EXPANSIVE REACTIONS IN CONCRETE DAMS IN PORTUGAL
the Old and the New ones

Carlos Pina
Principal Research Officer
National Laboratory for Civil Engineering (Portugal)
Board of Directors, President

Chambéry, Symposium 2017 du Comité Français des Barrages et Reservoirs
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Internal expansive reactions
*reactions de gonflement interne*

- **AAR (Alkali-Aggregate Reaction)/ASR (Alkali-Silica Reaction)**
  - *RAG (Réaction Alcali-Granulat)/RAS (Réaction Alcali-Silice)*
  - Identified in USA in 1940 (in Portugal in the 90s)

- **DEF (Delayed Ettringite Formation)/ISR (Internal Sulfate Reaction)**
  - *RSI (Réaction Sulfatique Interne)*
  - Identified in Germany in the 90s (in Portugal in 99)
Alkali-Aggregate Reaction (AAR)

Reactive aggregate

Gel

Ettringite

Delayed Ettringite Formation (DEF)/Internal Sulfate Reaction (ISR)
Dams, Bridges, Buildings, Pavements, Industrial Plants, ...
### Portuguese AAR affected dams (19/52)

<table>
<thead>
<tr>
<th>DAM</th>
<th>STRUCTURAL TYPE</th>
<th>YEAR OF COMPLETION</th>
<th>HEIGHT (m)</th>
<th>TYPE OF REACTION</th>
<th>AGGREGATES</th>
<th>MAXIMUM ACCUMULATED VERTICAL STRAIN UNTIL 2015 ($x 10^{-6}$)</th>
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Portuguese AAR affected dams

- Location of the AAR affected dams (19 dams, more than 30% of the total number of monitored large concrete dams)

- Predominant lithologies of the Portuguese mainland
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Portuguese AAR affected dams

Portuguese concrete dams monitored and affected by AAR, organized by structural types

- Arch: 7
- Multiple-arch: 2
- Arch-gravity: 4
- Gravity: 4
- Gate (gravity): 3
- Buttress (gravity): 3

Dams affected by swelling processes:

- Arch: 3
- Multiple-arch: 1
- Arch-gravity: 4
- Gravity: 4
- Gate (gravity): 3
- Buttress (gravity): 3

Portuguese concrete dams monitored and affected by AAR, organized in function of the construction decade

- 1941-1950: 3
- 1951-1960: 5
- 1971-1980: 8
- 1981-1990: 10
- 2001-2010: 7

Dams affected by swelling processes:

- 1941-1950: 3
- 1951-1960: 5
- 1971-1980: 8
- 1981-1990: 10
- 2001-2010: 7

No signs of AAR on dams built in the last 20 years
Miranda dam

Buttress dam, 80 m high, built in 1961

WATER ELASTIC EFFECTS

THERMAL EFFECTS

EFFECTS OVER TIME

OBSERVATION DATA AND COMPUTED CURVE

WATER LEVEL IN THE RESERVOIR

25 years

R = 0.98581
d.p. = 0.53937

Buttress dam, 80 m high, built in 1961

Miranda dam

Comité Français des Barrages et Reservoirs – Symposium 2017
Portuguese AAR affected dams

Average values of the monitored free strains by the stress-free Carlson strain-meters and strains obtained from geodetic levelling, in function of the dam age

The free strains measured by the stress-free strain-meters are about twice the vertical strains obtained from the geodetic levelling results
Alto Ceira dam

Thin arch dam, 34 m high, built in 1949

- Progressive cracking of dam’s body
- Progressive displacements, radial upstream and vertical upwards
Alto Ceira II dam - 2014
Alto Ceira II dam - 2014
Pracana dam

Buttress dam, 60 m high, built in 1951
Pracana dam *after rehabilitation*
New concrete structures – Preventive measures

- Presently, as European standards only EN 206 and EN 12620 deal with ASR, but they just state that actions shall be taken to prevent ASR using procedures of established suitability.

- DEF prevention is not covered by any standard. Although, some general guidance is given in EN 13670, EN 13230-1, and fib Model Code for Concrete Structures.

- Due to the complexity and multiplicity of factors involved in ASR and DEF, no such established procedures exist and each country has to rely on national regulations.
New concrete structures – Preventive measures

- Therefore, Specification LNEC E 461 was published in 2007. Due to developments occurred since then, a new version will be published soon on ASR and DEF prevention.

- The main differences reside in the methodology followed to identify an aggregate alkali-reactivity and in the assessment of the level of precaution and choice of appropriate precautionary measures.
Classes:
I - very unlikely to be alkali-reactive
II - potentially alkali-reactive or alkali-reactivity uncertain
III - very likely to be alkali-reactive

Petrographic examination (LNEC E415)

Is the rock potentially reactive?
- Yes: Class II or III
- No: Class I

Rapid screening test?
- Yes: Class II or III
- No: Class I

Is expansion higher than the maximum expansion limit?
- Yes: Class II or III
- No: Class I

Concrete Prism Test, CPT

Is expansion higher than the maximum expansion limit?
- Yes: Take preventive measures or do not use
- No: No No No
AGGREGATES TESTING

- Petrographic examination
  - LNEC Specification E 415 (RILEM AAR-1).

- Accelerated Mortar Bar Test, AMBT
  - RILEM AAR-2 & ASTM C 1260
  - Inadequate for slowly reactive aggregates.

- Concrete Prism Test, CPT
  - RILEM AAR-3.1 & RILEM AAR-4.1
  - Lab/Field performance & expansion limits under discussion
  - Test duration must be extended for slowly reactive aggregates or Long-service structures (e.g. concrete dams).

Example of a slowly reactive aggregate passing the AMBT and failing the CPT at 60 °C. Aggregate has been found to be deleterious reactive in a structure.
Classification of the structure into a risk category
- R1 - low risk
- R2 - normal risk
- R3 - high risk

Identification of the service environment category
- E1 - essentially protected from extraneous moisture
- E2 - exposed to extraneous moisture
- E3 - exposed to extraneous moisture and aggravating factors.

Establishment of the level of prevention according to risk and environment categories

Risk categories:
- R1 - low risk
- R2 - normal risk
- R3 - high risk

Environment categories:
- E1 - essentially protected from extraneous moisture
- E2 - exposed to extraneous moisture
- E3 - exposed to extraneous moisture and aggravating factors.

Precaution level:
- P1 - no special precautions
- P2 - normal precaution level
- P3 - special precaution level
- P4 - extraordinary precaution level

Preventive measures:
- M1 - restricting pore solution alkalinity
- M2 - using non-reactive aggregate
- M3 - reducing moisture ingress
- M4 - modifying ASR gel properties
PREVENTIVE MEASURES

☐ M1 – restrict pore solution alkalinity
  • Limiting concrete alkali content, considering all constituents
    ▪ Class II $\leq 3.0 \text{ kg/m}^3 \text{ Na}_2\text{O}_{eq.}$
    ▪ Class III $\leq 2.5 \text{ kg/m}^3 \text{ Na}_2\text{O}_{eq.}$
  • Using type II additions, *e.g.*
    ▪ Low-lime fly ash ($< 8 \% \text{ CaO and } < 5 \% \text{ Na}_2\text{O}_{eq.}$) $> 30 \%$
    ▪ Ground granulated blast furnace slag ($< 1.5 \% \text{ Na}_2\text{O}_{eq.}$) $> 50 \%$

☐ M2 – use non-reactive aggregate
  • Using “non-reactive aggregate” combinations;
  • Not always feasible, *e.g.* dams.
**Type II Additions Testing**

- **Concrete Prism Test, CPT**
  - ASTM C 1293
  - Expansion shall be less than 0.04% at two years.
PREVENTIVE MEASURES

- **M3 – reduce moisture ingress**
  - Reducing access of moisture and maintaining concrete in a sufficiently dry state;
  - Not always feasible, e.g. dams.

- **M4 – modify ASR gel properties such that it is non-expansive**
  - Using chemical compounds like lithium salts;
  - Expensive and doubts on long-term effectiveness.
Classification of the structure into a risk category

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Identification of the service environment category

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Establishment of the level of prevention according to risk and environment categories

- P1 - no special precautions
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Preventive measures:

- M1 - restricting concrete temperature
- M2 - controlling concrete alkali content and cement C3A and SO3 contents
- M3 - reducing moisture ingress
- M4 - controlling Ca(OH2) content
**PREVENTIVE MEASURES**

- **M1 – restrict concrete temperature**
  - Limiting temperature in concrete at early ages, < 65 °C.
  - Changing concrete composition.
  - Cooling concrete and using metal formwork.

- **M2 – restrict cement and concrete composition**
  - Limiting binder SO$_3$ content
    - SO$_3$ ≤ 3.5 % if C$_3$A ≤ 3.0 %
    - SO$_3$ ≤ 2.5 % if 3.0 % ≤ C$_3$A ≤ 5.0 %
  - Controlling concrete alkali content, considering all constituents.

- **M3 – reduce moisture ingress and extended contact with water**
  - Designing the structure to avoid water accumulation and stagnation zones;
  - Water proofing.

- **M4 – control Ca(OH2) content**
  - Using type II additions.
CONCRETE TESTING

- LPC method nº. 66
  - Assess type II additions effectiveness;
  - Assess concrete composition susceptibility to DEF/ISR.
Merci de votre attention!