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# Inelastic Analysis of Infilled Frames Bamboo Reinforcement with "Equivalent Diagonal Strut"

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**ABSTRACT**

**Background:** Infill panels usually are known as partition in reinforced concrete structures. Infill panels are often considered as non-structural components. But actually, they support lateral force, contributing significantly to stiffness and strength of the structure. The collapse behavior of infill panel frame is different from that against the open frame. In such situation, when the infill panels are placed in uneven location, such structures that have been design as ductile frame can turn into soft storey collapse. **Objective:** The collapse behavior of reinforced concrete frame with infill panels due to lateral force from the earthquake is complicated and non linier. The behavior is depending on the interaction between frame and infill panels so that it is difficult to predict just by using ordinary elastic methods. **Results:** Saneinejad - Hobbs (1995) provided predictions to the result of research using the method of Equivalent Diagonal Strut. The method is simpler and gives more complete output than the previous methods. The method will be utilized to analyze the performance of RC frame – infill panels. This research is the portal – infill panels, which is made from lightweight concrete and bamboo reinforcement. **Conclusion:** The result values are rather upper bound compared to the experiment and appropriate for design purpose



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## INTRODUCTION

Open frame structure is planned to behave as ductile portal during the earthquake. Structures that have uneven infill walls can cause the structure to have a soft-storey collapse mechanism. The collapse of soft-storey earthquake is very dangerous. The upper part is used as a place with lots of wall as a partition, while because the bottom is used as a place for business (store), a little infill walls are applied. The condition causes the upper part to be very stiff compared to the bottom so that when the earthquake destroys the structure of the bottom, the top falls on the intact.

Behavior-portal fill to lateral loading has long been investigated, such as Holmes (1961), Stafford Smith (1962, 1966, 1967), Mehrabi etal (1996, 1997), Madan and MadMander *et al*. (1997) and others. From a variety of existing research, methods Equivalent Diagonal Strut proposed Saneinejad - Hobbs (1995) which is very promising to be explored further. The method has accounted for elastic and plastic behavior of portal-fill taking into account the limited ductility of infill walls material. The method gives a better prediction of the experimental and analytical results (meh) compared with other methods. Equivalent Diagonal Strut method can be used to predict the strength and stiffness-portal fill by incorporating various possibilities exist, such as aspect ratio of infill walls; various types of connections (joint / semi-rigid).

Understanding the behavior of portal-aware content and analysis methods will actually provide solutions for the planning and construction of earthquake resistant buildings in Indonesia which are more realistic and economical. This research discusses Equivalent Diagonal Strut method to re-evaluate the structure-portal fill (lightweight concrete panels of bamboo reinforcement) so as to know the advantages and deficiency compared to the actual condition of collapse.

***The configuration a Portal-Content to be reviewed:***

The configuration of infilled frames to be analyzed involves the frame with bamboo reinforced concrete. Panels as fill are made of bamboo reinforced lightweight concrete with the following configuration:

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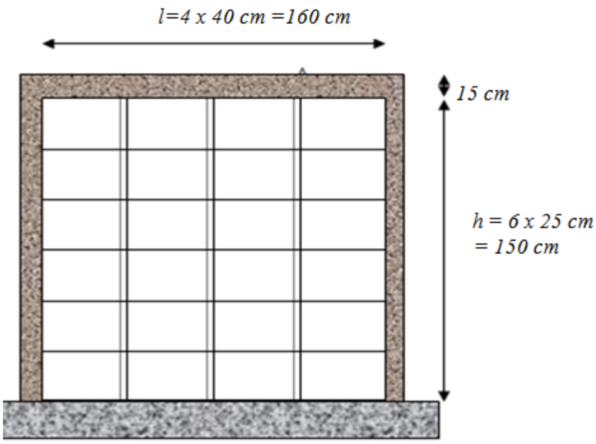


**Fig.1:** Infilled frame.

Beam bottom clamp is fastened with steel that can be wedged full column. Lateral loads were given monotonously until gradual collapse occurred. Infill walls used a series of bamboo reinforced lightweight concrete panels. The 400 x 250 x 20 mm panels were assembled using the bamboo reinforced and attached with mortar, and the panel size was 1600 x 1500 x 20 mm. Normal concrete compressive strength was 30 MPa, compressive strength of lightweight concrete was 10.6 MPa, and bamboo reinforcement tensile strength was 108 MPa.

Load on infilled frame is enhanced lateral loads in the several stages of loading. Each phase started from right to work the next from the left, followed the next load stage. Each stage of the load experience an increase by 3.45 kN = 15 stripe loading cell (1stripe = 0.23 kN). (Fig 2).

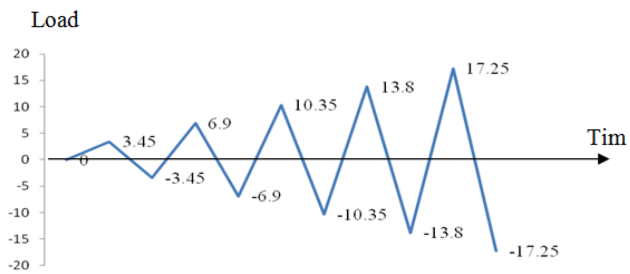


**Fig. 2:** Stage of load.

Infilled frame failure behavior observed is a diagonal crack in the wall. The collapse was due to the maximum lateral load in one direction. These studies have identified a number of complicated failure mechanisms that can possibly be caused by the frame-panel inter-action. These mechanisms can be seen in figure 3.

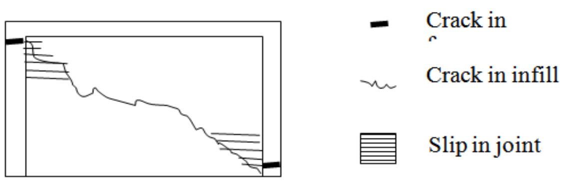


**Fig. 3:** Failure Mechanism of Infilled Frame.

***Results: Application of Equivalent Diagonal Struts Method:***

Method of equivalent diagonal struts will be used to evaluate the result research of configuration infilled frame, in the following order.

1. Determination Of Parameters

$\mu = 0.45$ (ACI 530-88)

$\varepsilon_c = 0.0029$

$r = h/l = 150/160 = 0.9375$

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$\theta = \tan^{-1} r = \tan^{-1} 0.9375 = 43^o9'9''$
$f_c = 0.6\phi f'_m = 0.6 \times 0.65 \times 10.68 = 4.165$ MPa.

2. Column and Beam

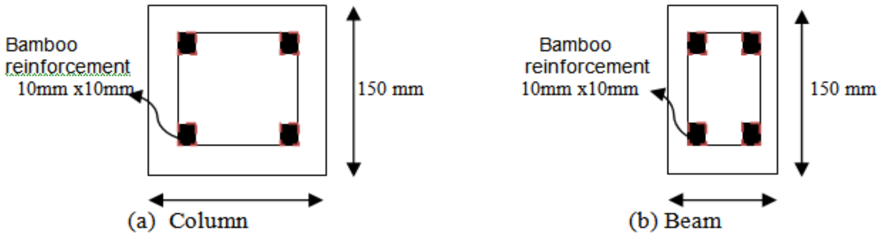


**Fig. 4:** Column and beam dimension.

Plastic moment of the column and the beam
$M_{PC} = \phi P_N.e = 9651$ kN mm = 9.651 kN m
$M_{PB} = 2361$ kN mm = 2.361 kN m
Length of the contact area frame with infill. Relation between beams and columns integrated then $M_{PJ}$ is the smallest value of $M_{PC}$ and $M_{PB}$

$$\alpha_c h = \sqrt{\frac{2M_{pj} + 2\beta_c M_{pc}}{\sigma_c t}}$$

$\alpha_c h = 0.408$ m
$\alpha_c = 0.408/h = 0.408/1.5 = 0.2722$

$$\alpha_b l = \sqrt{\frac{2M_{pj} + 2\beta_b M_{pb}}{\sigma_b t}}$$

$\alpha_b l = 0.339$ m
$\alpha_b = 0.339/l = 0.339/1.6 = 0.212$
Contact tension
$Ac = r^2.\sigma_{CO}.\ \alpha_c.\ (1- \alpha_c- \mu.r) = 0.2515$
$A_b = r^2.\sigma_{bO}.\ \alpha_b.\ (1- \alpha_b- \mu.r) = 0.2244$

For $Ac > Ab$ , so:

$\sigma_C = \sigma_{CO}(Ab/Ac) = 3.4362\ (0.2244/0.2515) = 3.0665$ MPa
$\sigma_b = \sigma_{bO} = 3.29$ MPa
$\tau_b = \mu.\sigma_b = 1.48$ MPa

Corner Crushing (CC)

$$R_{CC} = \frac{(1-\alpha_C)\alpha_C.t.h.\sigma_C + \alpha_b.t.l.\tau_b}{\cos\theta} = 38.73 kN$$

Diagonal Crushing (DC)

$$l_{eff} = \sqrt{(1-\alpha_C)^2 h^2 + l^2} = 1936\ mm$$

$$f_a = f_C\left[1-\left[\frac{l_{eff}}{40.t}\right]^2\right] = 3.73\,kN$$

$$R_{DC} = \frac{0.5.h.t.f_a}{\cos\theta} = 77\ kN$$

Shear Crushing (SC)

$$\tan\theta' = (1-\alpha_c)\tfrac{h}{l} = 0.682$$

$$R_S = \frac{\gamma.v.t.l}{(1-0.45\tan\theta')\tan\theta} = 16.15\ kN$$

R smallest is $R_S = 16.15$ kN, so ultimate collapse load leads to the following:

$$H = R.\cos\theta + \frac{2.M_{PJ}}{h} = 14.73\ kN$$

The horizontal component of the infill cracking load gives the following:
Cc = σc. t. αc. h = 25.04 kN
Fb = τb. t. αb. *l* = 10.04 kN

$$H_t = 2\sqrt{2}\,.t.h.f_t.\cos^2\theta = 9{,}7\ kN \text{ (first crack)}$$

3. Lateral Deflection And Secant Stiffness Infilled Frame
An empirical relation to predict the horizontal infill deflection at the peak load as follows:

$$\Delta_h = 5.8.\varepsilon_c.h.\cos\ \theta(\alpha_c^2 + \alpha_b^2)^{0.333} = 9{,}053mm$$

The secant stiffness of an infilled frame at the peak load is defined as follows:

$$K = \frac{H}{\Delta h} = 1.627\ kN/mm$$

The typical load-deflection diagram of infilled frames is parabolic formula. Until a more consistent value is established for initial stiffness of infilled frames, it may be approximated as twice the secant stiffness at the peak load. Hence

$$K_0 = 2\frac{H}{\Delta h} = 3.254\ kN/mm$$

4. Equivalent Diagonal Struts parameters
The cross section area of the struts is as follows:

$$A_d = \frac{R}{f_C} = 3878\ \ mm^2$$

The initial (elastic) modulus of elasticity of the strut is needed for the analysis. It may be taken as twice as the secant value:

$$E_{d0} = \frac{2.h.f_C}{\Delta h..\cos^2\theta} = 2766\ \ MPa$$

***Discussion:***

Experimental test results obtained the following data (table 1). In the test load, secant-stiffness defined as the slope of the line from the starting point of the load-deflection curve to the point where 50% of the maximum resistance force is reached.

**Table 1:** Experiment Test Results.

| Sample | Secant stiffness (kN/mm) | First crack wall | | The maximum lateral test | | Failure mechanism |
|---|---|---|---|---|---|---|
| | | Load kN | Displacement mm | Load kN | Displacement mm | |
| The EDS Method | 3.254 (100%) | 9.70 | - | 14.73 (100%) | 9.1 (100%) | Shear |
| Infilled frame | 2.670 (82 %) | 10.35 | 3.39 | 13.8 (94%) | 12.15 (133%) | Diagonal crack |
| | 2.470 (76 %) | 10.35 | 3.88 | 12.65 (86%) | 10.24 (123%) | |

The EDS Method is The Equivalent Diagonal Strut method

The method presented by Saneinejad and Hobbs (1995) will be compared with experimental results (Table 1). The maximum lateral force of experimental results that occur of lower value than the calculation of Equivalent Diagonal Strut method. Comparison of load EKS / EDS is 90%. The failure occurred when the concrete has spalling. The Equivalent Diagonal Strut method assumes that the failure occurred after yielding reinforcement. But in this study, reinforcement of bamboo has not yielded. This suggests that bamboo reinforcement does not expend all the forces, so it is not as expected load prediction EDS. Comparison of the average displacement between the EKS / EDS is 128%.

***Conclusion:***

It can be concluded that the Equivalent Diagonal Strut provide numerical prediction method that is over the frame infilled experimental results. Results in a corresponding upper bound limit but can used for planning.

In such methods, there are several parameters that must be determined. Parameters are taken from the related regulations. That can be suspected that the selection of the parameters cause quite a lot of differences between the prediction results and the experimental results.

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