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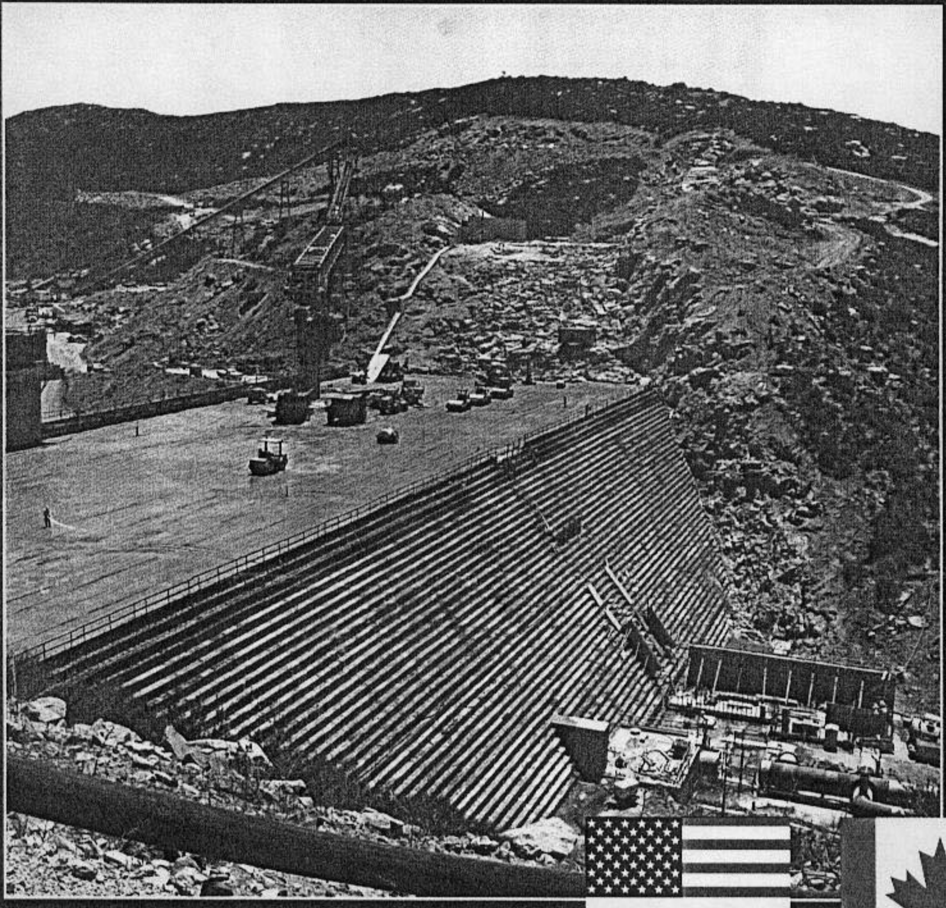

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## HYDRO AND DAMS NORTH AMERICA

## RCC DAMS ~ FISH PROTECTION ~ FLOW MEASUREMENT

# Ultrasonic energy to determine RCC setting times

G. Hermida and J. Sánchez, Sika Colombia, Colombia
F. R. Andriolo, Andriolo & Ito Engenharia, Brazil
E. Arfelli, Odebrecht, Brazil

**A method has been developed to identify RCC setting times, based on analysis of an ultrasonic wave. Using ultrasonic energy makes it possible to detect the progressive growth of hydrates inside the RCC material. The setting times of a plain RCC were studied, as well as one that included a plasticizing-retarding admixture. Measurements were done in various atmospheric conditions at the Miel I dam site in Colombia.**

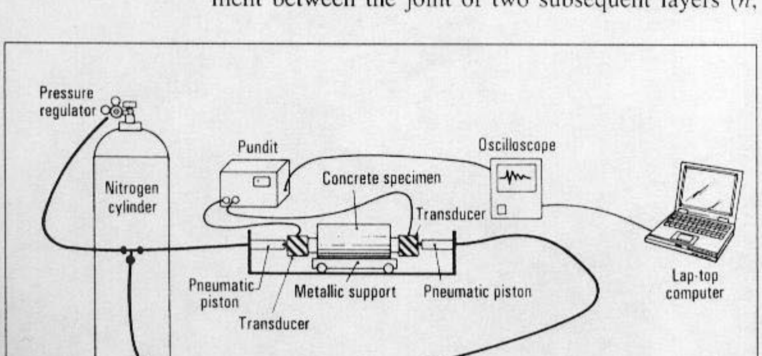
The characteristics and properties of RCC, both in its fresh and hardened states, have generally been studied using procedures designed for conventional concrete. Significant variations in the consolidation mode and the initial sieving of the material must be taken into account. However, the setting times of RCC, which is the most important property at the fresh stage, cannot successfully be evaluated using normal procedures for conventional concrete.

There is a difficulty in using a method of penetration resistance similar to the one described in the ASTM C403 standard, because it is necessary to evaluate a material in which all the fractions above 4.76 mm have been eliminated. Also, using the 'needle method' for non-sieved material leads to problems with coarse aggregates; for RCC, this is an essential aspect. Needle methods have had to be used, with limited success, to represent the setting that really occurs in the field, in the absence of another method.

It is important to be able to identify the setting time of RCC which has just been compacted and is still fresh, to ensure adequate adhesion between layers. The horizontal joints, in terms of impermeability, comprise one of the most vulnerable parts of an RCC dam. Identification of the setting time for various atmospheric conditions allows the engineer or contractor to determine the time limit for which superficial treatment of the joint is required, or for which a mortar should be used, to guarantee the necessary level of adhesion between layers.

For RCC that has been compacted forming a layer ($n$), previous studies have identified the initial setting time limit, up to which it is possible to place and compact a new layer ($n$+1) and obtain appropriate adhesion without any superficial treatment. Where treatment between the joint of two subsequent layers ($n$, $n$+1) is not needed, this is known as a hot joint. Hot joints are much more economical than the alternative of surface preparation or the use of mortar, and permit higher placing rates to be achieved.

*Fig.1. The equipment for measuring ultrasonic energy through an RCC specimen.*




If current methods do not provide accurate results for determining the setting times of the RCC material, it is not possible to establish correctly the precise time limit for achieving a hot joint. Several methodologies have been proposed to solve this important problem, but a general consensus has not yet been reached.

The new methodology presented here allows for the identification of the moment when initial setting begins, using ultrasonic energy as the parameter. Tests were carried out on the RCC being used at Miel I in Columbia in atmospheric conditions and using different doses of a plasticizing-retarding admixture. The direct tensile strength between layers and the setting time were correlated. The results obtained by this technique can optimize the definition of the placing times and the determination of the time limits for obtaining hot joints in an RCC dam.

## Ultrasonic energy

The use of sound in studying concrete goes back to the 1930s. The idea, since its origin, has consisted of taking advantage of the close relationship between sound velocity and the composition of the material through which the sound wave travels. By measuring the velocity of a high frequency wave pulse through a material, it is possible to characterize its internal structure. The velocity parameter has been used to detect voids or cracks, and to determine approximately the elastic modulus and density of a hardened concrete. Furthermore, the measuring instruments for wave analysis currently available provide much more information from a wave than just its transit time.

The ultrasonic energy concept is one such additional piece of information. It permits detection of the progressive growth of the solid phase (crystals) in a composite material. The energy parameter takes into account the amplitude, frequency and intensity variations of the wave going through the material.

RCC material in its fresh state has a set of proportions (in gaseous, liquid and solid phases) which change when the concrete becomes rigid and sets. With a 24 kHz emitting transducer which sends a stream of ultrasonic waves through the RCC in its fresh stage, the signal goes through the material (Fig.1) and is then picked up by a receiving transducer. The signal is then analysed by an oscilloscope to calculate an energy value. A signal is sent every minute, and its energy value is obtained. The resulting ultrasonic energy values, which represent the state of the solid phase inside the material, are plotted against time.

The resulting graph reveals the appearance of the 'crystalline net' and indicates the moment when C-S-H hydrates appear on the mass, defined as the moment of initial setting. Fig. 2 shows the evolution of the ultrasonic energy values obtained at the Zanja Honda dam in Colombia (70 kg of cement per cubic metre of RCC).

As can be seen, the curve begins horizontally, then changes considerably when the material is nearly 5 h old, indicating the massive appearance of solids. This 'taking-off' of the curve, indicating that the material has become rigid, corresponds to the initial setting of the concrete.

On the other hand, the final setting corresponds to a concavity which appears a short time later, and can be determined by tracing two tangents to the curve. However, for the recent investigations presented here, measurements were focused on the initial RCC setting time and its relationship to adhesion between the RCC layers.

## Determination of the RCC setting times at Miel I

Mixtures were created under controlled temperature conditions and relative humidity (RH) in the laboratory (see Table 1).

Indoor conditions at a controlled temperature and constant humidity (26±2°C, 85±5 per cent RH) were used, and an ultrasonic wave was passed through the specimens at the fresh stage. The various energy values were then calculated every minute. The results are shown in Fig. 3.

The initial setting time of the RCC without any admixture was 6 h after being mixed. For the RCC which included 0.7 per cent of admixture, the initial setting time increased to 11 hours 20 mins. For the RCC mixed with 1 per cent of admixture, the initial setting took place after 19 hours 50 mins.

The admixture dose is determined by the placement needs for construction. These results, obtained under controlled atmospheric conditions, demonstrate the admixture's performance. The dam engineer/contractor was interested in having a material which would keep fresh for more than 15 h, so that the next layer could be placed without any special surface treatment (a hot joint) necessary to obtain sufficient adhesion. Based on the test results, a 1 per cent dose of admixture was chosen, and field tests were carried out.

To approximate the hydration or setting process in the field, tests were carried out using specimens exposed to typical temperature, humidity, wind conditions and solar radiation found at the site.

**Table 1: Types of mixture**

| | Mix 1 | Mix 2 | Mix 3 |
|---|---|---|---|
| Cement (kg) | 150 | 150 | 150 |
| Sand (Barmac) (kg) | 397 | 405 | 405 |
| Crushed sand (kg) | 787 | 793 | 793 |
| Coarse aggregate, 63.5 mm (kg) | 112 | 112 | 112 |
| Coarse aggregate, 38.1 mm (kg) | 312 | 314 | 314 |
| Coarse aggregate, 9.5 mm (kg) | 630 | 635 | 635 |
| Moisture (per cent) | 5.1 | 4.5 | 4.5 |
| Admixture (Plastiment RCC-M) | 0% | 0.7% | 1.0% |

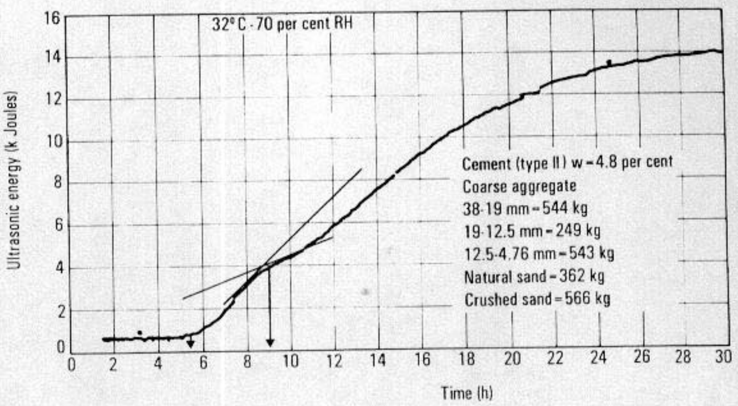



*Fig. 2. Ultrasonic energy values and RCC setting time for Zanja Honda dam, Colombia. (RCC, plain concrete, 32 °C, 70 per cent relative humidity).*

The relationship between initial setting time and the adhesion between layers was also studied.

## Conclusions

The main conclusions can be summarized as follows:

1. The study of fresh RCC using ultrasonic energy allowed for the identification of the setting times of the material in various atmospheric conditions.

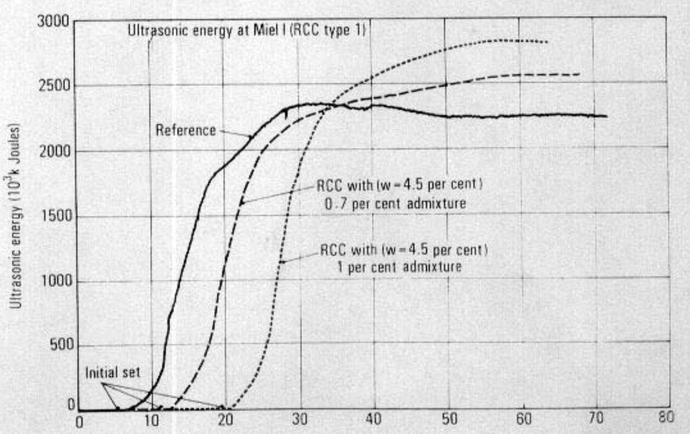
2. The evolution of ultrasonic energy values showed the effect of different doses of plasticizing-retarding admixture on the setting times, allowing for an appropriate dose to be selected according to construction needs.

3. Using 1 per cent of the admixture in comparison with the weight of cement for different atmospheric conditions quadrupled the initial setting time in comparison with plain RCC without any admixture.

4. The direct tensile strength of the horizontal joints decreased after the initial setting time of the base layer, to between 50 to 60 per cent of the value obtained if the joint was made immediately after the base layer had been compacted (that is, to 50 to 60 per cent of the strength possible to obtain).

5. The direct tensile strength of a horizontal joint decreases progressively with the time of exposure of the base layer, even before initial setting takes place. The definition of a limit for hot joints as the instant of

*Fig.3. Ultrasonic energy values and initial setting times for three different admixture doses (under controlled temperature and relative humidity conditions).*



initial setting inevitably includes a decrease in the bond capacity to 77 to 86 per cent of the direct tensile strength obtained in joints fabricated immediately after the base layer is compacted. ◊

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*G. Hermida*

*J. Sánchez*

*F. R. Andriolo*

*E. Arfelli*

**Germán Hermida** graduated as a Civil Engineer from the National University of Colombia, and gained a 'magister' qualification at the Ecole National des Ponts et Chaussées in France. He then became Director of the Laboratory of Materials at Sika in Colombia, where he has worked on the analysis of RCC for the Porce II and Zanja Honda dams. He gained an award for excellence for his research on concrete in 1998. His research interests include the design of special concretes and the performance of admixtures.

**Jorge Sánchez** graduated as a Civil Engineer from the Pontificia Universidad Javeriana, Colombia. He is now a Technical Assessor at Sika Andina SA, Colombia, with more than 10 years of professional experience, particularly in the field of hydroelectric projects and underground works. His areas of expertise include concrete, special mortars, grouts, and admixtures.

Sika Colombia, Calle 17 #69A-45, Bogotá, Colombia.

**Francisco R. Andriolo** is a Civil Engineer with international experience as a materials consultant. He has published four books and a number of papers about RCC and concrete. He is manager of the company Andriolo & Ito Engenharia.

Andriolo Ito Engenharia, Rua Cristalandia 181 05465 000, São Paulo, Brazil.

**Erlom Arfelli** is a Civil Engineer with more than 20 years of experience in the design and construction of large buildings and dams, as well as transmission lines. Today he is Project manager for the Miel 1 project, working for the contractor Odebrecht.

Odebrecht, Avenida 15 No. 101-09, Of. 603, Bogotá, Brazil.