MAINTENANCE SYSTEM FOR HIGHWAY STRUCTURES DAMAGED BY ASR

K. Okada
Professor Emeritus, Kyoto University
(Yosida-honmachi, Sakyou-ku, Kyoto 606, Japan)

M. Fujii
Professor, Kyoto University
(Yosida-honmachi, Sakyou-ku, Kyoto 606, Japan)

Y.Yamaguchi
Deputy head, Design Div., Kobe Construction Dept., Hanshin Expressway Public Corporation
(16-1, shinkocho, chuoh-ku, Kobe 650, Japan)

K. Imada
Director, Design and Investigation Div., Fuji Engineering Consultant Co., Ltd
(4-13-3, Higashi Mikuni, Yodogawa-ku, Osaka 532, Japan)

ABSTRACT

This paper describes the ideas and methods of maintenance of structures damaged by Alkali Silica Reaction (ASR) as proposed by the Hanshin Expressway Public Corporation. Bridges damaged due to Alkali Silica Reaction were firstly observed in Japan in 1982.The causes of damage were gradually clarified,while the growth of reaction with time has been continuously observed. Meanwhile, the <Guideline of Maintenance of Concrete Structures with ASR (Tentative Plan)> was published in 1985, including the judgement standards of ASR. Then, aiming at improving the durability of structures damaged by ASR, various experiments were carried out and the basic principles of surface protection work were published in 1989. These are the fundamentals of the maintenance program.

Moreover, as a result of the investigations of damage to structures by Hyogoken Nanbu Earthquake, which occurred on January 17, 1995, it is shown that structures judged to be ASR damaged may not be suffered more seriously from the earthquake than ordinary structures without ASR damage. The latter may have even a higher rate of damage due to earthquake.

Keywords: Alkali Aggregate Reaction (Alkali Silica Reaction), Judgement standards, Field investigation, Steel jacketing method, Repair

INTRODUCTION

As to the Hanshin Expressway Public Corporation, damages due to Alkali Aggregate Reaction (mainly Alkali Silica Reaction, hereafter called ASR) was first observed in the piers of a highway bridge in 1982. From then onward, the investigation of damage by ASR, as well as detailed inspection (field investigation) to obtain basic information on proper maintenance have been continued. In the meantime, the <Committee of Investigation and Research on Integrity of Concrete Structures> and the <Committee of Investigation and Research on Reactive Aggregate Concrete> were organized. After

analyzing the causes of the ASR damage and evaluating the integrity of the damaged structures, the repair methods to be adopted were discussed. In 1985, the <Guideline of Maintenance of Concrete Structures with ASR (Tentative Plan)> was published. This Guideline shows the necessity of investigation, the judgement standard and the basic principle of repair.

Concerning materials for restoring works, the experiments were carried out on real bridges and specimens were made of various restoring works materials to verify their suitability. Based on the results, the basic principles of surface protection for structures damaged by ASR were described in the <Outline of Repair of Highway Structures (Concrete Structures)> in 1989.

On the other hand, repair methods were discussed, based on the verification by field investigation that showed concrete strength decreasing with the progress of inner cracks due to ASR in structures, as well as confirmed enough structural safety against earthquakes. In 1993,some representative bridge piers with considerable ASR damage were strengthened by the steel jacketing method. The effect of the strengthening method is now under field investigation.

PRESENT CONDITION OF ASR MAINTENANCE INSPECTION

For the maintenance of highway structures, needless to say, the early finding of damage is quite important. After clearing out causes of damage, it is necessary to repair or strengthen the structure properly. Therefore, the inspection especially the regular inspection of structures is very meaningful to assess their rank of damage. For this purpose, the inspection is carried out every 5-7 years for each route.

GUIDELINE OF ASR MAINTENANCE(TENTATIVE PLAN)

The Hanshin Expressway Public Corporation prepared promptly the <Guideline of Maintenance of Concrete Structures with Alkali Silica Reaction (Tentative Plan)> and put it in operation as the basis of ASR maintenance.

The Guideline is applicable to massive structures, such as bridge piers, but not to thin elements, such as concrete railing or slab.

Once the causes of damage observed by inspection are clarified, the proper countermeasures of repair should be taken. In case the causes are not clear, more field investigations should be conducted and the condition and causes of the damage should be determined. The judgement of ASR damage should conform to the judgement methods shown in the guideline. This is the second stage of the maintenance.

Judgement of ASR deterioration
* Gel is observed
* Total length of cracks (over 0.3mm wide for RC, over 0.2mm wide for PC) exceeds 100m, or
* Total expansion strain (open expansion + residual expansion) exceeds 1000×10^{-6}

MEASURES FOR REPAIR AND STRENGTHENING

Where ASR is judged to be the cause of damage, the measures for repair and strengthening should be discussed taking into account the condition and rank of damage. Concerning the measures for repair, the Guideline shows the methods of grouting

epoxy resin into cracks and of surface coating. It also prescribes regulations for various cases, in which such as too small or too large residual expansion exists to apply the surface coating materials.But this is not an established Guideline for strengthening. The current situation is that there is only one construction example (steel jacketing method) carried out experimentally.

Moreover, in order to evaluate the effect of repair, a representative structure is examined for field investigation.

The flow chart for maintenance mentioned above is shown in *Fig.2.1*.

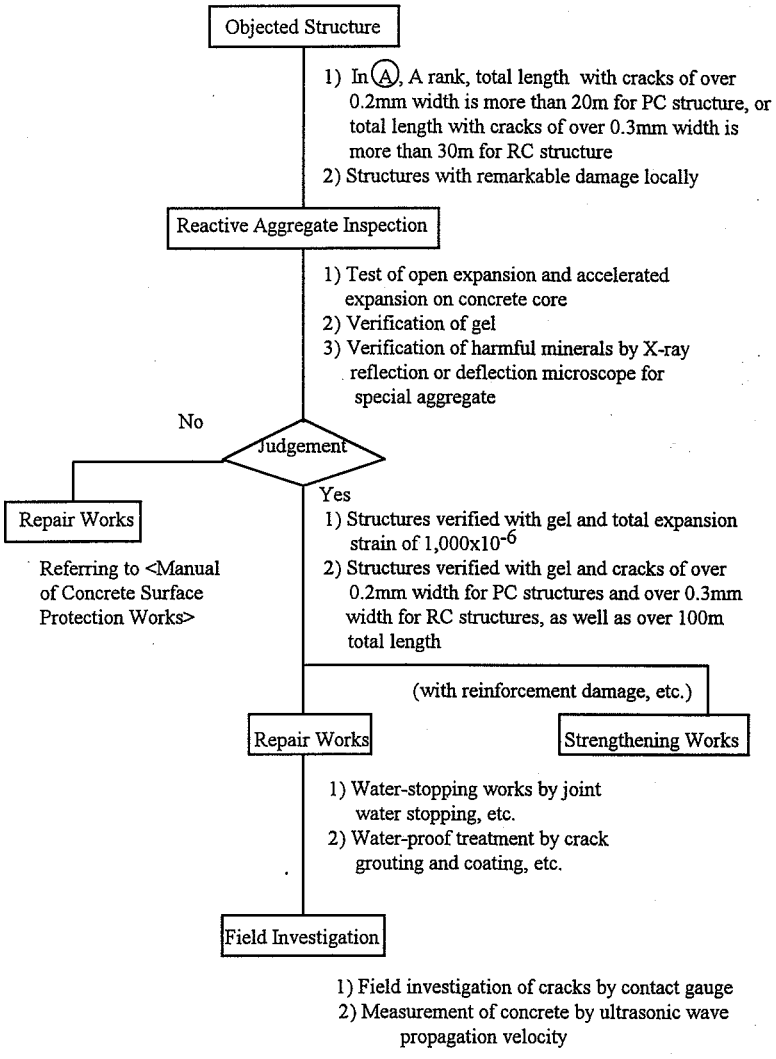

Fig.2.1 Flowchart of ASR structure maintenance

FIELD INVESTIGATION OF STRUCTURES DAMAGED BY ASR

OBJECT STRUCTURE AND INVESTIGATION FREQUENCY

Structures that are judged or suspected as ASR are selected and 55 typical bridge piers are taken as samples. Moreover, basic investigation is carried out once a year.

PURPOSE OF INVESTIGATION

The field investigation aims at understanding the change with time of ASR damage to structures and evaluating the effect of reducing reaction by various repair materials. Eventually, the purpose is to estimate the ultimate state of ASR and to collect the basic information on maintenance.

INVESTIGATION RESULTS

The progress of ASR damage is dependent on the expansion potential of structures. Figures 3.1 to 3.3 show the results of a typical example of ASR damage from the field investigation of seriously damaged bridge piers. *Fig.3.1* shows the change of crack width with time, *Fig.3.2* does the dimension of a bridge beam and *Fig.3.3* the change of ultrasonic wave propagation velocity with time.From these figures it is shown that the damage by ASR is still progressing although a second repair was carried out. Therefore, it is necessary to modify the ASR repairmethod depending on the reaction potential of structures.

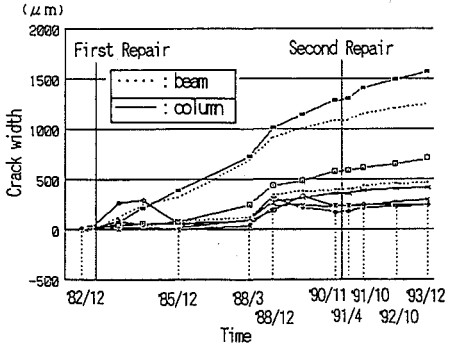

Figure 3.1 Change of crack width with time

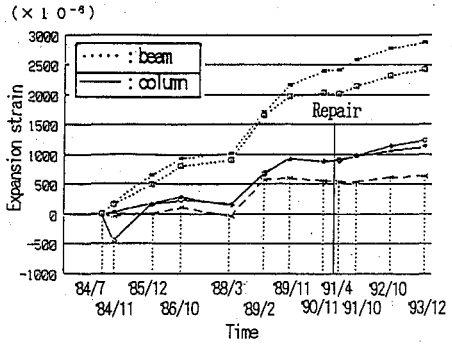

Figure 3.2 Change of bridge pier dimension with time

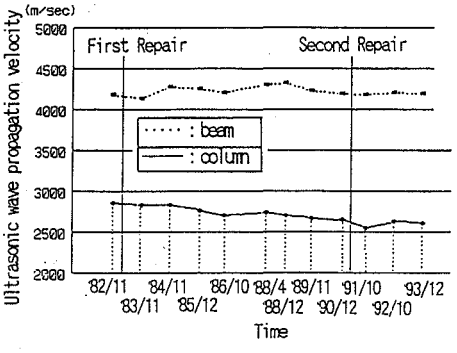

Figure 3.3 Change of ultrasonic wave propagation velocity with time

REPAIR MEASURES

SITUATION OF REPAIREDBRIDGE PIER

Repair of ASR structures mainly aims at protecting them from secondary damage (corrosion ofreinforcement)and stopping the water supply to restrain the reaction. Repair was carried out on several old ASR damaged bridge piers by grouting epoxy

resin into the cracks and coating the surface to protect it from water. As described above, in real bridge piers the magnitude of residual expansion is fairly large and thus the restraining effect of the repair material itself is difficult to show, in the present stage.

REPAIR SPECIFICATIONS

Water supply is referred to as one factor accelerating ASR reaction, therefore, the basis of ASR repair is waterproofing. If grouting epoxy resin into cracks or surface coating is the primary repair measures, then protecting from water at the joints is the secondary repair measures. Waterproofing on the top of the bridge pier is able to stop water supplied from the joint. It is the important point.

Moreover, it is necessary to apply several methods as repair. The ASR repair materials in surface protection work prescribed in the<Repair Guideline of Highway Structures (Concrete Structures)>,are listed in *Table 4.1.*

Table 4.1 Coating Specifications for ASR

(Water-proof series : residual expansion is large)

Works	Coating materials	thickness (μm)	Standard amount (kg/m^2)
Pretreatment	Epoxy resin primer		0.15
	Epoxy resin putty		0.40
Middle painting 1	polybutadiene resin	500	0.75
Middle painting 2	polybutadiene resin	500	0.75
Final painting 1	polyurethane resin	30	0.12
Final painting 2	polyurethane resin	30	0.12

STRENGTHENING MEASURES

Generally, the load carrying capacity of ASR-affected structures does not so deteriorate. So, the investigation of strengthening has not been enough. For the present situation such that ASR ultimate state is not clear, it is important to examine the measures against strength loss. Moreover, it is considered that the concrete deterioration due to ASR damage remains on the surface of the cover layer. According to the confirmation from field investigation, the strength of the inner concrete is reduced. Therefore, the load-carrying capacity, especially structural safety against earthquake, is a anxious problem. The repair and strengthening methods are examined by the modelling of a T-type RC single-column bridge pier where the ASR damage is in progress.

STRENGTHENING TEST OF SPECIMEN

A strengthening experiment was carried out on a specimen of a beam model with bonded steel plates on the compressive surface and the side surfaces. The compressive strength of the concrete was 5.0MPa. The effect of strengthening by bonded steel plates was examined and the results are shown as follows.

(1) The bending moment and shear force capacity of the beam model will be lower, if the concrete compressive strength is less than 10MPa.

(2) It is necessary to strengthen ASR damaged beams for both bending and shearing.

(3) Bonded steel plate on the compressive side and the view sides of a beam is substantially effective as a strengthening model for real T-type single-column bridge piers.

Therefore, based on the results of a strengthening test, the same method is applied to

the real bridge strengthening works and expected to obtain basic data for strengthening measures of ASR-affected bridge piers in the future.

STRENGTHENING WORKS ON REAL BRIDGE PIERS

Two types of strengthening works were carried out on the bridge piers, one is the measures for arresting ASR against progress by limiting water, and the other is the steel jacketing method for the beam and column parts of a bridge pier. Various basic principles are described as follows.

(1) In order to protect against loss of concrete compressive strength, 16mm thick steel plate is used.

(2) Bonded steel plates on the sides and the bottom of the beam are welded so as to be a unit with the beam concrete. Therefore, a penetration hole is drilled horizontally into the beam and PC steel bars are fastened at two ends (average bond force : 0.1MPa, 12tf/beam)

(3) In order for the column of the bridge pier to resist earthquake force, the strengthening must be extended to the connection with the footing.

(4) Steel plate is installed between bearings at beam ends, two surfaces of steel plates and beam upper surface are partially connected and thus the strengthening result is improved because of the steel plate unification.

(5) After strengthening, in order to observe the concrete surface, and measure ultrasonic wave propagation velocity, an observation hole is set on the steel plate.

Furthermore,a load cell is installed for the PC steel bar extension.

Photo 5.1 shows the general view after steel jacketing method.

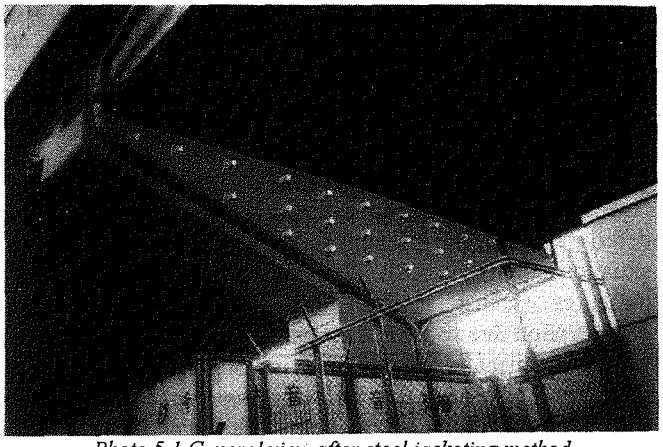

Photo 5.1 General view after steel jacketing method

EARTHQUAKE EFFECT ON ASR STRUCTURES

On January 17, 1995,the Hyogoken Nanbu Earthquake, with an epicenter north of Awaji Island (Magnitude 7.2), took place. Around Kobe city, extensive damage to roads, railways, harbor facilities, buildings and houses occurred. Especially in highway structures, some highway viaducts collapsed.In Hanshin area this magnitude of earthquake had not even been experienced before.

On the other hand, among the structures damaged by the earthquake,some were judged originally to be deteriorated by ASR.The data of the effects of earthquake are statistically collected on both kinds of structures in Route 3 (to be Route),ones judged to be originally ASR damaged and the others not subjected in the past to any other known damages.Judgement ranks for damage are listed in Table 6.1.

Along Route 3 (Main Route about 32.6km), there exist 943 concrete piers. In this route, the major damage area was from the junction with the Meishin highway to the

west end of the Route 3. In this major damage area, there exist 660 piers excluding rampway piers. Among them, 28 piers are judged to be ASR damaged. *Fig.6.1* shows the classification and comparison of bridge piers judged to be ASR damaged (called ASR piers) and those not ASR damaged (called other piers).

Table 6.1 List of damage judgement ranks

Rank	Damage	State
As	Collapsed	Total collapse and destruction
A	Severe damage	Damage that remarkably affects load carrying capacity or the possibility of crucial damage, such as a falling bridge
B	Medium damage	Load carrying capacity is reduced, but damage due to aftershock and live load do not progress
C	Minor damage	In short term, load carrying capacity is not reduced
D	No damage	No special abnormal effect on load carrying capacity is found

The load carrying capacity of bridge piers of ranks As and A is greatly affected as shown in Table 6.1.Such deteriorated piers occupy 15% among all ASR piers,whereas 20% among all other piers.When piers of rank B are included,the above rate increases to 36% and to 33%, respectively.

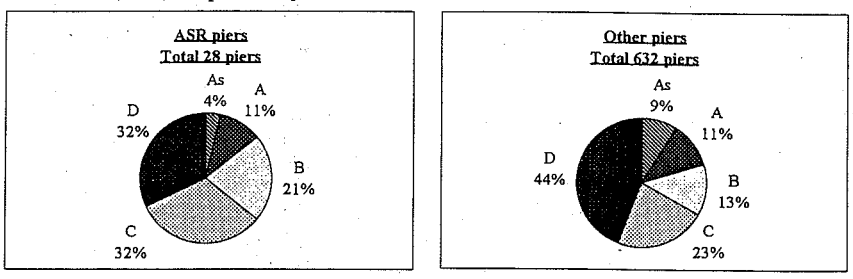

Figure 6.1 Occurrence rate of damage according to Table6.1 (whole Route 3)

Next, the comparison between the damage occurrence rate of ASR piers in Rout 3 and that of other piers in specifically seriously damaged construction division is shown in *Fig 6.2*.When considering that Rout 3 is rather long in the east-west direction, it is clear that the rank of damage is affected dependently on location.

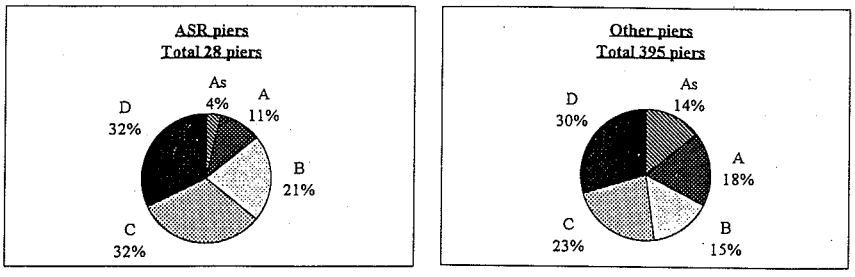

Figure 6.2 Occurrence rate of damage according to Table6.1 (construction zone largely damaged)

Fig.6.2 shows that the occurrence rate of ranks As and A among ASR piers is 15%, while that among the other piers as high as 32%.When piers of rank B are included, the

above rate increases to 36% and 47%, respectively, the latter value being almost a half of all piers.

Accordingly, when judging ASR from these data, the real structures damaged by ASR may be not so specifically weak against earthquake, because that ASR piers gave lower occurrence sate of severe damage. This also can be understood by the fact that ASR damage was mainly concentrated on the beam part of the bridge pier, whereas earthquake damage was concentrated on the column part. Moreover, it is also considered that the repair ever carried out for all of the ASR piers in Route 3 contributed to a low occurrence rate of damage.

CONCLUSION

Seventeen years have passed since ASR was firstly found in this area of Japan. During these years, various misjudgment have been made, but current maintenance of structures is kept on the basis of the ASR Maintenance Guideline (Tentative Plan), Basic Principles of Repair (Surface Protection Works) and Basic Policy of Maintenance. Investigations of ASR structures in the field have lasted for as long as 15 years and very valuable data have been obtained. Also, ASR is still in progress and will grow more the in the future. So, it is very important for highway managers to carefully observe its behavior to keep safety for vehicles.

On the other hand, the measures of repair for ASR alone are not enough for future maintenance. The measures, for both durability and load carrying capacity, should be important in the complete program. The present strengthening work using the bonded steel jacketing method plays an important role in this program.

The Hanshin Expressway Public Corporation experienced the unexpected disaster on January 17, 1995. They are now facing much restoration work and are cooperating with people in various fields. The results of the investigation on the structures damaged, or destroyed by the earthquake, show that ASR-affected structures have a lower occurrence rate of very serious damage. This is probably because that earthquake is more harmful to piers which support the bridge while ASR effects are more pronounced in beams. Moreover, the magnitude of this recent earthquake was very high and destructive, and the behaviors of ASR structures and other ones might be different in the weaker earthquake. However, damage is affected by the superimposed effect of various causes, so that further investigation should be conducted.

We are aiming at obtaining a reasonable and effective method of maintenance for the future and doing our best for this purpose.

REFERENCES

- Hanshin Expressway Public Corporation : Guideline of Maintenance of Concrete Structures with ASR (Tentative Plan) , 1985 . 6 (in Japanese)
- Hanshin Expressway Public Corporation : Outline of Repair of Highway Structures (Concrete Structures) , 1989 . 6 (in Japanese)
- Proc. of the 48th annual conference of JSCE , 1993 . 9 (in Japanese)
- Commitee of Measures for an Earthquake on Hyogoken Nanbu Earthquake;Report of the investigation on damages in Highway bridges by Hyogoken Nanbu Earthquake, 1995 . 12 (in Japanese)