occurred during the hydration heating and cooling cycle, an appropriate conclusion would be that the impacts of creep and/or shrinkage were negligible.

As concrete, by its nature, is inherently susceptible to autogenous shrinkage and creep, such a conclusion can be considered surprising and it is necessary to advance a meaningful hypothesis on which basis the mechanism that causes the related behaviour of RCC to be so different from that of CVC can be meaningfully proposed. In addition, it must be remembered that Wolwedans Dam is an arch structure and the measured displacements relate specifically to the structural behaviour of the arch and particularly the upper part of the structure. Consequently, it would be of value to investigate the actual stress condition is this upper section of the arch whilst the dam temperature was elevated by the hydration heat.

6.3. SIMPLIFIED ANALYSIS OF WOLWEDANS BEHAVIOUR UNDER HYDRATION TEMPERATURE RISE

6.3.1. GENERAL

As mentioned in Chapter 5, most of the structural arch action in Wolwedans Dam is carried within the upper 20 m in the centre of the dam. Consequently, it is in this particular area that the specific early behaviour of the RCC is most relevant and accordingly, it is considered of value to review the associated stresses and strains that would be developed there due to the hydration temperature rise.

6.3.2. MODELLING

To construct a true, three-dimensional model of the actual conditions experienced within the dam structure immediately after construction completion would be extremely complicated and it would never be possible to assure a high degree of accuracy. In the case of an RCC dam, as any particular part of the dam structure is being placed, the temperature of the part beneath that is one week old is approaching its peak hydration temperature. Consequently, RCC at any point is generally placed on top of other RCC that has been effectively swollen by thermal expansion, assuming that restrained expansion stresses are not dissipated in creep. While this will develop consequential internal stress mechanisms of indeterminate impact, it also implies that any related modelling cannot realistically be anything more than indicative.

6.3.3. ANALYSIS

With the above in mind, the hydration temperature rises measured within the Wolwedans Dam(1) wall were applied in a simplified and simplistic manner to a Finite Element model. Acknowledging that the model will tend to overstate the reality as the temperature rises are applied to the final structure instantaneously, the resultant stresses and displacements can only be evaluated on a qualitative basis.

Figure 6.1 indicates the distribution of the temperature rises that was applied in conjunction with a coefficient of thermal expansion of 10 x 10^{-6}/°C and an E modulus of 20 GPa.

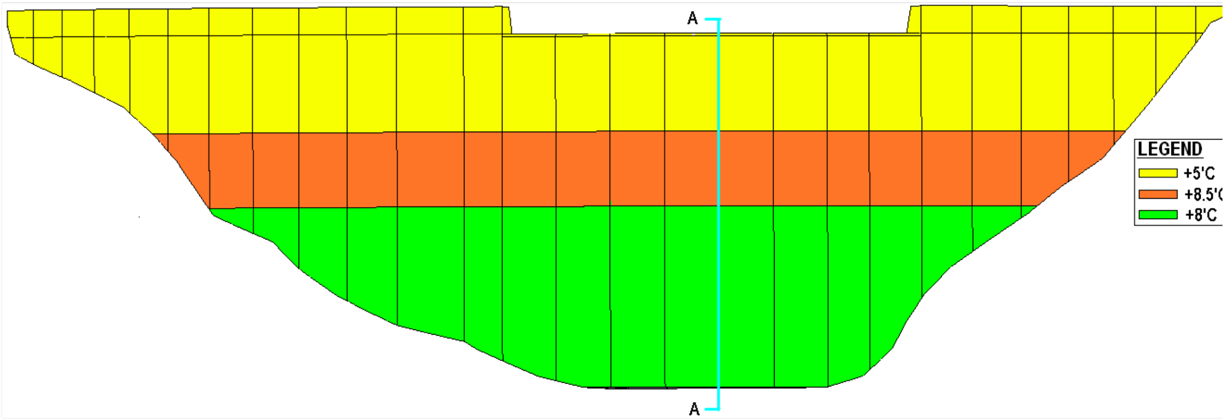


Figure 6.1: Simplified Hydration Temperature Rise Inputs

6.3.4. ANALYSIS RESULTS

Figures 6.2 to **6.5** present the resultant displacements and the arch (lateral - abutment to abutment) stresses on the crown cantilever (Section A-A) for the above temperature rises, with and without the inclusion of gravity. Compression stresses are indicated as -ve.

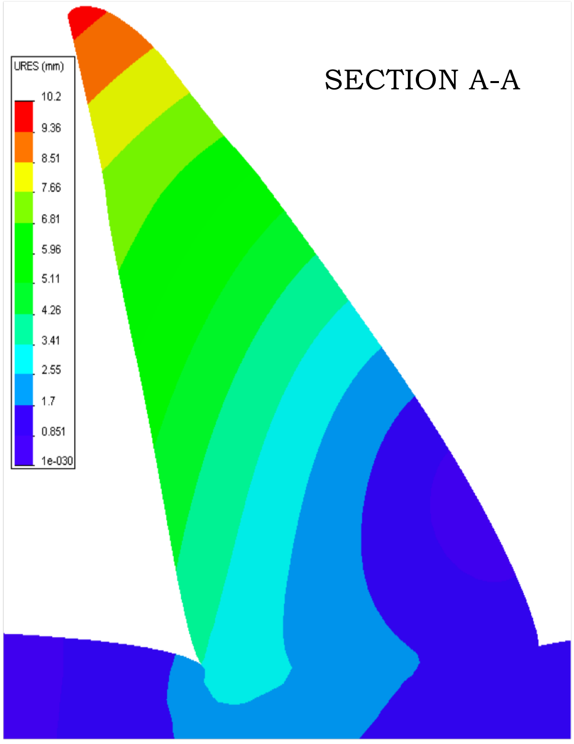


Figure 6.2: Deformation – Temperature Rise + Gravity

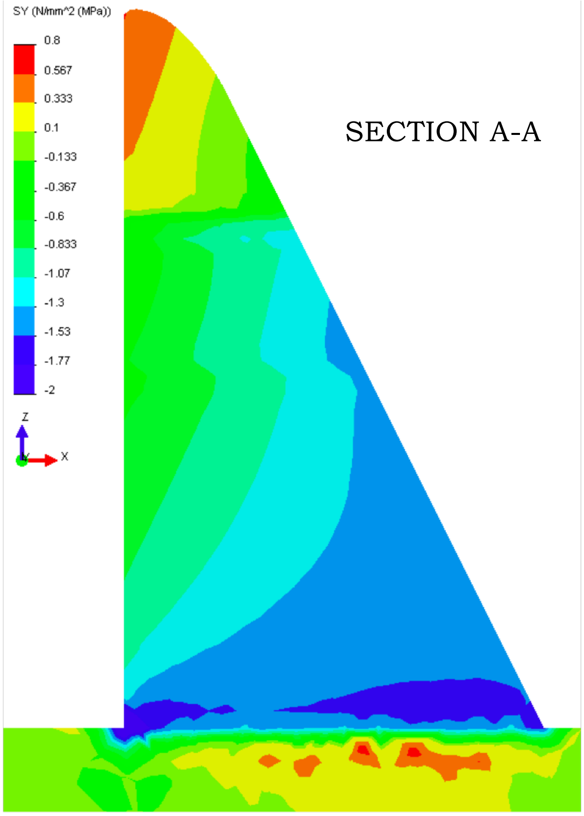
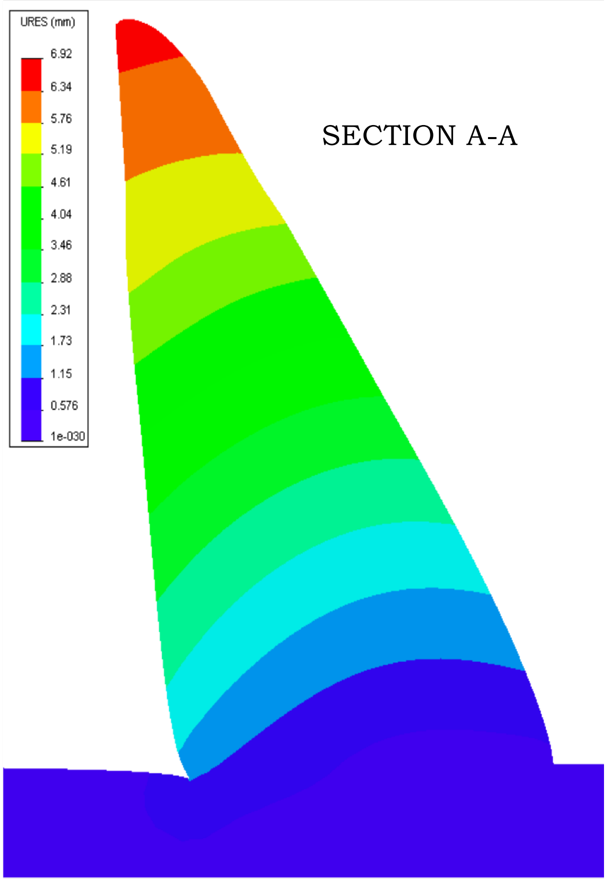


Figure 6.3: Arch Stress – Temp. Rise + Gravity



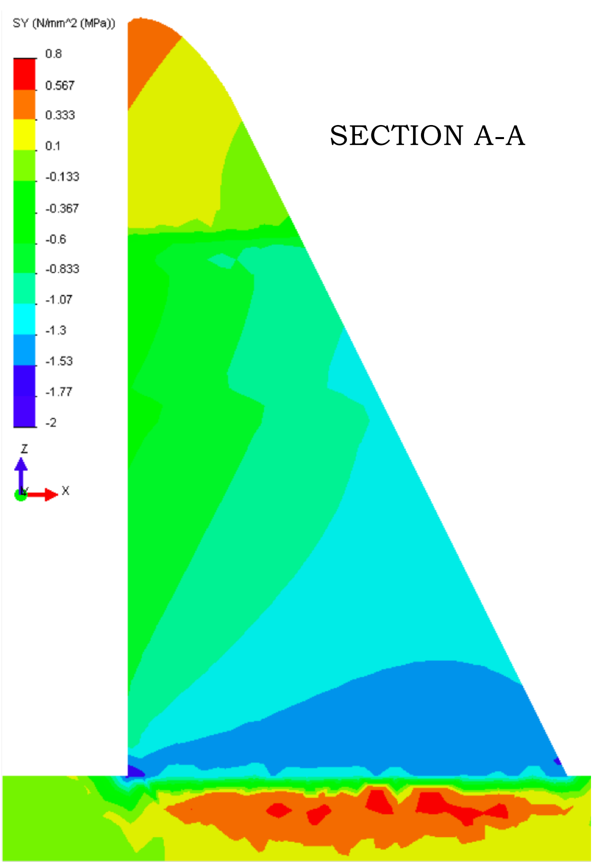


Figure 6.4: Deformation – Temperature Rise (No Gravity)

Figure 6.5: Arch Stress – Temp. Rise (No Gravity)

6.3.5. RESULT INTERPRETATION

The analysis results indicate that thermal expansion causes the crest of the dam structure to displace upstream. With gravity load, the upstream displacement increases. Reviewing the arch (lateral) stresses, it can be seen that the thermal expansion and upstream gravity movement cause tensile stresses to develop in the top 20 m of the dam structure in the centre, increasing towards the upstream face. At mid-height, the level of the instrumentation at which the joint openings were referenced for the analyses in Chapter 5, lateral compressions vary from approximately 350 kPa at the upstream face to approximately 1 MPa at the downstream face.

For a contained thermal expansion associated with a temperature rise of approximately 8°C, a coefficient of thermal expansion of 10×10^{-6}/°C and an E modulus of 20 GPa, a direct lateral compression of 1.6 MPa could be anticipated. On the stress plots, such high lateral compressions are only indicated close to the base of the dam.

It can accordingly be seen that the evident upstream movement of the crest effectively increases the radius of curvature of the arch with height, causing increasing tension in the direction of the arch (laterally) to be experienced with increasing height and distance from the downstream face. This would imply that the RCC in the crest of the dam structure would have been able to expand in an unconstrained manner when subject to the hydration temperature rise.

6.3.6. RESULT IMPLICATIONS

The indicated behaviour will have effectively given rise to low, or no lateral containment stresses in the RCC placed in the upper section of the dam structure at Wolwedans. With strain gauges in this type of RCC indicating no measurable creep due to internal restraint under thermal expansion, even on very large RCC sections, it is accordingly not surprising that none would then have been incurred in the relatively thin section of the crest at Wolwedans Dam. With no lateral containment stress, it would seem very likely that completely unrestrained thermal expansion consequently occurred and without stress, no stress-relaxation creep can occur.

At mid-height, some compression/containment stresses are evident, although on average probably less than half the value that might have been anticipated for full containment. In view of the fact that no quantifiable creep/shrinkage could be determined through the evaluation of the joint openings at this level, it would appear that the indicated stress levels remain too low to incur any significant creep.

6.3.7. DISCUSSION & CONCLUSIONS

While the analysis completed is simplistic in nature, the impacts of the arch geometry, gravity forces and thermal expansion in effectively opening up the crest of the arch at Wolwedans is clear. While this effect could go some way in explaining the lack of measurable creep in the RCC in the important structural areas of Wolwedans Dam, particularly when considering the evident ability of high-paste RCC to expand relatively freely under a temperature rise, the RCC similarly does not seem to have suffered creep under compressive stress levels of up to 1 MPa.

Due to the simplifications made in the model and analysis presented, it is considered that the beneficial, stress reduction effect demonstrated is overestimated, although not by a particularly significant margin. The arch geometry, gravity and the overall swelling caused by thermal expansion will, however, undoubtedly have contributed to a reduction in the containment stresses in the direction of the arch curvature in Wolwedans Dam, as it will in any RCC arch dam, and this can only be seen as beneficial in reducing the risks and/or magnitude of creep in RCC during the hydration heating cycle.

It is further considered that the indicated effect is likely to be more pronounced in RCC than CVC due to the former’s increased resilience to creep under thermal expansion, as demonstrated at Çine and Changuinola. In CVC, creep under internal restraint during the hydration temperature rise will limit the extent of the thermal expansion that serves to reduce constraining stress in the arch towards the crest.

6.4. RCC BEHAVIOUR MECHANISMS

6.4.1. LITERATURE & INVESTIGATIONS

Discussing the typical influences listed in published literature, it is clear that the materials composition and the compaction process applied for high-paste RCC gives rise to perhaps the most ideal conditions possible in a concrete for minimising shrinkage and creep. Furthermore, the fact that the reduced creep behaviour of an RCC with aggregate particle-to-particle contact has been previously recognised(2) confirms the fact that roller compaction can develop such a structure in an RCC mix.

The evident unrestrained expansion measured under a temperature rise at both Çine and Changuinola 1 dams provides evidence that the early behaviour of high-paste RCC would seem to be determined much more significantly by its aggregate skeletal structure and aggregate-to-aggregate particle contact than its paste content, as is the case for CVC.

6.4.2. AGGREGATE SKELETAL STRUCTURE

It is considered that the method of compaction is a factor in decreasing the susceptibility of RCC to shrinkage and creep. The skeletal structure of the aggregates in concrete acts to restrain the shrinkage of the paste during hydration and the compaction energy exerted on RCC undoubtedly ensures that this skeletal structure is better developed, with significant inter-aggregate particle contact.

In an over-pasted RCC, with a low modified Vebe time, the roller compaction squeezes the aggregates together, lubricated by the paste. With the kneading action and energy of the roller, the aggregate particles re-orientate and displace paste until full inter-particle contact is created and the minimum void ratio of the particular blend of aggregates used is achieved, with all voids filled with paste and the excess paste displaced onto the top surface.

Plates 6.1, **6.2** and **6.3** compare typical mass concrete cores from dams with a core from a typical modern high-paste RCC.

The higher coarse aggregate content in the RCC is very evident, as is the better particle shaping and the continuity of the aggregate grading. The significantly better developed aggregate skeletal structure in the RCC compared to the CVC can also be readily discerned.

Plate 6.1: Typical Low Grade Dam Mass Concrete (1950s)

Plate 6.2: Typical Modern Dam Mass Concrete

Plate 6.3: Typical Modern High-Paste RCC

Essentially, in a concrete with a structure made up of aggregate-to-aggregate contact, compacted together tightly, autogenous shrinkage of the in-filling paste will be of substantially less impact than for a concrete in which loose aggregates are effectively suspended in a medium of paste. In the former case, while the paste shrinkage will be reduced by the restraining action of the surrounding skeletal structure, the skeletal aggregate structure itself will further resist the consequential tendency for the concrete to shrink due to the fact that it is already at its minimum void ratio. Accordingly, while the paste can shrink within the spaces between the aggregates, these spaces cannot reduce in size without movement, or collapse of the skeletal structure. In the case of aggregate suspended in a medium of paste, paste shrinkage and any subsequent moisture loss will result in significantly more direct shrinkage of the concrete.

Where paste shrinkage does not result in a fully equivalent shrinkage of the concrete, some internal micro-cracking must be incurred. This, in turn implies that voids have been developed within the concrete, which will increase its susceptibility to creep under compressive loading. Similarly, any subsequent loss of moisture will give rise to voids and an increased susceptibility to creep under compression. A well-developed and fully compacted aggregate skeletal structure will again serve to reduce the susceptibility to creep under low levels of compressive stress, as the majority of micro-cracking will occur inside the in-filled voids of the aggregate skeletal structure and a greater amount of strength will accordingly be maintained within the structure itself.

A comparison can be made between RCC and Rubble Masonry Concrete, which seemingly never exhibits cracking in dams. This material is formed by the insertion of large rock plums into a medium of mortar. Again the rock structure seems to predominate, with all shrinkage occurring in the form of micro-cracking within the mortar. During paste and mortar shrinkage, the overall volume of the matrix is maintained by the structure of the interlocking large rock particles.

The above discussion and the associated differences between RCC and CVC are illustrated in **Figures 6.6** and **6.7**.

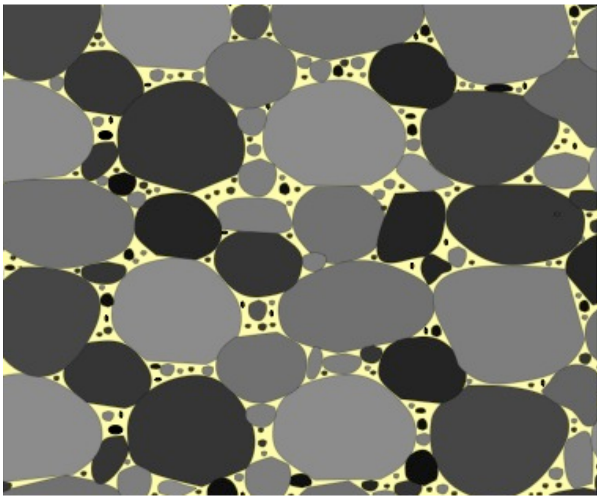


Figure 6.6: RCC Aggregate Skeletal Structure

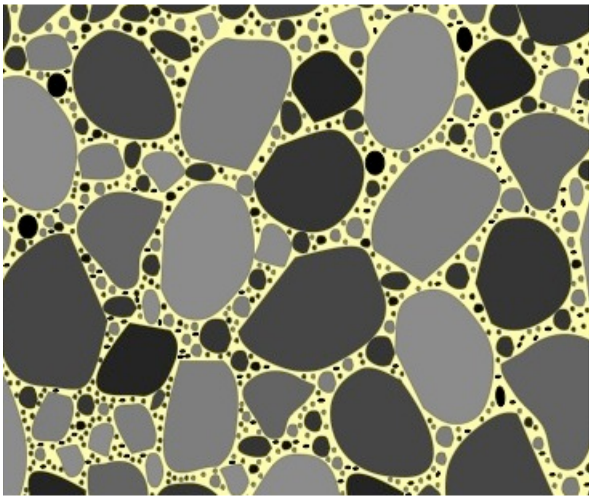


Figure 6.7: CVC Aggregate Skeletal Structure

With the process of compaction of a modern, mobile, high pozzolan content RCC involving expelling of the air and paste from the internal structure until the aggregates achieve their minimum void ratio, the resultant concrete is a structure of aggregates, with the voids filled with paste. In the case of CVC, the paste must provide a more liquid medium through which to move the aggregates and to lubricate their motion with substantially less energy. An immersion vibrator-compacted concrete is consequently more a structure of paste containing aggregate particles.

In a constrained condition the aggregate skeletal structure in high-paste RCC will be maintained in its closed, tightly compacted state, implying a certain ability to carry load even without any paste strength and a significant resistance to a reduction in volume, which would be maintained despite internal shrinkage of the paste. When expanded by temperature in an un-constrained state, the tightly bound and interlocked aggregate skeletal structure may even result in exaggerated expansion. Should this occur, a certain amount of aggregate point-to-point contact would be developed. With time, some crushing/collapsing of these aggregate points may well occur, resulting in a gradual relaxation (creep) of the expansion.

It is considered likely that fly ash in an RCC mix adds significant benefits, through increasing the mobility of the paste and slowing the rate of moisture loss by reducing permeability. Despite the fact that modern, high pozzolan content RCC takes on a spongy appearance once all the air is removed and full compaction is achieved, experience has repeatedly demonstrated that this RCC remains exceptionally resilient to shrinkage and creep. In view of the fact that fly ash has been demonstrated to reduce creep in concrete(3), it is considered likely that the autogenous shrinkage of cementitious paste is reduced when fly ash is used in relatively large proportions.

6.4.3. SUMMARY

On the basis of the preceding review, it is quite clear that the best performance from RCC, in respect of least shrinkage and creep during the hydration cycle, can be anticipated in a high-paste, low water content mix, with well-graded, high quality aggregates and particularly sand with a relatively low compacted void ratio.

6.5. A NEW UNDERSTANDING OF THE EARLY BEHAVIOUR OF RCC IN DAMS

6.5.1. DISCUSSION

The investigations and analyses completed as part of the studies addressed in earlier chapters have demonstrated that a high-paste, high strength RCC mix in an arch structure need not exhibit any significant levels of shrinkage, or creep during the hydration cycle. Lower strength and lean RCCs and mixes with less than ideal materials, however, remain likely to exhibit shrinkage and creep and a correspondingly increased susceptibility to creep under stress. Particularly low strength RCC mixes and those designed for a high deformability can actually demonstrate very high levels of creep under load(4).

It is, however, high quality, high-paste RCC that is of greatest interest as part of this Thesis, the type of RCC that would be used for the construction of a significant arch dam. In this regard, it is significant to note that the typical mix proportions, the improved aggregate specifications, the mobility of the mix under compaction, the aggregate skeletal structure developed and the continuity of construction associated with high-workability RCC create possibly the ideal circumstances for the minimisation of creep during the hydration cycle. Constructing a dam structure on a curve and thereby reducing the constraining stresses in the crest is also considered beneficial in reducing the likelihood of creep. The thinner and more flexible the arch, the lower the associated constraining stresses.

The strain gauge (SGA gauges) data recorded at Çine Dam and Changuinola 1 Dam are considered of particular importance. The apparent linear thermal expansion evident in a location that would be assumed to be subject to significant internal restraint is considered to provide evidence of a behaviour that is dominated by aggregate-to-aggregate particle contact. The fact that such linear expansion occurs in RCC at such an early age provides further evidence of an inherent early resistance to creep and the likelihood of increased creep resistance in the mature concrete.

As a result of the fact that early shrinkage and creep in concrete are interdependent effects that occur simultaneously during the process of maturation, a realistic separation of the two is not practically possible. Furthermore, the early development of internal shrinkage obviously creates a susceptibility to creep under load. With drying shrinkage in the core of a mass concrete block generally agreed as being negligible(5), unless related to a specific problem in the aggregates, the important shrinkage is autogenous shrinkage. While the terms shrinkage and creep are used together in this Thesis, the dominant effect is undoubtedly manifested as creep; a stress relaxation that occurs when the temperature rise associated with the hydration process attempts to cause thermal expansion in immature concrete.

6.5.2. DEFINITION OF RCC SHRINKAGE AND CREEP BEHAVIOUR

On the basis of the findings of these studies, it is clear that high-paste RCC indicates less shrinkage and creep than an equivalent CVC during the hydration and cooling cycle. Certainly, the conventionally accepted combined shrinkage and creep values varying between 125 and 200 microstrain are not evident in such an RCC.

For a high-paste, high pozzolan content RCC mix, with well-graded, high quality aggregates in an arch dam, it is undoubtedly possible to produce an RCC with negligible shrinkage and creep.

In view of the fact that the shrinkage/creep characteristics of any RCC will always be dependent on the nature, gradings and the effective compaction of its constituent materials, it is considered essential to treat each set of circumstances on a case-specific basis. If a low shrinkage/creep RCC is important to the dam design, as would be in the case of an arch, specific efforts should be invested in materials testing and the construction and instrumentation of a full scale RCC trial. In such circumstances, all aggregate sizes should undergo absorption and shrinkage testing.

For the preliminary design of a gravity dam constructed with a high quality, high-paste RCC, it is considered appropriate to assume a total shrinkage and creep of approximately 50 microstrain.

In the case of an RCC arch, or arch/gravity dam, it would generally be appropriate to design the RCC mix for minimum shrinkage and creep, which would require high quality aggregates and a mix comprising approximately 200 kg/m^3 cementitious materials, of which approximately 70% would be a high quality fly ash. In such a situation, however, it is considered appropriately conservative at this stage to assume a total shrinkage/creep of the order of 20 microstrain for preliminary design, but verification testing would be required before a definitive reliance could finally be placed on such performance.

In the design analyses for an RCC arch/arch gravity dam, it is considered important to include some form of an evaluation of the anticipated construction behaviour and the associated stresses in the critical parts of the structure.

As the findings of the investigations described herein gain broad exposure and become generally accepted, more dams will be appropriately instrumented, more information will be reported and a significantly greater database of RCC shrinkage and creep behaviour will be developed. With the confidence that a broader base of information will provide, it may eventually be possible to design RCC for negligible shrinkage and creep with complete certainty. However, until that time, it considered appropriate that some degree of conservatism be retained.

Significant attention should be given to the composition and structure of RCC mixes and the findings of this study are not considered to be applicable in the case of lower quality aggregates, with a tendency for drying shrinkage.

6.5.3. NECESSARY TESTING

The SGA strain gauges at Çine Dam and the first strain gauge installed in Changuinola 1 Dam demonstrated that it is in fact possible to predict over a relatively short period, the typical creep behaviour under thermal expansion that might be anticipated for a particular RCC mix. It is consequently recommended for all significant RCC dams, where the early thermal behaviour is of importance, that strain gauges be installed in the full scale RCC trial embankments, such that a record of temperature and strain can be developed and any plastic behaviour can be observed and measured. This monitoring should be preceded by aggregate and mortar laboratory testing to ensure that the characteristics of the constituent materials are well known by the time a full-scale trial is constructed.

6.5.4. SUMMARY

As a consequence of a substantially better developed aggregate skeletal structure, high-paste RCC indicates less shrinkage and creep during the hydration heating and cooling cycle than an equivalent CVC. With a high-paste mix and good quality materials and within the context of a reasonably flexible arch dam in a relatively temperate climatic environment, it is further possible to substantially eliminate the effects of shrinkage and creep in RCC. With lower quality materials, low paste mixes and mixes with high moisture contents, shrinkage and creep should be anticipated. Generic rules in respect of creep and shrinkage that were developed for CVC, however, should not be assumed to be applicable for RCC.

6.6. RCC MIX REQUIREMENTS FOR IMPROVED EARLY BEHAVIOUR

6.6.1. INTRODUCTION

It is clear from the various references, investigations and discussion that there is a specific composition and type of RCC that indicates increased resilience to creep and shrinkage. All of the examples quoted where the associated behaviour has demonstrated negligible shrinkage and creep have been what is defined as "high-paste" RCC and all of the testing in published literature that relates to high creep relates to a "lean" RCC. With "high-paste" RCC defined as a mix with a cementitious materials content exceeding 150 kg/m^3 and "lean" RCC defined as a mix with less than 100 kg/m^3 cementitious materials, two additional factors common to the RCCs that have demonstrated low creep/shrinkage performance are high fly ash contents and total cementitious materials contents approaching, or exceeding 200 kg/m^3.

With particular reference to the author's experience and knowledge of RCC mixes, the key attributes that will indicate a greater resilience to creep are discussed in the subsequent text.

6.6.2. KEY ISSUES

The key issues in respect of increasing the resilience of an RCC mix to creep can be summarised as follows:

- Developing a strong aggregate skeletal structure with aggregate-to-aggregate contact.
- Providing sufficient paste to ensure that the process of compaction is well lubricated and that a strong aggregate skeletal structure can be formed, with all surplus paste squeezed up to the placement surface.
- Only high quality aggregates are used.
- The content of non-cementitious fines does not become excessive (< 100 kg/m^3).
- Included non-cementitious fines are non-plastic.

- Autogenous shrinkage of the paste is minimised.

It is becoming common practice in high-workability RCC to apply specifications for the aggregates that are stricter than generally applied for CVC and this is seen as particularly beneficial in respect of ensuring a well developed skeletal structure. While continuous aggregate gradings have generally been applied for RCC, maximum aggregate particle flakiness and elongation, for all sizes, is typically now specified as 25% (tested in accordance with BS812 Part 105), as opposed to an earlier typical maximum of 35%. Furthermore, a maximum compacted bulk density (CBD) void ratio of 32% is applied for the fine aggregate fraction, although it is quite common to aim for 27 to 28%.

6.6.3. RCC COMPOSITION

High-paste RCC is designed on a volumetric basis and it is generally considered that the best performance under compaction is achieved when the nominal paste/mortar ratio exceeds the void content of the sand by approximately 12%. In this manner, effective lubrication to the compaction process is provided. For a sand CBD void content of 30%, a paste/mortar ratio of 42% would accordingly be applied for best performance.

As indicated in Chapter 2 for each of the dams investigated, the paste content in high-paste RCC is usually approximately 200 litres/m^3 (excluding aggregate fines), with aggregates comprising 800 litres/m^3. Modern mixes indicate a maximum aggregate size of approximately 40 mm, to limit segregation, and the fine aggregate content usually represents between 35 and 40% of the total aggregate content. Water contents will obviously depend on the nature of the aggregates, but the main purpose of the tighter aggregate specifications is to limit the water content required to achieve a workability equivalent to a modified Vebe (19.1 kg surplus mass) time of around 8 seconds. Typically, high-paste RCC water contents are between 100 and 125 litres/m^3.

While the dam structure design and the construction programme will play a role in determining the containment stresses incurred in the key structural zones during the period that the structure is heated by hydration, the total hydration heat evolved will also play a role in determining the levels of containment stress developed. Although the high-paste RCC described may exhibit a particularly significant resilience to creep, the likelihood and degree of creep that might be experienced will increase with the intensity of the containment stresses and accordingly, a low heat cement would be advantageous, in tandem with a mix design approach seeking to minimise the heat of hydration.

It is considered that the ideal RCC, in respect of developing resilience to creep, would indicate the following composition:

Constituents	Portland Cement	Fly Ash	Water	Coarse Aggregate	Fine Aggregate	Retarder
By Mass (kg/m^3)	62	143	115	1400	800	3.4
By Volume (litres/m^3)	20	62	115	500	300	3

Net Paste (l/m^3)	Fines (l/m^3)	Aggregate (l/m^3)	Paste/ Mortar	Sand/ Aggregate
200	30	800	0.40	0.375

6.6.4. TESTING REQUIREMENTS & RCC MIX DEVELOPMENT

While it is considered of absolute importance to test the characteristics of RCC mixes on a project-specific basis, the technical feasibility of an RCC arch dam may depend on the availability of high quality cementitious and aggregate materials. It is not uncommon to import cementitious materials for large RCC dams, the cement and fly ash used for Changuinola 1 Dam in Panama for example are imported in bulk by ship from Tampa Bay, Florida in the USA. During the dam type selection study for a particular project, an economic comparison should be made of the various possible dam types and this will include reference to available materials and the costs of sourcing high quality materials for an arch dam would be compared with other dam type options with lesser concrete performance requirements.

However, with the number of variables that impact concrete mix design, it is not considered appropriate at this stage to be able to propose a “negligible-creep” RCC without appropriate site-specific materials testing, which should include the construction and instrumentation of a large-scale RCC placement trial.

With a new understanding of the early behaviour of high-paste RCC in large dams, it was considered necessary to evaluate and to illustrate the impact of the new model on the design of large dams. Chapter 7 is consequently dedicated to exploring, through example, the influence of the new RCC materials understanding on future dam design.

6.7. REFERENCES

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[4] López, J, Castro, G & Schrader, E. *RCC Mix and Thermal Behaviour of Miel I Dam – Design Stage.* – Roller Compacted Concrete Dams. Proceedings. 4th Int. Symposium on Roller Compacted Concrete (RCC) Dams, Madrid, pp 789 - 797. November 2003.

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