ASSESSMENT OF CONCRETE BRIDGE DECKS WITH ALKALI SILICA REACTIONS

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Abstract

Based on investigations of concrete from an approximately 40 years old bridge a procedure to support the management of maintenance and repair of alkali silica damaged bridges is proposed.

Combined petrography and accelerated expansion testing were undertaken on cores from the Bridge at Skovdiget, Bagsværd, Denmark to provide information on the damage condition as well as the residual reactivity of the concrete.

The Danish Road Directory's guidelines for inspection and assessment of alkali silica damaged bridges will be briefly presented, and proposed modifications will be described.

KEYWORDS: residual reactivity, alkali silica reaction, concrete structures, management

1 INTRODUCTION

Bridge management makes use of inspection and assessment routines for optimization of budgets and improved safety. As an example the Danish Road Directorate's minimum requirements to special investigations of concrete structures possibly affected by alkali silica reactions (ASR) and/or frost damage are summarized in TABLE 1.

Thaulow and Geiker [2] evaluated the applicability of methods for determining residual ASR, see TABLE 2. Nielsen [3] proposed a decision making procedure to be used for planning maintenance and repair of ASR affected structures, see principle in Figure 1. This procedure is based on observation of phases during development of ASR: initiation, acceleration, and a rest period due to exhaustion of one of the parameters necessary for ASR, as well as consideration of a characteristic dimension (l) affecting rate of ingress of water and alkalis.

The present paper presents an improved procedure for decision making to be used in connection with planning maintenance and repair of ASR affected structures. The paper is based on a recent MSc thesis by the second author, Jansson [4].

The 40 year old bridge at Skovdiget in Bagsværd north of Copenhagen was used as test-object because a) it is severely damaged due to ASR; and b) it has been extensively monitored through the last 25 years. The bridge also suffers from corrosion and other damages, and therefore several investigations have been performed to asses the damage development and the bridge's deterioration; for examples and history see e.g. Goltermann et al. [5],[6].

2 MATERIALS AND METHODS

2.1 General

Six cores (diameter 100 mm, length ca. 100 mm) were drilled from two concrete slabs (about 700 mm x 700 mm x 300 mm) cut out from one of the box girders of the bridge at Skovdiget. The two slabs represent areas without (A) and with (B) visible moisture exposure signs. Moisture exposure was caused by a defective membrane on part of the bridge deck.

2.2 Methods for assessment and analysis

General

The analyses undertaken are summarized in TABLE 3. All cores were subdivided in the same way, see Figure 2, except for two cores which were treated differently: B1 because it contained a large

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crack, B4 because it disintegrated during drilling due to delamination; the thin sections of both B1 and B4 comprise these cracks.

Petrography

Thin sections, 20μm thick and 30×45mm, were prepared using standard procedures with fluorescent epoxy impregnation under vacuum. Micro analysis takes place by polarization and fluorescence microscopy, following principles as outlined in ASTM C 856 [7] and the Danish Test Method TI-B 5 [8].

Residual reactivity

Residual reactivity was measured according to a modified version of TI-B 51 [9]. Quarters of cores were cut from the cores in the length direction (see Figure 2) and exposed to either a saturated NaCl solution (marked -S) or 100 % relative humidity (marked –F), both at 50 °C, and length changes measured up to 22 weeks.

One sample from each of the slabs A and B was tested at 23 °C to investigate the hypothesis that expansion at 23 °C would be higher than for testing at 50 °C.

Chloride content

Chloride profiles were determined by cutting 15 mm thick slices and determining chloride content according to DS 423.28 [10].

3 RESULTS

The petrographic examination was made to determine to which degree the concrete slabs had been exposed to water and the extent of ASR before further testing. The initial examination of the slabs showed that one of these (slab B) was delaminated in one of the corners; no intact cores could be drilled from this area. The other slab (A) was not delaminated and all cores were intact. The samples from the water exposed slab (B) only showed minor re-precipitation of ettringite, but several reactive particles from ASR were observed in all thin sections. This indicates varying water exposure of the B-slab. An example of a reactive particle in a thin section after testing of residual reactivity is shown in Figure 5.

The results from determination of residual reactivity in either saturated NaCl solution or 100 % relative humidity at 50 °C are given in Figure 3 and Figure 4. All prisms exposed to NaCl exhibit a major expansion compared to the acceptance limit at 0.1 %. Prisms from both slabs expand between 0.4 and 0.7 %, and the expected lower residual reactivity of the prisms from slab B can not be observed. These observations indicate either variations in initial content of reactive aggregates or variation in exposure to moisture and degree of reaction. All prisms exposed to 100 % humidity comply with the acceptance limit at 0.1 %. The shrinkage observed after four weeks is due to an experimental error caused by partial drying of the prisms; however based on the curves this seem not to have affected the overall expansion. The results show that future development of ASR requires not only moisture but also alkali metal ions.

The results for testing of 2 single samples in saturated NaCl at 23 °C showed very high expansion for the sample from slab B, but no expansion for the sample from slab A. An explanation might be that the reactions in slab B have developed more in the structure than for slab A, however, the result is inconclusive and should be re-tested for more samples.

Measurements of chloride content supports the expectations of a more severe exposure of slab B to water with deicing salt compared to slab A, especially in the delaminated area; see TABLE 4.

4 DISCUSSION

To estimate the degree of reaction of the concrete before exposure, cracking intensity before and after exposure was compared, see TABLE 5. The influence of the weight given to large cracks compared to small cracks is illustrated in Figure 6, which shows the anticipated development of ASR in the box girders from 1967-2006 calculated for various factors for fine versus coarser cracks. It is found that the various factors applied lead to a similar result for the range of the modelling. The length of the initial period was calculated to be three years by using experiences from other similar bridges. Data from the bridge suggest that the bridge deck was exposed to water for the first time in 1973, since then water has penetrated into the bridge. It is important to emphasize that the model shows how the development of ASR in the box girders may have been, and not how it has been.

5 CONCLUSIONS

Based on the investigations performed it is suggested that measurements of residual activity should be performed as part of an inspection. The results can be used to prioritise the bridges that are most likely to develop ASR or continue ASR development. The test is simple and low cost, especially since cores often are extracted for other purposes during inspections. The flow diagram in Figure 7 illustrates an improved procedure for decision making to be applied in connection with planning of maintenance and repair of ASR affected structures.

6 REFERENCES

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TABLE 1: Properties to be investigated in case of possible ASR and/or frost damage [1]

Structural element	HCP corrosion rate	Cover and hammer tapping	Chloride content	Carbona-tion*	Cutting out**	Cores***	Moisture
Columns	100 %	100 %	3 profiles	Min. 3 places	Min. 3 places	Min. 1	Min. 1 place
Edge beams	-	100 %	3 profiles	Min. 2 places	Min. 2 places	Min. 1	Min. 1 place
Bridge deck, lower surface	-	Cracked areas	2 profiles	Min. 3 places	Min. 3 places	Min. 1	Min. 1 place
Bridge deck, upper surface	-	-	At sites for cutting out	-	-	Min. 1	Min. 1 place
Abutments etc.	-	-	-	-	-	-	-

Notes

* More if carbonation depth is above 10 mm

** To calibrate HCP mapping (no corrosion, risk of corrosion, corrosion)

*** For macro analyses, moisture measurements, and if necessary micro analyses

TABLE 2: Applicability of methods for determining residual ASR [2]

Method	No alkalis from environment	Alkalis from environment
Expansion measurements, in situ	Applicable	Applicable
Expansion measurements on cores in 100 % RH	Applicable	Not applicable
Expansion measurements on cores in NaCl solution	Pessimistic	Applicable
Petrography	Pessimistic	Applicable
Chemical shrinkage measurements	Pessimistic	Applicable
Combined method; determination of fixed and available alkalis as well as reacted and non-reacted silica	Applicable	Not applicable

TABLE 3: Experimental programme

	Cores					
	No exposure to moisture		Moisture exposure			
Investigation	A1	A2	B1	B2	B3	B4
Macro analysis	X	X		X	X	
Micro analysis	X	X	X	X	X	X
Residual reactivity test at 50°C	X	X	-	X	X	-
Residual reactivity test at 23°C	-	X	X	-	-	-
Chloride profile determination	X	-	X	-	-	X

TABLE 4: Chloride content, weight % (w/w) of concrete

Core A		Core B1		Core B4	
Depth, mm	Chloride, %	Depth, mm	Chloride %	Depth, mm	Chloride, %
0-15	0.085	0-15	0.244	0-15	0.211
15-30	0.019	15-30	0.233	15-30	0.125
30-45	0.007	30-45	0.202	35-50	0.144
45-60	0.006	45-60	0.093	50-65	0.144
60-75	0.009	60-75	0.158	65-90	0.158
75-90	0.011	75-90	0.192	90-105	0.174
90-105	0.014	90-100	0.158		
105-120	0.017				
120-135	0.028				

TABLE 5: Number of cracks in thin sections and calculated degree of reactivity

F: 100 % RH, 50 °C S: Saturated NaCl, 50 °C S23: Saturated NaCl, 23 °C	Core no.	Number of cracks		Total number of cracks, recalculated*	Percentage reacted [%]
		Fine < 0.1 mm	Coarse > 0.1 mm		
Thin section before measurement of residual reactivity	A1	14	0	14	39
	A2	16	2	20	56
	B2	10	0	10	28
	B3	15	0	15	42
Thin section after measurement of residual reactivity	A1-F	11	0	11	31
	A2-S	28	3	34	95**
	B1-S23	39	8	55	(154)***

* Fine cracks is weighed by a factor of 1 and coarser cracks with a factor 2.

** A2-S is the sample that showed the highest expansion in the standard test at 50°C and is used as a reference. The degree of reaction is arbitrarily set to 95 % as the expansion had almost ceased after 22 weeks.

*** Expansion at 23 °C is relatively higher than for tests performed at 50 °C.

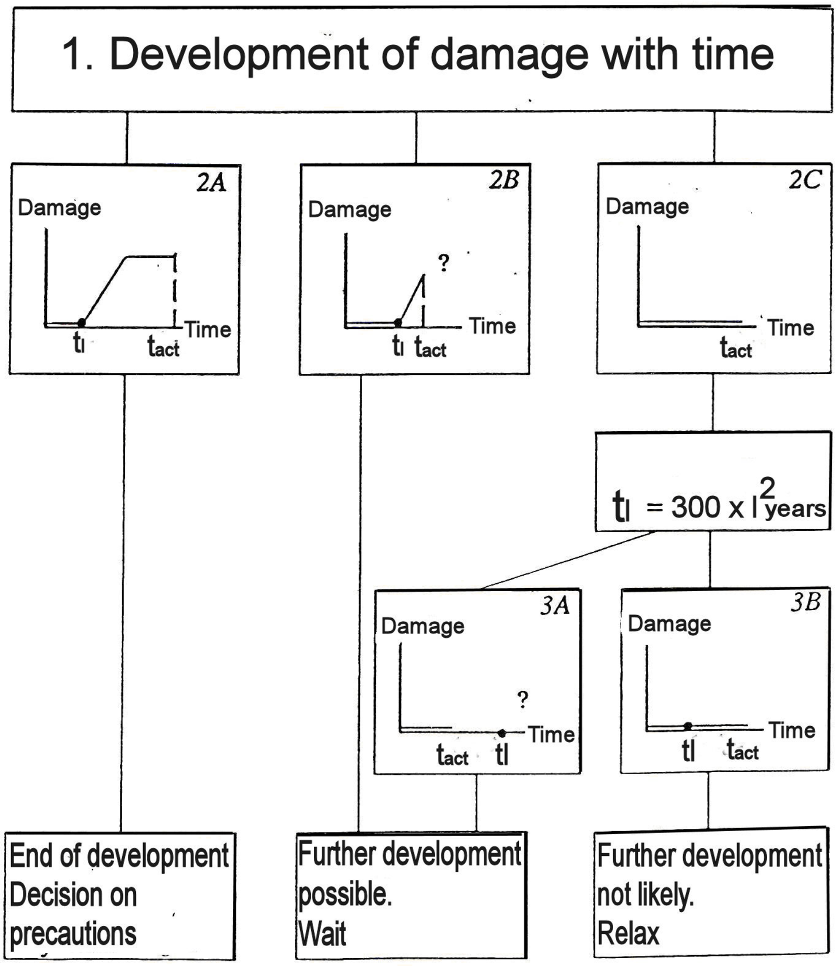

Figure 1: Possible decision making procedure to be used for planning maintenance and repair of ASR affected structures, [3], revised diagram. l = characteristic dimension. t_{act} = actual time. t_l = time when moisture has penetrated to the zone of the characteristic dimension.

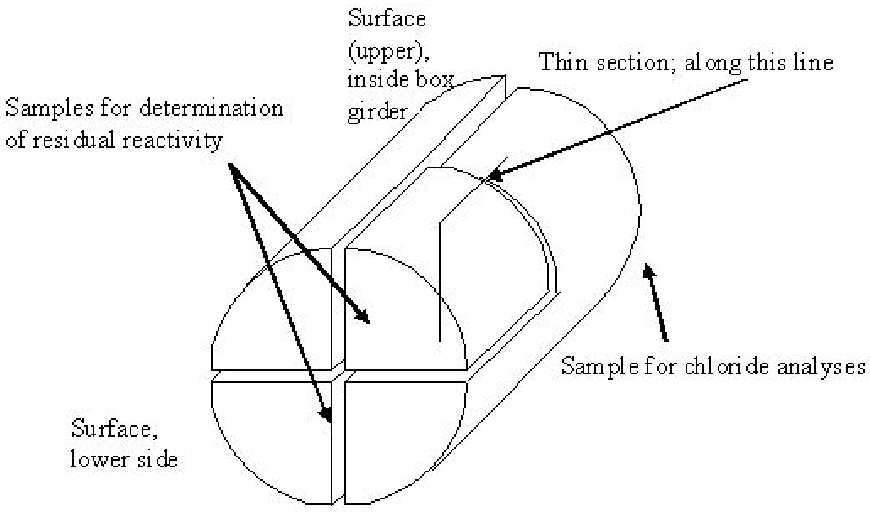

Figure 2: Subdivision of cores.

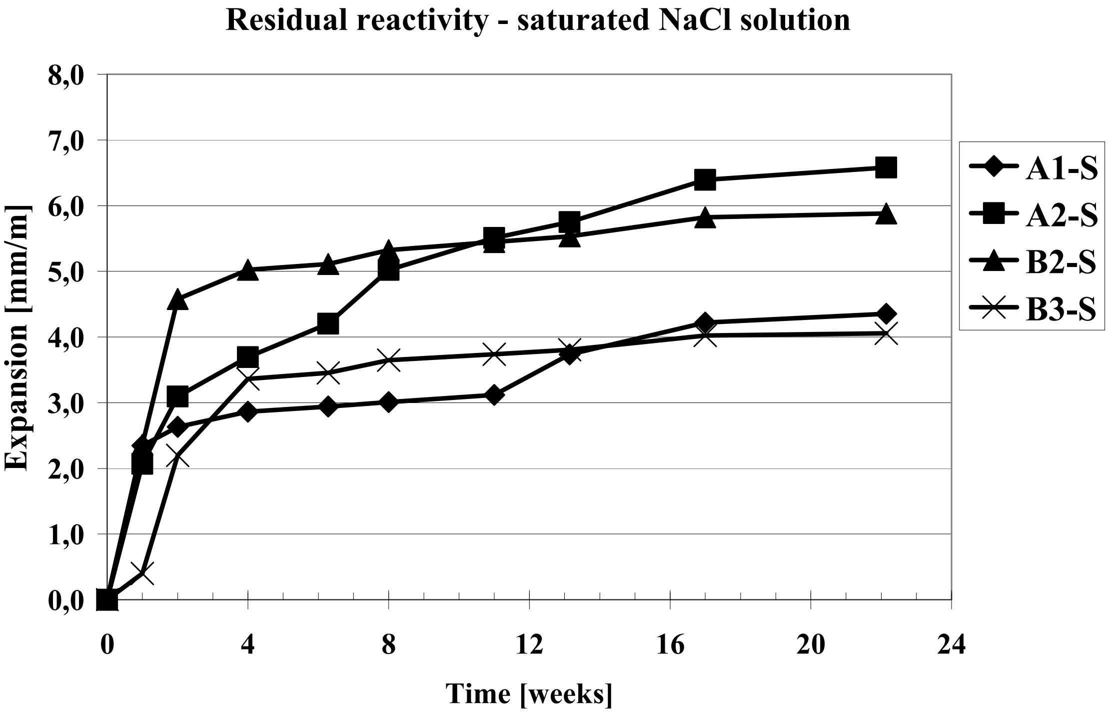

Figure 3: Expansion of prisms in saturated salt solution (NaCl).

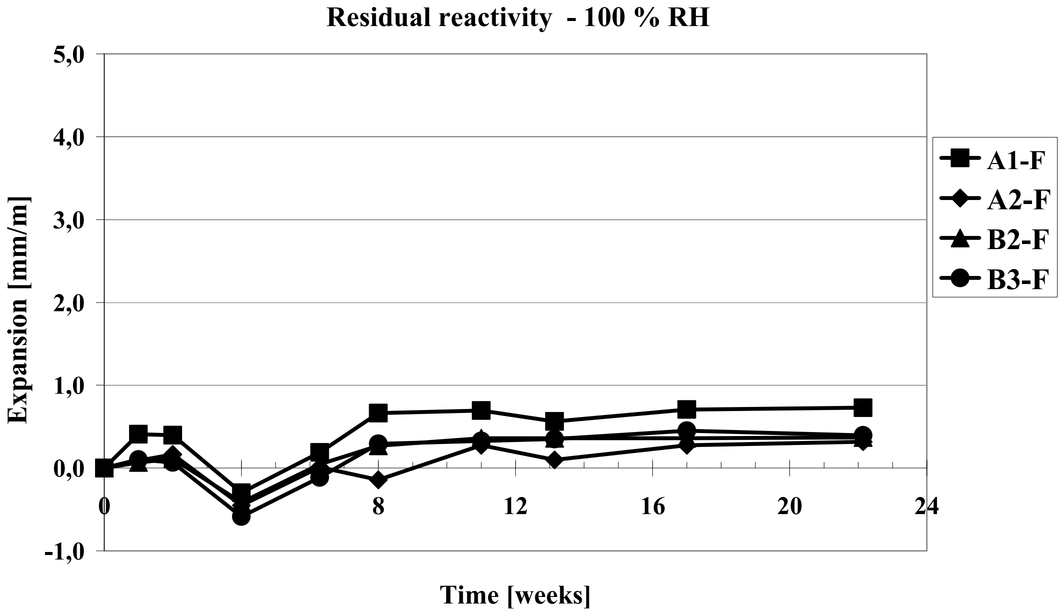

Figure 4: Expansion of prisms in 100 % relative humidity, without NaCl.

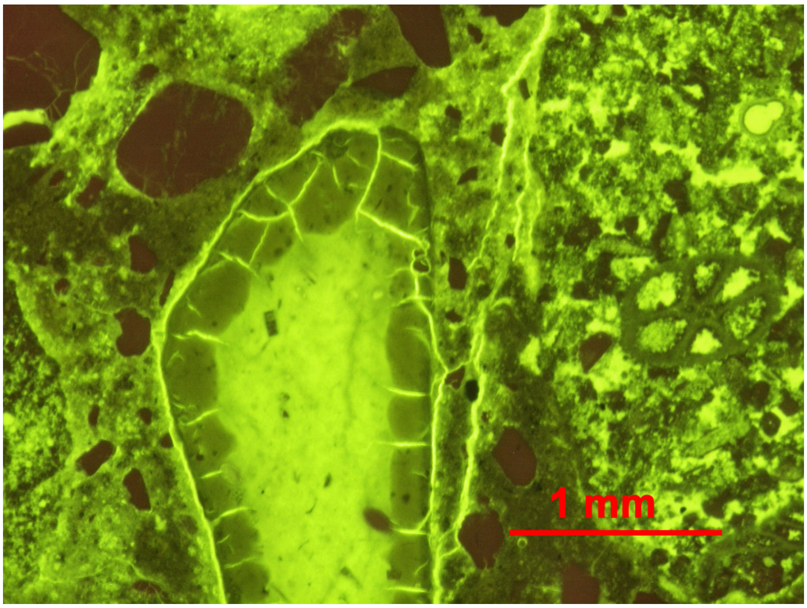

Figure 5: Thin section B1, after residual expansion testing at 23 °C, but also typical for thin sections from slab A and B after residual reactivity testing at 50 °C. Reactive particle of porous flint shows shrinkage cracks due to ASR reactions, and a particle rim zone which has become less porous due to ASR reactions and precipitation of Ca-gel.

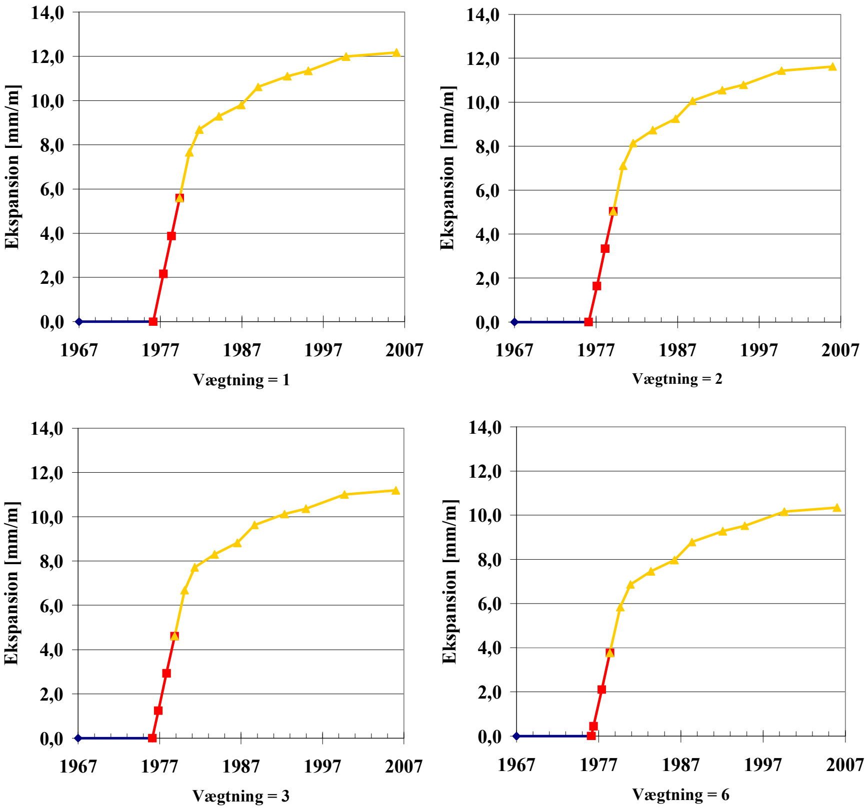

Figure 6: Modelling damage development; weighing of large cracks 1, 2, 3 and 6, respectively.

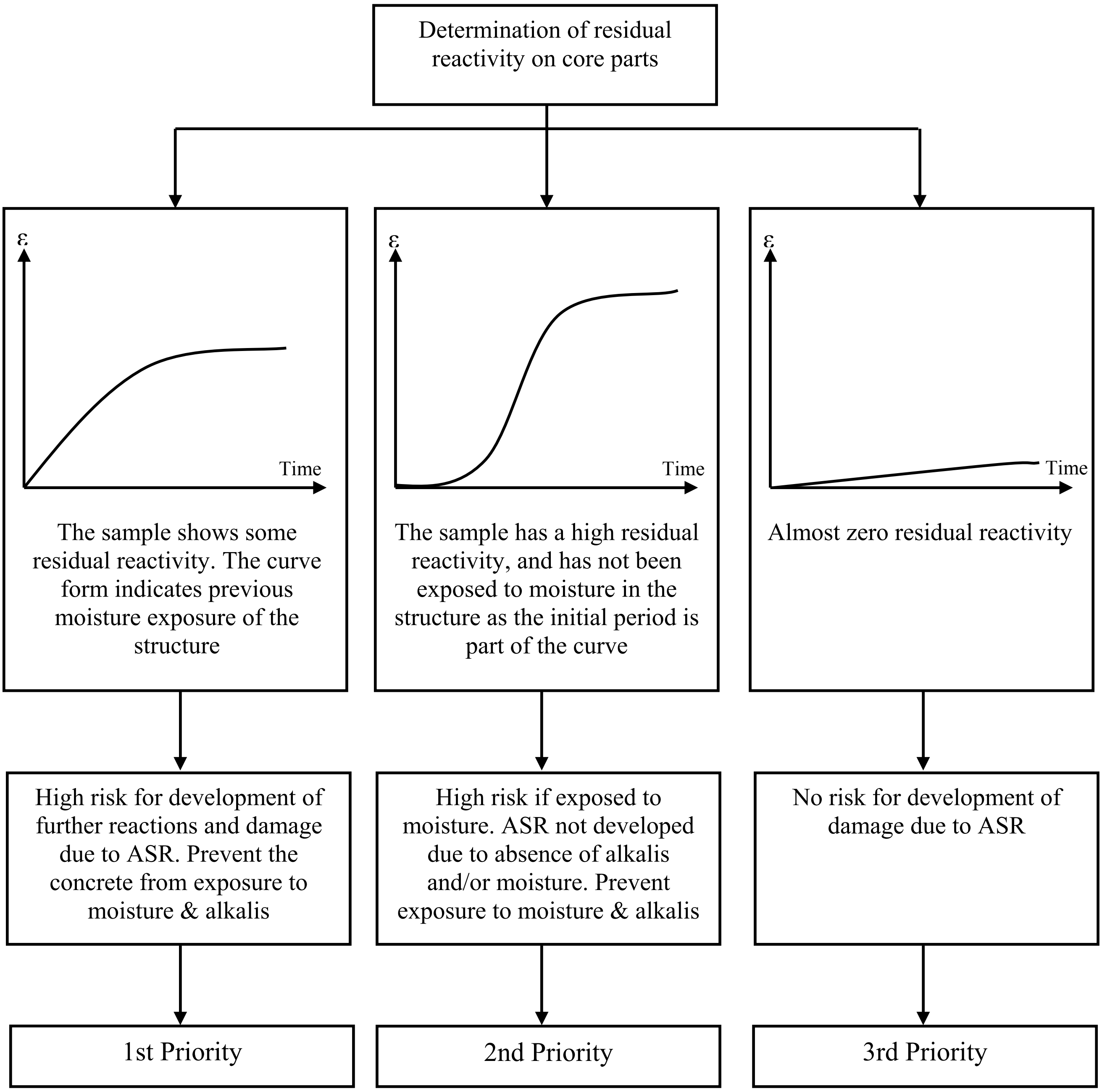

Figure 7: Flow diagram for an improved procedure for decision making to be used in connection with planning maintenance and repair of ASR affected structures.