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Research paper

Improvement of Seismic Capacity of Reinforced Concrete Frame Building by Installing Infilled Walls

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Abstract

This paper aims to analytically examine the retrofit effect of two different construction methods for the infilled walls by RC and form block. Accordingly, it compares the performance point on the demand-capacity curve via the capacity spectrum method, and the degree of plastic deformation of the structure between RC and form block infilled walls.
As for the gravity load on the building that extended from the three-story to the five-story structure, the external force on the beam located at the center of the second floor was 2.4 times higher than the internal strength, and for the lateral force, the external force on the beam on the floor of the second core part increased by up to 2.6 times to the internal strength, showing that the reinforcement on the members would be necessary. The members of the building extended to the five stories were determined to be susceptible to gravity load and lateral load, and the load combination of each member showed that it would be effective to install the infilled wall on the shorter side for gravity load and on the longer side for lateral load.

Keywords: *Retrofit effect, infilled walls, RC and form block, capacity spectrum method, five-story building*

1. Introduction

The recent series of seismic activities in South Korea have led to a growing interest in seismic designs or reinforcement for buildings to promote structural safety against earthquakes [1]. Particularly, there have been a number of seismic retrofit design and related construction projects for aged school buildings that are susceptible to earthquakes [2].

The objective of this study is to determine the structural safety of the strength improvement method that installs infilled walls inside the reinforced concrete (RC) frame structures, which have been extended from the three-story to the five-story buildings, to offer seismic reinforcement capacity. Specifically, the study aims to analytically examine the reinforcement effect of two different construction methods for the infilled walls—RC and form block. Accordingly, it compares the performance point on the demand-capacity curve via the capacity spectrum method, and the degree of plastic deformation of the structure between RC and form block infilled walls.

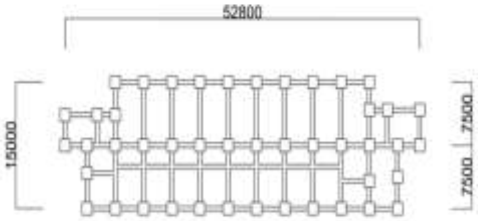
2. Seismic Evaluation on A School Building

2.1 Finding Proper Place for Retrofit

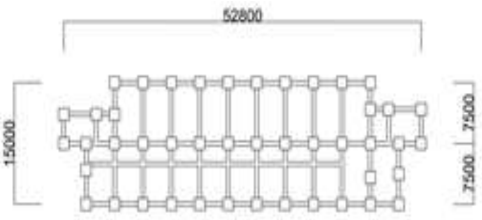
As the first step, the evaluation determines the location of unstable members caused by extending aged structures and selects the location at which infilled walls are to be installed. Form block and RC infilled walls are installed at the selected location for retrofit, and the degree of deformation is determined by the nonlinear analysis of the reinforced structure.

The target building is a 30-year old three-story school building, and its floor plan and elevation are shown in Figure 1. This building was extended to the five-story structure, and the column arrangement of the extended floors was identical to that of the existing floors. Figure 2 shows the modeling of the building using the analytical program. The concrete strength of the existing and extended buildings is 21MPa and 24MPa, respectively.

After the extension of the building, the gravity load on the beam located at the center of the second floor increased by 2.4 times to its capacity, and the load on the beam on the floor of the second core part increased by up to 2.6 times to its capacity due to the increase of the lateral force. The thick solid line in Figure 3 is the location of the member weakened by gravity load and lateral force. The location of the infilled walls was centered on this solid line, and the infilled wall installed in the staircase on both sides was designed to resist the lateral force, and the one installed in the direction of the shorter side of the building was to resist the gravity load.



(a) 2nd floor



(b) Roof flor

Figure 1: Floor plan

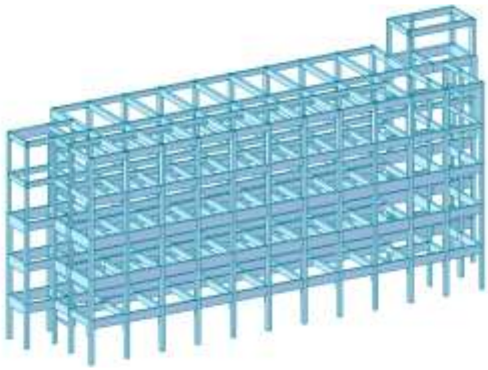
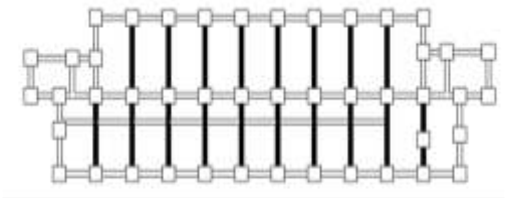
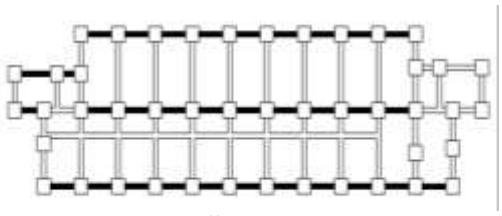


Figure 2: Structure model of the building



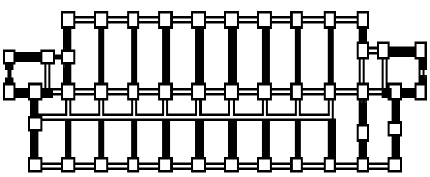
(a) Members affected by gravity load



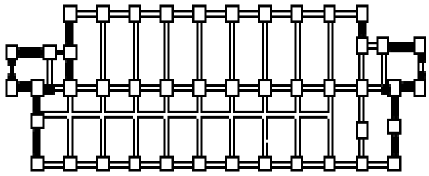
(b) Members affected by horizontal load

Figure 3: Members affected by loads

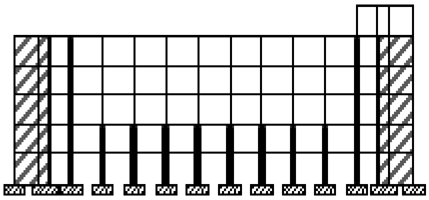
The location of the form block infilled wall is shown in Figure 4. The block wall has been developed for new construction as well as retrofit of frame building [3,4,5]. Considering that the beam located in the shorter side direction at the center floor of the second and third floors is mostly under gravity load, the infilled wall was installed under the beam located at the center of the first and second floors. Furthermore, the whole floor of the staircase was installed in the core type to have it resist the lateral force in the longer side direction, and the outer walls in the shorter side direction were installed in all floors. It was assumed that the walls would show elastic hysteresis behavior, and the material properties of concrete were based on the design code. As shown in Table 1, the elastic module and shear module, the material properties of the block wall, were derived from the design equation of JASS 7 [6].



(a) 1^{st}, 2^{nd} floor



(b) 3^{rd}, 4 and 5^{th} floor



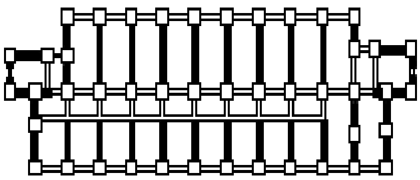
(c) Section

Figure 4: Locations for infilled form block

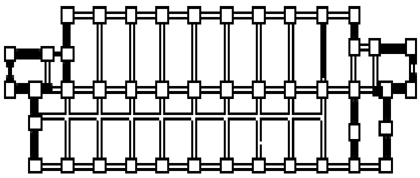
Table 1: Material properties of form block wall

Properties	Value
Elastic module (N/mm2)	1.71e+007
Possion ratio	0.089
Volumetric weight (N/mm3)	23.54
Shear module (N/mm2)	5.12x103
Tensile strength (N/mm2)	0.834

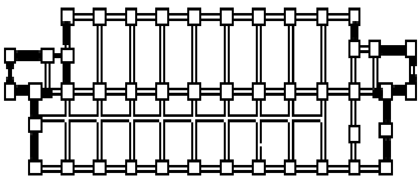
Shown in Figure 5 is the location of the RC infilled wall. The staircase was installed in core type up to the fourth floor, and on the first floor, it was installed in the shorter side direction. The amount of the RC wall optimized by the repetitive calculation was 238m3, and the amount of the form block structure was 341.61 m3, 30.3% smaller than the form block wall. Also, the comparison of economic performance based on the above results showed that the RC wall showed the identical effect to that of the form block wall at the 75.2% of the cost for the latter. Considering the location of the openings and corridors of the building, some walls were not extended. Shown in Figure 6 is the structure model of the building strengthened by infilled wall using the analytical program, Midas Gen. [7].



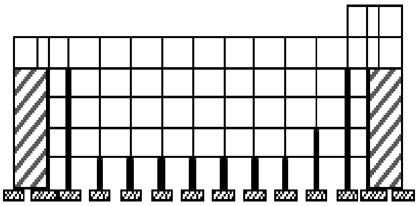
(a) 1^{st}, 2^{nd} floor



(b) 2^{nd} floor



(c) 3^{rd}, 4 and 5^{th} floor



(d) Section

Figure 5: Locations for infilled RC wall

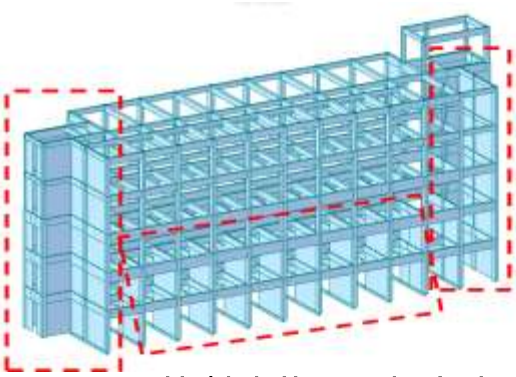


Figure 6: Structure model of the building strengthened with infilled walsl

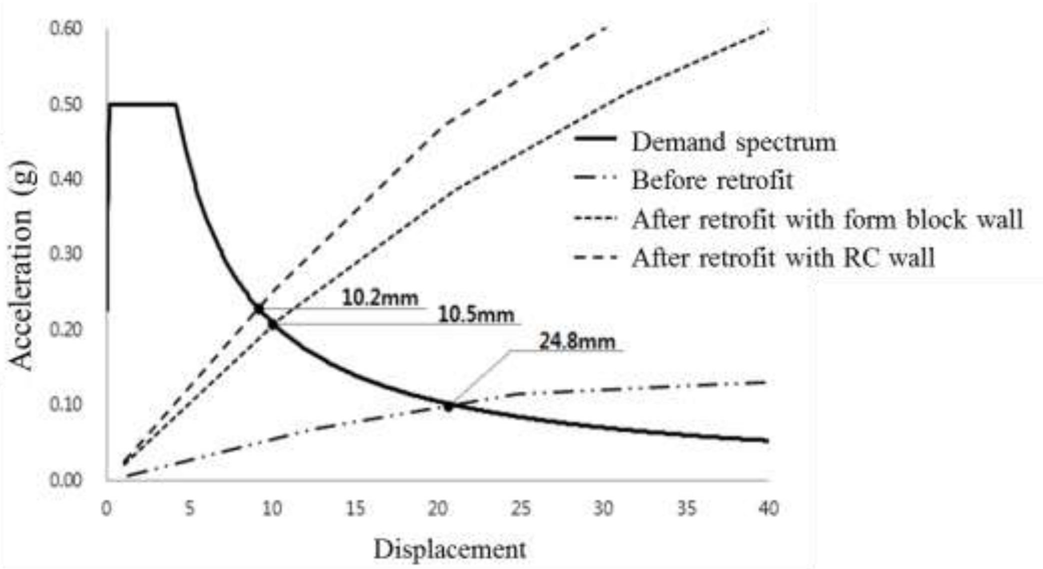


Figure 7: Evaluation on the performance of the buildings

2.2 Retrofit Effect

The maximum negative moment and positive moment of the beam under the largest gravity load before retrofit were 203.7kN·m and 290.5kN·m, respectively. After the retrofit with the form block wall, the maximum negative and positive moments at the location with the installed wall were 71.5kN·m and 121.4kN·m, respectively, and the maximum negative moment at the location without the wall considering the openings was 11.1kN·m. In case of RC, the maximum moment at the location with the RC wall was shown to be similar to that of the form block wall and the maximum negative moment at the location without the RC wall was 34.2kN·m. Before the reinforcement, the beam resisted all the moments, but it is believed that after the reinforcement, the moments were distributed so that the moments the beam had to bear were reduced. The ratio of the working moment to the own moment ($M_u/\phi M_n$) before and after the reinforcement showed that the ratio before the reinforcement was 2.67, requiring structural reinforcement. When the beam at the same location was reinforced with the RC wall, the ratio was 0.83, and when it was with the form block wall, the ratio was 0.85, demonstrating structural safety.

In the beam under the largest lateral load, the maximum shear force before the retrofit, after the retrofit with the form block wall or with the RC wall were 81.8kN, 86.7kN, and 86.5kN, respectively. The reason for the largest maximum shear force after the retrofit rather than before the retrofit is because the right side of the beam joins the reinforced core so that the left side of the beam undertakes more shear force than before the reinforcement. The analysis results showed that the ratio of the working shear force to the own shear force of the beam ($V_u/\phi V_n$) was 1.06, but it was reduced to 0.43, demonstrating structural safety, when it was reinforced with the RC wall and with the form block wall.

2.3 Pushover Analysis

Shown in Figure 7 is the push over analysis result before and after the reinforcement, a graph comparing the spectrum and the performance curve. The analysis results showed that before the reinforcement, the performance point was identified at the displacement of 24.8mm with the highest floor as the reference, and after the reinforcement with the form block wall, it was 10.5mm, and after that with the RC wall, it was 10.2mm. Even before the reinforcement, the performance point was formed at the crossing between the demand and capacity curves. The displacement of the performance point is very large, but after the reinforcement, the strength greatly increased, and accordingly, the performance point was formed at the lower displacement.

3. Conclusion

In this study, the form-block infilled wall, one of the seismic retrofit methods, was used to reinforce an aged school building, and using a structural analysis program, the RC infilled wall and the form block infilled wall were compared and evaluated.
(1) As for the gravity load on the building that extended from the three-story to the five-story structure, the external force on the beam located at the center of the second floor was 2.4 times higher than the internal strength, and for the lateral force, the external force on the beam on the floor of the second core part increased by up to 2.6 times to the internal strength, showing that the reinforcement on the members would be necessary.

(2) The members of the building extended to the five stories were determined to be susceptible to gravity load and lateral load, and the load combination of each member showed that it would be effective to install the infilled wall on the shorter side for gravity load and on the longer side for lateral load.
(3) When the ratio of the working moment to the own moment affected by gravity load (Mu/ϕMn) after the reinforcement was compared to that before the reinforcement, the ratio for the RC infilled wall and for the form block infilled wall was reduced by 68.91% and 69.07%, respectively, and the ratio of the working shearing force to the own shearing force affected by lateral load (Vu/ϕVn) showed that the ratio for the RC infilled wall and the form block infilled wall was reduced by 59.07% and 59.05%, respectively.
(4) The pushover analysis of each structure reinforced by the form block infilled wall and the RC infilled wall, considering gravity load and lateral load, showed that before the reinforcement, the performance point was identified at the displacement of 24.8mm with the highest floor as the reference, and after the reinforcement with the form block wall, it was 10.5mm, and after that with the RC wall, it was 10.2mm. Even before the reinforcement, the performance point was formed at the crossing between the demand and capacity curves. The displacement of the performance point is very large, but after the reinforcement, the strength greatly increased, and accordingly, the performance point was formed at the lower displacement.

Acknowledgement

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