# In-Filled Lightweight Concrete Frame Reinforced with Sisal Fiber Bars Subjected to Lateral Loading

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**Abstract.** The use of plant fibers as composite materials was widely explored to provide green and smart technology for sustainable future materials with specific strength. Behavior of sisal fiber reinforcement of lightweight concrete frame infill with brick masonry was examined in this study under lateral loading. Representing doors and windows commonly used in the wall building system, four types of frames were employed as F0 for bare frame, F1 for fully in-filled frame, F2 for in-filled frame with door opening, and F3 for in-filled frame with window opening. Test results indicated that the opening portion of the in-filled frame proportionally affected the lateral strength of the frame. Compared to the bare frame of F0, the lateral strengths of F2, F3 and F1 were increased to 1.41, 1.78, and 2.45, respectively. Residual strengths of the frames were also increased to 1.45, 1.75, and 2.25, respectively. In addition, the normalized stiffness's of the frames were also improved to 1.57, 1.57 and 2.93, respectively. Since ductility factors of the whole frames were varied from 1.50 to 4.50, this indicated that all of the structures performed beyond elastics range. Based on the results, the possibility of the use sisal reinforcement are widely open especially for the low-cost housing program in developing countries.

## Introduction

Fiber plants exist in nature with their massive availability at low price. In the most tropical places, as well as Lombok Island, these plants can be picked up easily and generally thrives in the mountains and the dry ground. These natural fibers can be considered in polymer composites materials to provide specifics strength with low density. Economical and sustainable materials are another reason why using these materials in the industry [1]. Additions of sisal fibers into concrete mixture significantly affect the compressive strength and modulus elasticity of fibrous lightweight concrete [2]. Application of sisal fiber mesh to reinforced wall sandwich concrete panel for housing material has been investigated under axial and flexural loading. The addition of sisal fiber mesh increased significantly to the flexural strength of the wall [3].

Integrity and strength of building materials are strongly affected by their exposure to the environment. Building materials under earthquake are expected to experience a loss of strength. The loss of strength may or may not be recovered after damage. Numerous investigations have been carried out with regard to seismic strengthening technique of in-filled reinforced concrete frame. The damage usually occurs in the infill walls which have material strength weaker than the column and beam in the frame system. Repairing or replacing the components with various strengthening systems has been the intention of the researchers in order to develop the performance of the in-filled frame [4, 5].

Interesting experimental report has been published that the load carrying capacities of in-filled frame under cyclic loading was approximately equal to monotonic loading [6]. Even though ductility under cyclic loading was reduced by 10%, these results can be used for interpretation of results obtained during statics lateral loading. Investigation on the behavior of hybrid reinforced lightweight concrete frame infill with pumice brick masonry has also been conducted under statics lateral loading. The result indicated that the lateral strength, ductility and residual strength of the frame were significantly affected by the presence of the opening [7]. In addition to the experimental investigation, large numbers of reports dealing with structural and numerical analyses have also been published. Shear strength of in-filled frame with opening has been modeled using finite element analysis [8].

## Experimental Program

**Test specimens**. The experimental investigation was carried out at Structural and Material Laboratory of Mataram University. The columns are made of pumice lightweight concrete with compressive strength of 12.5 MPa. The beams, both in the top and the bottom of the frame, were normal strength concrete with compressive strength of 17 MPa. Longitudinal sisal reinforcement installed continuously to the column consists of four 12 mm diameter sisal reinforcement of 34 MPa. While four 12 mm diameter plain steel bars of 250 MPa yield strength were used for longitudinal reinforcement of the beam. The shear links provided at 150 mm spaces with plain steel bar of 6 mm diameter were used for both column and the beam. The beam column joints were not confined. The gross dimension of cross section was 100×150 mm for both column and beam.

Four specimens of one-third scale, one-bay and single-story sisal reinforced lightweight concrete frames were constructed and tested under lateral loading. The opening of the in-filled frame represents doors and windows commonly used in the wall building system. The test specimens with their opening type and opening ratio are presented in Table 1.

Table 1. Test specimens

| Specimen | Opening Type | Opening Ratio [La/L] | [X/L] |
|---|---|---|---|
| F0 | Bare Frame | 0 | - |
| F1 | Solid Frame | 1 | - |
| F2 | Door Opening | 0.25 | 0.5 |
| F3 | Window Opening | 0.36 | 0.5 |

All frames were in-filled with pumice bricks with size of 45×120×300 mm that made of mixture of cement, sand and pumice with composition by volume of 1, 3 and 5 respectively. The bricks were laid such that their smallest thickness was vertically oriented. The thickness of mortar joint was about 10 to 15 mm. The infill wall was constructed centrically on the axis of the frame. The columns of the frames were constructed from pumice masonry lightweight concrete with longitudinal sisal reinforcement and steel link at 150 mm distance. Cast in-place concrete for the beam was cast using plywood formwork with a size of 100×150×1150 mm and plywood casting of 150×200×1400 mm for foundation.

**Materials**. The brick masonry infill walls were produced using mix proportion by volume of cement, sand and pumice of 1, 3 and 5 respectively. This mixture produces strength of bricks infill approximately 5.17 MPa on the day of testing. Mortar used for the bricks was made by 1:2 volume proportions of cement and sand to produce design strength of 20 MPa. The lightweight concrete strength of 12.5 MPa for the column and 17 MPa for the beams were obtained by concrete mix-design in the laboratory.

**Test setup and instrumentation**. Instrumentation was installed in this test to measured horizontal displacement and the rate of loading. The bottom of the frame was fixed to the rigid floor by high-strength steel anchored. Static lateral loading were applied concentrically to the beam at the top of the frame. Initially, a small load was applied to ensure the equipment working properly. The lateral load was generated by 25 ton capacity ENERPAC hydraulic jack and five LVDT’s were mounted to measure displacements. During the test, the lateral loads applied to top frame and the displacements were recorded. Cracks were scrutinized at each load increment and the failure mechanism was observed. Prior to the frame tests, the cylinder specimens of 150 diameter and 300 mm height were tested to obtain the compressive strength of beam and column. Loads and deformations have been monitor by automatic recording equipment of data logger type TDS-630 Tokyo Sokki Kenkyujo. Recorded data of the experiment were set under 5 second intervals. The tests were terminated upon the deformation reach 50 mm due to equipment capacity and it is believed that collapses have been already occurred.

## Results and Discussions

**Frame behavior under lateral loading**. All of the specimens have similar type of failure. For further explanation the performance of F1 (solid frame) will be describe in the following. Fig. 1 (left) shows the condition of frame F1 subsequent test under maximum lateral loading. While Fig. 1 (right) show the load-displacements results of all test frame specimens.

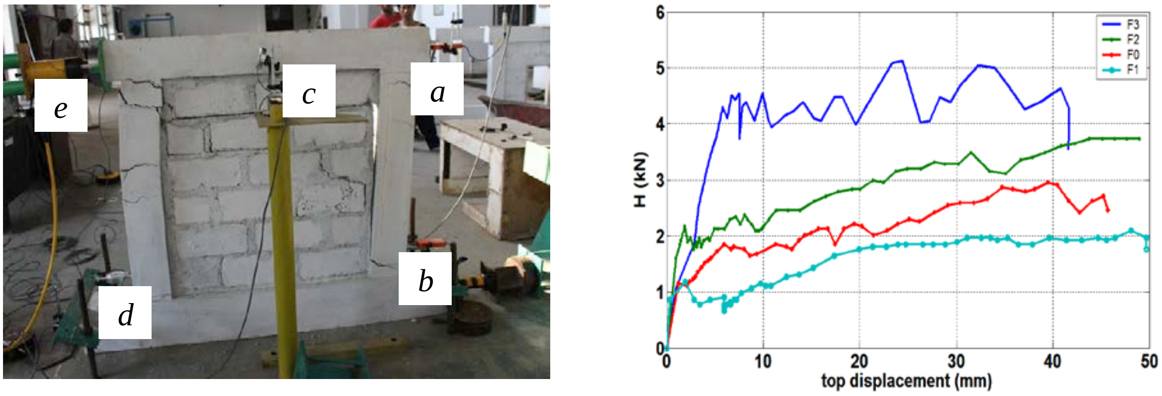

Fig. 1. Frame F1 under testing (left) and load-displacements of all test results (right)

Five LVDT's were shown in the figure with notation of *a*, *b*, *c*, *d*, and *e*. The main LVDT in this figure was LVDT *a* and *e* while LVDT *b* to *d* were used to control behavior of the frame during experimental investigation. When the lateral loading start working, deflection of the top frame (LVDT a) clearly detected after the loading reach at around 1 kN. Flexural cracks start occurred at the bottom of the column frame (LVDT b and d) when the loading reach 2 kN. Increasing the loading will increase the frame deflection proportionally followed by deeper crack and even generated a new crack. Significant flexural cracks occurred at about 4 kN loading with crack opening parallel to the direction of the loading. At this position the recorded loadings were constant since the load bearing capacity of the column was exceeded and the loading has been transferred to the sisal reinforcement. Further loading will generate a crack at the beam-column connection which occurred gradually from little to large crack perpendicular to the direction of the loading. This type of crack is identified as a shear crack.

When the load bearing capacity of the column was exceeded, the loads were transferred to the infill masonry causing diagonal and shear cracks spreading to the wall as seen in the Fig. 1 (left). This mechanism of load transferred causing the lateral load bearing of the frame was slightly up and down which is indicated at the load-deformation curve after 4.5 kN load with deflection of 10 until 40 mm. The load-deformation of the frame F1 can be seen in Fig. 1 (right). The test was stopped when the strength of the frame starting dropped with deflection at around 42 mm.

**Load-deflection characteristics**. As explained in the previous discussion, with increasing deflection the load increase gradually and the cracks began to spread from column to the infill walls of the frame. Cracks start to occur at lateral deflection of 3 mm and major cracks were observed at deflection of about 9 mm. The first cracks was noticed occur at column element where exactly in the joints between the block-masonry units. This was expected as the block masonry unit column was connected using mortar where these materials have different properties.

The load-deflection curves of all specimens are presented previously in Fig. 1 (right). All tested specimens behave similar with variation in lateral load carrying capacity and deflection relationship. However, it is clear from the figure that the solid frame of F1 behaves slightly different with others in terms of their load carrying capacity. The ascending curve has a slope that represents the stiffness of the specimens before cracking. The load versus deflection curve can be used for estimating shear strength capacity, drift ratio, stiffness and ductility of the specimens.

It has also been noticed from the physical test result that all of the frames had typical cracks propagation in the form of diagonally spread in the infill wall. The cracks approximately made a 45-degree angle which begun from the top compression corner to the base of the frame linked with horizontal sliding cracks developed along the bed joint near the mid-height of the infill wall. These cracks can be seen in Figs. 2 (left), (middle) and (right) for F0, F2 and F3 respectively.

Fig. 2. Failure Pattern of F0 (left), F2 (middle) and F3 (right)

**Lateral strength variation**. Shear strength of the in-filled frame, commonly used the term lateral strength or base shear capacity, is defined as the ability of the base frame to resist lateral load acting on the frame. The lateral load carrying capacities of the frames were presented in Table 2. The normalized shear strength capacities were presented in column (3) of the table with the bare frame as a frame reference. The ratio of shear strength capacity to the shear strength theory is presented in column (4) of the table where the shear strength theory ($H_{theo}$) is 2.4 kN.

It can be seen from the table that lateral strengths of all in-filled frames were noticeably greater than that of the basic frame. The ratio of the lateral strength of the in-filled frame to the lateral strength of the basic frame varied from 1.41 to 2.45. The maximum lateral strength of the solid frame, F1, was 2.45 of the bare frame or increase by 145% of the bare frame lateral strength, F0. The in-filled frame with opening ratio of 0.36 (F3) has no significant with in-filled frame having opening ratio of 0.25 (F2). In conclusion the presence of opening with ratio less than 40% have no significant effect in terms of lateral strength. These results have a good agreement with the numerical result of the previous study [8].

Table 2. Shear capacity, drift ratio and residual strength of in-filled frames

| Specimens | Shear Strength Capacity | | | Drift Ratio | | Residual Strength | |
|---|---|---|---|---|---|---|---|
| | $H_{max}$ | $v$ | $H_{max}/H_{theo}$ | $\gamma_y$ (%) | $\gamma_u$ (%) | $H_{limit}$ (kN) | $\beta_{res}$ |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| F0 | 2.09 | 1.00 | 0.87 | 0.20 | 4.50 | 2.00 | 1.00 |
| F1 | 5.13 | 2.45 | 2.14 | 0.55 | 2.40 | 4.50 | 2.25 |
| F2 | 2.95 | 1.41 | 1.23 | 0.20 | 4.00 | 2.90 | 1.45 |
| F3 | 3.71 | 1.78 | 1.55 | 0.20 | 4.50 | 3.50 | 1.75 |

**Drift ratio and cracks**. Drift ratio is defined as the ratio between the lateral deflection and height of the frame. This ratio can be used to control the extent of structural and non-structural damage. Lateral load-deflection curves of F1 presented in previous discussion can be modified in the form of load-drift ratio relationship. The figure can be used to classify the cracks in the frame in terms of their drift ratio. Table 2 also summarized the drift ratio in which major crack and ultimate cracks occur on the frame for all specimens tested. The table shows that in all specimens the major cracks, $\gamma_y$ , occur at a drift value between 0.20% and 0.55% which can be regarded as serviceability limit state for this type of structure. The ultimate drift ratio of F1 and F2 were 2.40% and 4.00%, respectively. While the ultimate drift ratio of both F0 and F3 was 4.50%.

**Residual strength, $\beta_{res}$.** Residual strength can be obtained from the maximum drift of 4.5 % and corresponding value of the lateral load H. When residual strength was measured at maximum drift ratio of 4.5% then the residual strength of all frames tested are obtained and presented in Table 2. Ratios of the residual strength of the frames to the residual strength of the bare frame, βres, are presented in column (8) of the Table 2. It can be seen from the table that the normalized residual strength of the frame with infill wall to the bare frame varies from 1.45 to 2.25 and did not seem to be relies on infill wall opening ratio.

**Ductility of the frame**. In addition to the drift ratio, it is commonly used a parameter of ductility ratio to measure the performance of structure beyond elastic range. The ductility factor, μ, is defined as the ratio between the ultimate deflection and the yield deflection which is produced by obtaining the ultimate load reduction to 85% on the curve. This would correspond with two intersection points of Δy and Δu which is corresponding to yield deflection and ultimate deflection respectively. Table 3 summarizes the results obtained for the ductility factor, μ. It can be seen from the table that the ductility factor for all frames specimen varies from 1.50 to 4.50. While the ductility factor for the solid frame and the bar frame was 4.50 and 2.67 respectively. The ductility factor of the frames with door opening have no significant different to the frames with window opening.

Table 3. Ductility and stiffness of frames

| Specimen | Ductility | | | Stiffness | | | |
|---|---|---|---|---|---|---|---|
| | $\Delta_1$, mm | $\Delta_2$, mm | $\mu_{0.85}$ | $H_y$ (kN) | $\Delta_y$ (mm) | $K_o$ (kN/mm) | *k* |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) =(5)/(6) | (8) |
| F0 | 18.00 | 48.00 | 2.67 | 1.15 | 6.00 | 0.19 | 1.00 |
| F1 | 6.00 | 27.00 | 4.50 | 4.50 | 8.00 | 0.56 | 2.93 |
| F2 | 28.00 | 42.00 | 1.50 | 1.80 | 6.00 | 0.30 | 1.57 |
| F3 | 22.00 | 36.00 | 1.64 | 2.40 | 8.00 | 0.30 | 1.57 |

**Frame stiffness**. Frame stiffness is defined as ratio between force acting and deformation. Thus, the initial stiffness, Ko, is defined as ratio of the yield load, Hy, and the yield deflection, Δy. Therefore: Ko = Hy / Δy. The results of investigations for all frames are presented in Table 3. When the frames stiffness values are normalized to bare frame stiffness denoted by *k*, then the normalized stiffness of the frames are given in column (8) of the table. The table clearly shows that the existence of infill wall increases frame rigidity significantly. The observations indicated that ratio stiffness of the in-filled frames to bare frame were varies between 1.57 and 2.93. The ratio stiffness of in-filled frames with opening have values about half of the solid frame. This indicated that the opening ratio of infill wall significantly affect the value of stiffness of the in-filled frames with opening. The presence of infill wall will improve the stiffness of the frame. The observation show that compare to the bare frame, the improvement of the infill frame stiffness varied from 1.57 to 2.93. The solid frame has highest stiffness and then gradually reduces with the presence of the openings. Therefore, the presence of the openings in the in-filled frame affected the stiffness of the frame proportionally.

## Summary

The following summaries can be drawn based on the experimental results; The lateral strength of bare frame F0, frame with door opening F2, frame with window opening F3 and frame with fully infill wall F1 were 2.09 kN, 2.95 kN, 3.71 kN and 5.13 kN, respectively. In other word, compared to the bare frame of F0, the lateral strength of F2, F3 and F1 were increased to 1.41, 1.78 and 2.45, respectively, Drift ratio of the frames at serviceability limit state varies from 0.2% to 0.55% and at the ultimate limit state were varied between 2.4% and 4.50%. The ductility factor of the frame varied from 1.5 to 4.5. The residual strength of the frame with openings were varies between 1.45 and 2.25 of the residual strength of the bare frame. Stiffness of the in-filled frames with openings have variation values from 1.57 to 2.93 of the bare frame stiffness. The presence of openings in the in-filled frame affected the stiffness of the frame proportionally.

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