# MONITORING OF AAR BRIDGE PIER BY VIBRATION MEASUREMENT

Koichi Ono, Konoike Construction Co., Ltd., Kitakyuhoji-machi Chuo-ku Osaka Japan
Osamu Yoshikawa, Hanshin Expressway Public Corporation
Hirosuke Imai, Hanshin Expressway Administration and Technology Center
Kiyoshi Okada, Kyoto University

It is not so easy to evaluate the existing strength of AAR damaged concrete structure. Loading test of bridge pier, for instance, yields time and money consuming problem. However, it is relatively easy to measure the vibration of pier caused by traffic loading. Natural frequency of a structure will drop if the stiffness of the structure drops. Therefore, if we could detect the loss of natural frequency of a structure or structure member by measuring the vibration, we could also detect the deterioration of the structure. Field test for AAR damaged beam of a highway bridge pier was carried out under various loading conditions. Besides the vibration characteristics, deflection of the beam, ultrasonic velocity, compressive strength and Young's modulus of the concrete were also measured. This paper will discuss the applicability of the vibration method to detect deterioration of AAR concrete structure or member.

## APPRAISAL OF DETERIORATION

There are many ways to appraise deterioration of concrete structures. For instance, by density or distribution of cracking, by compressive strength or Young's modulus of concrete core, by ultrasonic velocity or by deformation of the structure under load.

In this paper, vibration technique is proposed. Appraisal of deterioration of a concrete structure or member is done by assessing over-all Young's modulus of the concrete calculated from the natural frequency obtained by the vibration measurement.

Drop of the natural frequency is the order of the square root of the decrease in the rigidity of the structure or structure member. Therefore, drop of the natural frequency is normally within an error of the measurement. However, if a significant drop of natural frequency is observed, it means that loss of the rigidity or progress of the deterioration is very significant. The over-all Young's modulus is evaluated so that the natural frequency calculated by the structural model matches to the measured natural frequency.

Vibration measurement of bridge pier is relatively easy. In application of this method for motorway bridge piers, special traffic control is not necessary and loading condition caused by running vehicles is not required to be known. This method is preferable to monitor the bridge piers of motorways in Japan, where there are many piers to be monitored.

## MODELLING OF BRIDGE PIER

T-shape pier with pile foundation is employed to develop the vibration technique. This type of pier is very popular in the urban area of Japan (Figure 1). T-shape pier with pile foundation can be modelled two-dimensionally as shown in Figure 2 for the evaluation of the natural frequency. However, this model A contains many difficult problems to overcome. That is:
(i) Allocation of piles is 3-dimensional, and

(ii) vibration response of the pier is affected by soil condition
Therefore, model A is not preferable for the practical use of the vibration technique.

Figure 3 shows the simplified model where the top of the footing is fixed. In this model B, effect of piles and soil do not come into the consideration. The first natural frequency calculated by the model A and B assuming the Young's modulus to be nominal value of $9.8KN/mm^2$ is 1.39Hz and 1.50Hz, respectively. Therefore, the gap of Young's modulus obtained by the model A and B is about 15% in this example. This range of gap is tolerable for the practical purpose.

Figure 4 shows the first mode of vibration of Model A and B. Both modes indicate that bending vibration of the column is dominant in T-shape bridge pier. Figure 5 (a) and (b) show observed acceleration response in the vertical direction at the end of the beam and in the horizontal direction at the top of column. Figure 5 (c) shows calculated dynamic response of Model B after unloading a point load from the end of the beam, which corresponds to the observed response in Figure 5 (a). Both observed and calculated response are more or less simple harmonic vibration corresponding to bending of the column although the analysis gives a mixed bending response of the column and beam at the immediately after unloading. Furthermore, both observed response at the end of beam and at the top of column are very similar to each other. Therefore, it is not easy to detect vibration characteristics of beam in this case. For the practical application, the model B is employed and appraisal of only column of T-shape pier is possible at this stage.

## PRACTICAL APPLICATION

### Application 1

The vibration technique was applied to the T-shape bridge pier as shown in Figure 1. In this pier P109, deterioration of the beams is dominant comparing with the column. For the comparison, the technique was also applied to the adjacent pier P110, which is relatively less deteriorated. These piers were constructed about 20 years ago. Static loading test, measurement of compressive strength and Young's modulus of the concrete by core and measurement of ultrasonic velocity were also done for both of the piers.

Figure 6 shows the vibration response of P109 caused by traffic loading. Similar response was also obtained for P110. Analysis of these vibration response gave the first order natural frequency dominantly, which represents bending of the column as shown above. Static loading was applied to the beam at the near end by dump track with about 36 tons in total weight. Displacement of the beam at the point of the loading and uplift of the beam at the end of the opposite side were measured as shown in Figure 7. From the measured uplift U, displacement D and the calculated uplift Uc and the calculated beam deflection at the loading point dc, Young's modulus of the column $E_p$ and the beam $E_b$ were evaluated as follows. $U_c$ and $d_c$ were calculated by the model B assuming $E_p = E_b =$ nominal Young's modulus E

$$E_p = E\, U_c / U$$

and the displacement at the loading point due to rotation of the column

$$D_1 = l_1 / l_2 \ U$$

The deflection of the beam at the loading point

$$d = D - D_1$$

then

$$E_b = E d_c / d$$

Table 1 shows the obtained Young's modulus by the vibration measurement, static loading test and compression test of drilled core. In this table, compressive strength of drilled core and ultra sonic velocity of the pier is also included.

TABLE 1 - Test result of P109 and P110 pier

| | | | P109 | P110 | P109/P110 |
|---|---|---|---|---|---|
| Analized the first natural frequency (Hz) ($E_p=E_b=9.8KN/mm^2$) | | | | | |
| | | Model A | 1.52 | 1.39 | |
| | | Model B | 1.63 | 1.50 | |
| Observed first natural frequency (Hz) | | | 2.06 | 2.25 | |
| Corresponding over-all Young's modulus of column ($KN/mm^2$) | | | | | |
| | | Model A | 18.0 | 25.7 | 0.70 |
| | | Model B | 15.7 | 22.1 | 0.71 |
| Young's modulus obtained from the static loading ($KN/mm^2$) | | | | | |
| | beam | | 22.9 | 31.9 | 0.79 |
| | column | | 30.8 | 42.2 | 0.72 |
| Young's modulus by drilled core ($KN/mm^2$) | | | | | |
| | beam | minimum | 10.2 | 26.8 | 0.38 |
| | | average | 15.3 | 30.3 | 0.50 |
| | column | minimum | 27.3 | 28.7 | 0.95 |
| | | average | 29.9 | 32.6 | 0.92 |
| Compressive strength* by core ($N/mm^2$) | | | | | |
| | beam | minimum | 22.3 | 38.1 | 0.59 |
| | | average | 28.5 | 45.7 | 0.62 |
| | column | minimum | 33.4 | 35.0 | 0.95 |
| | | average | 36.3 | 37.8 | 0.96 |
| Ultrasonic velocity (m/sec) | | | | | |
| | beam | range | 3550~3960 | 4360~4680 | |
| | | average | 3580 | 4490 | 0.80 |
| | column | range | 4280~4560 | 4410~4650 | |
| | | average | 4450 | 4540 | 0.98 |

* Design value: $34.3N/mm^2$ for beam and $23.5N/mm^2$ for column.

According to these results, Young's modulus obtained by vibration method, static loading and drilled core differ each other. However, young's modulus obtained by the vibration method seems to indicate that both columns of P109 and P110 are normal as obtained by the other measurements. These results also indicate that drilled core gives normal value of Young's modulus and compressive strength if concrete is undamaged by AAR.

Application 2

The vibration technique was applied to bridge piers P1 and P2 of another motorway. These piers were constructed about 15 years ago. Figure 8 shows P2. In these piers, deterioration of the column is dominant, comparing with the beam. Deterioration of P2 column looks more than P1 column. Figure 9 is one of the acceleration response of P2. Young's modulus and the compressive strength of core drilled from these columns were also measured. Table 2 shows the summary of the test results.

TABLE 2 - Test result of $P_1$ and $P_2$ pier

| | | P1 | P2 | P2/P1 |
|---|---|---|---|---|
| Analized the first natural frequency (Hz) (Ep=9.8KN/$mm^2$) | | 1.83 | 2.21 | |
| Observed natural frequency (Hz) | | | | |
| | at the right beam end | 3.01 | 2.83 | |
| | at the left beam end | 2.89 | 2.83 | |
| The corresponding over-all Young's modulus(KN/$mm^2$) | | 26.5<br>24.4 | 16.1<br>16.1 | |
| | average | 25.4 | 16.1 | 0.63 |
| Young's modulus by drilled core (KN/$mm^2$) | | | | |
| | minimum | 9.1 | 6.2 | 0.68 |
| | average | 11.6 | 8.0 | 0.70 |
| Compressive strength(*) by drilled core (N/$mm^2$) | | | | |
| | minimum | 24.3 | 20.1 | 0.82 |
| | average | 27.6 | 22.1 | 0.82 |

(*) Design value is 20.6N/$mm^2$ but cylinder strength of corresponding normal concrete at 1 year was 46.6N/$mm^2$

Over-all Young's modulus obtained from vibration measurement is higher than that of drilled core as before. However, tendency of loss in Young's modulus obtained from both methods is similar. In addition, less Young's modulus indicates less compressive strength. These test results indicate that the vibration technique is applicable to detect deterioration of column of T-shape bridge pier.

## CONCLUDING REMARKS AND FUTURE RESEARCH

Proposed vibration technique to monitor bridge piers is easy to apply and less expensive. The applicability is approved only for T-shape pier at the present stage. Detection of deterioration of T-shape pier by this method is limited to the column since bending vibration of the column is dominant in T-shape pier.

In this approach, deterioration of concrete structure is represented by the loss of over all young's modulus of concrete. Young's modulus obtained from the drilled core is much lower than that obtained from deformation or vibration characteristics of the structure or structure member, as usual. Definition of Young's modulus should be clarified in discussing AAR deterioration. Furthermore, it should be also discussed that how much loss will be critical for a particular structure or structure member.

For practical application of this method, sequential measurement is important for each deteriorated structure or structure member. The vibration technique should be improved to be able to detect deterioration of beam as well. Furthermore, the applicability of this technique for some other type of structure should be also discussed. There are still many problems to be solved to apply the vibration technique. Nevertheless, application of this technique is expected in Japan since there are many structures to be monitored to avoid future disaster.

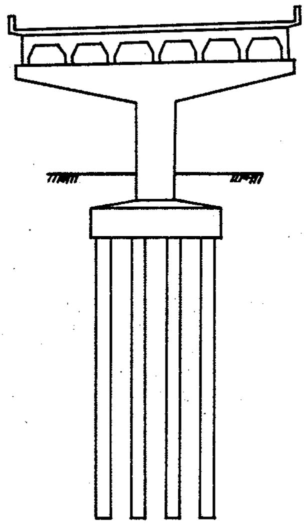


Figure 1 T-shape bridge pier of highway

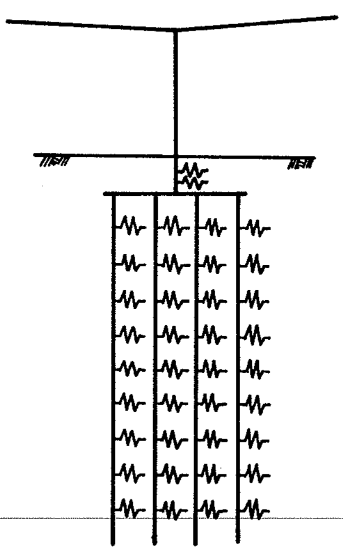
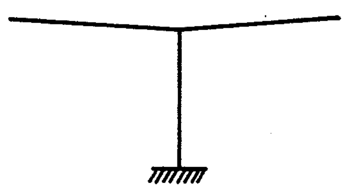


Figure 2 Model A



(fixed at the top of footing)

Figure 3 Model B

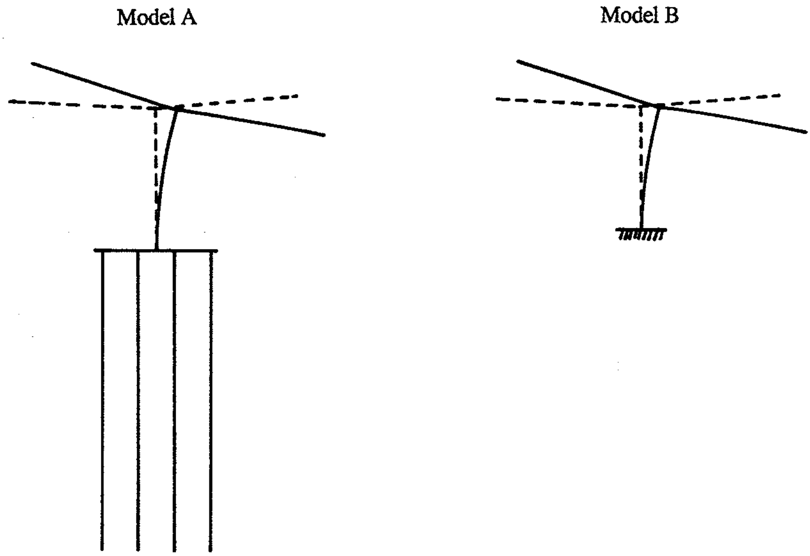



Figure 4 The first mode of vibration

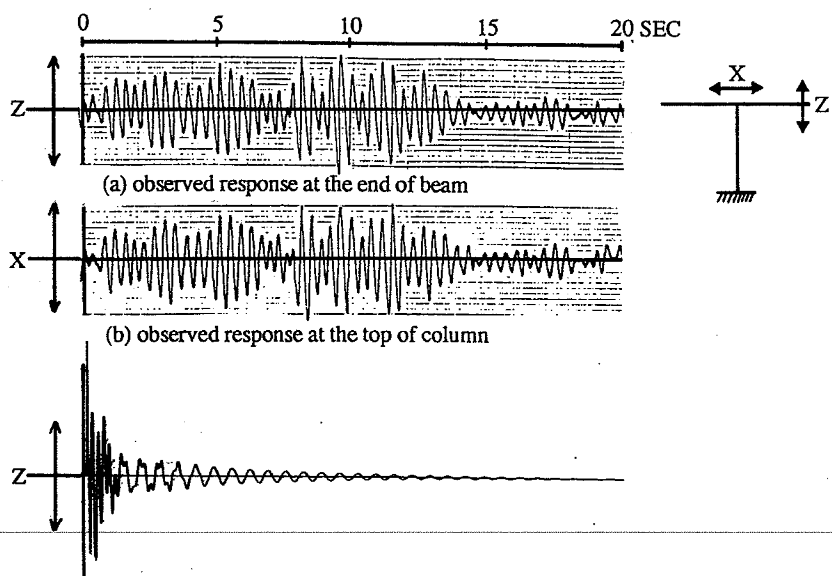



Figure 5 Dynamic response of pier

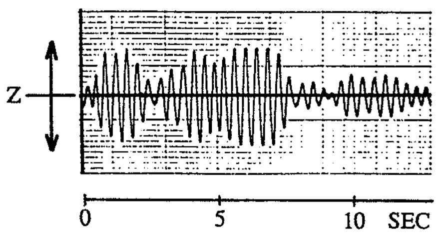



Figure 6 Observed vibration response (P109)

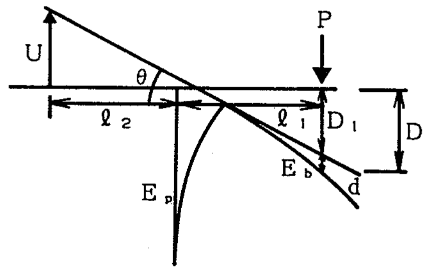



Figure 7 Measurement of displacement under static loading

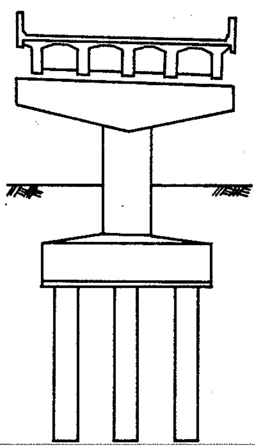


Figure 8 T-shape pier (P1)

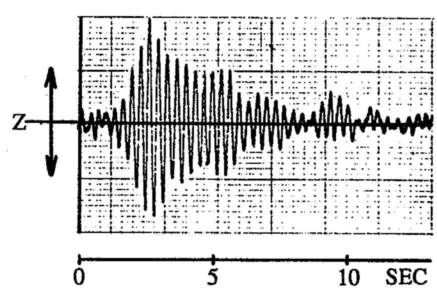



Figure 9 Observed vibration response (P1)