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)

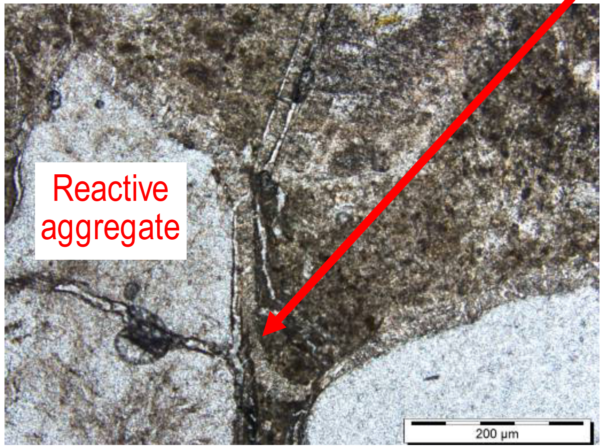
- DEF(Delayed Ettringite Formation)/ISR(Internal Sulfate Reaction)

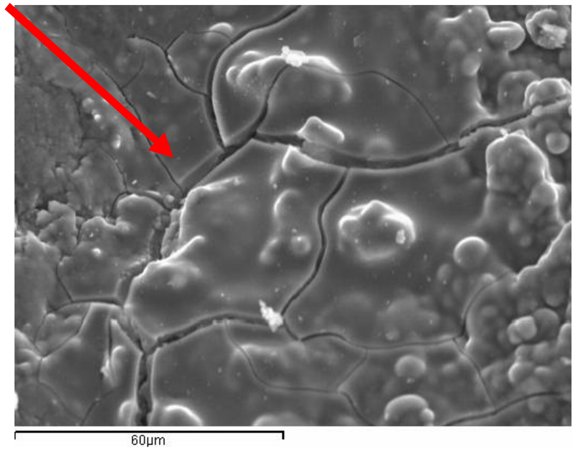
  RSI (Réaction Sulfatique Interne)

  - Identified in Germany in the 90s (in Portugal in 99)

Effects MACRO <<<<<<>>>>> MICRO

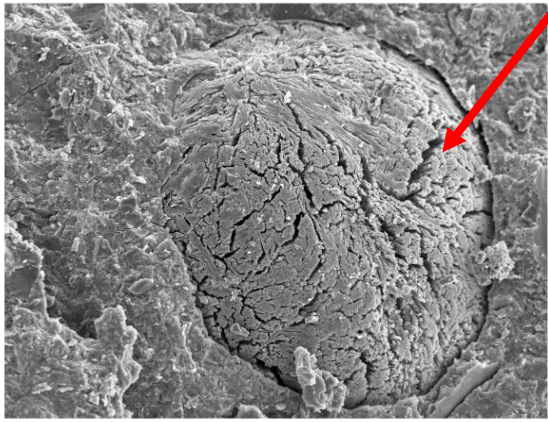
Gel

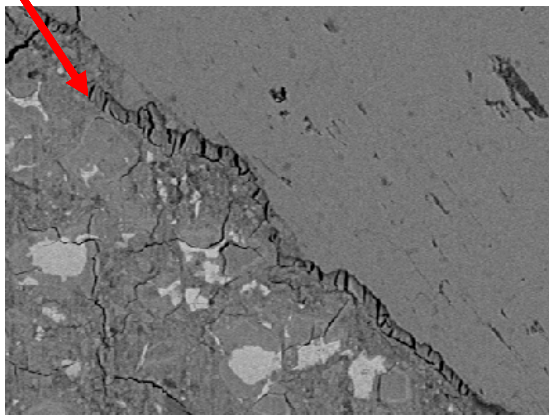




Alkali-Aggregate Reaction (AAR)

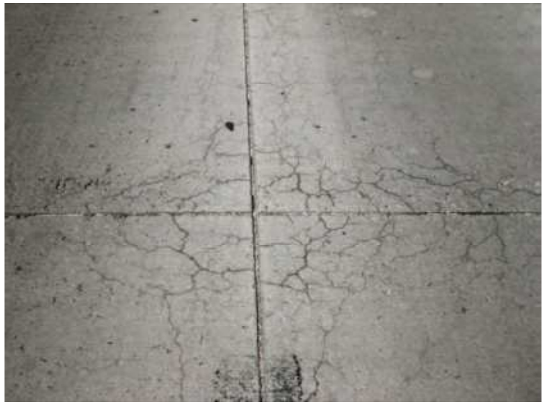
Ettringite

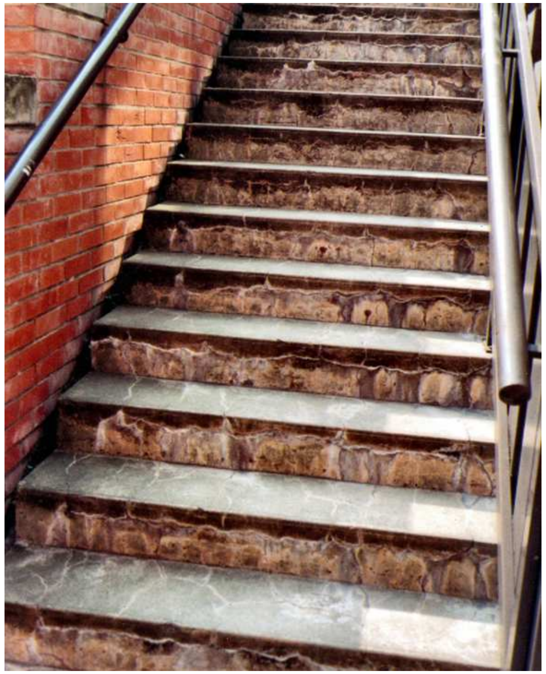




Delayed Ettringite Formation (DEF)/Internal Sulfate Reaction (ISR)

❑ Dams, Bridges, Buildings, Pavements, Industrial Plants, …





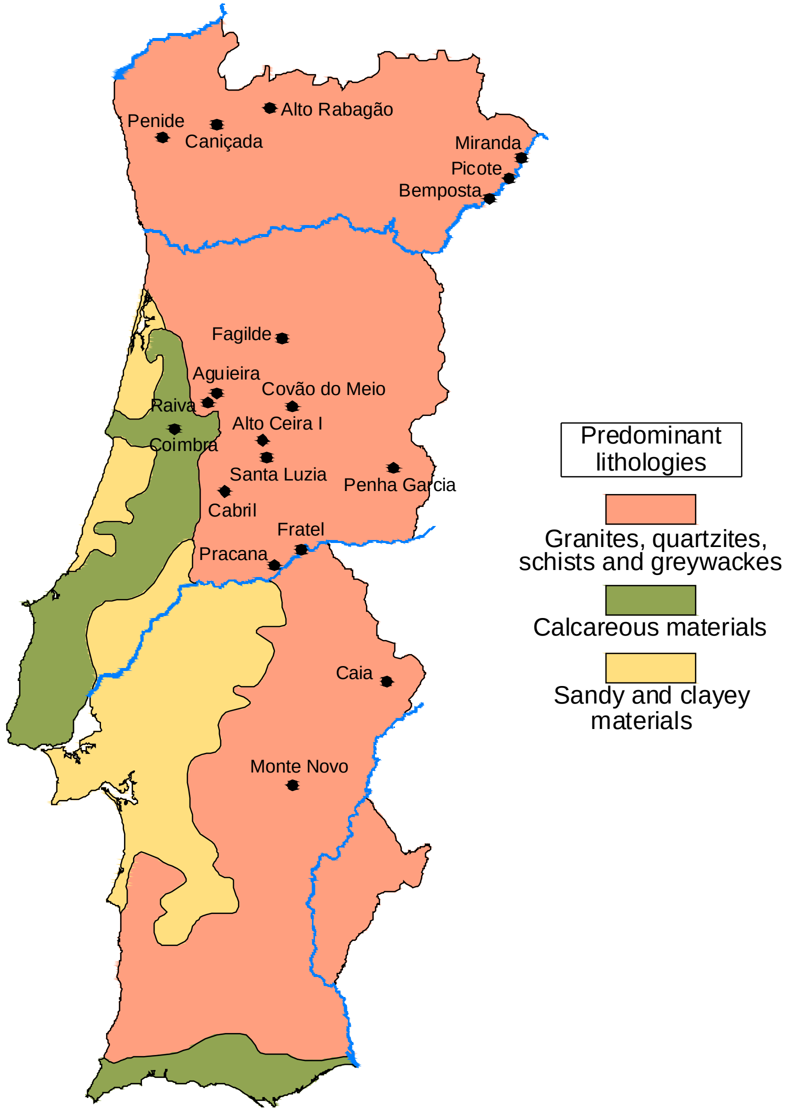
Portuguese AAR affected dams (19/52)

DAM	STRUCTURAL TYPE	YEAR OF COMPLE-TION	HEIGHT (m)	TYPE OF REACTION	AGGREGATES		MAXIMUM ACCUMULATED VERTICAL STRAIN UNTIL 2015 (x 10^{-6})	AVERAGE ANNUAL RATE IN THE LAST 5 YEARS (x 10^{-6})
					COARSE	FINE		
Santa Luzia	Arch	1942	76	ASR	Quartzite	Quartz	2200	20
Alto Ceira (old)	Arch	1949	36	ASR	Quartzite	Quartz	4600	120
Penide	Gravity	1949	18	ASR (?)	Granite	Quartz	150	10
Pracana	Buttress	1951	60	ISR - ASR	Quartzite/granite	Quartz	2000	10
Covão do Meio	Arch	1953	28	ASR	Granite	?	500	25
Cabril	Arch	1954	132	ISR – ASR	Granite	?	100	5
Caniçada	Arch	1955	76	ASR	Granite	?	100	5
Picote	Arch	1958	100	ASR	Granite	Granite	50	< 5
Miranda	Buttress	1961	80	ASR	Granite	Granite	150	5
Alto Rabagão	Arch	1964	94	ASR	Granite	Granite	100	5
Bemposta	Arch-gravity	1964	87	ASR	Granite	?	200	10
Caia	Buttress	1967	52	ISR – ASR	Granite	Quartz	?	5
Fratel	Gate	1973	43	ISR – ASR	Granite	Quartz	200	10
Penha Garcia	Gravity	1980	25	ASR (?)	Quartzite/granite	Quartz	100	< 5
Aguieira	Multiple arch	1981	89	ASR	Granite	Quartz	?	?
Raiva	Gravity	1981	36	ASR (?)	Granite	Quartz	120	5
Coimbra	Gate	1981	40	ASR (?)	?	Quartz	?	?
Monte Novo	Gravity	1982	30	ASR	Granite	?	100	10
Fagilde	Gravity	1984	27	ISR	Limestone	Quartz	2200	120

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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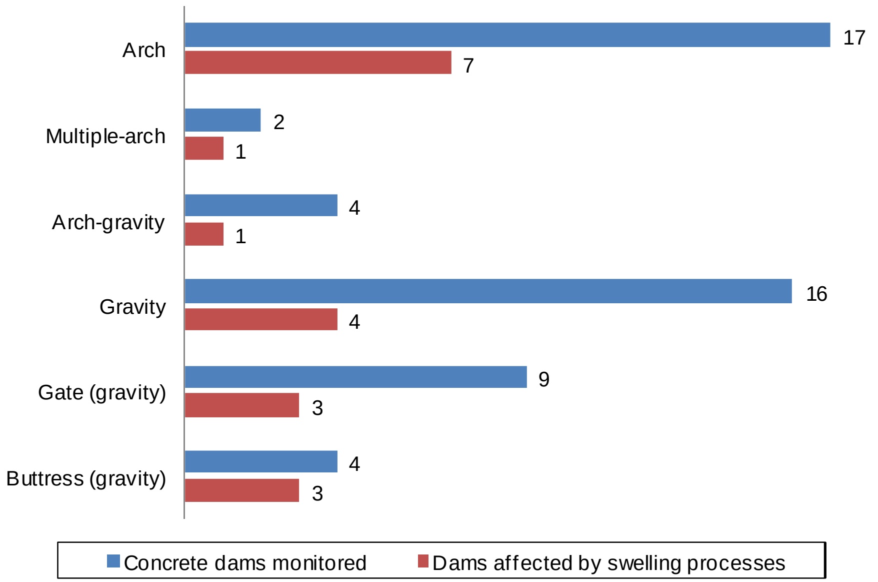
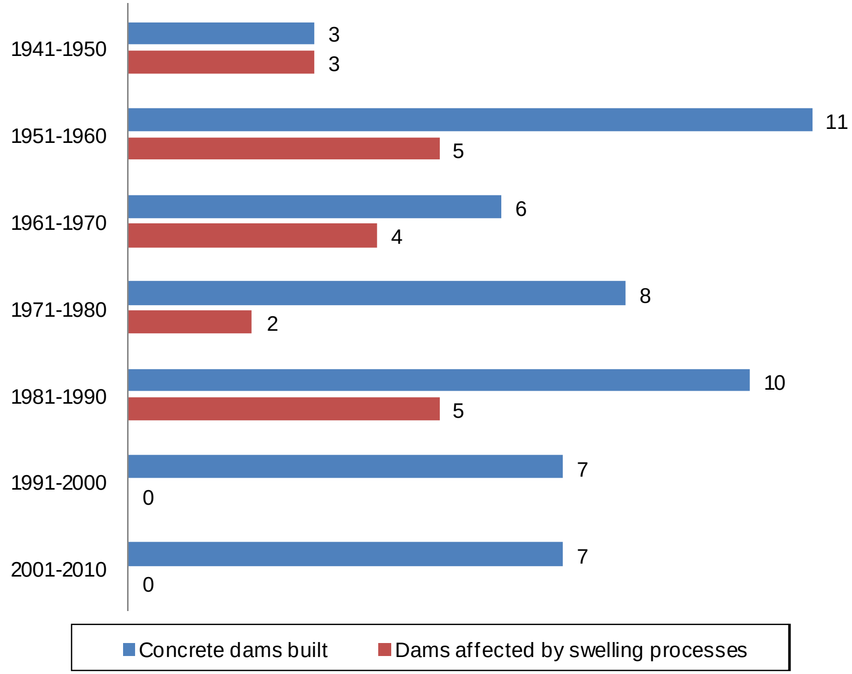
Portuguese AAR affected dams

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



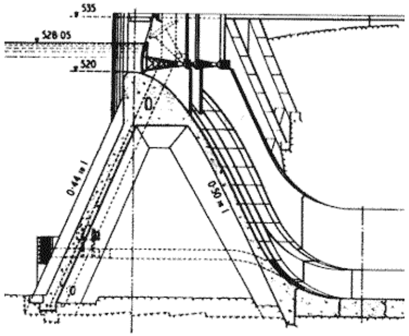
Portuguese concrete dams monitored and affected by AAR, organized in function of the construction decade

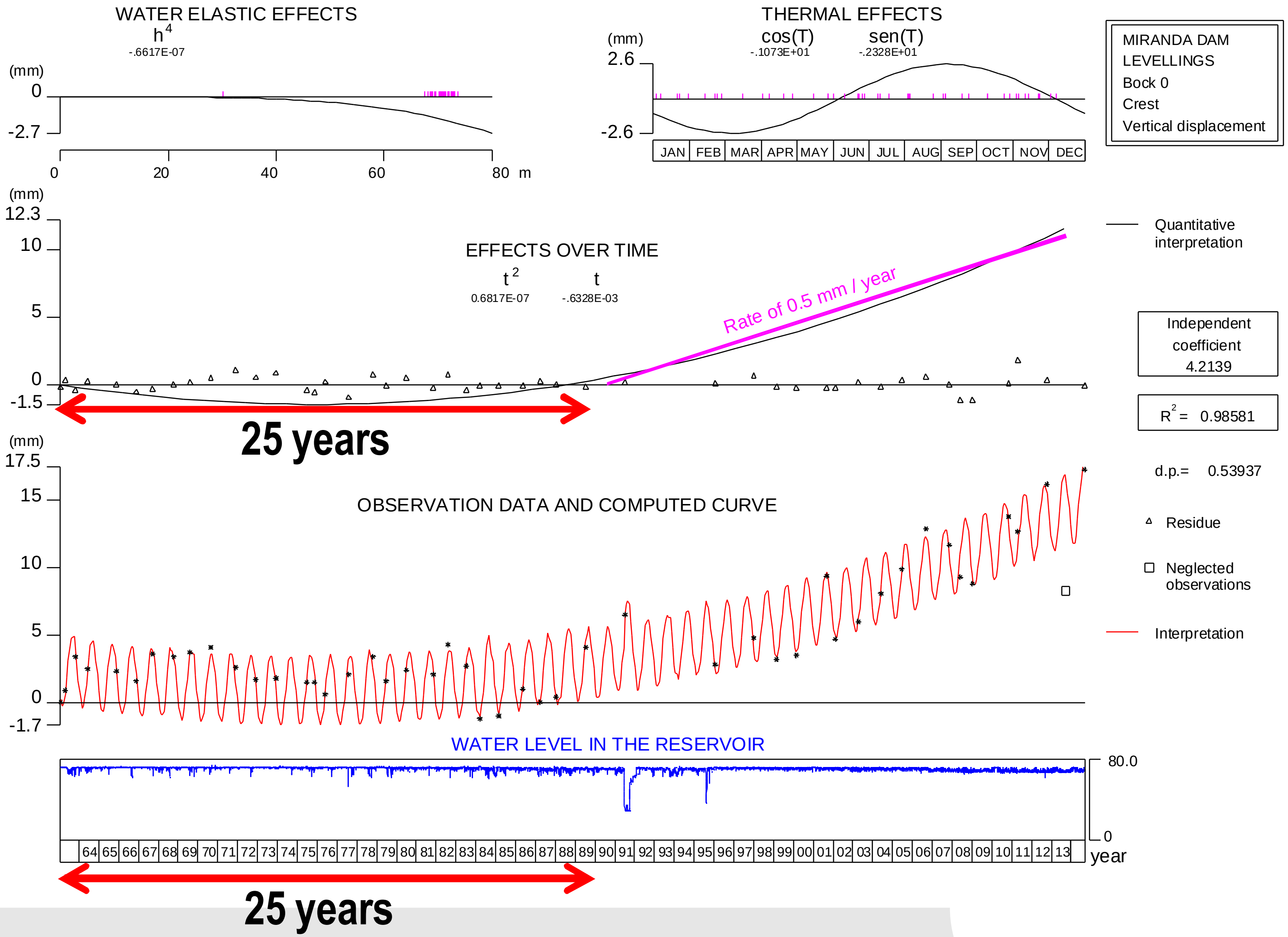


No signs of AAR on dams built in the last 20 years

Miranda dam

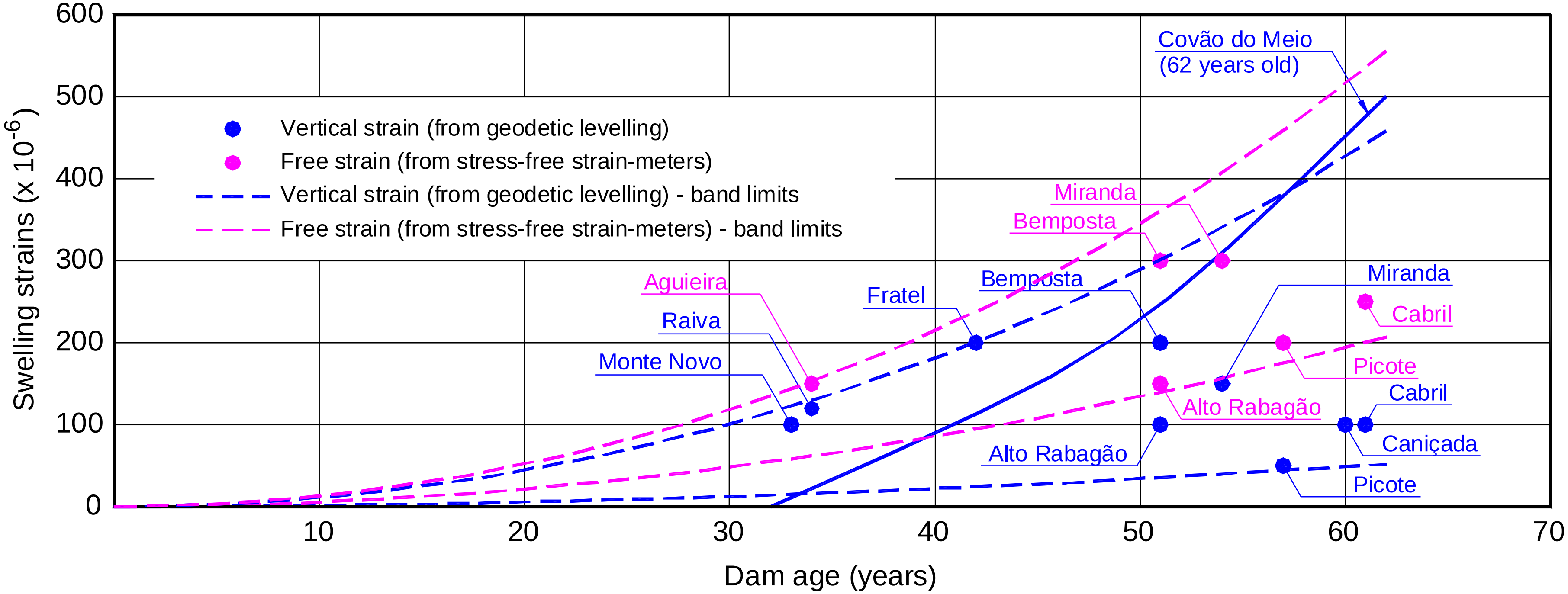
Buttress dam, 80 m high, built in 1961





Portuguese AAR affected dams

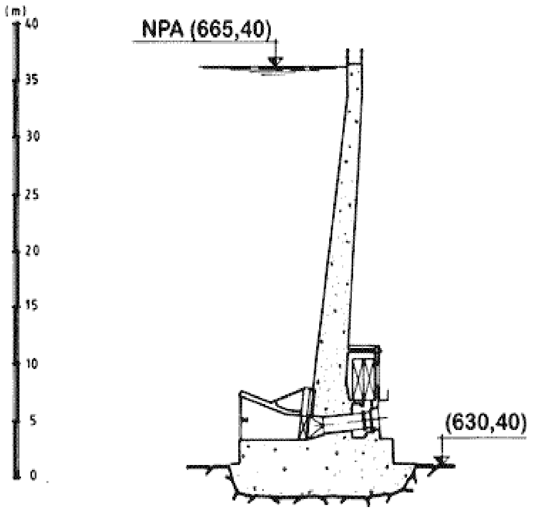
Average values of the monitored free strains by the stress-free Carlson strain-meters and strains obtained from geodetic levelling, in function of the dam age



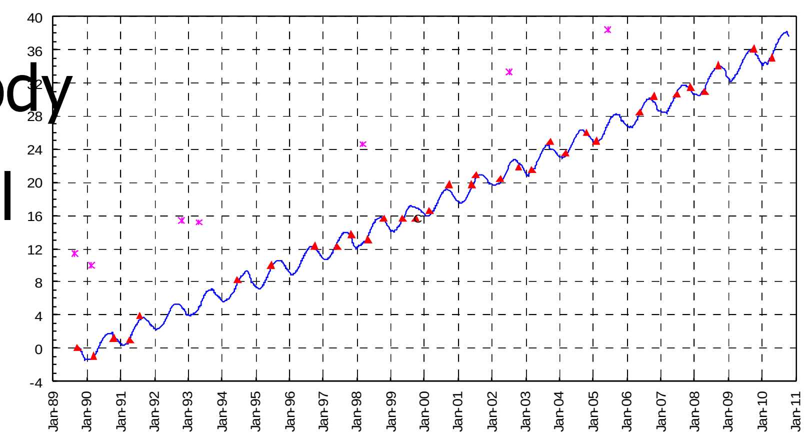
The free strains measured by the stress-free strain-meters are about twice the vertical strains obtained from the geodetic levelling results

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

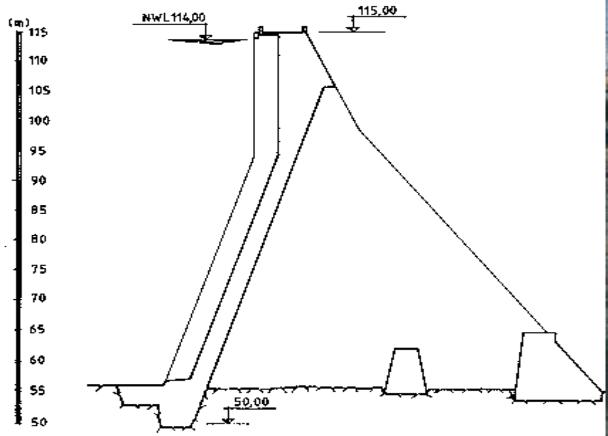


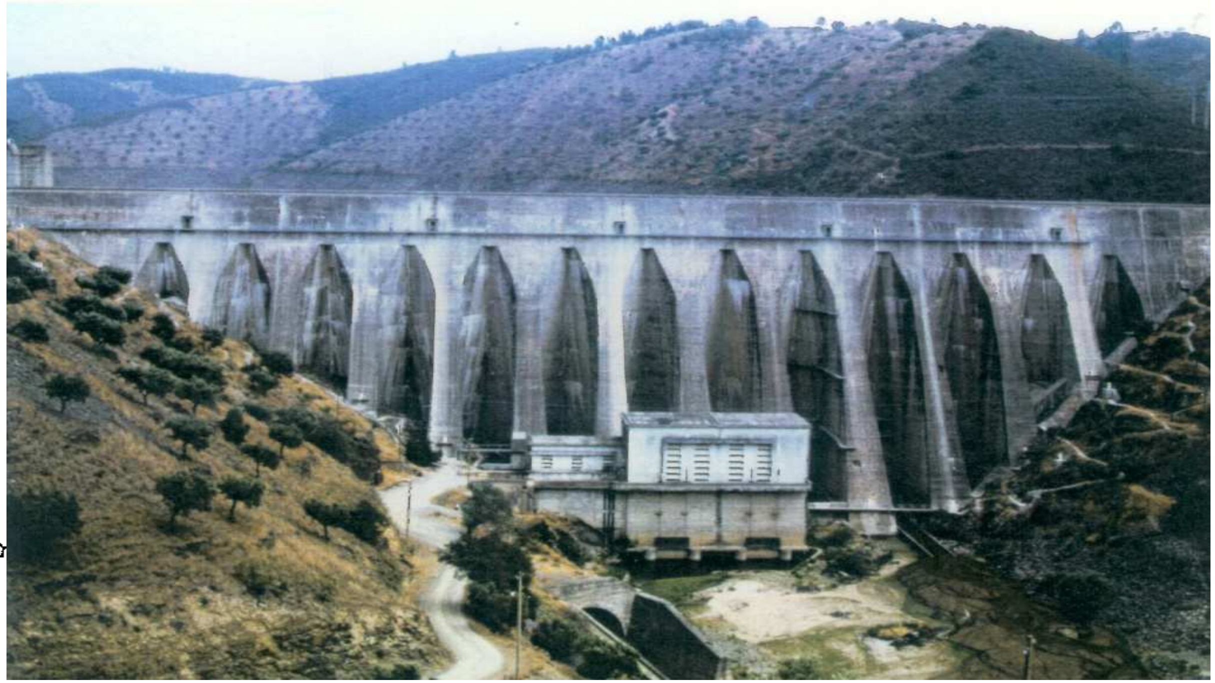
Alto Ceira II dam - 2014

Alto Ceira II dam - 2014

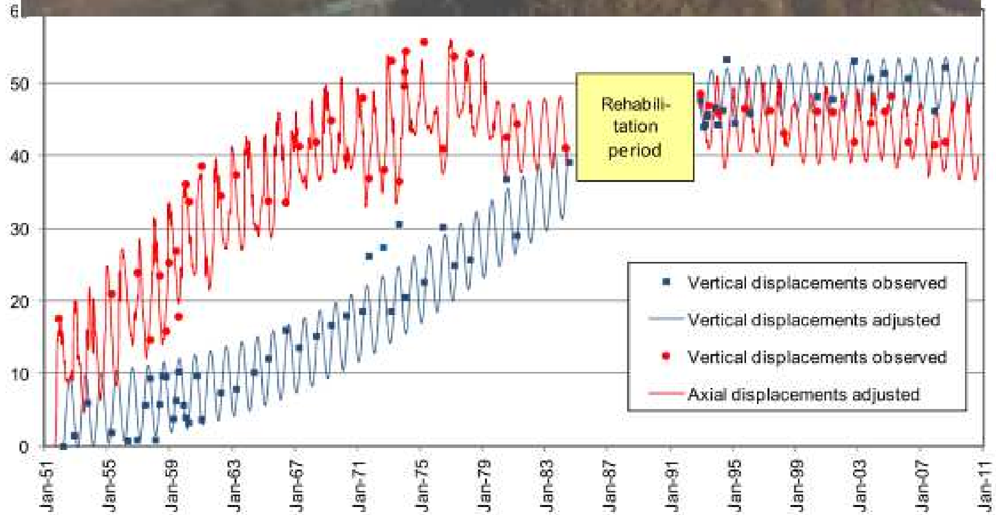
Pracana dam

Buttress dam, 60 m high, built in 1951





Pracana dam *after reahabilitation*

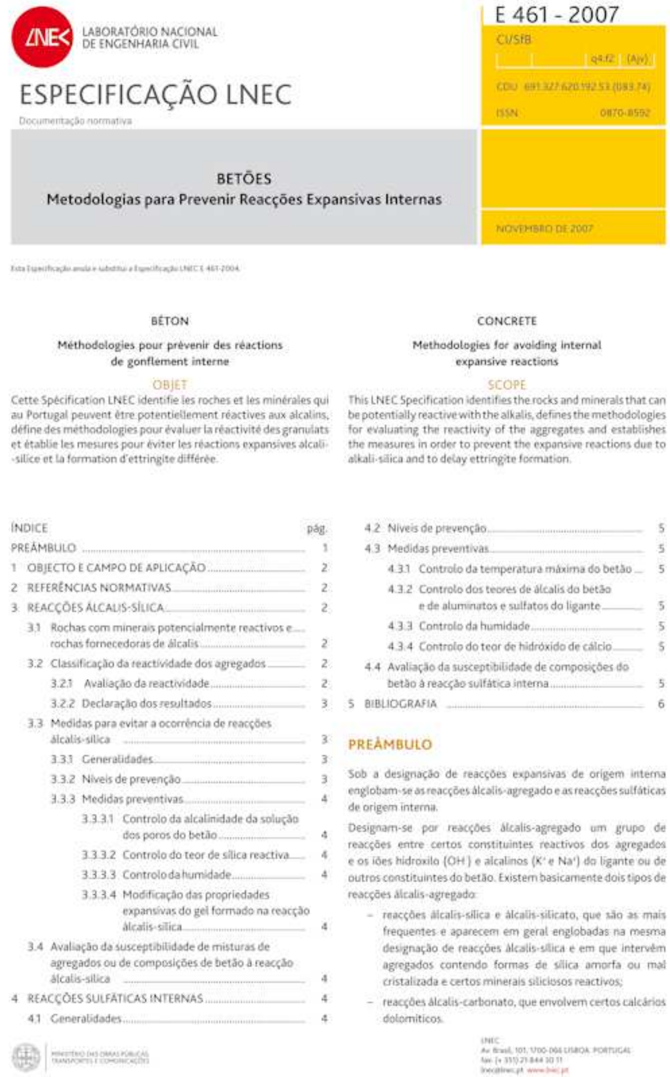


New concrete structures – Preventive measures

- 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.


LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

E 461 - 2007

CI/SfB q4.f2 (Ajv)

CDU 691.327:620.192.53 (083.74)

ISSN 0870-8592

ESPECIFICAÇÃO LNEC

Documentação normativa

BETÕES

Metodologias para Prevenir Reacções Expansivas Internas

NOVEMBRO DE 2007

BÉTON

Méthodologies pour prévenir des réactions de gonflement interne

OBJET

Cette Spécification LNEC identifie les roches et les minérales qui au Portugal peuvent être potentiellement réactives aux alcalins, définе des méthodologies pour évaluer la réactivité des granulats et établie les mesures pour éviter les réactions expansives alcali-silice et la formation d'ettringite différée.

CONCRETE

Methodologies for avoiding internal expansive reactions

SCOPE

This LNEC Specification identifies the rocks and minerals that can be potentially reactive with the alkalis, defines the methodologies for evaluating the reactivity of the aggregates and establishes the measures in order to prevent the expansive reactions due to alkali-silica and to delay ettringite formation.

ÍNDICE pág.

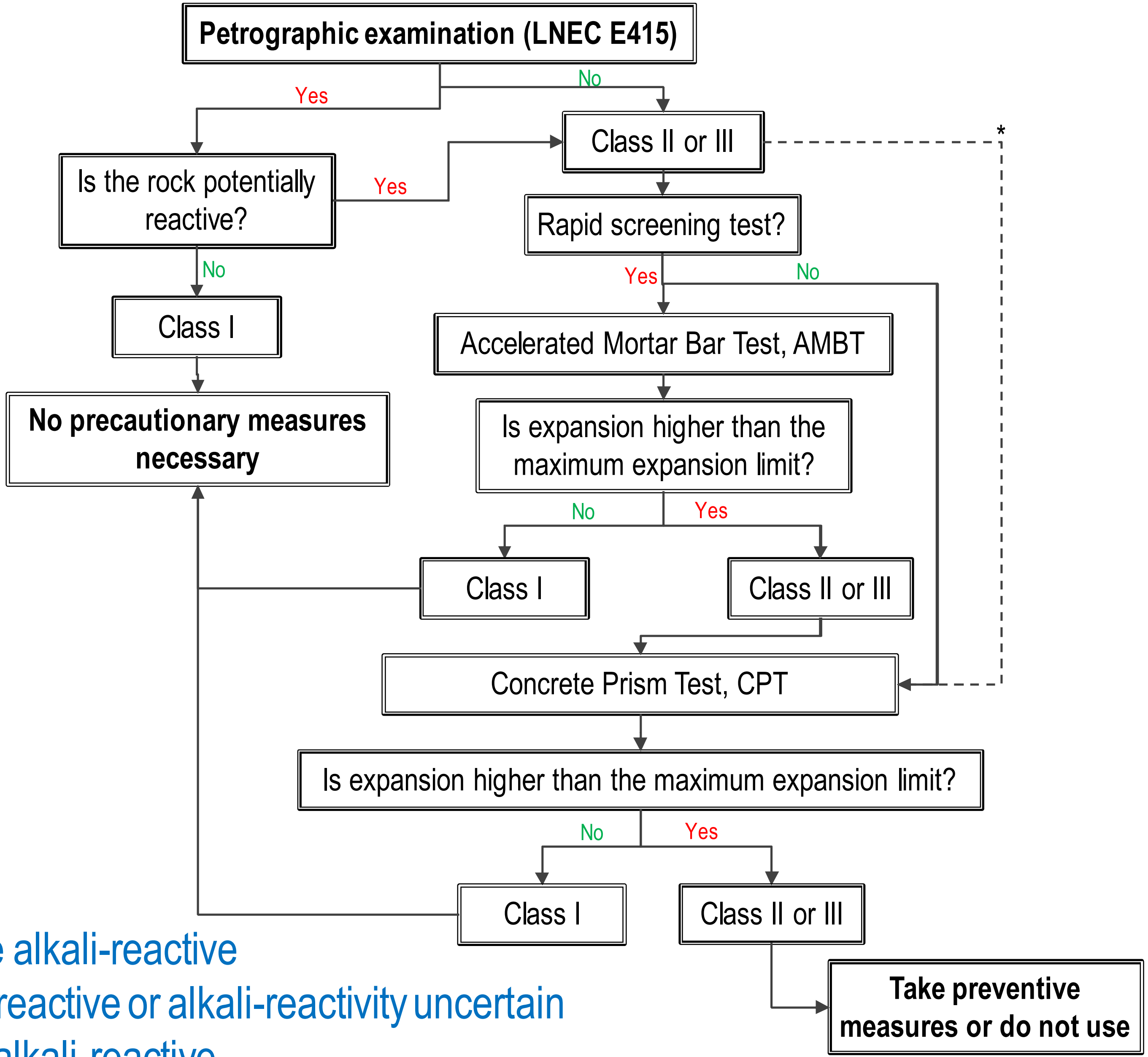
PREÂMBULO

Sob a designação de reacções expansivas de origem interna englobam-se as reacções álcalis-agregado e as reacções sulfáticas de origem interna.

Designam-se por reacções álcalis-agregado um grupo de reacções entre certos constituintes reactivos dos agregados e os iões hidroxilo (OH^-) e alcalinos (K^+ e Na^+) do ligante ou de outros constituintes do betão. Existem basicamente dois tipos de reacções álcalis-agregado:

- reacções álcalis-sílica e álcalis-silicato, que são as mais frequentes e aparecem em geral englobadas na mesma designação de reacções álcalis-sílica e em que intervêm agregados contendo formas de sílica amorfa ou mal cristalizada e certos minerais siliciosos reactivos;
- reacções álcalis-carbonato, que envolvem certos calcários dolomíticos.

ASR



Classes:

I - very unlikely to be alkali-reactive

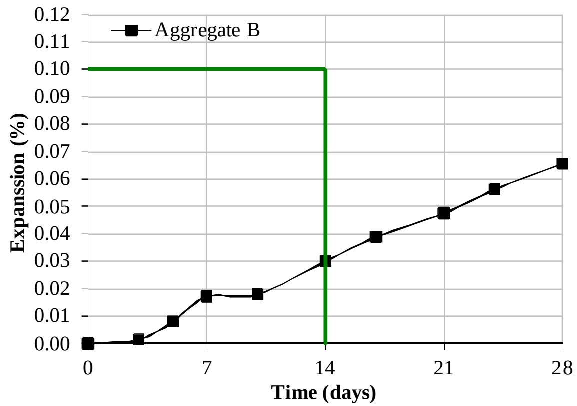
II - potentially alkali-reactive or alkali-reactivity uncertain

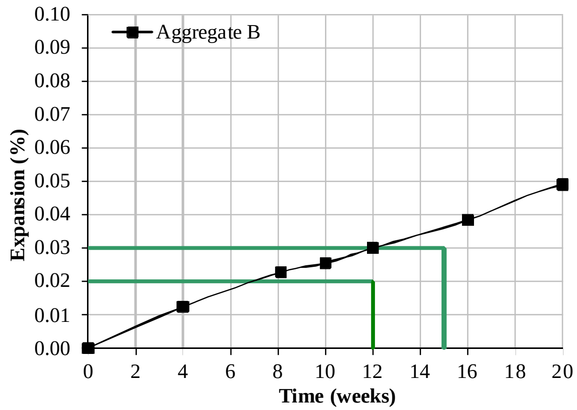
III - very likely to be alkali-reactive

AGGREGATES TESTING

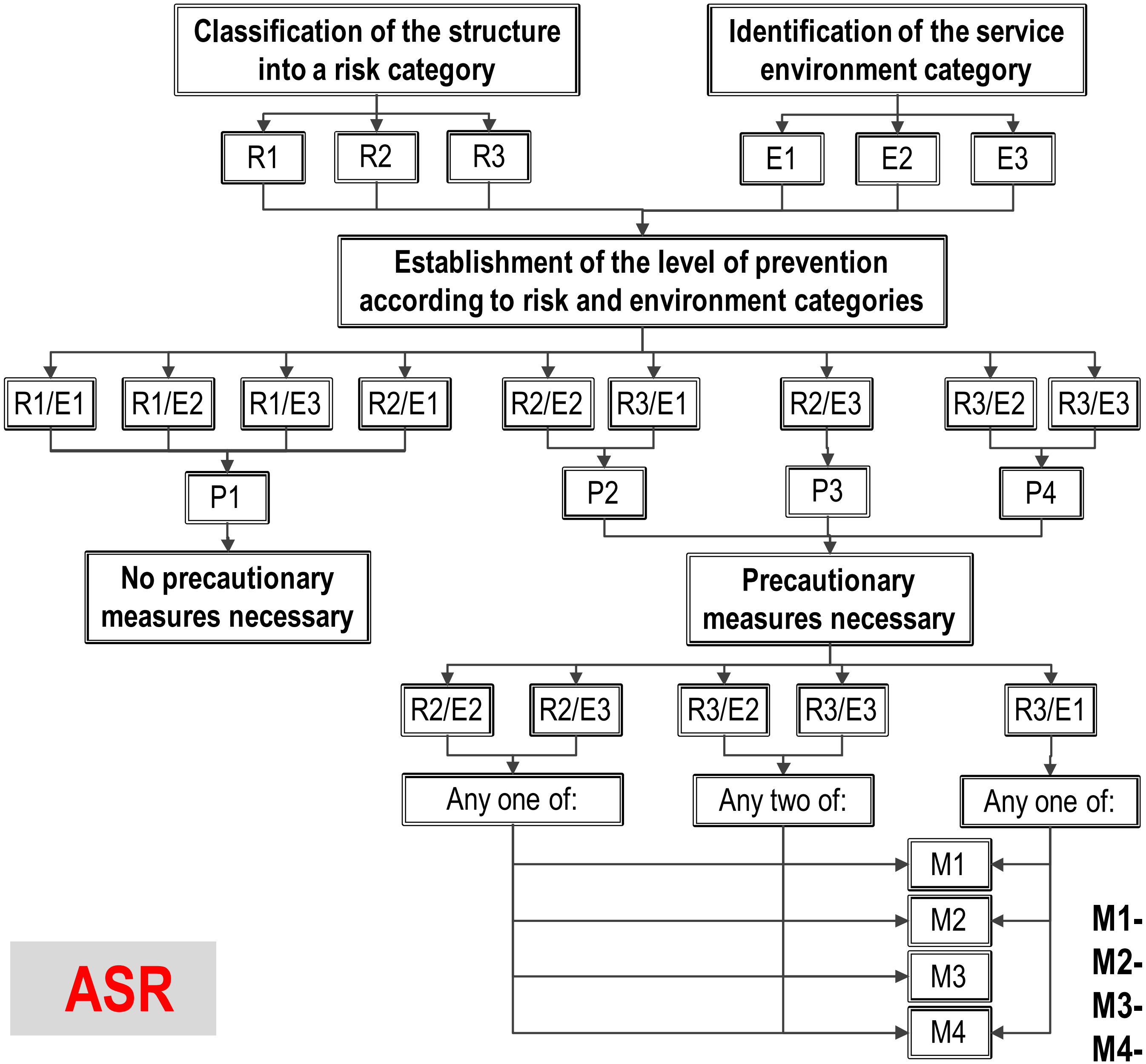
- **Petrographic examination**
  - LNEC Specification E 415 (RILEM AAR-1).
- **Accelerated Mortar Bar Test, AMBT**
  - RILEM AAR-2 & ASTM C 1260
  - Inadequate for slowly reactive aggregates.
- **Concrete Prism Test, CPT**
  - RILEM AAR-3.1 & RILEM AAR-4.1
  - Lab/Field performance & expansion limits under discussion
  - Test duration must be extended for slowly reactive aggregates or Long-service structures (e.g. concrete dams) .

ASR





Example of a slowly reactive aggregate passing the AMBT and failing the CPT at 60 ºC. Aggregate has been found to be deleterious reactive in a structure.



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 ≤3.0 kg/m^3 $Na_2O_{eq.}$
  - Class III ≤ 2.5 kg/m^3 $Na_2O_{eq.}$.
- Using type II additions, *e.g.*
  - Low-lime fly ash (< 8 % CaO and < 5 % $Na_2O_{eq.}$) > 30 %
  - Ground granulated blast furnace slag (<1.5 % $Na_2O_{eq.}$) > 50 %

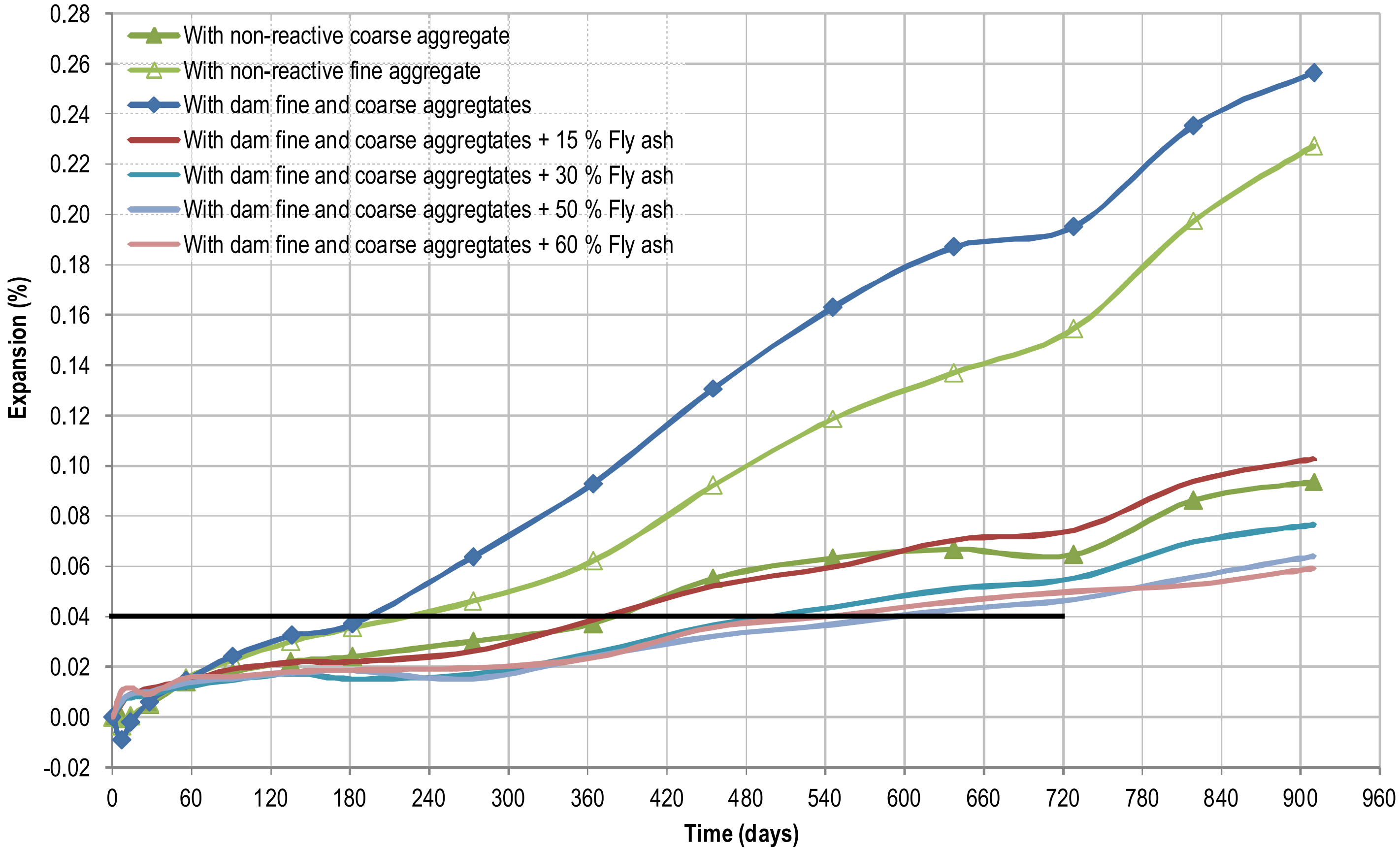
M2 – use non-reactive aggregate

- Using "non-reactive aggregate" combinations;
- Not always feasible, *e.g.* dams.

ASR

Type II Additions Testing

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



ASR

PREVENTIVE MEASURES

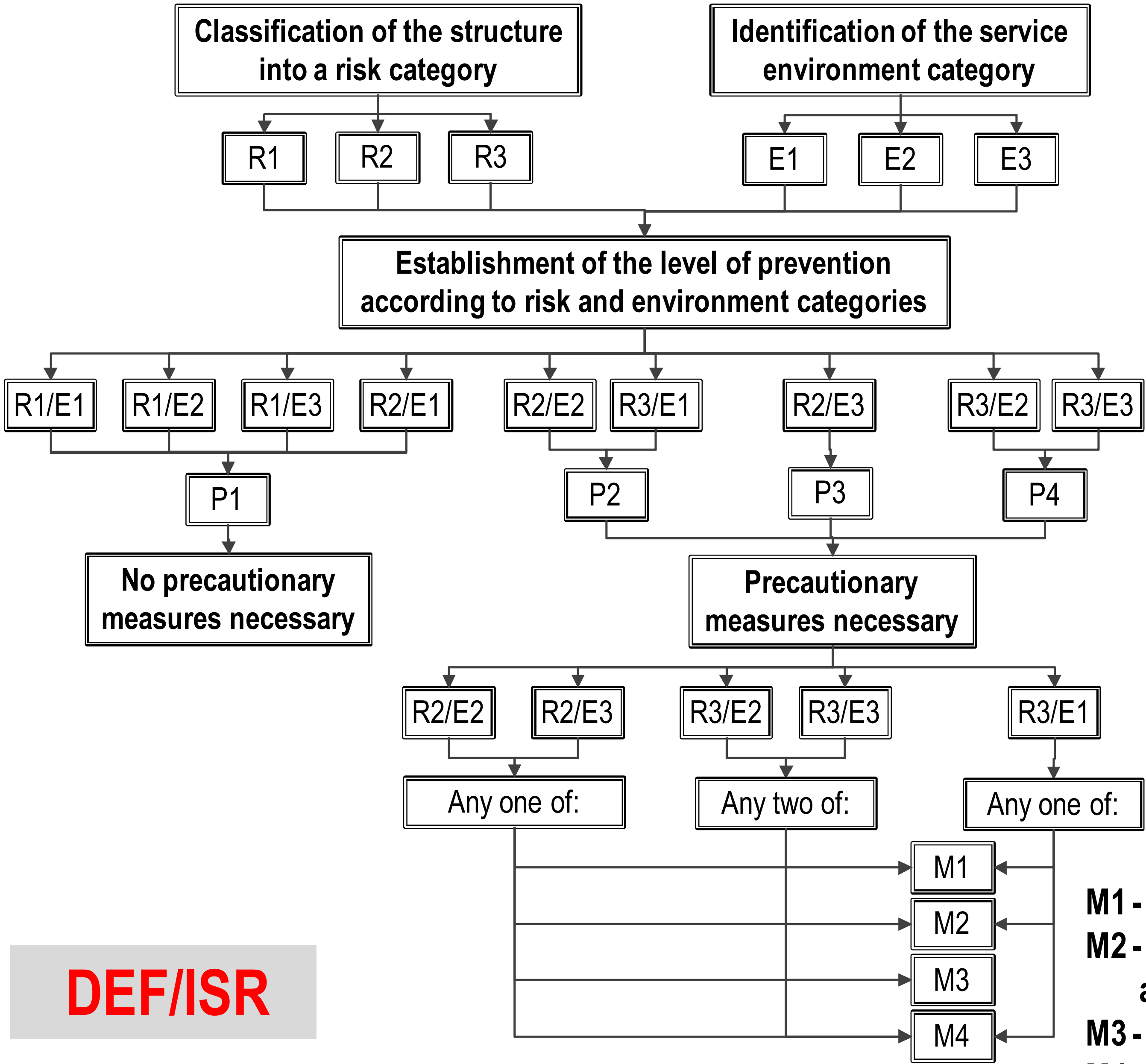
M3 – reduce moisture ingress

- 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.

ASR



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P4 - extraordinary precaution level

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

DEF/ISR

PREVENTIVE MEASURES

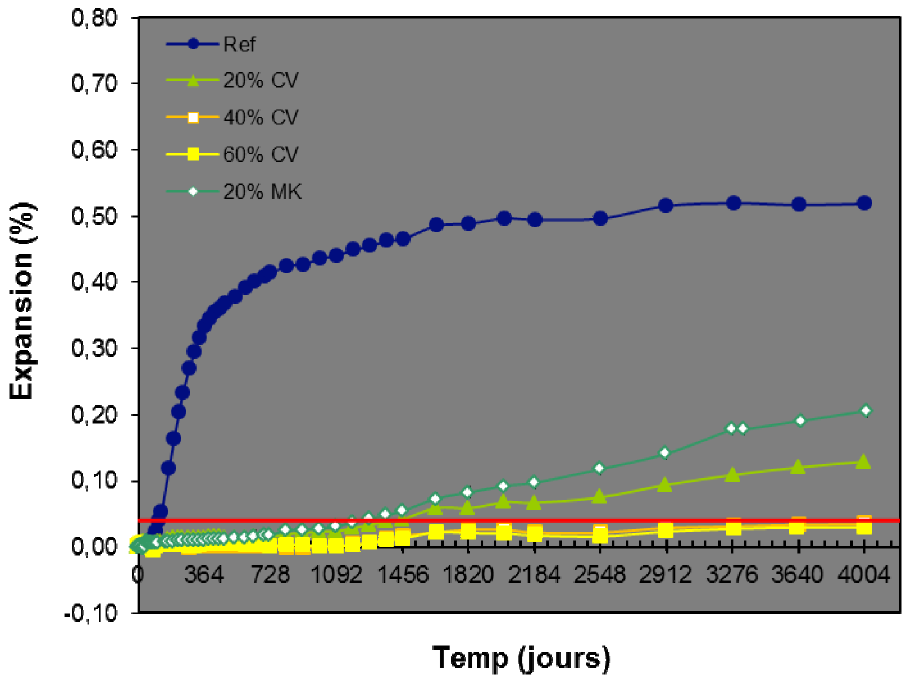
- M1 – restrict concrete temperature
  - Limiting temperature in concrete at early ages, < 65 ºC.
  - Changing concrete composition.
  - Cooling concrete and using metal formwork.
- M2 – restrict cement and concrete composition
  - Limiting binder SO_3 content
    - $SO_3 \leq 3.5$ % if $C_3A \leq 3.0$ %
    - $SO_3 \leq 2.5$ % if 3.0 % $\leq C_3A \leq 5.0$ %
  - 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.

DEF/ISR

CONCRETE TESTING

❑ LPC method nº. 66

- Assess type II additions effectiveness;
- Assess concrete composition susceptibility to DEF/ISR.



DEF/ISR


Merci de votre
attention!