CONTROL OF ASR RELATED RISKS IN THE NETHERLANDS

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Abstract

During the past ten years the Netherlands has made considerable progress on the control of Alkali Silica Reaction (ASR) related risks for structures. A national guideline on the prevention of ASR (CUR recommendation 89) has been used for a few years, taking control of risk of ASR on one hand, while on the other hand it leaves industry sufficient freedom to make an optimal concrete mix. Existing structures that suffer ASR damage, can be assessed for structural consequences using the new guideline for the inspection and structural evaluation of ASR (CUR-recommendation 102), based on risk assessment and new calculation methods. The effectiveness of maintenance measures has been evaluated based on a fully automated monitoring system applied to sixteen bridges. Recently a controlled load test method has been developed to determine the structural reliability for ASR affected bridges. Both CUR-recommendations mentioned in this article are free downloadable in English.

Keywords: ASR, prevention, monitoring, structure management, load tests, guidelines

1 INTRODUCTION

Until 1995 the general belief in the Netherlands was that ASR was a foreign problem. This idea changed rapidly after ASR was detected in 20 structures in the Dutch highway 59 [1].
These bridges, all dating from the 1960s and beginning of the 1970s, suffered from a slow expanding ASR reaction, mainly caused by flint, chert and porous sandstone in aggregates out of the Meuse-river [2,4]. Even though the scale of ASR damage in the Netherlands is still relatively small (estimated at several hundred structures), the effort from both industry and authorities to gain control on ASR-related problems has been considerable. The main reasons are:

- The Dutch economy is highly dependent of the intensively used infrastructure. Most highway structures are made of concrete. Large scale ASR damage due to the wrong use of materials invokes serious economical risks;
- The aggregates used in Dutch concrete vary because they are increasingly imported from other countries. Furthermore, the Dutch concrete industry is relatively progressive and makes a continuously increasing variety of concrete mixtures. Both the large variety of used aggregates (including recycling materials) and concrete mixtures may induce unexpected risks due to ASR. Therefore regulations need to be robust.
- Structural reliability is anchored in Dutch law. Therefore, uncertainty about structural reliability due to damage is not acceptable. Structural evaluation methods for ASR effected structures were not available in the past;

The Dutch Ministry of Transport, Public Works and Water Management (Rijkswaterstaat), together with partners from industry, research institutes and universities have worked together on dealing with ASR. Rijkswaterstaat and partners followed a policy aiming at open discussion and sharing of knowledge. This has proved to be very effective so far. This paper covers the main achievements in the past decade, from Rijkswaterstaat perspective.

2 DUTCH GUIDELINES ON PREVENTION OF ASR

2.1 General

In the second half of the nineties, Rijkswaterstaat was confronted with the first large scale ASR-damage. At that time, there was a Dutch recommendation on ASR-prevention, more or less copied from foreign regulations [3]. The content however did not cover ASR-risks sufficiently [7]. From Rijkswaterstaat perspective, ASR-risks should be minimised for new structures. Therefore an interim policy was defined on ASR-prevention, demanding both a sub-critical aggregate and CEM II

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(>25% of fly ash) or CEM III (> 50% slag) type cements. In the Netherlands cements with high slag content (CEM IIIB) and fly ash cements (CEM II) are widely available at comparable cost to CEM I. Sub-critical aggregates are available, mainly from the river Rhine. The negative effects of the interim policy for society however were not justifiable by the actual ASR-risks involved. For environmental reasons sea dredged material (often regarded reactive because of high flint and chert content) was preferable to river-dredged material but could no longer be used. Concrete prefabrication industry complained that their production process was delayed due to the demanded cement types. Concrete industry complained that the limitations would frustrate innovation, and claimed that the limitations were not justified for all structures.

In a combined effort between suppliers, industry, research institutes and Rijkswaterstaat a new guideline (CUR-recommendation 89 [5]) on prevention of ASR was made, based on limited research, thorough literature study and involvement of international specialists from UK, Germany and Canada. The recommendation was finished in 2002 and published at ICAAR 2004 [6]. The first revision followed soon after. Improvements were made in testing procedures. Furthermore the article on ASR prevention by using the right cement types was adjusted in order to improve the possibilities to produce different concrete mixtures. Finally, some new articles were dedicated specifically to fine limestone in self compacting concrete. The revised version of CUR recommendation dates from 2006 The flowchart in Figure 1 below summarises the procedure. For concrete in dry environment there is no risk of ASR , unless the thickness of the concrete structure is more than 1 metre. Above this limit, there is a possibility that the concrete doesn't dry out, and sufficient moisture remains for ASR. In that case, the concrete is considered as "humid". In humid surroundings there can be no alkali ingress from the surroundings. Therefore, the commonly accepted limit of 3.0 kg m^{-3} sodium equivalent for concrete is maintained in the new Dutch guideline. In other environments the risk of ASR can be dealt with using either a cement according to Table1 (the "cement chapter") or by using an aggregate mixture that fulfils the testing procedures described in the bottom half of figure 1 (the " aggregate chapter"). Testing procedures for aggregates were based on the tests described in (at that time concepts of) RILEM AAR-1, AAR-2 and AAR-3 [8,9,10]. Between the part of figure 1 dealing with the "cement chapter" and the part dealing with the "aggregate chapter" there is a section dealing with fine limestone fillers in self compacting concrete. Fine limestone is used as filler and not as an aggregate. Therefore, it needs to be more or less inert, since it is not tested in the aggregate article. The limestone is considered to be "pure limestone" if the SiO_2 content is lower than 2vol%.

The partners responsible for the recommendation have agreed to make an English translation, which can be downloaded for free from the CUR- Bouw & Infra website (the URL is in reference [5]).

2.2 Experience with CUR recommendation 89

Practically, in most cases ASR-risks are controlled by using cement that fulfils the cement paragraph. The experiences with the cement paragraph, after the revision of the recommendation 89 in 2006, are positive and there are not many complaints about this paragraph. Some doubt the effectiveness of the cement chapter in self compacting concrete with high amounts of fine limestone. They expect that the amount of sodium and potassium ions in the pore solution will be higher than in other concretes with a comparable sodium equivalent, because more calcium ions will bind with the cement, taking the place of the potassium and sodium during the cement hydration process. Some fear that the cement paragraph in the current recommendation may not cover the ASR-risk in these cases. Others claim that the concrete density of self compacting concrete will cover this risk.

The experiences with the aggregate paragraph so far are not very positive. Aggregate suppliers complain that only few aggregates pass both the Ultra Accelerated Mortar Bar Test (UAMBT) and the petrography. On the other hand, the probability to pass the test isn't only depending on the aggregate, but largely on the laboratory that performs the tests. Recently, Rijkswaterstaat has organised a round robin test among different laboratories that perform these types of tests (some of these laboratories have limited experience). There was a big difference between the test results of the different laboratories. For this reason, the aggregate paragraph is still not accepted by Rijkswaterstaat. This does not cause much trouble however, since the cement paragraph is commonly used.

3 A HANDBOOK FOR INSPECTION FOR ASR

For existing structures, ASR is often not recognised by inspectors. To deal with this problem a handbook for the recognition of ASR is made. This handbook explains how to recognise indications of ASR during site inspections. It contains reference pictures for the most typical appearances of ASR. The handbook is free downloadable from the Rijkswaterstaat Civil Engineering division website [11].

4 DUTCH GUIDELINES FOR INSPECTION AND STRUCTURAL EVALUATION

4.1 General

At the time the first large scale ASR-damage was discovered in the Dutch highway 59, somewhere at the second half of the nineties, not much was known about the structural consequences of ASR. Some claim that in some cases structures can actually get stronger, due to an pre-stressing effect of ASR. This assumption did not hold for Dutch circumstances however. The pre-stressing effect due to expansion would be neglible and diminish by creep effects in the relatively ductile steel used in most affected bridges, also considering the 30 to 40 years needed for the damage to develop to the current stage. In the case of highway 59 there was another critical problem: The ASR affected bridges were constructed without any shear reinforcement. This implies that the concrete has to be able to withstand axial tensile stresses. Since the concrete was internally cracked over the total depth of the bridge deck (Figure 2) there was reason to fear brittle collapse [12], [14].

Rijkswaterstaat has set op a research programme in cooperation with research institute TNO and the Delft University of Technology. This research included load tests on twelve beams (figure 3) that were taken from two bridge decks with considerable ASR damage. This has resulted in a calculation method for structural evaluation of ASR affected plate-type structures [12], [13].

Based on the highway 59 experiences, a national committee was formed to produce a recommendation on the structural evaluation of ASR. After years of discussion this resulted in CUR recommendation 106 [15]. The partners responsible for the recommendation have agreed to make an English translation, which can be downloaded for free from the CUR- Buow & Infra website (the URL is in reference [15]).

The recommendation suggests a stepwise investigation, going deeper each step depending on the need. Figure 4 shows a flow chart of the steps in the process. After the initial inspection identifies a possible case of ASR, a technical inspection will verify if this is the case, and result in a first assessment. Next, the effect of ASR needs to be determined based on the tensile strength of a limited set of concrete cores. This is the main parameter that will affect the structural safety due to the ASR damage. In case of an indication of a "low tensile strength", more cores will be taken and the effect on structural safety will be calculated in detail, using the new formulae stated in the CUR-report.

One part of the recommendation deals with risk control on ASR. Depending on the type of structure, the environment, the detailing of reinforcement and the consequences of failure the measures to control the risks may vary from do nothing scenarios to full structural evaluation, combined with preventive measures and monitoring.

4.2 Experiences with CUR recommendation 102

The recommendation is no more than a good start. The uni-axial tension test on concrete cores is a critical element of the structural evaluation. The test itself is very disputable however, due to all sorts of influences other than the actual concrete strength that might influence the measured result. Unfortunately, so far there is no better method available.

5 MONITORING OF ASR

An intensive monitoring programme has been running for 5 years on the highway 59 bridges [16,17,18]. The monitoring started from one to two years after the bridges had been renovated. This "renovation" involved concrete repair, improvement of drainage, the sealing of the upper surface of the bridge deck for water ingress, and a silane treatment at the bottom side of the bridge decks.

A fully automated monitoring system, according to figure *5*, consisted of moisture, temperature and expansion measurements. Hourly readings for each measurement, combined with a web-based analysis tool made it possible to follow the slow ASR-process closely. Every three months, the monitoring system produces standard reports about the overall condition of the bridges (figure 6) and the changes in moisture content and expansion during the monitoring period (figure 7).

Since the beginning of the monitoring, all bridges have shown more or less stable or slightly increasing moisture content. Most bridges showed none or even negative expansion, vertical to the plane of reinforcement. Surprisingly however, the monitoring showed that those bridges that were affected the most by ASR damage had a higher average moisture content (even after sealing for moisture), and did not stop expanding. This puts a big question mark against the effectiveness of preventive measures. On the other hand this emphasises the necessity to monitor ASR damage in critical situations, even after repair.

6 CONTROLLED LOAD TESTING FOR BEARING CAPACITY OF ASR AFFECTED BRIDGE DECKS

Based on the monitoring results, several of the highway 59 bridges have been demolished. However, due to recent developments there now is an alternative, even if structural safety cannot be proven in calculations. A new method for controlled load testing combined with monitoring of both deformations and internal cracking (Acoustic Emission) has been developed at the Hochschule Neubrandenburg in Germany (the EXTRA-method).

Normally load testing on bridges is not acceptable in the Netherlands, because of the risk of collapse and the possible consequences to the traffic flow. Controlled load testing however is different, because the loads are applied incrementally and the monitoring will identify the development of failure mechanism well in time.

The "EXTRA-method" for controlled load testing was evaluated on one of the Highway 59 bridges [19]. This bridge 'Heidijk' was closed five years ago for all traffic. Based on the concrete strength measurements and structural modeling, a considerable reduction of shear capacity was expected due to ASR. During the past five years since the road was closed, the bridge had continued to expand. Therefore, replacement was scheduled in 2008. Before the final decision was made, the EXTRA-method was tested on the bridge to evaluate the usefulness for determination of the shear capacity for (ASR affected) concrete bridge decks. Figure 8 shows how a frame was placed over the bridge. Hydraulic jets apply loads to the structure in steps of 100 kN. Each load step was repeated three times. The effect on displacements and the acoustic emission of the concrete was monitored. Figure 9 [19] shows a typical example of an AE-measurement.

The planning, execution and evaluation of loading tests has been performed according to the "Richtlinie für Belastungsversuche an Betonbauwerken" (guideline for loading tests on concrete structures) [20]. The main aim of the load test was the experimental determination of the ultimate test load, F_{lim}, according to [20]. On load testing bridges it is used analogously, slightly adjusted at the ultimate test load criteria, which should be defined more restricted on bridge structures. Advice and proposals are to be found in [21]. F_{lim} is defined as the maximum load, which does not generate any progressive damage into the structure to such extend that the load-bearing capacity is affected. By definition the ultimate test load in every case is lower than the maximum load bearing capacity.

The test results allowed a classification of the tested bridge into the bridge class 30 according to [22], equal to the original design class of the bridge. This result indicated that there was no need to demolish the bridge; in fact, the presumed negative effect of ASR on the shear capacity was not confirmed at all. Based on the test results it was concluded that load tests are an applicable method to determine the load bearing capacity also of bridges with the risk of non-ductile shear-failure. Load-deformation measurement combined with acoustic emission measurement delivers information with a sufficient indication of damage.

7 CONCLUSIONS

This paper deals with a variety of developments in the Netherlands in the field of ASR during the past decade. Some of the work has previously been published in more detail.

Dutch recommendations on prevention, inspection and structural evaluation of ASR are translated into English in order to encourage exchange of knowledge with other countries. So far, these recommendations are workable, but still not perfect.

A large scale ASR-monitoring project shows that sometimes ASR cannot be stopped by drying the concrete, especially those structures intensively damaged by ASR. This shows that monitoring is always needed for critical structures with ASR damage.

Structural evaluation of ASR based on inspection, destructive and/or non-destructive testing and modelling remains a difficult task. A new method for controlled load testing has been shown to give a considerable added value. The combination between structural evaluation, monitoring and controlled load testing seems to be an effective way to ensure the safe use of ASR affected structures.

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Table 1: Alkali limits for cements considered to prevent development of ASR.

Type of cement	CEM II/B-V			CEM III/A	CEM III/B
Cement with a fly ash or slag content [% *(m/m)*] of	≥ 25		≥ 30	≥ 50	≥ 66
Na_2O_e of fly ash in cement [% *(m/m)*]	$x \leq 2.0$	$2.0 < x \leq 3.0$	$3.0 < x \leq 4.5$	n/a	n/a
	maximum alkali content of cement [% *(m/m)*]:				
If alkali contribution of other components ≤ 0.6 kg/m^3 [1)]	1.1	1.3	1.6	1.1	1.5
If alkali contribution of other components $0.6 < y \leq 1.2$ kg/m^3 [1) 2)]	0.9	1.1	1.5	0.9	1.3
If alkali contribution of other components $1.2 < y \leq 1.6$ kg/m^3 [1) 3)]	0.8	1.0	1.4	0.8	1.2

[1] In this table "other components" is understood to include all constituents of the concrete, except cement and fly ash.

[2] If it is proven that the alkali content of the admixtures and additions other than fly ash is < 0.1 kg/m^3 then the alkali contribution of the other constituents can considered to be 1.2 kg/m^3 at maximum.

[3] If the requirement "alkali content of other components ≤ 1.6 kg/m^3" is not met the alkali content must be calculated in accordance with Appendix G of this CUR Recommendation.

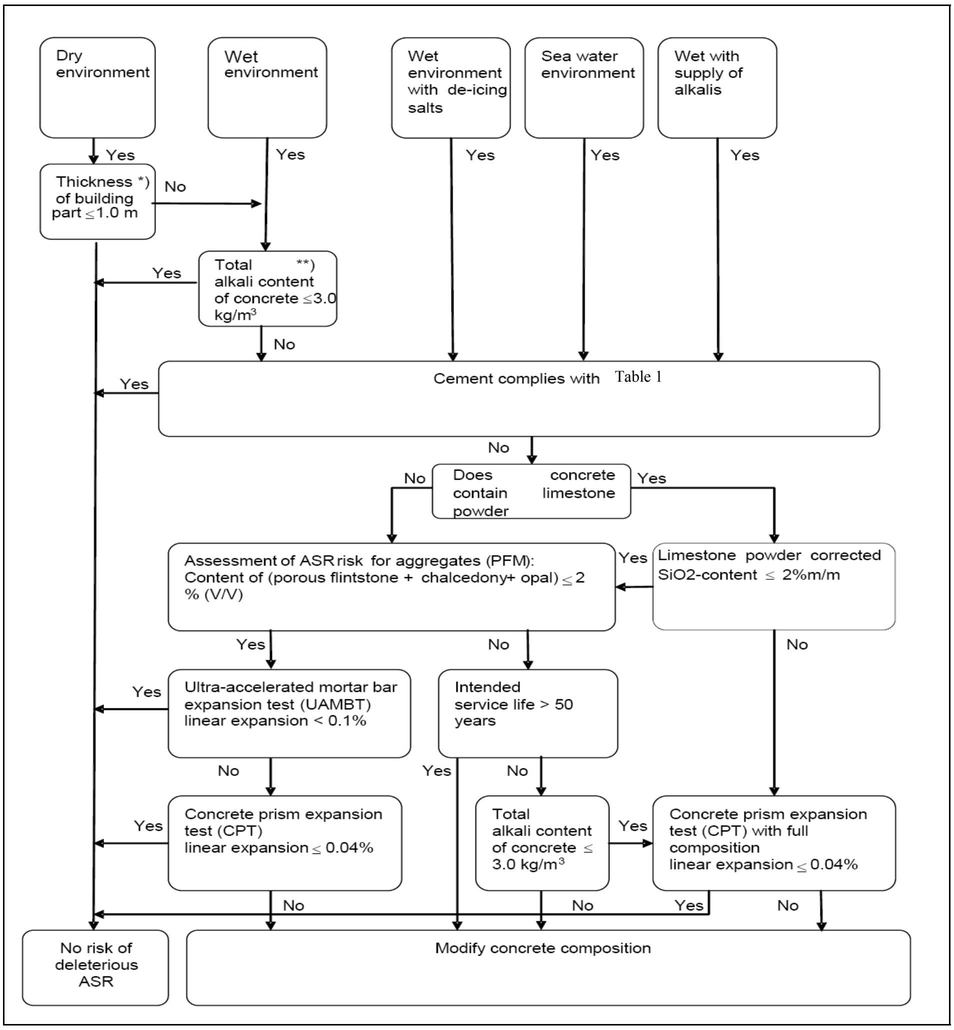

Figure 1: Flowchart for the evaluation of ASR reactivity of concrete

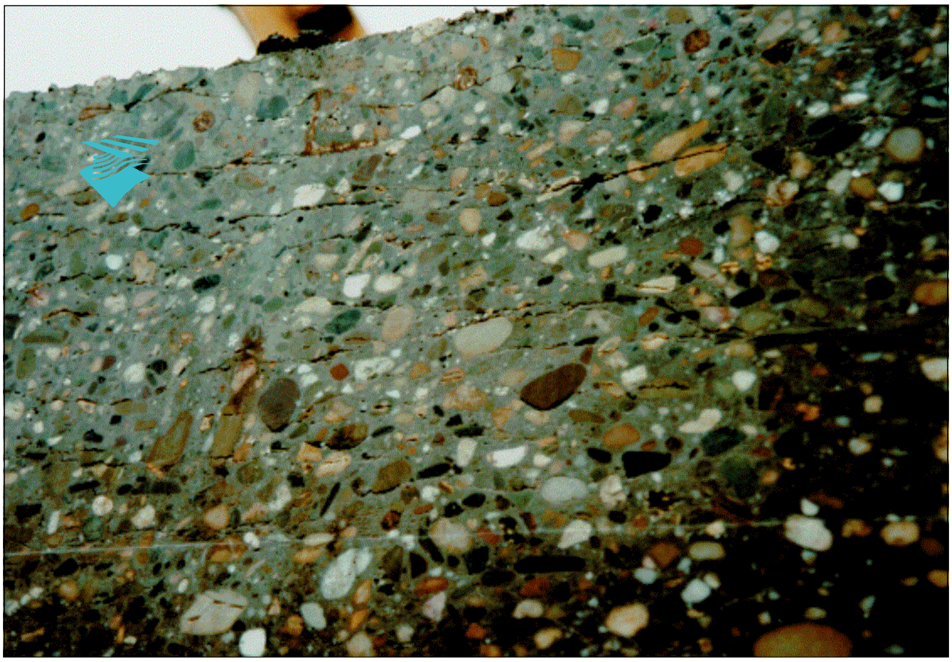
Figure 2: Extreme internal ASR cracking in a vertical cross section of the bridgedeck

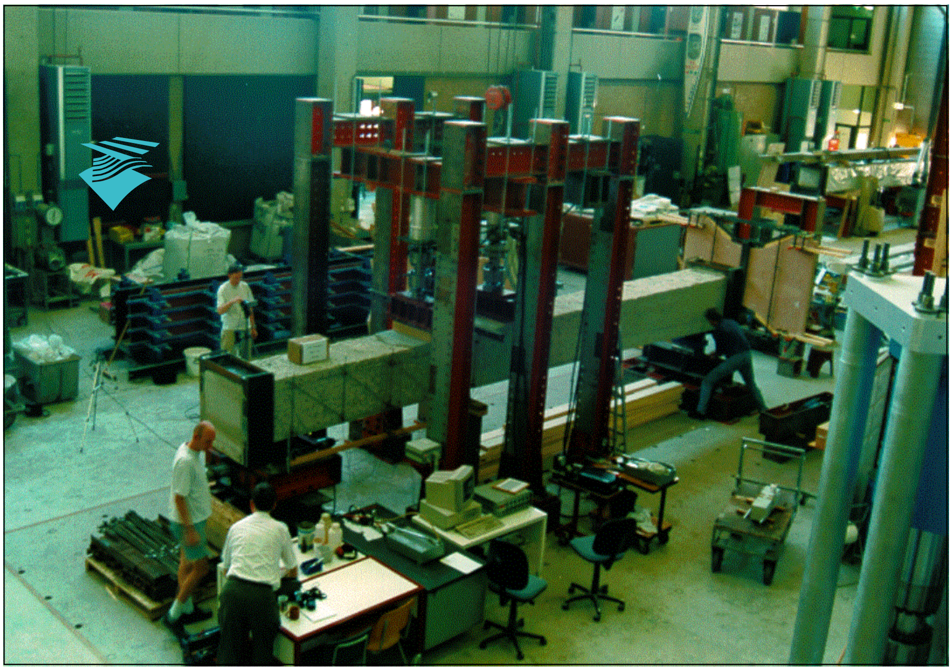
Figure 3: Testing of the structural capacity of beams derived from a concrete plate bridge deck

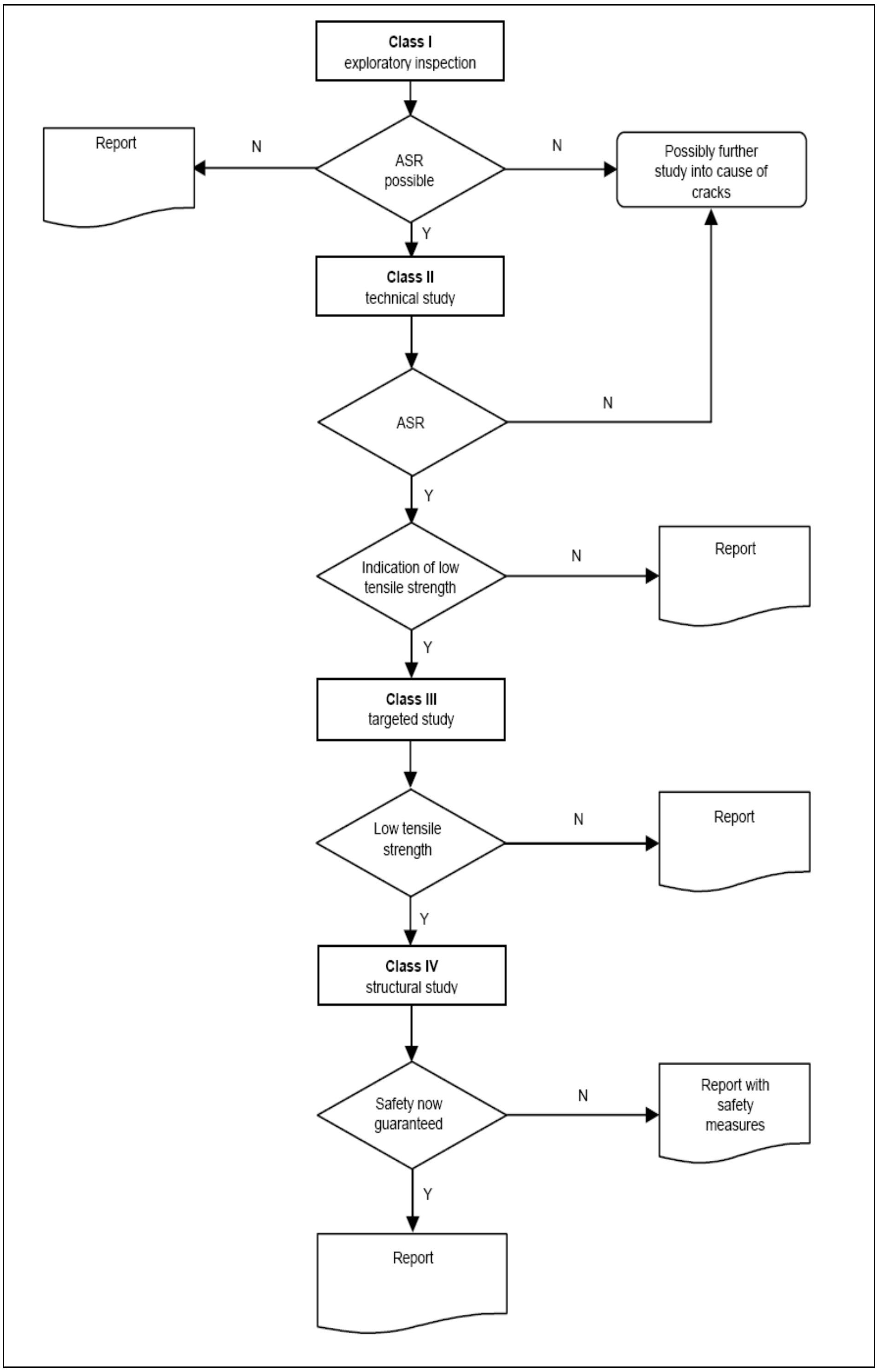

Figure 4: Flowchart for inspection and investigation

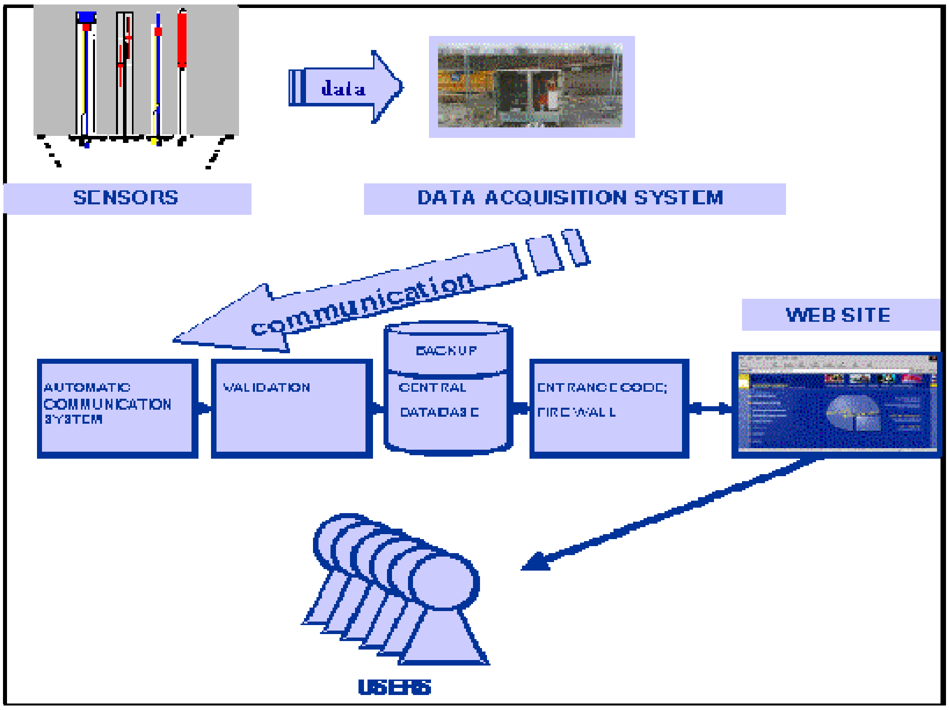

Figure 5: Fully automated ASR monitoring system

Figure 6: 3-monthly overall condition report on the highway 59 bridges. The red dots show the highway structure with a measured (temperature corrected) expansion larger than 0,1 mm/m during the monitoring period.

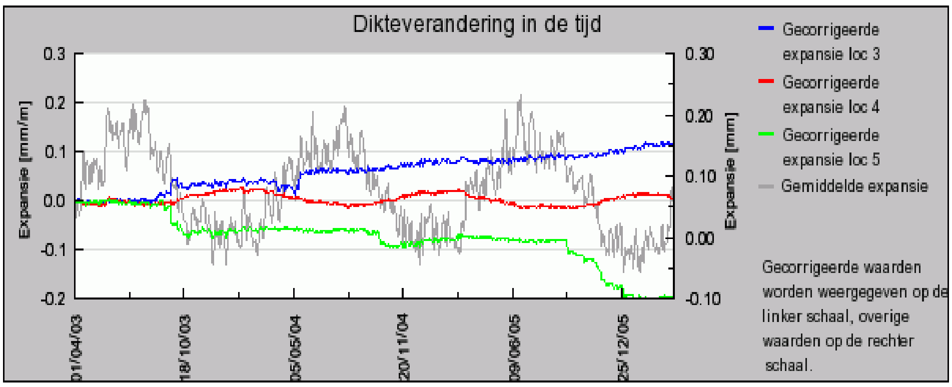

Figure 7: part of the 3-monthly report is a presentation of the measured expansions during the monitoring period. The grey line is the average expansion, not corrected for temperature. The colored lines are the temperature corrected individual expansion measurements.

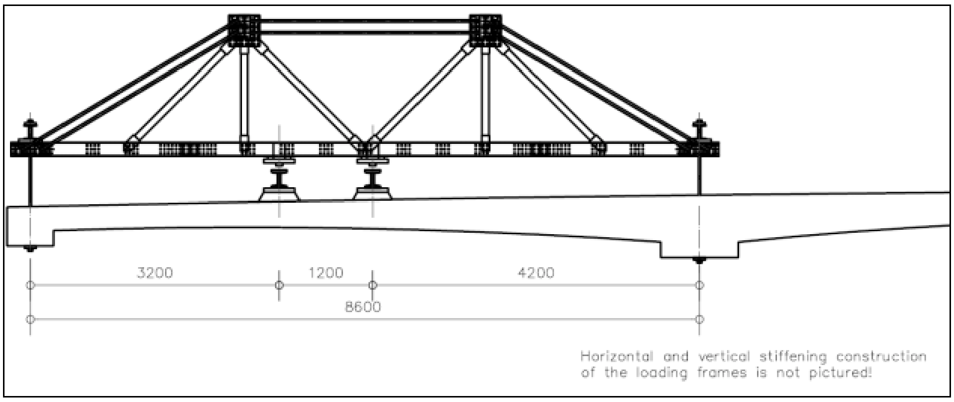

Figure 8: Controlled load testing: A frame is anchored at the supports. Hydraulic cylinders apply cyclic loads to the structure in the critical areas

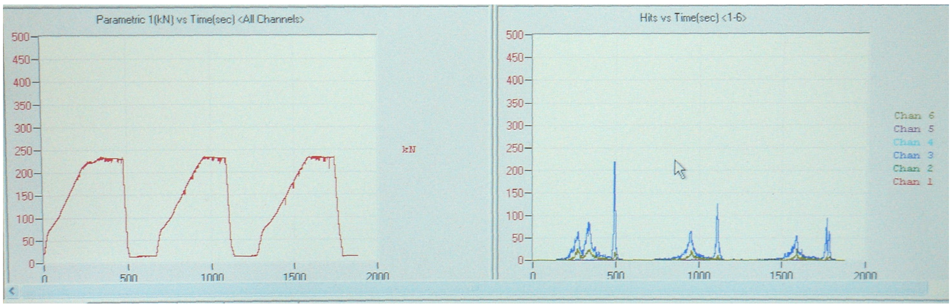

Figure 9: Left: graph of three cyclic loads; right: AE-response: first cycle: stress redistribution cracks; second and third cycle: cracks decrease as long no failure damage develops