International RCC Symposium reviews design and construction technology

CONFERENCE REPORT

R. Ibáñez de Aldecoa, Dragados USA, and SPANCOLD, Spain
F. Ortega, FOSCE Consulting Engineers, Germany and SPANCOLD, Spain

Since 1991, two pioneering and leading countries in RCC technology, Spain and China, have been combining their efforts to organize the RCC International Symposia, with a wide range of contents and worldwide scope. Last autumn, the state-of-the-art of RCC dam design and construction was reviewed comprehensively during the three-day 6th International Symposium on Roller Compacted Concrete in Zaragoza, Spain, updating the knowledge attained at the five previous events in this series.

This sixth Symposium followed those held in Beijing (China) in 1991, Santander (Spain) in 1995, Chengdu (China) in 1999, Madrid (Spain) in 2003, and Guiyang (China) in 2007. About 350 delegates from 40 countries gathered for the event, which was organized by the Spanish National Committee on Large Dams (SPANCOLD), the Chinese National Committee on Large Dams (CHINCOLD), the European Club of ICOLD and the Spanish Institute of Cement and its Applications (IECA), in collaboration with the Spanish Ministry of Agriculture, Food and Environment, and ICOLD.

The Symposium was attended by ICOLD President Adama Nombre, as well as the President of SPANCOLD, José Polimón, and Hon. President of ICOLD and Vice President and General Secretary of CHINCOLD, Jia Jinsheng, the latter heading a large delegation from China.

A total of 104 papers from 27 countries were accepted and published in the Proceedings, together with the seven special lectures given by eminent international experts on RCC dams. A significant number of the accepted papers were presented during the technical sessions.

Symposium attendees also received a CD with an update on the RCC chapters of the Technical Guidelines for Dam Safety published by SPANCOLD, to increase the distribution of these Guidelines and to demonstrate the high level of RCC technology in Spain. Also, a complimentary copy of Issue 5, 2012, of *Hydropower & Dams* was distributed to all participants, which included several articles related to RCC

The Opening Session of the RCC Symposium in Zaragoza on 23 October.

Opening of the Technical Exhibition by Ms Liana Ardiles, General Director of Water at MAGRAMA.

prepared by CHINCOLD and SPANCOLD members, and a general update of the technique by Dr Malcolm Dunstan of UK.

The Opening Session, see photo below left, was chaired by Ms Liana Ardiles, General Director of Water at the Ministry of Agriculture, Food and Environment (MAGRAMA), who later also chaired the Opening of the Technical Exhibition, see photo above.

The technical quality of the Symposium was enhanced by the fact that experts from all the pioneering and leading countries in RCC dam design and construction had assembled to exchange experience and report on progress in their respective countries.

As part of the Symposium, the existing agreement between the Spanish and Chinese Committees was extended for another three years, to continue the transfer of technology and knowledge in the field of dams between these two countries.

In the Closing Session, with the support of ICOLD, to recognize major achievements in RCC dam technology and to define milestone projects in this field, International Milestone Awards were given to three recent RCC dams. This was the second time that these prizes had been granted, following those given in Guiyang in 2007.

A three-day post-Symposium Study Tour was arranged, departing from Zaragoza and ending in Bilbao, to connect with HYDRO 2012 organized by *Hydropower & Dams*.

1. Special presentations and lectures

A total of seven special lectures on various aspects of RCC dams were given throughout the symposium by international experts. The main topics were as follows.

Dr J.C. de Cea, General Secretary of SPANCOLD, during his special lecture on RCC dams in Spain.

1.1 RCC dams in Spain

The design philosophies, construction methodologies and essential characteristics of the 28 RCC Spanish dams that are currently in operation (27) and under construction (1) were summarized in this lecture, by Dr J.C. de Cea of Spain, see photo above. He pointed out that his country has a large tradition in RCC dams, with the first RCC experience dating back to 1984.

De Cea's comparative description of Spanish RCC dams focused on several particular aspects, such as the typical cross section, imperviousness, materials and mixes, transverse and horizontal joints, construction aspects, test sections, other uses and behaviour.

Delegates heard that the largest RCC dam in Spain is La Breña II, see photo below, with a maximum height of 119 m and a total concrete volume of 1.60×10^6 m^3. La Breña II, completed in 2008, is also the largest RCC dam in Europe.

Spanish RCC dams have followed the main principles of simplicity in design and a high content of cementitious materials in the mix proportions (average of 210 kg/m^3). The cementitious materials used are mainly cement and flyash class F. The imperviousness of these dams is achieved by the high quality of the mix itself, and appropriate specification of the construction procedures. Developments and improvements in the technology have been quite evident in Spain. In recent projects, the interface concrete against the formwork and abutments has been some kind of enriched RCC (enriched by either grout or mortar).

View of La Breña II RCC dam (119 m high, with an RCC volume of 1.44 × 10^{6}m^3) completed in 2008 in Spain. It is the largest RCC dam in Europe.

Dr Jia Jinsheng, Honorary President of ICOLD, during his special lecture on RCC and CMD dams in China.

However, the latest tests carried out at the beginning of construction of the 102 m-high Enciso RCC dam, with a very workable and super-retarded mix, were very successful in showing the efficiency of the direct immersion vibration of RCC without any additional grout (IVRCC). Preliminary results of these tests indicate that a significant step forward has been made towards the improvement of the in-situ quality and the general behaviour of RCC dams.

1.2 RCC and CMD dams in China

China is undoubtedly the world-leader in RCC dam construction. A total of 157 RCC dams (30 per cent of the total) have been built or are under construction in the country. The world's highest RCC dam is Guangzhao (200.5 m high), which was completed in 2009. Seven RCC dams in China are higher than 150 m, and there are 12 arch-type RCC dams higher than 100 m. The highest of these is the Wanjiakouzi RCC arch dam, which is under construction at present and will have a total height of 160.5 m.

Experience and design principles for RCC dams higher than 200 m were reviewed in a special lecture by Dr Jia Jinsheng of China, see photo above. In particular, the research on high water pressure fracturing was presented as a key aspect requiring special attention, to evaluate the safety of future high RCC dams.

The second part of Jia's presentation focused on the Cemented Material Dam (CMD) and its application.

The rockfilled concrete (RFC) technology that was used for the reinforcement works of the 69 m-high Hengshan arch dam in China, as discussed by Dr Jia Jinsheng.

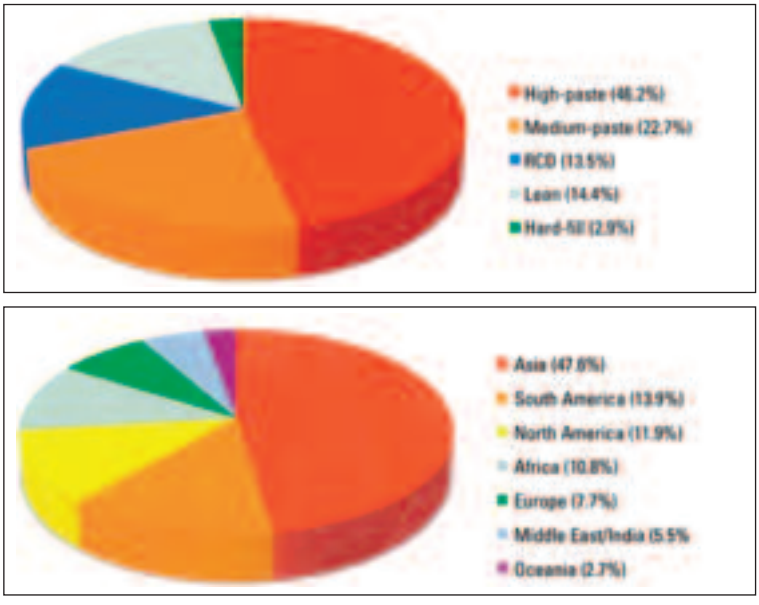
Dr M.R.H. Dunstan during his special lecture, 'New developments in RCC dams'.

This concept aims to build on previous design experience such as CSG, hardfill, masonry and rockfilled concrete (RFC) dams. CMD has been created to promote safer and faster construction, with low investment costs and based on environmentally friendly technology. Various forms of composite concrete construction materials are used under this new concept of optimizing the dam structure, to make a better use of local materials. RCC dams have developed towards traditional concrete dams in many respects and CMD can be considered as a dam type which is somewhere between a rockfill and concrete dam. The concept seems to have been accepted rapidly for application for small and medium-sized dams in China.

1.3 New developments in RCC dams

Following a series of papers presented at the previous RCC Dam Symposia, an extension and update of data had been prepared for this 6th Symposium by Dr M.R.H. Dunstan of the UK. His paper traced the changes that have taken place over the 20 years since the first Conference (Beijing, 1991) in terms of the distribution of RCC dams around the world, the expansion of RCC dams in the leading RCC dam building countries, and the different design philosophies and cementitious materials which have been used in RCC for dams, see the Figures above. In addition, Dunstan described the developments of the methods of forming the faces of RCC dams. This development is remarkable, he pointed out, as now a significant proportion of new dams use a form of RCC which is vibratable by immersion vibration.

RCC dams are now located in at least 58 countries. The six leading countries are China, Japan, Brazil, USA, Spain and Morocco. Recently, rapid growth has been noted in areas such South and Central America, and countries such as Vietnam and India. Dunstan observed that once countries start to build RCC dams, they tend to build more. The number of high-paste RCC dams seems to be increasing, and the actual proportion of this design philosophy compared with all others is 46 per cent (by number) or 62.5 per cent (by volume). In these dams, the average content of cementitious materials (cement and any kind of pozzolan) is 196 kg/m^3 and the mean water/cementitious material ratio is 0.56. Of particular interest is a comparison of this parameter with the respective values for hardfill (1.86) and lean RCCs (1.55), which are much higher despite the greatly reduced workability.



Distribution and design philosophy of RCC dams around the world (2011), reported by Dr M.R.H. Dunstan.

The highest, largest (by volume) and fastest ten completed RCC dams are listed in this paper for reference. The dams with the best-reported in-situ properties are also included. As a conclusion the importance of the rate of placement based on the simplicity of the design was emphasized by Dunstan as an important goal for the success of future RCC dams.

1.4 Innovations in RCC dams

This lecture, by B. Forbes of Australia, included reference to significant innovations that have been adopted on RCC dams recently, which in the author's opinion provide for improved quality, more efficient construction and reduced costs. Besides traditional topics such as the advantages and disadvantages of the sloped layer construction procedure and the use of grout-enriched RCC (GE RCC) in place of conventional vibrated concrete, some recent new approaches and procedures had been introduced, Forbes pointed out. He highlighted the opportunity for innovative thinking and trialling in RCC dams as a way to deliver improvements in quality and to reduce construction time and project costs.

Recent innovations he referred to included the use of a slip form paver to finish the grout-enriched RCC on the wide top of downstream face steps, to reduce manual labour and improve surface tolerances; pre-mixing of GERCC; excavation of horizontal galleries through hardened RCC using rock trenches; and, pre-casting

Precast concrete elements at spillway crest of Meander RCC dam in Tasmania, Australia, referred to by Brian Forbes.

Typical aspect of the surface of a compacted "RCC-friendly" mix, referred to by Ibáñez de Aldecoa.

concrete of a spillway ogee crest elements to accelerate the completion of the crest works and reservoir impoundment.

1.5 RCC as a dam construction material

This lecture, by R. Ibáñez de Aldecoa, Spain, focused on the particular characteristics of high-cementitious content RCC mixes used for dam construction. The properties of the RCC as a construction material, he said, are very much related to the way of placing it in many consecutive layers, with the aim of obtaining a monolithic, impervious and durable structure.

The specific properties of the various individual components of the RCC mix have been reviewed and in some cases compared with those traditionally used in conventional vibrated concrete (CVC) dams. Special focus was given in the presentation to the advantages of using mineral admixtures and fillers to replace a certain amount of cement, the effects of the aggregate fines and their desirable quality and limits, the reduction of the maximum size of aggregate to control segregation, and the tendency to increase the use of retarders to extend the allowable exposure time between consecutive RCC layers.

Ibáñez de Aldecoa also presented some considerations on the optimum mix design. The critical design parameter in large RCC dams is the in-situ vertical direct tensile strength across the horizontal joints. In the long term (control age of 180 or 365 days), this is about 20 times less than the cylinder compressive strength measured in the laboratory. The design of the mix should concentrate more on obtaining the desired bond between layers, rather than a high strength of the concrete matrix, Ibáñez de Aldecoa pointed out. Some guidelines for the mix design were included in his paper, as well as some important considerations regarding the placement and the quality of the joint treatments.

1.6 Lessons learned and innovations for efficient RCC dams

Conclusions of the last 25 years of experience working on RCC dams were summarized in this special lecture by F. Ortega of Germany/Spain. The optimization of mixes towards a cohesive and workable material which does not segregate and which improves bonding between layers has led to the development of a modern, simple and innovative approach in RCC dam construction, he said. Very workable and super-retarded RCC mixes had been successfully used at recent RCC dams with extraordinarily good results in terms of quality, economy and simplified construction processes, he pointed out.

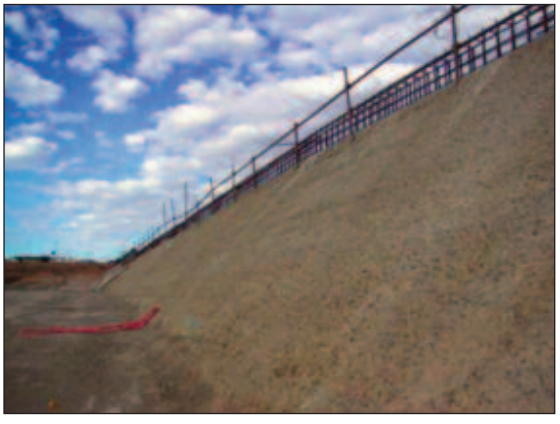
Immersion vibration of RCC without grout (IVRCC) at the Enciso dam in Spain, in 2011, which was first developed by F. Ortega at De Hoop dam in South Africa.

The value of the speed of construction should be underlined, and achieved by realistic planning as well as during the selection of the type and capacity of the plants. The investment costs will be soon compensated by the lower overall cost when placing RCC at high rates. Furthermore it has been found, Ortega observed, that well designed RCC mixes allow for the use of economic and simple equipment, such as transportation by gravity (chutes) or trucks driving on fresh concrete without any damage. Less cohesive RCC mixes with VeBe times of more than 12 seconds might be critical in the same working conditions. Key parameters of the optimized mixes and materials were included in this paper. Important efforts have been made in the reduction of the water content of very workable RCC mixes (water/cementitious ratio less than 0.47 with 9 seconds VeBe) by improving the quality of the fine aggregate, Ortega pointed out.

It was agreed that one of the most innovative findings of this 6th Symposium was the introduction of the Immersion Vibrated RCC (IVRCC) technology. As a result of this optimization of the mixing process, it has been possible to design a concrete mix which can be consolidated either by traditional pokers or by vibratory rollers. Reference was given in Ortega's talk to his recent experiences in South Africa and Spain (including the Enciso dam in Spain, see photo above). He anticipated that the application of this technique in the future would further simplify the construction of concrete dams and would enhance the quality of the RCC.

1.7 Performance of RCC dams

This lecture, by E. Schrader of the USA, was an update of the presentation on the performance of RCC dams given in 2003 at the 4th Symposium in Madrid and concludes that, overall, RCC dams of all types have performed very well. His analysis excluded RCD dams from Japan as well as RCC dams in China and Spain, which had been well covered in other papers. The types of RCC dams and mixes are split between high and low cementitious content. The typical content of the paste, including everything less than 0.075 mm, had increased to 21-24 per cent to control segregation and to improve lift joint quality, he said. The efficiency of RCC mixes was analysed particularly in terms of compressive strength versus content of cementitious materials.



Unformed RCC face at the Paradise dam in Australia.

The surface appearance of RCC dam faces was discussed in some detail. Several methods have been reviewed: unformed RCC, slip-forming, CVC, precast panels and grout enriched (GE) RCC. GE RCC is more popular now than at the time of early experiences when drier mixes were used. Adequate curing and well designed joint spacing are important to control surface cracking. Watertightness was a major issue in early RCC dams. Nowadays it is commonly accepted that all properly built RCC dams are impervious. High-cementitious content RCC dams are impervious by themselves, and low-cementitious content ones are not impervious and require either bedding mixes at lift joints or impermeable upstream watertight barriers. Shear strength tests have been useful to estimate actual cohesion and friction angle for different joint scenarios and mixes.

2. Technical sessions

Theme 1: New Developments in RCC Dams

A total of eight papers were presented under this topic:

- F.I. Arreguin-Cortes explained the main characteristics of the 12 RCC dams completed or under construction in Mexico, as well as relevant aspects of the construction procedures, the behaviour under the stresses, and the prospects for future use of RCC in the country.
- A.F. Chraibi presented a summary of the Moroccan experience in design, construction and maintenance of RCC dams, with particular reference to the use of uncommon solutions.
- J. Waters of Australia described the methodologies developed to reduce the impacts of extreme rainfall (annual average of between 4000 and 4500 mm) during placement of the RCC at Changuinola 1 dam in Panama.
- E. Schrader of the USA provided the status and options for RCC mixes for the Diamer Basha dam project in Pakistan, an upcoming dam of enormous dimensions, which will have some $16.5 \times 10^6 m^3$ of RCC with $2 \times 10^6 m^3$ of conventional concrete and a height of 272 m.
- J. Conway of Puerto Rico, USA, gave the details of the comprehensive record of the foundation obtained through close range photogrammetry and mapping implemented at the Portugués thick-arch RCC dam in Puerto Rico.
- C. Du of Germany discussed the notable structural features of the Gomal Zam arch-gravity RCC dam in Pakistan, describing the arrangement and grouting of temporary transverse contraction joints, as well as the pre- and post-cooling systems adopted to control the RCC temperature.
- A. Gonzalo of Spain explained the advantages of using the corrective measure of high pressure resin injections where necessary in the dam body, after impounding of a reservoir, instead of the preventive measure of installing a waterproof membrane.
- P. Buchanan of Australia discussed the process adopted to identify the benefits of 400 mm-thick RCC lifts, compared with the usual industry standard of 300 mm, at the Enlarged Cotter dam.

Theme 2: Planning and design

A total of 15 papers were presented on this subject, in two sessions, see photo below. Nine of them referred to the planning and design of real cases already completed, under construction, or at the design stage: Waldbärenburg flood retention dam in Germany, presented by G. Leyendecker; Aladereçam dam in Turkey, presented by L. Canale of Switzerland; a slightly curved gravity RCC dam (not named) in Portugal, presented by D. Botelho; Portugues thick-arch RCC dam in Puerto Rico, presented by A. González and P. Vázquez; Tabellout dam in Algeria, presented by A. Si-Chaib of France; thermal analysis for Cuira dam in Venezuela, presented by L. Lacoma of Spain; the Beyhan 2 scheme in Turkey, presented by E. Yildiz of Turkey; Changuinola I in Panama, presented by G. Erlendsson of Denmark and Q.H.W. Shaw of South Africa; and, De Hoop dam in South Africa, presented by H.J. Wright.

The other six papers referred to specific topics, some of them also related to specific RCC dams or dam designs, and were as follows:

- M. Romana of Spain presented two papers. The first discussed the minimum requirements for the foundation of RCC gravity dams in border-line terrains, and the second focused on the foundation and the seismic behaviour of hardfill dams.
- A. Dolatkhahi of Iran described a study, using finite element software, of the effect of the starting time of concrete pouring on the distribution of heat and the thermal cracks developed on the Zhave RCC dam.
- Q.H.W. Shaw of South Africa gave details of the research carried out to study the low-stress relaxation creep behaviour for flyash-rich RCC, which implies significant opportunities for large RCC dam design and specifically RCC arch dams. The concepts had been applied, he said, for the design of the 105 m-high Changuinola I dam in Panama.

The technical session on planning and design. Chairmen J. Yagüe of Spain and Wu Shiyong of China, during the presentation of G. Leyendecker of Germany.

• A. Scuero of Switzerland discussed the design issues and installation details of cases where an upstream geomembrane liner had been applied at three RCC dams in different configurations and with different purposes. The case histories described were Karebbe in Indonesia, Rizzanese in France and Mauá in Brazil.
• Zheng Cuiying of China presented a study of improved equivalent stress relating to the finite element method for gravity dams and its application for the analysis of Shoukoubao dam, the first CSG dam in China.

Theme 3: Materials and mixtures

Fourteen papers split in two sessions were presented under this theme. Twelve of them dealt with materials or mixtures for specific projects:

• The choice of cementitious materials, influenced by changes in the world economy, at the Changuinola I dam in Panama, presented by M.R.H. Dunstan of the UK.
• The choice of pozzolans at Yeywa dam in Myanmar, and Son La dam in Vietnam, presented by D. Morris of Switzerland.
• The selection of raw materials and RCC mixture optimization for the El Puente de Santolea dam, in Spain, presented by J. Gracia of Spain.
• Experience with retarder admixtures at the Yeywa and Upper Paunglaung dams in Myanmar, presented by U Zaw Min San of Myanmar.
• Limestone filler used as mineral admixture at La Breña II dam in Spain, presented by R. Ibáñez de Aldecoa of Spain.
• High-intensity basalt gravel aggregate production system at the Guandi dam in China, presented by Zhang Chaofeng of China.
• RCC mix design development for the Enciso dam in Spain, presented by F. Ortega.
• RCC mixtures formulation for the Tabellout dam in Algeria, presented by A. Si-Chaib of France.
• The RCC trial mix programme for Lai Chau dam in Vietnam, presented by M. Conrad of Switzerland.
• The use of low cost RCC in a thick cross section at Rizzanese dam in Corsica Island (France), presented by F. Delorme of France.
• Optimization of the RCC mix design for the Spring Grove dam in South Africa, presented by J. Nyakale of South Africa.
• Use of a high shrinkage aggregate at Enlarged Cotter dam in Australia, presented by D. Nott of Australia.

The other two papers referred to specific topics:

• J.E. López of Colombia discussed the history, development and application of a procedure for accelerated cure of RCC, which makes it possible to determine the one-year strength and elastic properties within two weeks.
• Q.H.W. Shaw of South Africa, see photo below, presented a second paper on the research carried out to study the low-stress relaxation creep behaviour for fly-ash-rich RCC, to complement the one presented under Theme 2.

Theme 4: Construction and quality control

This was the theme which attracted the highest number of submissions; a total of 23 papers divided between four sessions were submitted under this subject. Two of them discussed specific matters, and both were presented by J.E. López of Colombia. The first of these focused on a non-standard procedure for nuclear gauge densimeter calibration. The second discussed the choice between all-conveyor systems or trucks for the transport of the RCC to the point of placement on top of the dam, and the impact on schedule, overall cost and quality of the RCC.

The other 21 contributions referred to specific projects:

• Development of the RCC for the Middle Vaitarna dam in India, presented by M.R.H. Dunstan of the UK.
• The use of a geographic information system (GIS) as a work tool for the follow-up of the RCC construction process at Pirrís dam in Costa Rica, presented by F. Ortega of Spain.
• A unique seaborne supply system for cement and fly-ash implemented at the Changuinola 1 dam in Panama, presented by A. Ligthart of The Netherlands.
• Comparison of RCC construction methodology between Yeywa and Upper Paunglaung dams in Myanmar, presented by U Zaw Min San of Myanmar.
• Characterization and quality control of the RCC for El Puente de Santolea dam in Spain, presented by A. Sánchez of Spain.
• Construction of the Pirrís dam in Costa Rica, presented by I. Arguedas of Costa Rica.
• Design and build of Rizzanese dam in Corsica (France), presented by A. Lochu of France.
• Design and construction of the Nakai dam in Laos, presented by G. Stevenson of Canada.
• Construction details at El Puente de Santolea dam in Spain, presented by M.J. Cabrera of Spain.
• Geological and geotechnical constraints of the foundation at Enciso dam in Spain, presented by A. Soriano of Spain.
• Construction of the Nakai dam in Laos, presented by

Q.H.W. Shaw of South Africa presented a series of three papers on the low stress-relaxation creep characteristics of flyash-rich RCC.

Far right: I. Arguedas of Costa Rica presenting his paper on Pirrís dam.

The technical session on construction and quality control. Chairmen P. Vázquez of Puerto Rico,USA, and Yang Baihua of China, during the presentation of C. Granell of Spain.

A. Rousselin of France.
• Construction of Javeh dam in Iran, presented by A. Dolatkhahi of Iran.
• Various RCC dams built by Spanish construction companies abroad, presented by A. Capote, R. Ibáñez de Aldecoa and V. Flórez of Spain.
• Construction of Xiangjiaba dam in China, presented by Gao Peng of China.
• Review of the construction of Son La dam in Vietnam, presented by D. Morris of Switzerland.
• Scenario of RCC dams in Mexico, presented by A. Garduño of Mexico.
• Construction in two different stages with a longitudinal joint at Castanhão dam in Brazil, presented by W. Jardim of Brazil.
• First world experience of immersion-vibrated RCC at the De Hoop dam in South Africa, presented by J. van Niekerk of South Africa.
• Construction of the Guandi dam in China, presented by Wu Shiyong.
• Design and construction advantages of Hardfill Symmetrical Dams and application for Safsaf dam in Algeria, presented by T. Guillemot of France.
• Design features and the investigation of concrete materials and mixes for the Cuira dam (Project Tuy IV) in Venezuela, presented by C. Granell of Spain.

Theme 5: Performance and monitoring

Eight papers were presented under this topic:

• R. Gómez of Spain described safety monitoring at the Val dam, giving a short description of the principles followed and itemizing the main conclusions drawn from the safety inspections.
• A. Dolatkhahi of Iran discussed the evaluation of the safety and structural stability of the Jegin RCC dam in his country, based on data collected from the monitoring instruments and results obtained from structural back analysis carried out using finite element software.
• Q.H.W. Shaw of South Africa raised the proposal of a standardized stress-strain instrumentation scheme for RCC dams, based on long-base strain gauges and so-called effective concrete stressmeters. This paper was the third presented by this author on the low-stress relaxation creep behaviour for flyash-rich RCC (see Themes 2 and 3 above).
• Li Shuguang of China presented a quantitative analysis of the microcrack characteristics in air-entrained RCC with different degrees of freeze-thaw damage using the digital-image-processing (DIP) technique.
• Qian Xiaohui of China gave details of the seepage analysis carried out for the Guangzhao dam using a finite element model of the typical dam section.
• Zhao Quansheng of China presented a summary of safety monitoring and operation relating to some ultra-high RCC gravity dams in his country, including a discussion on the achievements and existing problems.
• T.P. Dolen of the USA described the development of the relationship between the direct tensile strength and compressive strength of RCC, both in the laboratory and in the field, making a comparison between 'labcrete' and 'realcrete'.
• K.D. Hansen of the USA gave details of nine case studies of dams which have experienced some cracking. Observations and conclusions were presented, as well as recommendations for improved crack control for new RCC dams. Repair methods and an insight into concrete cooling methods to include costs were also discussed.

Theme 6: Other applications of RCC

Within this theme the following six papers were presented:

• K.D. Hansen of USA described various precedents of the use of RCC in cofferdams, for example being a part of embankment cofferdams (core, or cap, or downstream protection), entire RCC cofferdams, RCC cofferdam integrated in the main RCC dam, and repair of a breached embankment cofferdam, among other.
• Chen Xianming of China presented some key features of the RCC cofferdam construction for the Three Georges project, where the significant potential for RCC cofferdam technology had been fully explored. This scheme provided valuable experience for cofferdam construction with high speed, good quality and cost effectiveness.
• L. Pinilla of Chile described the design and construction of small engineering projects where both cost and construction schedule had been significantly reduced compared with similar conventional concrete structures.
• P.E. Loisel of France gave details of the hydraulic scale-model study for a 50 m-high RCC stepped spillway for the New Al Khawd embankment dam, in the Sultanate of Oman. The hydraulic modelling had been carried out in Grenoble (France) on a model with a scale factor of 1:70.
• S. Estrella of Ecuador discussed a research project in which the hydraulic behaviour of stepped spillways without sidewalls had been analysed using a 1:15 scale-model study carried out in the Polytechnic University of Barcelona.
• Nobuaki Kita of Japan presented details of a hydraulic model test, with a scale factor of 1:65, which had been conducted for the spillway of the RCC main dam at the Nam Ngiep 1 hydro project in Laos, with the aim of optimizing the dimension of the flip bucket, and the dissipation effect of the ski jump spillway.

3. Awards for International Milestone RCC projects

Continuing with the tradition initiated at the previous (5th) Symposium in Guiyang, in 2007, International Milestone RCC Projects Awards were also given in Zaragoza, with the aim of recognizing projects implemented in recent years which represent major achieve-

Above, the awards ceremony for International Milestone RCC Projects in the course of the Closing Session of the Symposium.

Right, the certificate awarded for La Breña dam in Spain.

ments in dam technology, and can be used as valuable references for future developments in the field of RCC dams.

The main basic eligibility criteria for an International Milestone RCC Dam Projects are as follows:

- Technical innovation in design, construction, operation or other aspects.
- Good performance after completion.
- Emphasis during the construction and operation stages on environmental protection and social aspects.
- Attention paid to raising awareness of technical achievements and advanced experience.

The proposals received had been analysed by members of SPANCOLD and CHINCOLD, along with an international team of experts, who decided to reward the following three projects:

- Taum Sauk upper reservoir dam restoration project (USA);
- Guangzhao RCC dam (China); and,
- La Breña II RCC dam (Spain).

The prizes were awarded during the Closing Session by ICOLD President Adama Nombre and Honorary Presidents Prof Luis Berga and Dr Jia Jinsheng, and were received by representatives of the selected dams (owners, designers and contractors).

4. Study tour

A post-Symposium Study Tour had been arranged by the organizers to the following three RCC dams:

- Arriarán dam (58 m high, with a volume of 110 000 m^3) completed in 1993;
- Val dam (94 m high, with a volume of 667 000 m^3) completed in 1998; and,
- Enciso dam (102 m high, with a volume of 705 000 m^3) currently under construction.

All three dams are typical examples of high flyash content mixes. The performance of the two completed RCC dams have been excellent, as reported at previous symposia. The study tour provided an overview of the development of RCC technology in Spain over the last 20 years. The Arriarán and Val dams were constructed in several blocks, but it is planned to build Enciso dam in a single block, using a retarded mix, which will allow for a much longer setting time of the RCC.

Another notable development is the way of forming the faces of the dam. In many early RCC dams in Spain, such as Val, a conventional concrete mix was used at the dam faces against formwork. At Enciso, the use of a very workable mix allows for internal vibration of the same RCC without the addition of any grout. The excellent finish of the faces could be observed in the full-scale trial section which has been built on top of the upstream cofferdam.

Vertical cores taken from this structure could also be inspected at the site laboratory. The lack of visible joints of untreated surfaces with exposure times of more than 20 hours has represented a great improvement in the RCC mixes which are being used at present in Spain.

5. Conclusions

The 6th International Symposium on RCC dams in Zaragoza provided an excellent opportunity to exchange experience and know-how between owners, developers, designers, contractors and suppliers from all parts of the world. The increasing number and size of RCC dams, and the development of several design and construction techniques, made this a unique opportunity for concrete dam engineers to share infor-

SPANCOLD President, José Polimón, during the closing session of the Symposium.

Study tour participants with ICOLD President Adama Nombre, visiting trial section at the Enciso dam site.

mation on their own activities and findings. RCC dams have become very popular in all continents, in areas with different environmental and social conditions. The main reason for this popularity is the economy derived from the speed of construction. In this respect, as agreed during this Symposium, there is even still room for further improvements and innovations.

The Spanish and the Chinese Committees on Large Dams will continue with the joint and alternate organization of these international symposia. Preliminary details of the next RCC Symposium, to take place in China in 2015, were announced during the closing ceremony. The next Symposium will take place in China in 2015.

R. Ibañez de A.

F. Ortega

Rafael Ibáñez de Aldecoa is Technical Director of Dragados USA. He graduated in Civil Engineering from the Polytechnic University of Madrid, Spain. He is Chairman of SPANCOLD's Technical Committee on Concrete Dams and a Member of ICOLD's Technical Committee on Concrete Dams. He has been involved in the design and construction of more than 30 large hydraulic projects, ten of which have been RCC dams. He has published and presented a number of papers, most of them in the field of RCC dam design and construction.

Dragados USA, 2 Alhambra Plaza, Suite 660, Coral Gables, FL 33134, USA.

Francisco Ortega is a Consulting Engineer, specializing in the design and construction of RCC dams. He is member of the Spanish National Committee on Large Dams (SPANCOLD). He graduated in civil engineering from the Polytechnic University of Madrid, Spain, and has a strong background experience as a contractor. Since 1999 he has been running FOSCE Consulting Engineers, Germany. He has extensive experience in concrete mix design optimization and the logistics of RCC production, transportation and placement on major RCC dam projects. He has been directly involved in the design and construction of more than 50 RCC dams throughout the world.

FOSCE Consulting Engineers, Lorentzenstr. 30, 23843 Bad Oldesloe, Germany.