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Experimental Study on the Seismic Behavior of Retrofitted Concrete Infill

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ABSTRACT: Nowadays, Infill is widely used in retrofitting structures. Low sensitivity to construction quality is one of the advantages of concrete infill in comparison to other methods such as the application of steel braces. On the other hand, there are some weak points in this method mainly like sudden and brittle fracture in the corner which causes serious degradation. Due to such a weak point, concrete infill could not attract researchers so much and a limited number of studies were thus conducted on them. The experimental behavior of concrete infill with a scale of 1/2 was studied under cyclic and monotonic loading. This research includes three experiments: 1- compound frame consisted of steel frame and simple concrete infill, 2- a steel frame with concrete infill included confined corner 3- the third model encompasses second model accompanied with frictional sliding fuse (FSF). Results show that a Strengthened corner delays corner fracture to a great extent but the fracture still happens and causes much degradation. A frictional sliding fuse not only delays infill fracture to a great extent but also prevent degradation after failure of the corner. The used FSF also acts as a friction damper and increases the area of the hysteresis loops of the compound frames and consequently increases energy absorption.

Key words: Concrete Infill, Frictional Sliding Fuse, Retrofitting, Strengthening

INTRODUCTION

Nowadays, strengthening existing buildings in order to improve their behavior against earthquake is an essential and complicated issue in structural and earthquake engineering. Most existing buildings are not resistive, flexible and rigid enough to survive against earthquakes. The main reasons are the lack of new regulation requirements at the construction period and/or low quality of performance in construction of building. There are different methods of retrofitting structures such as the application of concrete infill, prefabricated panels, steel bracing, using FRP, concrete jackets or a combination of them.

Sometimes, strengthening of the members alone is not sufficient. The structure may be weak in terms of lateral rigidity and do not meet the requirements related to lateral displacement. Using shear walls or metal bracing is one the methods suggested for solving this problem. However, building a shear wall or new bracing in a structure can cause numerous problems in terms of architecture and structure. Hence, using concrete infill for strengthening seems to be a more proper solution. According to previous researches, it was revealed that using infill is the easiest and most effective way to improve the seismic properties of a structure (Moghaddam, 2002; Karimian, 2003). The concrete infill both increases lateral stiffness and relieves frame elements of bearing extra load. It also shows low sensitivity in construction quality. However, there are two main weak points in concrete infill. The first is the brittle fracture in the corner of infill frame which is unpredicted and sudden. The second is the severe reduction in resistance and rigidity after a fracture in infill in a way that there is no other obstacle against earthquake force when the infill is fractured and indeed the structure remains vulnerable to earthquake (Moghaddam, 1990).

This research aims to present methods to improve the seismic properties of infill with the aid of laboratory experiments in a way that we first tried to delay the occurrence of the corner fracture until the diagonal fracture which has little reduction. Next, the sharp reduction after the fracture of the infill is prevented in order to improve resistance, flexibility, energy absorption capability etc.

MATERIAL AND METHODS

The experiments were done in the laboratory civil engineering faculty of Sharif University of Technology. The experiments were conducted step by step to retrofit the seismic properties of the concrete infill. The simple concrete compound frame was tested in the first experiment to be used as the control one for other experiments. Providing necessary strengthening in the two next experiments, we tries to overcome the weaknesses in the first experiment as well as the ones observes in other researchers' studies.

The mentioned compound frame includes a steel frame and a simple concrete infill. IPB120 and IPE140 profiles were used for the columns and the beams respectively to make the steel frame. The dimensions and geometry of the frame are shown in Figure 1 and its joint details are illustrated in Figure 2. The scale of the applied steel frame to the real one was 1:2. Considering the area of the mentioned cross-sections and the specified scale, the profiles used in this steel frame are almost equal to the profiles of the lower floors in an 8-story building in Tehran.

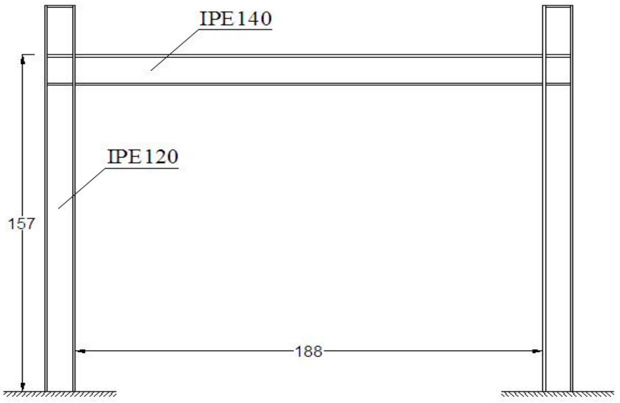

Figure 1. The dimensions of involved steel frame

The properties of the applied cross-sections obtained through the bending test and according ASTM standards are indicated in table 1 (ASTM). A hemicyclic test was conducted on the steel frame to determine the rigidity of the frame and beam-column joint type before building the infill. The results of the test showed that the frame stiffness was 2367 kg/cm and the behavior of this joint is very close to the hinge joint regarding the model of this frame made in Sap2000 software.

Table 1. The properties of the applied cross-sections

Section	F_y(kg/cm2)	E(kg/cm2)	I_X(cm4)	H(cm)
IPB120	2470	1845759	864	12
IPE140	2679	1254560	541	14

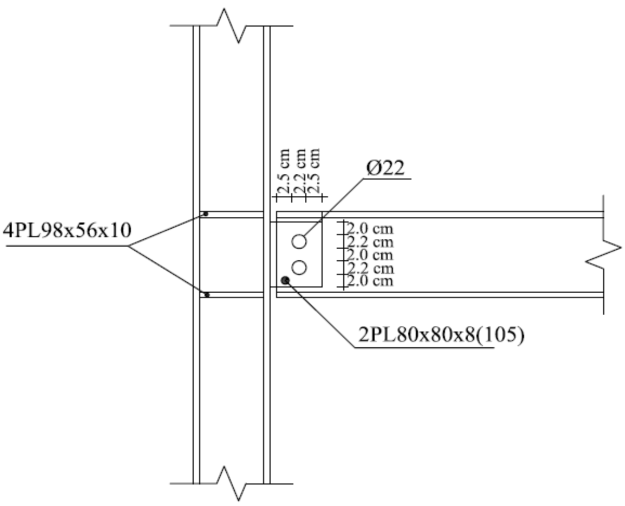

Figure 2. Beam-column joint details

The thickness of the built concrete infill was equal to the flange width of the beam in the frame (IPE140) and 73 mm in all three experiments. The infill has a mesh of vertical and horizontal rebar no. 8 (AII) with 20 cm spacing which is placed in the middle of the thickness of the infill. Also, the built infill is not joined to the steel frame at all. The two steel trusses which are supports for the applied force to the models as well as the strong floor of the experiment site can be seen in Figure 3. The lateral load in these experiments is applied as a two-way static load to the samples (Figure 4). The lateral load is applied to the samples by a two-speed 50 ton jack. The jack is able to reduce load exercising speed by increasing the force in order to record gauges more easily and in more spots. The forces were measured by a nanometer connected to the jack pump calibrated by load cell before the experiments start. Also in order to measure lateral displacement, displacement gauges were installed on the sides of the frame and a little lower than the force applying spot. The installed gauges have a precision of 0.01 mm and the force recording nanometer's is 100 kg. The number of sampling points increases in slope change spots i.e. at the moment of the beginning of plastic behavior in order to observe diagram’s curvature better.

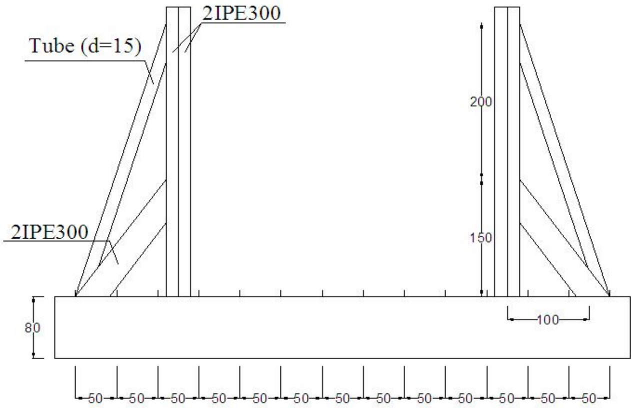

Figure 3. Steel trusses – supports for the applied force to the models

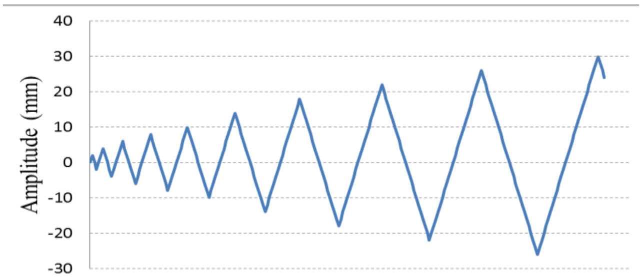

Figure 4. The schematic diagram of the load applying method

The mixture design used in the concrete of this series of experiments is a bulk mixture design including 6 volumes of sand, 5 volumes of ballpoint gravel, 2 volumes of cement and 2 volumes of water which all make an almost usual design of 300 kg/m3. The mentionable point in this stage is the age of concrete in the day of applying load in this way that preparatory steps like installing gauges and rubbing lime to the surface of the concrete had been completed in fourteenth day for all specimens and the experiment was initiated in fifteenth day. Given the studied by Oluokun et al, this mixture design reached 80 to 85 percent of its strength on the fifteenth day after concreting and with regard to the type of the cement and the ratio of water to cement and finally, it reaches a type of stability. Hence, experimenting samples on the fifteenth day would not cause any problems. It should be mentioned that finite element modelling was done by ANSYS program for all models in order to observe the behavior of the frame including force tolerance mechanism, stress distribution etc. and compare with the results by other researchers if necessary. Accordingly, finite element models were first calibrated with lab results and then other intended data were obtained from the software.

RESULTS

Simple concrete compound frame experiment: As it was mentioned earlier, the first experiment was carried out on the simple concrete compound frame. No strengthening was applied to this sample and the infill filled inside the frame just like a wall. After necessary controls and making sure of the installations and the accuracy of equipment, loading was started. The load-displacement curve obtained from the first experiment is presented in Figure 5. Boundary separation occurred in the opposite corner of the loading direction with the beginning of the experiment in very low force and displacement. Figure 6 indicates the developed mode of this event in continuous of loading. This phenomenon does not cause any tangible changes in the stiffness of the model. The truss behavior of the model is clearly exhibited through this separation. In other words, there is an element inside the frame preventing the two corners of the frame placed on the end of a diagonal to approach each other. Considering the distribution of compression stresses presented in Figure 7, this behavior is also clearly observable in the finite element model.

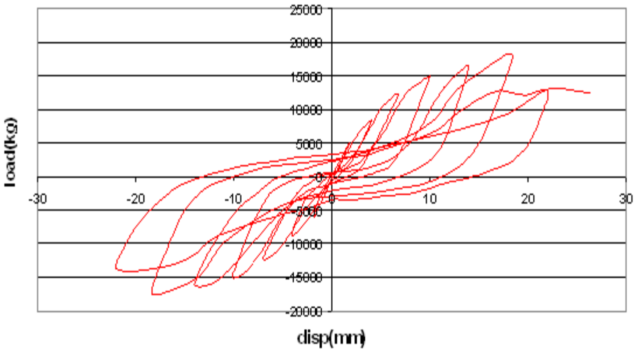

Figure 5. Load-displacement diagram recorded in the first experiment under cyclic loading

Figure 6. Boundary separation in the corner of the infill

In continuation of loading, the compound frame entered the nonlinear area later but no fracture was still observed on the model till signs of fracture can be seen in the corner near load applying spot in a displacement of 8 mm in forward loading. Why no fractures were observed while entering the nonlinear area was that the fracture started from the middle of the infill thickness and developed so much in 8 mm displacement that was observed on the surface of the infill. The corner of the infill bulged later in continuation of loading and peeled as indicated in Figure 8. The corner of the infill was completely emptied as the displacement increase to 20 mm (Figure 9).

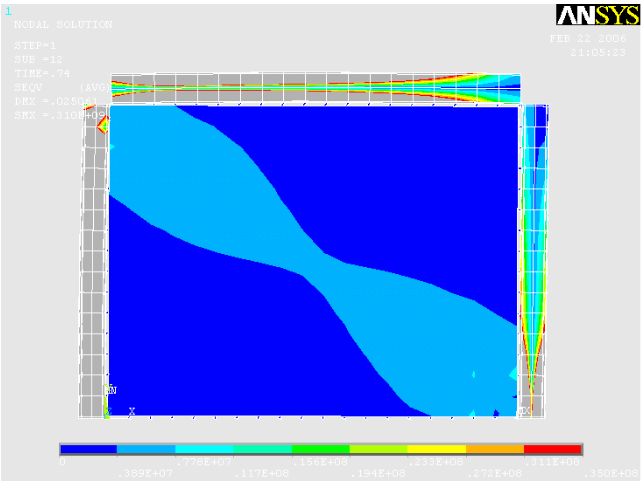

Figure 7. An illustration of the infill that functions like a diagonal member of the truss

Figure 8. Concrete peeling in the corner of the infill

Figure 9. Complete depletion of the infill corner

However, the reduction in resistance started in the previous cycle. In this displacement, the corner was totally smashed and thrown out. Although the signs of fracture and smashing were clearly seen in three other corners, they were not emptied or thrown out till end of the experiment.

Concrete infill experiment with retrofitted corner: In this stage, we tried to overcome one of the weaknesses of the concrete compound frame i.e. sudden breakage. Hence, all the four corners of the infill were retrofitted with two triangular plates as illustrated in Figure 10.

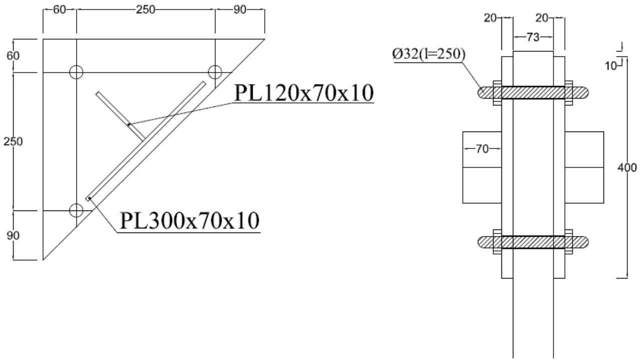

Figure 10. Corner retrofitting plate details

According to the Figure 11, there are two plates in each corner which confine concrete by three bullets from two sides. The plated were tightened as much as possible by torqometer in order to applied pre-stress and then carry out loading. The second model underwent monotonic loading since the goal of retrofitting the infill corner was to increase its resistance and not improving energy absorption properties, damping and other properties which require cyclic experiment.

Figure 11. A schematic of the second model before the experiment

The results of the experiment on the compound frame with a retrofitted corner can be seen in Figure 12. Like the first experiment, boundary separation appeared early in the experiment. This separation developed with the increase in displacement over the experiment. It seems that No fractures appeared in the model against a force of up to 5 ton in the beginning of the experiment. However, the stiffness of the model decreases with a constant and slow trend when the force increases. This trend continues up to a force of 27 ton. Afterward, a diagonal fracture appears on the surface of the infill. The width of the fracture increases as loading continues and develops towards two corners of the infill. Subsequently, other fractures appear parallel to the primary one and a little farther which also developed. However, the force has not increases yet in this stage but stiffness (rigidity) has decreased to some extent. A kind of fracture appears on the surface of the model at a force of 35 ton which is much similar to the corner fracture in the previous model. Fractures became apparent in front of the two stiffener plates without a regular and uniform pattern accompanied by bulging the surface of the concrete. The existing fracture in the corner and width of the diagonal fractures of the infill increased as loading continued. As the first model reached to its final resistance with the corner fractures, serious degradation in resistance happened after the occurrence of such a fracture at a force of 43 ton. However, regarding to the presence of stiffener plates, the corner fracture occurred in the area in front of the stiffener plates which is a much bigger area. This phenomenon is shown in Figure 13.

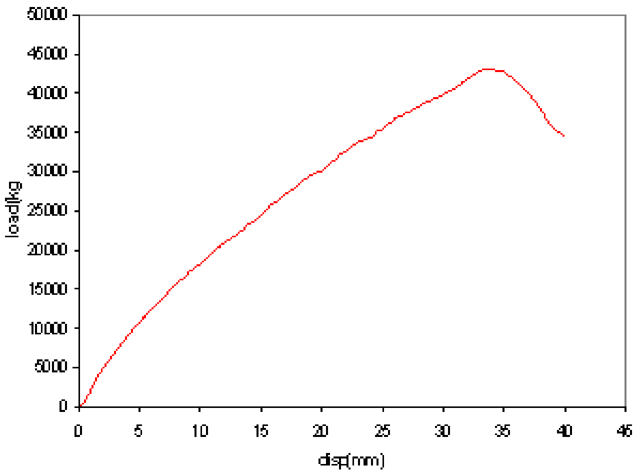

Figure 12. Load-displacement diagram achieved in the second experiment

Figure 13. The second sample breakage manner

Concrete infill with a frictional sliding fuse (FSF): Next, we tried to prevent sharp degradation after the fracture in infill. Therefore, a fuse was placed in the infill in order to operate and prevent cracking in infill before the force reaches cracking level. An image of this frictional sliding fuse is available in Figure 14.

Through tightening the bolts, an amount of vertical force can be created in the region between the plates which resist against the tension force as a resistance force. In other words, no slide takes place up to the level of friction force that is tolerable in the intersection part of the plates and then it continues sliding with almost the same force. If the bolts are fixed in a way that the fuse slides at a force lower than the lateral force of the infill fracture, the infill would not fracture and would tolerate earthquake force with almost no degradation.

The results of the third model with unfixed bolts are presented in Figure 16. As it can be seen, the fuse placed inside the infill is highly effective in the cyclic behavior of the compound frame and could increase the area of the hysteresis loops just like a frictional damper.

Figure 14. An image of the applied frictional sliding fuse

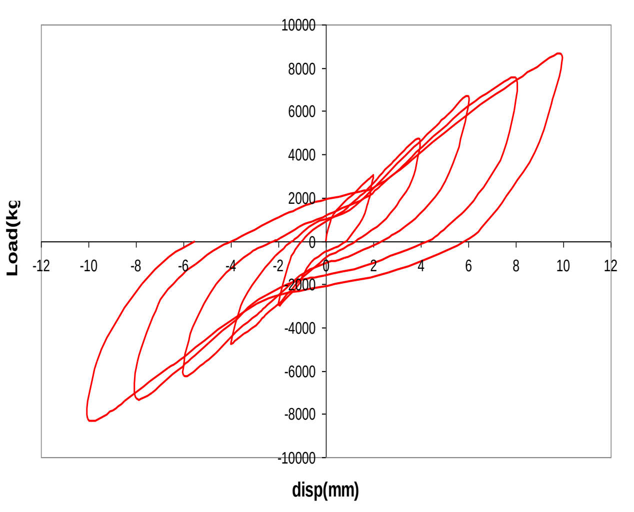

Figure 16. The results of the third experiment with unfixed bolts

Another experiment with monotonic loading was also conducted and its results are shown in Figure (16). Like previous models, Boundary separations occurred is different at very low forces but due to the presence of a fuse, formation of separations was different from former models i.e. instead of separations on the ends of the opposite diagonal of loading spot, separations are appeared in opposite ends of the top and bottom parts of the fuse.

It indicated that the system acted like the behavior of two infill ones on each other. According to Figure 17, the model faces a sharp reduction of stiffness at a force of about 25 tons in a way that we can infer from the stiffness reduction speed that a fracture similar to corner ones in previous infill caused such a breakage. However, in this stage, no obvious fracture has been observed on the surface of the model yet until at a displacement of about 35 mm, concrete spalling was observed in the corner under the pressure of the upper part of the infill where bolts are fixed. At a displacement of about 40 mm, a fracture was observed in the lower part of the fuse but in another side of infill. The compression fracture took place in a part of compressive diagonal of the lower and upper halves of infill. For this reason, it occurred at a force of between the corner fracture force in the simple concrete compound frame and the compound frame with retrofitted corners. Finally, with continuing the experiment, lateral displacement was applied over the model as much as the used jack allowed which caused the extension of the fractures in the model. Figure 18 indicates one of its instances.

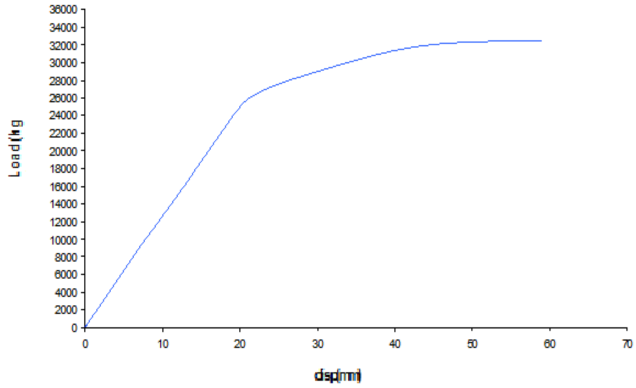

Figure 17. The results of monotonic loading on the third model

Figure 18. Fracture depletion and extension in the end of the third experiment

DISCUSSION

As can be seen in Figure 19, the model suffered resistance failure after going through 19 mm displacement equal to 1.26% relative evasion while in the second model, the resistance dropped in 35 mm displacement i.e. in a relative evasion of 2.33%; hence, the lateral deformation capacity of the model improved by about 37%. This point was also observed in other researchers' studies in which they do not consider great resistance for the concrete compound frame after 1% relative displacement while the model in the second experiment tolerated more than twice of that amount without any reduction in its resistance. Unlike the second model, the force decreased largely in the third sample which led to a reduction in the absorbed energy but the loops have much bigger area due the effect of the frictional damper. However, the greatest advantage of using FSF in the third experiment is that no drop in resistance occurred even after facing almost 4% relative displacement. Although the model faces severe fractures, no drop in resistance would be observed till the frame encounter with failure or the infill suffers another type of destruction. This is due to the fact that the lateral resistance of the infill would be because of the lateral resistance of the fuse just after the corner fracture occurs, and the lateral resistance of the fuse is also a function of the vertical force on it which is itself a coefficient of the applied lateral force. Therefore, the resistance of the infill will be equal to lateral force imposed on it. The system will stay without any resistance reduction unless this mechanism is disturbed. This limit will be so long due to two reasons; first, the utilized frame is very flexible and its failure limit is about a relative displacement of 10%; second, the vertical force applied to the fuse will not reduce because of the intact upper and lower areas of the fuse. Hence, it can still resist against lateral force. Concerning the smashing corners, more the displacement is, bigger the destructed area of the corner would be. Furthermore, the applied force mechanism would not change and the same conditions will certainly continue so very much and this exactly the characteristic we expect from a structure while an earthquake.

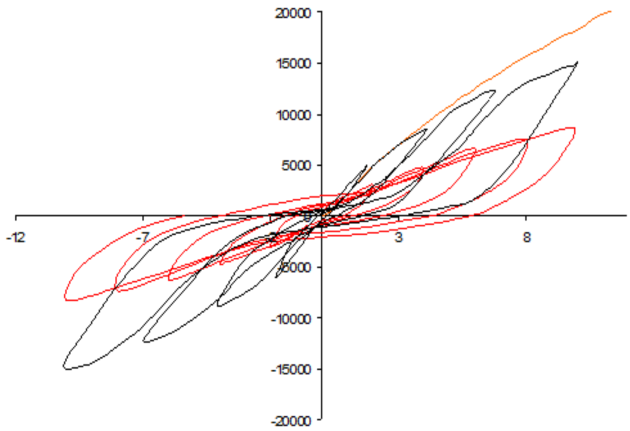

Figure 19. A comparison of the results of the three experiments

CONCLUSION

The simple concrete compound frame has a high lateral rigidity; moreover, it is not much sensitive to the performance quality and so it is able to change into a seismic element; however there are some related disadvantages.

The weak point of the concrete infill is its corner fracture which occurs in very low displacement, it is sudden and is accompanied by severe degradation in stiffness and resistance. With pre-stressing the corners of the concrete infill, the corner fracture in the infill can be considerable delayed in a way that corner smashing happen after the diagonal fracture. The diagonal fracture has a much lower degradation than corner fracture and does not happen suddenly like that.

Using corner retrofitting plates, the stiffness of the compound frame increases little. It shows that the resistance of the structure can increase without any rise in the allowed resistance. While in other methods like providing joints between the infill and frame, the resistance can increase but due to the rise in stiffness, also the demand resistance increases too much and the method will be inefficient.

With confining the infill corner, the resistance of the corner can rise a little in order for the fracture took place after the diagonal fracture but the occurrence of the corner fracture is still inevitable and we will face sharp drop in resistance and stiffness after the corner fracture. In order to overcome this weakness, an FSF can be placed inside the infill whose presence delays the fracture of the infill to a great extent and also prevents degradation after corner fracture.

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