Dynamic Behavior of Concrete Slabs Reinforced by Braided AFRP Rods under Impact Loads

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ABSTRACT

In this paper, the experimental study on concrete slabs reinforced by a new material is discussed. The new material used as reinforcement here is braided AFRP (Aramid Fiber Reinforcement Plastic) rods. The dynamic behaviors of concrete slabs under the impact loads and the relationships between the maximum impact forces and velocities are discussed based on the experimental results. The effects of adhering sand on the rod with respect to the bonding action are also considered.

1. INTRODUCTION

The new materials, for example, aramid fiber and carbon fiber rods, are excellent in resisting corrosion and non-magnetic in behavior, and have light weight and high strength properties compared with steel bar. Two methods of processing the materials for reinforcement and/or tendon have been developed. One is by manufacturing the rods by saturating them with resin after braiding the fiber. The other is by making a two or three-dimensional lattice to laminate the fiber with resin longitudinally and latitudinally. In order to consider the applicability of these new materials for reinforcement and/or tendon in concrete structures, material tests\(^{1,2,9}\) and static behavior of RC and PC beams\(^{3,6,7,8}\) and fatigue test of RC and PC beams\(^{9,10}\) using these new materials have been performed.

On the other hand, further research is required on the dynamic behavior of a concrete member reinforced by these new materials under dynamic loads (e.g., seismic and/or impact loads) in order to adequately establish their reliabilities. However, only the fatigue tests for RC and PC beams reinforced by new materials were executed by Mikami et al\(^{10}\) and Itch et al\(^{11}\).

In this paper, an experimental study on concrete slabs reinforced by braided AFRP rods under impact loads are executed basing on the background of the applicability of new materials in civil and architectural fields. The experiment was performed by allowing a steel-weight fall on simply supported concrete slabs. Braided AFRP rods were used to reinforce the concrete slab. The acceleration of the dropped weight and the strains on the reinforcing rods on both levels were measured by a wide-band data-recorder. The crack patterns at the back surface of each slab was marked after the impact test.

2. IMPACT TEST

Experiments were performed by using the weight-falling impact-apparatus shown in Photo-1. The falling weight is made of steel and 70kgf weight which is cylindrical in shape with 15.0 cm diameter. Impact load is generated by allowing it to drop freely through the linearway-unit to SMaRT 11 Transactions Vol. J (August 1991) Tokyo, Japan, © 1991
Table 1. Mechanical properties of AFRP rods

<table>
<thead>
<tr>
<th>Rod</th>
<th>K32 / K32s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface treatment</td>
<td>without sand / with sand</td>
</tr>
<tr>
<td>Nominal diameter</td>
<td>6 mm / 7 mm</td>
</tr>
<tr>
<td>Nominal cross section area</td>
<td>0.25 cm²</td>
</tr>
<tr>
<td>Density</td>
<td>1.44 g/cm³</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>2.8 tonf</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>6.45 ×10⁵ kgf/cm²</td>
</tr>
<tr>
<td>Maximum elongation</td>
<td>1.74 %</td>
</tr>
</tbody>
</table>

keep the consistency of dynamic responses and prevent eccentric loading. The concrete slabs were supported by steel rollers at the upper and lower sides so as to obtain a simple support effect. To investigate the dynamic behavior of concrete slabs between the elastic and plastic range where no actual fracture occurs, the impact loads were surcharged so as to produce a velocity of up to 4 m/sec.

The mechanical properties of concrete are $\sigma_{28} = 502$ kgf/cm², $E = 2.95 \times 10^5$ kgf/cm², and $\nu = 0.201$ and those of AFRP rods are shown in Table 1. In this experiment, the rods used were manufactured by saturating them with resin after the aramid-fibers were braided. The elastic limit of these rods is more than 17,000 μ strain which is 10 times more than that of steel bar. In order to investigate the effects of roughness of the rod’s surface to dynamic response of the slab, braided AFRP rods were used to reinforce concrete slabs with and without adhering sand on their surfaces. Fig. 1 shows the specimen of concrete slab having a 150 cm × 150 cm × 10 cm dimension with double reinforcements (approximately 1% per one level) in both directions and strain gages were glued to the rods of each level.

Measuring system used in this experiment is shown in Fig. 2. The total number of sensors are 25, 3 of which are 1000 g-acceleration transducers and 22 of strain gauges glued to AFRP rods. The out-put data from each sensor are recorded by wide-band data-recorder through a D.C. amplifier unit. The recorded waves are reproduced as the still pictures on the
3. EXPERIMENTAL RESULT

Of the 6 concrete slabs, 3 slabs were reinforced with AFRP rods without sand (AC-SLB) and the others with sand (AsC-SLB). The sequence of tests for each slab are listed in Table 2. In order to compare the behavior of slabs with AC-SLB and AsC-SLB, the slabs with I.D. no's -23 and -27, -25 and -26, -24 and -28 are surcharged with the same loading condition.

3.1. General view of the strain wave configurations of AFRP rods

Photos 2 and 3 show the configurations of strain waves on AFRP rods at the impact velocity \( V = 1 \text{ m/sec} \). In those Photos, the total sampling times is 40 msec and the upper and lower portion of the base line has been taken as tension and compression respectively. Photo-2 shows that the AC-SLB-23 slab vibrates with a damping free motion except at the beginning of impact while the strains on the upper and lower rods have a symmetrical pattern.
On the other hand, Photo-3 in relation to the behavior of the slab with sand (AsC-SLB-27) shows as follows; 1) the wave distribution after the generation of the 1st main wave attenuates rapidly, 2) the magnitude of strains on the upper part of the rods, especially at the beginning of impact, is bigger than that of the lower ones.

The axial strain distributions on the AFRP rod at each time after impact are shown in Fig. 3 to be lying in the lower portion of the slab. In this figure, the up- and downward direction from the base line are compression and tension side respectively. The main part of the strain wave propagates to the support point. The region of compression is generated during t=0.4msec and t=0.8msec after the steel weight impact, though the lower fiber stresses of the plate must be tensile due to the static load. AC-SLB-23 slab vibrates with the fundamental mode while AsC-SLB-27 slab vibrates with a mode which is a superimposition of the fundamental and the 3rd mode.

3.2. The crack pattern of the back surface of slab

The crack pattern at the back surface of the slab after all of test sequences have been finished are shown in Fig. 4. The left-hand side of this figure are for slabs using AFRP rods without sand (AC-SLB). The slabs with I.D. no.'s -23 and -24 have cracked diagonally, but the one with I.D. no. -25 shows a more complicate crack pattern than the former ones. Those crack patterns suggest that the 1st fundamental vibration mode may have been excited after which the slabs behaved similarly to the uniformly loaded ones.

On the other hand, in the case of slabs reinforced with AFRP rods with sand (right-hand side of fig. 4), the crack patterns are radially distributed at the central portion of the slab. This means that higher modes of vibration are superimposed by the fundamental one and the slabs withstand the impact through the bending deformations at the central portion of the slab. Adhesion of sand on surfaces of AFRP rods, the reduction of bending stiffness may then be prevented improving the bond capacity between concrete and AFRP rod.

3.3. The maximum impact load due to weight dropping

The maximum impact load resulting from the steel-weight drop is evaluated by multiplying the mass of steel weight and the maximum acceleration measured by the acceleration transducer attached to the sides of the steel weight. They were compared with the theoretical
values derived based on the elastic contact theory. The equation on the evaluation of the impact load \( P \) is formulated as follows:

\[
P = \frac{2E_a}{1-\nu^2} \frac{V e^{-\frac{A}{2\rho}}} {\omega \sqrt{1-\beta^2}} \sin \omega \sqrt{1-\beta^2} t \quad \text{...(1)}
\]

where

\[
\beta = \frac{1}{4h^2} \sqrt{\frac{3Ma}{2\rho}} \quad \omega = \sqrt{\frac{2E_a}{1-\nu^2}} / M \quad \text{...(2),(3)}
\]

in which

- \( E, \nu \): Young's modulus and Poisson's ratio of the concrete,
- \( a, M, V \): diameter, mass and impact velocity of steel weight,
- \( \rho, h \): mass per unit volume and thickness of concrete slab respectively.

The time at which the maximum impact load is generated is given as follows:

\[
t = \frac{1}{\omega \sqrt{1-\beta^2}} \tan^{-1} \frac{\sqrt{1-\beta^2}}{\beta} \quad \text{...(4)}
\]

Figure 5 shows the comparison of the maximum impact load between experimental and theoretical results. Figures (a) and (b) are the results for AC-SLB and AsC-SLB respectively and the numbers in these figures indicate the loading sequence number for each slab. The theoretical results for both cases may almost provide the lower limit value of those obtained from experimental test data. Then, these results mean that the concrete near the loading point has not cracked nor crushed yet and behaved like an infinite elastic plate. If impact velocity is increased up to \( V = 4.0 \text{ m/sec} \), the maximum impact load for concrete slab reinforced with AFRP rods with/without sand can be estimated using the elastic contact theory.

![Graph](image)

(a) AC-SLB slabs
(b) AsC-SLB slabs

Fig. 5. comparison of the maximum impact load between experimental and theoretical results

4. CONCLUSION

In order to study the dynamic behavior of the concrete slab reinforced by the new material, the experiment which allows a steel weight to drop on a slab with braided AFRP rods was executed. The acceleration of the steel weight and the strain on the rods were measured. The results obtained from these experiment are as follows;
1) The strain waves on the upper and lower rods behave almost symmetrically except near the loading point.
2) Adhesion of sand on the surfaces of AFRP rods may increase the bonding capacity between concrete and rod and prevent the reduction of bending stiffness.
3) The impact load can be estimated by using the elastic constant theory.

REFERENCES


