Experimental Evaluation of Reinforced Concrete Slab Reinforced by Composite Mortar in terms of Flexural Behavior and Floor Impact Noise Evaluation

Seung-Woong Ho and Seung-Joe Yoon

ABSTRACT

A total of 13 ferroconcrete slab specimens reinforced by composite mortar were used to conduct a strength performance evaluation with the types of reinforcement and the diameter of wire meshes as its parameters to determine failure modes, ductility and stiffness. A total of six floor impact noise tests based on KS F 2810-2:2012 were performed at the construction site of H apartment complex, which had just completed frame construction. The study used Ethylene-Vinyl Acetate Copolymer (EVA), Expanded Polystyrene (EPS), and Polypropylene (PP) as the reinforcement materials effective against floor impact noise, and employed the grid-shaped steel wire meshes for improving strength performance.

The test results showed that in the case of the reinforced slab specimens, there was no detachment of reinforcement materials like the wire meshes and composite mortar thanks to the bonding force of anchor bolts and composite mortar. Under the maximum strength, the EVA-reinforced slab specimen was the most effective by improving the heavyweight floor impact noise by 23% and the lightweight floor impact noise by 12%.

1. Introduction

Considering the international trend of the study, many new engineering methods have been suggested for earthquake-resistant reinforcement. However, there have been few studies on reinforcement engineering methods to reduce noise between floors for apartments, collective houses, etc. In addition, no engineering practices to integrate both have been introduced so far.

Methods for reducing floor shock sound in collective houses such as apartments, etc. can be classified largely into improving the substructure of the floor, changing the buffer within the slab, and using different floor finishing materials. For previous collective houses such as apartments, etc., which had a wall structure, reinforcement construction only for the floor could not achieve a noise-blocking effect of note. For earthquake-resistant engineering, an adhesive reinforcement method using fibre sheet, fibre steel plate, steel plate, etc. is now being widely used. Adhesion using epoxy improves the effect of reinforcement. Thus, now high-quality reinforcement depends greatly on minimising the deterioration of reinforcing materials, the general environment, and workers’ abilities.

In this study, a new engineering method is suggested to reinforce slab and wall body. Descriptions of engineering methods and the results of noise-blocking and durability evaluation are explained in detail as well.

2. Experiments

Shown in Figure 1 are the grid-shaped wire mesh for improving strength performance (250 × 250 mm, T = 0.6 mm). Shown in Figure 2 are the composite reinforcement materials for reducing floor impact noise. The thickness of the materials was 5 mm.

(1) Strength performance evaluation

The design of the one-way ferroconcrete slab specimens was based on the strength design method from the Concrete Structure Design Criteria (KBC 2012 Design Criteria) KCI-I-2012 (2012) by the Ministry of Land, Transport and Maritime Affairs. Shown in Figure 3 are the shape, size and reinforced state of the specimens.

(2) Floor impact noise performance evaluation

The heavyweight and lightweight floor impact noise evaluation was conducted at a multi-family housing construction site based on KS F 2810-1:2015 Korean Industrial Standards (2015) and KS F 2810-2:2012 Korean Industrial Standards (2012).

(3) Reinforcement method

As shown in Figure 4, the slab reinforcement method proceeded in the order of (a) surface grinding⇒ (b) primer application⇒ (c) epoxy putty processing⇒ (d) wire mesh installation⇒ (e) placing composite mortar⇒ (f) mortar surface treatment. To minimise the load and thickness of the reinforcement material, the total reinforcement thickness was designed to be less than 30 mm,
and the reinforcement was placed at the bottom of the slab specimen.

(4) Composite mortar
As shown in Figure 5, a 40 × 40 mm (B × D) specimen that complied with the KS F 2408 Korean Industrial Standards (2016) standard was fabricated to evaluate the flexural compressive strength of composite mortar. The mortar mix strength was designed to be 24 MPa. Shown in Table 1 is the test body list.

\[ f_b = \frac{3Pl}{2bh^2} \]  

where \( f_b \) is the flexural strength (MPa), \( P \) is the maximum strength indicated by the testing machine (N), \( l \) is the span (mm), \( b \) is the width of the failure section (mm), and \( h \) is the height of the failure section (mm).

(5) Flexural experiment plan
Figure 6 shows the status of specimen installation. Also shown in Table 2 is the specimen list.

The test was conducted by applying one-point loading to the top of the specimen with the use of a 2,000 kN UTM (universal testing machine). Each strain was measured using strain gauges attached to the concrete, tensile, compressive reinforcement, and reinforcement material surfaces, respectively, and the displacements were measured using the three 200-mm LVDTs (linear variable differential transformers) installed at the centre of the specimen and one 100-mm LVDT installed at the 1/3 point of the specimen. The cracks generated due to loading were displayed on the specimen in real time, and photographs were taken for recording purposes.

(6) Impact noise experiment plan
Table 3 displays the evaluation of crashing sound performance; a standard light and heavy crashing sound experiment was conducted based on the KS F 2810-1:2015 Korean Industrial Standards (2015) and KS F 2810-2:2012 Korean Industrial Standards (2012) standards at H apartment located in Chunjiu, Chungcheongbuk-do, of which the framework construction had been finished. In a 20-level apartment, the ninth floor was set as the standard floor having no reinforcements, and the seventh and fifth floors were reinforced with composite mortar using the same method as the resistance force specimen (Heo 2007; Yoon and Ho 2014).
Figure 7 displays the construction site, sound source room and sound receiving room for the ground crashing sound experiment.

3. Test Results

(1) Final failure pattern

Figure 8 shows the final failure modes that occurred at the bottoms of the specimens. The non-reinforced specimen S-None showed a flexural failure mode in which it reached final failure due to the compression crushing of the concrete after the yielding of the tensile reinforcement at the slab centre. The specimen group reinforced with composite mortar did not show de-bonding between reinforced mortar and slab as well as fracture phenomena, but underwent final failure as the flexural crack widths increased. This suggests that the fixing force of the anchor bolt prevented the wire mesh and composite mortar from falling off the specimen.
Table 1. List of test body (composite mortar).

| Specimens | Ratio (%) | Compressive strength (MPa) | Tensile strength (MPa) |
|-----------|-----------|----------------------------|------------------------|
| None      | 26.1      | 18.4                       |
| EVA       | 0.2       | 28.6                       | 18.7                   |
| EVA       | 0.5       | 27.9                       | 17.6                   |
| EVA       | 1.0       | 22.4                       | 15.2                   |
| EVA       | 1.5       | 19.3                       | 15.3                   |
| EVA       | 2.0       | 14.2                       | 12.9                   |
| EVA       | 3.0       | 11.7                       | 10.2                   |
| EPS       | 0.2       | 22.0                       | 12.2                   |
| EPS       | 0.5       | 19.1                       | 17.1                   |
| EPS       | 1.0       | 13.5                       | 15.9                   |
| EPS       | 1.5       | 13.2                       | 10.2                   |
| EPS       | 2.0       | 11.9                       | 7.1                    |
| EPS       | 3.0       | 8.0                        | 6.2                    |
| PP        | 0.2       | 24.7                       | 13.3                   |
| PP        | 0.5       | 24.4                       | 10.6                   |
| PP        | 1.0       | 22.7                       | 7.2                    |
| PP        | 1.5       | 20.1                       | 9.5                    |
| PP        | 2.0       | 17.2                       | 6.1                    |
| PP        | 3.0       | 12.1                       | 5.0                    |

EVA: Ethylene-vinyl acetate copolymer, EPS: Expanded polystyrene, PP: Polypropylene.

Table 2. List of test specimens (Flexural specimens).

| Specimens | Reinforcement | Type | Ratio (%) | Wire mesh diameter (mm) |
|-----------|---------------|------|-----------|-------------------------|
| None      | -             | Bottom | 1 -       | 4.2                     |
| EVA       | -             | EVA1-W4.2 | 1 -       | 3.2                     |
| EPS       | -             | EPS1-W4.2 | 1 -       | 3.3                     |
| G3.2-W4.2 | -             | G3.2-W4.2 | 1 -       | 3.2                     |
| G3.2-W3.2 | -             | G3.2-W3.2 | 3 -       | 4.2                     |
| PP        | -             | PP1-W3.3 | 1 -       | 3.3                     |
| PP        | -             | PP3-W3.3 | 3 -       | 4.2                     |
| PP        | -             | G4.8-W4.2 | 1 -       | 4.8                     |

EVA: Ethylene-vinyl acetate copolymer, EPS: Expanded polystyrene, PP: Polypropylene, G: Regenerative rubber plate.

(2) Load-displacement curves

Table 4 shows the test results. Figure 9 shows the load-displacement relationship according to the reinforcement ratio and the type of reinforcement used. The specimen group (reinforcement ratio 1% and wire mesh 4.8 mm) was up to 1.50 times higher than that of the non-
reinforced specimen (None). The specimen group (reinforcement ratio 1% and wire mesh 3.3 mm) was up to 1.43 times higher than that of the non-reinforced specimen. The specimen group (reinforcement ratio 3% and wire mesh 4.8 mm) was up to 1.46 times lower than that of the non-reinforced specimen. Shown in Figure 9 is the comparison of the maximum strength for each specimen. Figure 10 (a) is the comparison of stiffness of the specimen and Figure 10 (b) shows the ductile capacity of each specimen.

4. Impact noise performance evaluation

Table 5 is the Impact sound performance evaluation result. Shown in Figure 11 is the inverse A weighting

Table 4. Test result.

| Specimens   | $P_{max}$ (kN) | $\delta_{max}$ (mm) | $P_{max}$ increase |
|-------------|----------------|---------------------|--------------------|
| None        | 127.8          | 48.2                | -                  |
| EVA1-W4.2   | 191.1          | 33.94               | 1.50               |
| PP1-W4.2    | 187.4          | 28.23               | 1.47               |
| G3.2-W4.2   | 170.7          | 28.42               | 1.34               |
| EPS1-W4.2   | 182.5          | 40.82               | 1.43               |
| EPS1-W3.3   | 172.9          | 34.82               | 1.35               |
| PP1-W3.3    | 171.6          | 32.74               | 1.34               |
| G3.2-W3.3   | 149.7          | 51.25               | 1.17               |
| EVA3-W4.2   | 186.4          | 27.30               | 1.46               |
| EPS3-W4.2   | 186.0          | 29.56               | 1.46               |
| PP3-W4.2    | 184.2          | 33.76               | 1.44               |
| G4.8-W4.2   | 147.9          | 31.90               | 1.16               |

EVA: Ethylene-vinyl acetate copolymer, EPS: Expanded polystyrene, PP: Polypropylene, G: Regenerative rubber plate.
of the lightweight and heavyweight impact noise. Impact noise performance evaluation showed that compared to the measured value at the ninth floor without reinforcement, the lightweight impact noise measured at the EPS seventh was reduced by 6 dB, and that at the EVA fifth floor was reduced by 9 dB. And the heavyweight impact noise measured at the EPS seventh was reduced by 7 dB, and that at the EVA fifth floor was reduced by 6 dB.

5. Conclusions
The summary of the test results in this study is as follows.

(1) The flexural and compressive strength of composite mortar decreased as the ratio of reinforcement increased, and considering the impact noise prevention performance and KS F 4040, the reinforcement ratio of 1.0% would be appropriate.
(2) The composite mortar-reinforced specimen did not show drastic detachment of composite mortar; instead, it showed an increase of flexural crack width, which led to ultimate fracture. Accordingly, it is determined that the bonding force of anchor bolts and composite mortar prevented any detachment of reinforcement materials like wire mesh and composite mortar.

(3) The composite mortar-reinforced specimen groups with 4.2-mm-thick wire mesh showed its maximum strength 1.13 to 1.25 times higher than those with 3.3-mm-thick wire mesh. Therefore, it is believed that the thickness of mesh plays a dominant role in maximum strength, and that EVA reinforcement used in composite mortar offers somewhat superior bonding force between lower slab and wire mesh.

(4) Compared to S-None, the specimen without reinforcement, the reinforced specimen group showed higher initial stiffness, and the specimen group reinforced with composite mortar showed up to 17% higher stiffness than the specimen group reinforced with recycled rubber plate. Also, the ductility evaluation showed that the specimen group reinforced with composite mortar showed up to 20% higher ductility than those groups reinforced with recycled rubber plate. Therefore, it is determined that the composite mortar reinforcement is effective in stiffness and shows ductile behaviour improvement after maximum load.

(5) The lightweight and heavyweight impact noise tests based on the construction method with the 1% composite mortar ratio were conducted at a multi-family housing construction site. The lightweight impact noise test showed that EVA showed an improvement of 23%, and EPS by 14%, and the heavyweight impact noise test illustrated that EVA showed an improvement of 12%, and EPS off 14%. Therefore, it is believed that this method is effective in preventing inter-floor noise.

Disclosure statement

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Notes on contributors

SeungWoung Ho (First Author, Researcher Fellow of Korea National University of Transportation) is a Researcher Fellow, Department of Architectural Engineering, Korea National University of Transportation, South of Korea.

Seung-Joe Yoon (Corresponding Author, Professor of Korea National University of Transportation) is a Professor, Department of Architectural Engineering, Korea National University of Transportation.

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Figure 11. Inverse A weighting of lightweight and heavyweight impact noise.
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