# REINFORCEMENT OF AAR DAMAGED CONCRETE BEAM

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Deterioration of concrete structure has been considered to be limited only to the surface. However, recent survey detected that the inside concrete is also losing its strength in certain AAR damaged concrete structures. Therefore, it is required to recover the load bearing capacity of these structures so as to avoid the collapse in future particularly by earthquakes. Among many possible methods to reinforce AAR damaged concrete member, the steel plate adhesion method was tested for concrete beams of which concrete strength is the order of $5N/mm^2$. This paper will discuss the effect of the steel plate adhesion method to reinforce damaged concrete beam in bending and shear.

## INTRODUCTION

Most of AAR concrete structures in Japan were constructed within the last two decades. Practical survey of these structures started in 1982. According to the results obtained from the surveying at the early stage, deterioration of these structures was limited to the surface and the loss of the concrete strength was also insignificant. However, recent survey of these structures detected that the deterioration is also invading the inside of the structures and that the loss of the concrete strength is getting significant in some of AAR structures.

Generally speaking, loss of concrete strength of a concrete beam does not affect to the ultimate strength of the beam so much. However, if the compressive strength becomes less than the order of 5 to 10 $N/mm^2$, the drop of the ultimate strength not only in bending but also in shear becomes significant.. There are many restrictions to do reinforcing work to beams of bridge pier since they are under use and shoes and girders existing at the top of the beam interrupt the work. Steel plate adhesion method has been successful to repair slab of motorway. Steel plate is adhered to the concrete surface by epoxy resin. This method is also relatively easy to apply to the beams. The effect of this steel adhesion method is tested for concrete beam specimens with low compressive strength of concrete.

## LOSS OF CONCRETE STRENGTH IN AAR DAMAGED STRUCTURE

Loss of compressive strength and Young's modulus of AAR damaged concrete has been recognized by testing of drilled core from the structure or AAR concrete models (1).

Table 1 shows recent survey of concrete strength by cores drilled from AAR damaged bridge piers. These data include the previous test results as well.

TABLE 1 - Compressive strength of cores drilled from bridge piers

| Structure member | Age of concrete | Compressive strength ($N/mm^2$) Depth from the surface where core was taken 15cm | 45cm | 75cm |
|---|---|---|---|---|
| RC beam | 14 yrs | 16.6 | 13.9 | 13.5 |
| RC column | 21 yrs | 16.5 | 16.3 | 18.9 |
| PC beam 1 | 4 yrs | 30.7 | | |
| | 11 yrs | 27.0 | | |
| | 12 yrs | 22.8 | 28.8 | 29.5 |
| PC beam 2 | 8 yrs | 34.3 | | |
| | 21 yrs | 22.3~36.6 | 29.1 | |

These results indicate that compressive strength of AAR concrete decreased with age and that the inside concrete is also affected by AAR. The compressive strength of the RC beam and RC column is lower than the design value of about 24 $N/mm^2$. The compressive strength of the PC beams is also lower than the design value of about 35 $N/mm^2$. It should be noticed that these cores were taken from relatively less or no cracked part of the concrete. Therefore, the compressive strength of concrete in particular parts of the structure member is inferred to be lower than the values listed in the table, although it is difficult to define the compressive strength of concrete with many AAR cracks.

## LOSS OF BEAM STRENGTH DUE TO LOSS OF THE CONCRETE STRENGTH

Ultimate bending moment Mu of a beam with under reinforcement is given by ACI standard (2) as follows:

$$Mu=(A_s-A_s')\sigma_{sy}(d-\frac{c}{2})+A_s'\sigma_{sy}(d-d')$$
$$c=(A_s-A_s')\sigma_{sy}/0.85fb$$

where, $\sigma_{sy}$=yield strength of steel bar
As=section area of steel bar in tension
As'=section area of steel bar in compression
d=effective depth of beam
d'=distance between compression bar and the compression bottom of the beam
b=width of the beam
f=compressive strength of concrete

Mu of a beam with over-reinforcement is given by

$$M_u=k_u k_1 k_3 bd^2 f(1-k_2 k_u)$$

in which compression steel bar is ignored.

$$k_u=\sqrt{pm+(0.5pm)^2}-0.5pm$$

where $p=A_s/bd$
$m=E_s\varepsilon_{cu}/k_1k_3f$
$K_1=0.94-f/1830$
$K_2=0.50-f/5625$
$k_1k_3=(275+0.35f)/(225+f)$ and
$\varepsilon_{cu}=0.004-f/4.57\times10^5$

are suggested, where compressive strength of concrete f and Young's modulus of steel bar Es are in $kgf/cm^2$.

For lower shear span ration a/d in loading, shear failure becomes dominant. ACI standard (2) gives ultimate shear strength Su as follows:

$$Su=Sw+Sc$$

where Sw is the shear strength supported by stirrup and Sc is the shear strength supported by concrete.

According to the equation given by ACI standard, Mu of a beam decreases with decrease of the compressive strength as shown in Figure 1 and Figure 2 for each beam section, respectively. fo in these figures represents the compressive strength of a normal concrete and Muo represents the corresponding ultimate strength in bending. Beam A in Figure 1 was loaded in bending with shear span ration a/d=2.5 and beam B in Figure 2 was loaded in bending with a/d =5.0. The test results are also plotted in these figures. The concrete with lower compressive strength was made by adding excess of air entrained agent. According to these results, the loss of the ultimate strength of the beams becomes significant when the compressive strength becomes lower than the order of 10 $N/mm^2$.

## REINFORCEMENT BY STEEL PLATE ADHESION METHOD

Reinforcement of a bridge pier is not so easy if it should be done at the top face of the beam due to the restrictions mentioned above. However, it is relatively easy to reinforce the beam at the bottom or side. When a beam is subjected in bending, failure mode of a beam partly depends upon the loading condition, that is the shear span ration a/d. Generally speaking, bending failure is dominant for larger a/d and shear failure is dominant for smaller a/d. In actual T-shape bridge pier, a/d of the cantilever beam varies from about 1.5 to 6. In this research, Beam A in Figure 1 was used for smaller a/d which was fixed to be 2.5 and 1.5 and Beam B in Figure 2 was used for larger a/d which was fixed to be 5.0. Reinforcement of these test beams with low concrete strength was done by adhering steel plate to the surface of the beams using epoxy resin.

## REINFORCEMENT AGAINST BENDING

It is inferred to be effective to reinforce the tension side of the beam against bending. Unfortunately, the tension side is the top face of the beam in T-shape bridge pier. Reinforcement of compression side is preferable if it is effective. Therefore, different levels of reinforcement were tested. For group of Beam A, two different levels of reinforcement were operated. They are adhesion of steel plate only at the tension side and both tension and compression side as well. Steel plate of 2.3mm thick was used for these reinforcement. For group of Beam B, three different levels of reinforcement were operated. They are adhesion of steel plate at the tension side only, compression side only and both tension and compression side as well. Besides 2.3mm thick, steel plate of 1.6mm thick was also tested in this group.

Table 2 shows test result of Beam A. This result indicates that there is no effect of the reinforcement to recover the beam strength. This is probably due to the reason that shear failure was dominant in these beams and that steel plate adhered did not play a role.

Figure 3 shows a typical example of failed beams.

Figure 4 shows test result of Beam B. This result indicates that steel plate adhesion method improved ultimate strength of the beam in which bending failure is dominant. However, the amount of improvement is not sufficient if steel plate is adhered only at tension or compression side.

TABLE 2 - Recovery of beam strength by reinforcement (Beam A,steel plate thickness=2.3mm)

| a/d | | without reinforcement | tension side reinforcement | both compression and tension side reinforcement | |
|---|---|---|---|---|---|
| 1.5 | Mu (Nm) | 107 | 109 | 119 | f=3.4N/mm$^2$ fo=35.1N/mm$^2$ |
| | Mu/Muo | 0.15 | 0.16 | 0.17 | Muo=692Nm |
| 2.5 | Mu (Nm) | 322<br>299 | 348<br>351 | 325<br>419 | f=7.8N/mm$^2$ fo=34.6N/mm$^2$ |
| | Mu/Muo | 0.42 | 0.48 | 0.51 | Muo=732Nm |

## REINFORCEMENT AGAINST SHEAR

Reinforcement against shear failure was done by adhering steel plate or steel strip on the web of the beam. Beam A was used for this test. In order to make the reinforcement effective, steel plate or steel strip was also adhered on the top and/or bottom of some beams. Adhesion of steel plate or steel strip was done by epoxy resin. In some of the specimens, the adhered plate or strip was strengthened by anchor bolts of 8mm in diameter. Table 3 shows summary of the test specimens and Figure 5 shows some of the reinforced specimens. For the comparison, unreinforced specimens with low concrete strength and normal concrete specimens were also tested. In loading of these beams, a/d was fixed to be 1.5 and 2.5. The compressive strength of concrete was planned to be about 5 N/mm$^2$ . However, it was very difficult to control the compressive strength of concrete from each batch to be almost same. Therefore, there is a little difference in concrete strength between each beam although the compressive strength of concrete was kept under 10 N/mm$^2$ for all the beams tested.

TABLE 3 - Test beams reinforced against shear failure

| Reinforcement (thickness = 2.3mm) | | Name of specimen a/d=1.5 | Name of specimen a/d=2.5 |
|---|---|---|---|
| steel plate by epoxy resin and anchor bolt | web+ten. side | PT1 | PT2 |
| | web+comp. side | PC1 | PC2 |
| | web+ten. & comp. side | PTC1 | PTC2 |
| steel strip by epoxy resin | web only | S1 | S2 |
| | web+ten. side | ST1 | ST2 |
| | web+comp. side | SC1 | SC2 |
| | web+ten. & comp. side | STC1 | STC2 |
| steel strip by epoxy resin and anchor bolt | web only | SA1 | SA2 |
| | web+plate at comp. side | SP1 | SP2 |
| | web+plate and strip at comp. side | SPS1 | SPS2 |
| | web+strip at comp. side+steel band | SB1 | SB2 |
| Low strength concrete beam without reinforcement | | L1 | L2 |
| Normal concrete beam without reinforcement | | N1 | N2 |

Table 4 shows test results of ultimate shear strength of each beam. The ultimate shear strength here was defined as half of the failure load. Figure 6 shows the test beam of SB2 after failure. These test results indicate that reinforcement by PT, PC, PTC and SB improved the ultimate strength of the beam satisfactorily. Anchoring by bolt was found to be important in this method. Adhesion of steel plate at the web and compression side will be most practical method to reinforce a beam of T-shape bridge pier.

TABLE 4 - Test results of reinforced Beam A

| Reinforcement (thickness = 2.3mm) | | Name of specimen | | | |
|---|---|---|---|---|---|
| | | a/d=1.5 | f (N/mm$^2$) | a/d=2.5 | f (N/mm$^2$) |
| steel plate by epoxy resin and anchor bolt | web+ten. side | PT1 = 8.3 | 3.4 | PT2 =10.6 | 9.7 |
| | web+comp. side | PC1 = 16.0 | 7.5 | PC2 =13.9 | 7.5 |
| | web+ten. & comp. side | PTC1=10.9 | 3.4 | PTC2=16.0 | 9.7 |
| steel strip by epoxy resin | web only | S1 = 2.8 | 3.4 | S2 = 5.1 | 9.7 |
| | web+ten. side | ST1 = 3.0 | 3.4 | ST2 = 6.5 | 9.7 |
| | web+comp. side | SC1 = 5.6 | 7.5 | SC2 = 5.8 | 7.5 |
| | web+ten. & comp. side | STC1= 3.6 | 3.4 | STC2= 8.3 | 9.7 |
| steel strip by epoxy resin and anchor bolt | web only | SA1 = 6.9 | 7.5 | SA2 = 6.0 | 7.5 |
| | web+comp. side | SP1 = 5.5 | 7.5 | SP2 = 6.5 | 7.5 |
| | web+plate and strip at comp. side | SPS1 = 6.5 | 7.5 | SPS2= 6.3 | 7.5 |
| | web+strip at comp. side+steel band | SB1 =12.0 | 7.5 | SB2 = 9.0 | 7.5 |
| Low strength concrete beam without reinforcement | | L1 = 2.8<br>6.7 | 3.4<br>7.5 | L2 = 4.8<br>5.2 | 7.8<br>7.5 |
| Normal concrete beam without reinforcement | | N1 = 17.8 | 35.1 | N2 = 11.3<br>10.9 | 34.6<br>35.1 |

## CONCLUDING REMARKS

Following informations have been obtained through this research.
-Compressive strength of concrete drops by AAR.
-Ultimate strength of a beam drops significantly if compressive strength of the concrete drops lower than the order of 10N/mm$^2$.
-Reinforcement of AAR damaged beam should be done both for bending and shear.
-Steel plate adhesion method with anchor bolt is effective to reinforce AAR beam.
-Adhesion of steel plate at the web and compression bottom seems to be practical method to reinforce the beam of T-shape bridge pier.

The reinforcement work will be improved if steel plate is replaced by a lighter plate such as sheet made from composite materials.

## REFERENCES

1. K. Ono, 1990. 2, "Strength and stiffness of alkali-silica reaction concrete and concrete members", Structural Engineering Review, 121-125

2. ACI 318-63, Building Code Requirement for Reingorced Concrete

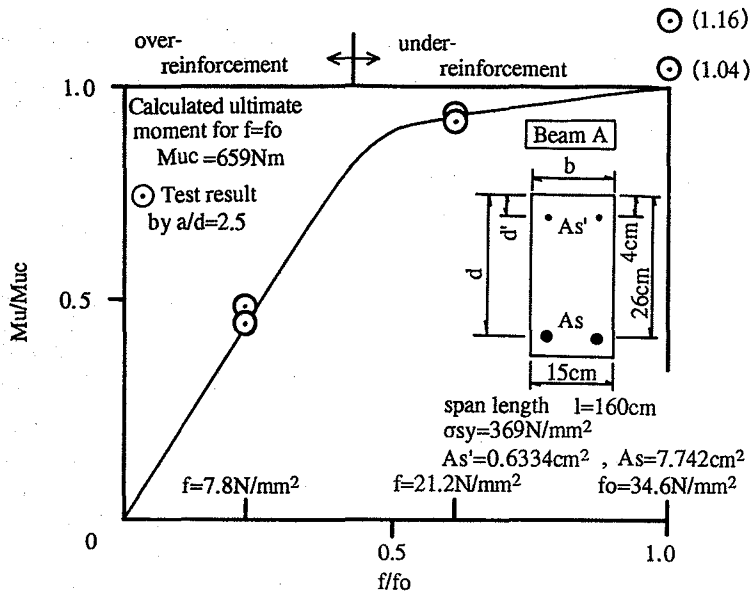


Figure 1 Mu/Muc vs f/fo of Beam A (a/d=2.5)

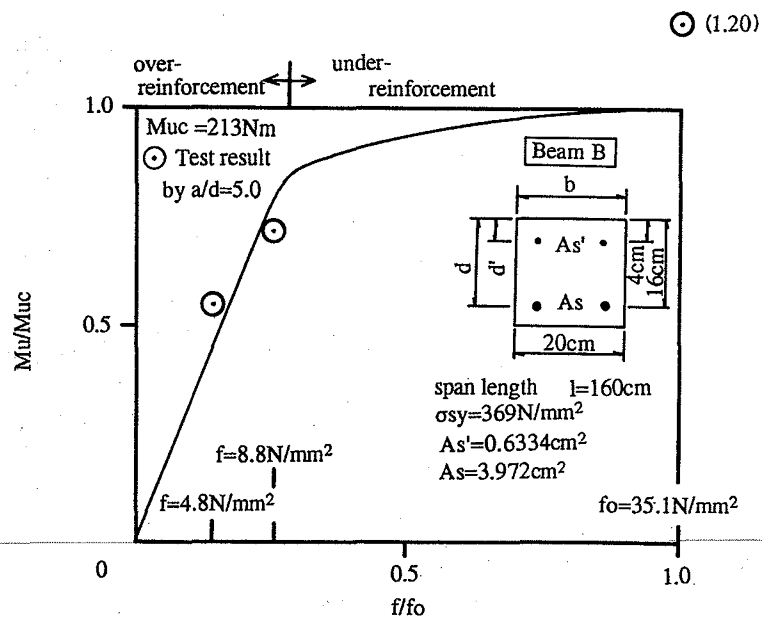


Figure 2 Mu/Muc vs f/fo of Beam B (a/d=5.0)

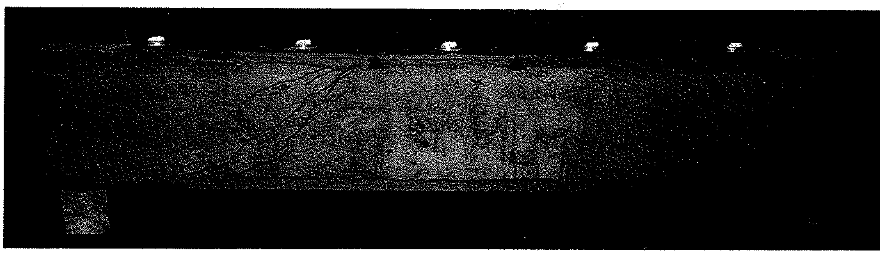

Figure 3 Failed Beam A(a/d=2.5, both compression and tension side reinforced)

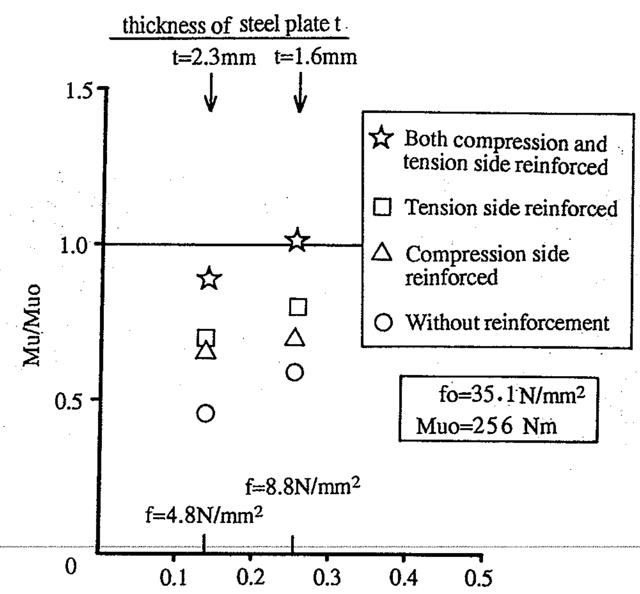


Figure 4 Mu/Muo vs f/fo of reinforced Beam B (a/d=5.0)

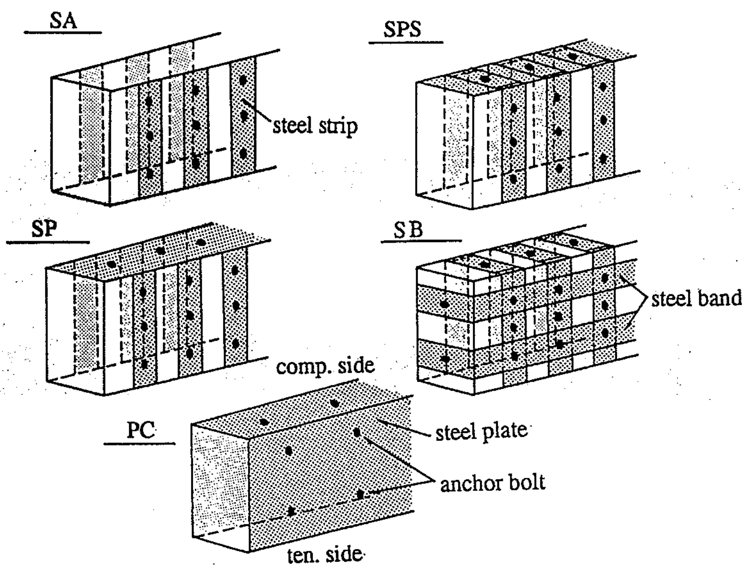


Figure 5 Reinforced specimens of Beam A

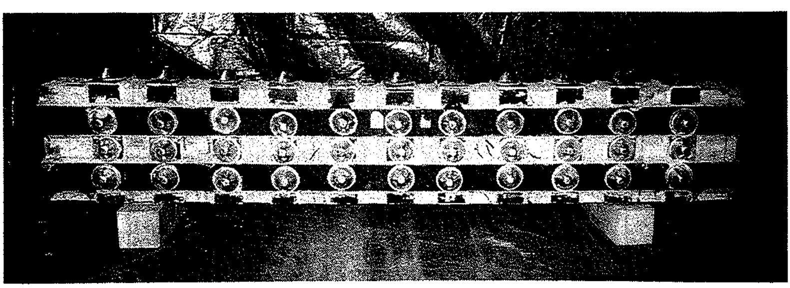

Figure 6 Failed beam (a/d=2.5, SB2)