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Efficiency of Reinforced Concrete Grade Beams with In-filled Panels

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ملخص البحث:

في الأعوام الأخيرة جذب انتباه الباحثين تصميم الإطارات من الخرسانة المسلحة المتصلة بالمبانى الطوب. وعديد من الباحثين درس السملات في مستويين متصلين بالمبانى الطوب. في هذا البحث تم استخدام برنامج التحليل الإنشائي ثلاثى الأبعاد SEISMOSTRUCT الذي يدرس هذا السلوك بواسطة طريقة العناصر المحددة. هذا التحليل يأخذ في اعتباره السلوك الغير خطى للخرسانة والطوب وايضاً اخذ في الاعتبار جودة الطوب و تأثير الاحمال الرأسية بتوزيع مختلف.

تم تحليل ثمانية عشر نموذج لدراسة تأثير جودة الطوب وطريقة التحميل. ثلاث حالات تحميل درست لمعرفة طريقة انتقال الاحمال. اول حالة تحميل تحت تاثير حمل موزع بينما الحالة الثانية والثالثة حمل مركز.

وأظهرت النتائج ان لها تأثير ايجابى على الحمل الأقصى وتوزيع القوى الداخلية حيث زاد الحمل الأقصى بمقدار 35% تحت تاثير الحمل الموزع وقلت الازاحة بنسبة 40%.

Abstract

The masonry infilled design has attracted the researchers’ attention in the last few years. Several researchers studied the behavior of grade beams with infilled panels. This work includes nonlinear finite element analysis of brickwork infilled panel. This panel consists of two levels of grade beams and two side columns. The idealization uses 3–D (SEISMOSTRUCT), this analyses consider the non – linear behavior of concrete and masonary. The effect of vertical load with various distributions is also considered. Eighteen models have been analyzed to study the effect of brick quality, and loading pattern. Three load cases were studied to investigate the behavior load transfer between upper and lower grade beams. The first case of loading is a uniform gravity load while the second and third cases are concentrated loads simulating stud columns.

The results verify the positive effect of infilled-panel on ultimate loads and internal forces distribution, the gain in ultimate load reached 35% under uniform loading and the deflection at failure was decreased by 40% as a result of the infill.

Keywords: Concrete; Brick; Infill; Panel; Interface; Grade Beam

1. Introduction

Structure may have stiffness problems to cope with differential settlement or to resist lateral loads. The stiffness of structure may be improved by introducing masonry infill panels of various types in buildings for structural and architectural reasons.

In the past, the behavior of masonry infill on panel structures was of great interest in the seismic design procedures and in the evaluation of existing old buildings. Masonry panels behavior as shear walls in masonry structures or infill walls for reinforced concrete panels. Such elements are generally designed as major shear resisting members for new reinforced masonry structures. These walls are often considered as non-structural components, such as partition walls. Both laboratory studies and damage observations of earthquakes have indicated that interaction between masonry panels with reinforced concrete panels affected the performance of infilled structure.

Mircea Barnaurre & Daniel Nicolae Stoica [1] reported that masonry infill increases the stiffness of the structure up to 3.5 times when compared to the panel structure without infill. Masonry infill with opening such as door opening also increases the strength of the structure in the seismic loading. The presence of gaps between the infill and the panel still limit this beneficial effect of masonry. For the modeled case, separating the infill from the panels by 20 mm gaps at the top and on the sides is enough to allow the panel to freely deform, similarly to the no-infill case.

Bhagyalaxmi sindagi, Anusha P Gowda, Harshitha R Kumar and M V Renukadevi [2] investigated the initial lateral stiffness of the infill panels with opening at the center with different sizes and various quality of masonry (2750 N/mm^2 and 1000 N/mm^2 quality) using finite element analysis, they reported that the initial lateral stiffness of infill panel is significantly reduced due to the presence of opening. The lateral stiffness decreased with increasing the size of opening. when the area of opening is about 15% of the section, the initial lateral stiffness was reduced by percentage 20 to 32 %. They also reported that the reduction percentage of initial lateral stiffness was about 52 to 53% with decrease in quality of masonry (2750 N/mm^2 to 1000 N/mm^2) in case of full contact case. In separation case the reduction percentage ranges from percentage 46 to 52%. For the same area of opening if the size of opening varies, the difference in initial lateral stiffness is less than 5%.

In case of two similar rectangular panels with equal sizes of openings, the panel having larger width of opening exhibits more initial lateral stiffness

2. Analyzed Panels

Confined masonry walls considered for in –plane analysis consist of one – story clay brick. Wall panel confined by 400 mm × 500 mm top and bottom reinforced concrete beams (bond-beams) and 400 × 400 mm reinforced concrete tie columns with height 2000 mm as shown in Figure 1. The upper and lower beams are equal in reinforcement percentage as shown in Figure 3a. The reinforced concrete columns details are shown in Figure 3b. All infill panels were subjected to three cases of loading which represent uniform load, two concentrated, one concentrated load as shown in Figures 2a, 2b and 2c. Infill panels are listed in Table 1.

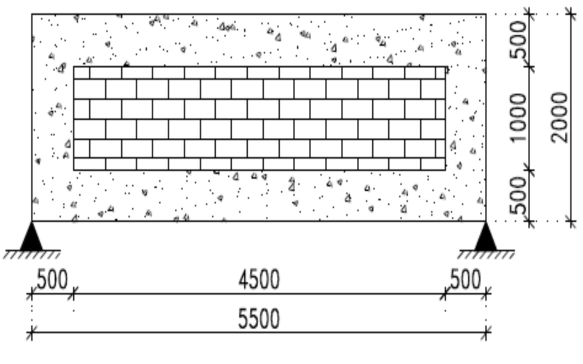

Figure 1. panel geometry

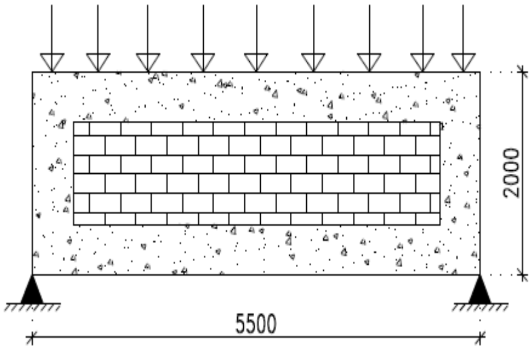

Figure 2a. Infill panel with uniform load at top

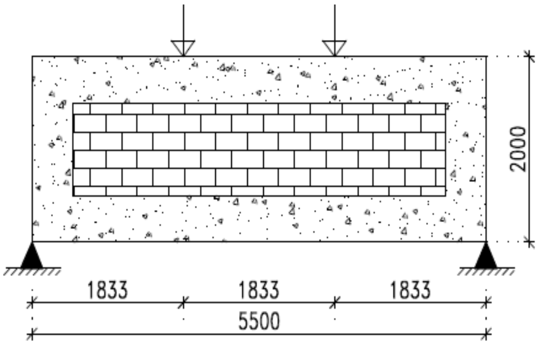

Figure 2b. Infill panel with two concentrated load

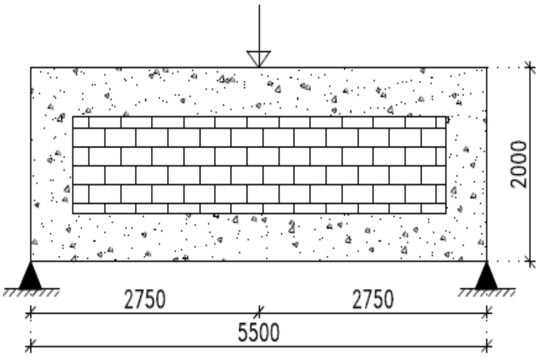

Figure 2c. Infill panel with one concentrated load

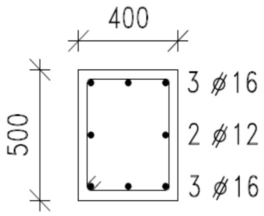

Figure 3a. Section of upper & lower beams of infill panel

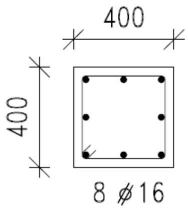

Figure 3b. Section of column of infill panel

3. Three Dimensional Finite Element Model

SeismoStruct [3] is a Finite Element can predict the large displacement behavior of space panels under static or dynamic loadings, it takes into account both geometric nonlinearities and inelasticity of material. Concrete, steel, frp and some material models can be analyzed, together with large case of 3D elements that may be used with a wide and different variety of pre-defined steel, concrete and composite section configurations. The inelasticity spread along the member length and through the section depth can be modeled, accurate estimation of damage distribution can be allowed. Coupled with the program's numerical stability and accuracy of high strain levels, it cans precise determination of the inelastic response and the collapse load of any panel type of structural configuration. SeismoStruct [3] accepts dynamic (accelerations) actions as well as static (forces and displacements) and can perform eigenvalues, nonlinear static push over (conventional and adaptive), nonlinear dynamic analysis, nonlinear static time history analysis, and incremental dynamic analysis.

Table 1. Infill panels characteristics

Group	Specimens	$E_{masonry}$ / $E_{concrete}$	Type of load pattern at top beam
Group (Z)	Z1	Without infill panel	Uniform load
	Z2		Two concentrated load
	Z3		One concentrated load
Group (A)	A1	0.1	Uniform load
	A2	0.25	
	A3	0.5	
	A4	0.75	
	A5	1	
Group (B)	B1	0.1	Two concentrated load
	B2	0.25	
	B3	0.5	
	B4	0.75	
	B5	1	
Group (C)	C1	0.1	One concentrated load
	C2	0.25	
	C3	0.5	
	C4	0.75	
	C5	1	

3.1 Material Properties

Material properties were obtained from articles or direct communication with experiment’s researchers. Uniaxial constant confinement concrete model proposed by Mander et al. [4] was applied with its modification made later by Martinez-Rueda and Elnashai [5] for reasons of numerical stability under larger displacement analysis as shown in Figure 4. Uniaxial steel model initially formulated by Menegotto and Pinto [6] and later enhanced by Filippou et al. [7] was used for reinforcement steel in the long direction with the introduction of new isotropic hardening rules. It utilizes a damage quality to represent more accurately the unloading stiffness.

It is advised to be employed for modeling reinforced concrete structures, especially those subjected to complex histories of loading, where significant load reversals might occur as shown in Figure 5.

A four-node masonary panel element were developed and implemented in SeismoStruct [3], for the modeling of the nonlinear response of infill panels in paneled structures. Each panel is represented by six strut members, each diagonal direction has two parallel struts to carry axial loads across the two opposite diagonal corners and a third one to that is on compression, hence its activation depends on the deformation of the panel. The axial load struts use the masonary strut hysteresis model, while the shear strut uses a dedicated bilinear hysteresis rule as shown in Figures 6 and 7.

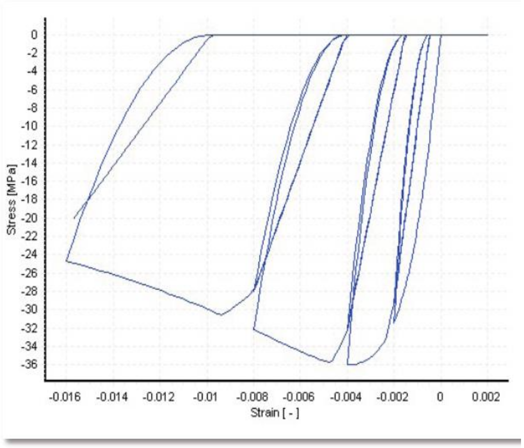

Figure 4. Mander et al. nonlinear concrete model

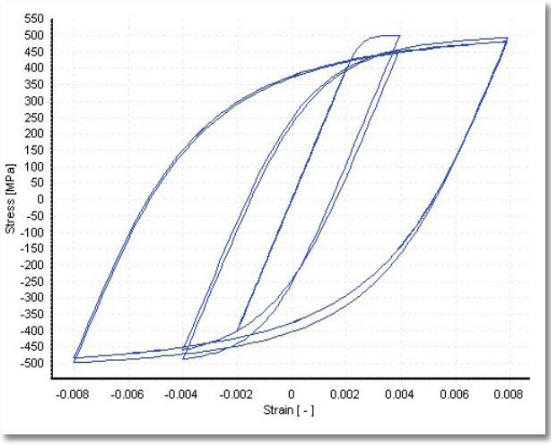

Figure 5. Menegotto-Pinto steel model

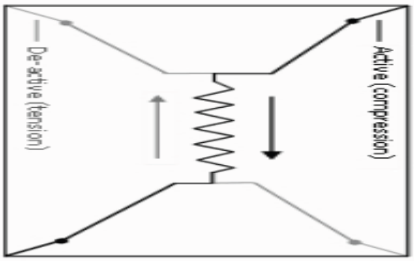

Figure 6. Masonry compression/tension strut

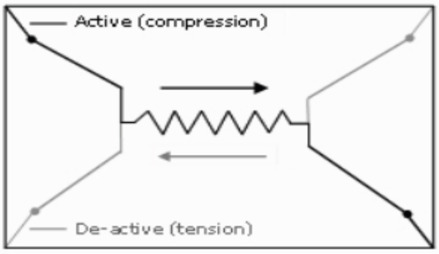

Figure 7. Masonry shear strut

4. Analysis of Results

Eighteen models subjected to incremental loading up to failure have been analyzed to study the effect of brick properties and load pattern. The results include deflections, failure load, ratio between upper and lower beam in moments, and shear and the load was applied incrementally.

4.1 Vertical Deflections

Figures 8, 12 and 16 show the load-deflection for the analyzed cases of panels. The diagram indicates that, reinforced concrete infill walls improve the carrying capacity by increasing the stiffness of the structure. The maximum value of the deflection occurs in case of infill with weak quality of masonry and the minimum deflection in case of infill with strong quality of masonry.

For uniformly distributed load, Figure 8 shows the load-deflection relationship for group (A), the deflections at ultimate load decreased as the quality of infill increased. The ultimate load increased by a percentage of 81% due to the contribution of infill. The deflection at failure was decreased by 70% as a result of the infill. The stiffness of the infilled panel characterized by the initial slope of the load-deflection curves increased as the quality of the infill improved.

The load-deflection curves for the panels of group (B) are shown in Figure 12. The gain in ultimate load is up to 35% over the no infill sample using the highest quality of fill. The deflection at failure was decreased by 40% due to the positive effect of infill.

The load-deflection characteristics for the top beam are shown in Figure 16. The same trend which was observed for the uniform load and the two concentrated loads was observed as well for the case of one concentrated load.

4.2 Maximum Moments and Shear

The participation of the top and bottom beams in the flexural capacity of the panel is represented by the moment ratio between top and bottom beams. The low ratio of moment induced in the top beam relative to that induced in the bottom beam M top/M bot is direct indicator of higher participation of the infill by increasing the overall system structural efficiency.

The variations in +Mtop/Mbot for the maximum positive moment section are shown for the uniform load, the two concentrated loads and the mid – span load in Figures 9, 13 and 17 respectively. The variations in –Mtop/Mbot for the maximum negative moment are shown for the three loading cases are given in Figures 10, 14 and 18 respectively.

The low values of ratios of + Mtop/Mbot and the ratios of – Mtop/Mbot prove the advantage of load distribution toward effective role of the infilled panel. It is evident that as the quality of infills enhanced, the percentage of Mtop/Mbot is reduced. The reductions are 80%, 72% and 63% for the uniform load, the two concentrated loads and the mid span concentrated load.

The variations in (-Mtop/Mbot) for the maximum negative moment are shown for the three loading cases in Figures 10, 14 and 18. The curves exhibit the expected beneficial effect of infilled panel on moment distribution between elements of the panel.

The ratios between induced shear forces in top and bottom beams (Q top/Q bot) are plotted against incremental loads up to failure in Figures 11, 15 and 19.

For the uniform loading case, the bottom beams participate in load transfer for all load levels and types, the contribution of the panel in relieving top beam became significant for the relatively higher fill quality. This observation can be applied only for the qualities of $E_{fill} / E_{concrete}$ of 0.5 and more.

Rahul et al. [8] reported that infill panels have significant effect on frames behavior under seismic loading. In general, infill panels improve stiffness of the structure.

They found that the increase in the opening area has a great effect on decreasing the lateral stiffness of infilled frame. Bare frame deflection is very large but in case of infilled frame with and without opening the deflection is lower than bare frame. Center opening causes large deflection compared with corner opening and for panel dimension above 5 m long, the infill frame is less effective.

Nikhil et al. [9] indicated that Infill panels increase stiffness of the structure and improve seismic behavior. Their results are in agreement with those obtained by Raul et al.[8].

Hanaa et al. [10] investigated the analysis of two categories of infilled-frame. The first is studied with outer columns and the other is studied with removal the outer columns in both sides of the frame at the first level. In each category, three types of frame are studied (without infill, full infill and partial infill).

These problems are solved by using ADINA program. Some parametric studies are taken, the first is the position of the partial infill and the other is the brick properties. Their results showed that:

- The behavior of empty frames and infilled-frames is very different especially when sudden collapse occurs in the structures.
- In infilled-frame, the wall and the frame act together with the brick wall to produce both stiff and strong structure. By changing the position of the partial infill, the

distribution of the stresses and the vertical displacement changed especially in case of no infill at the first level which may be due to the concentration of the stresses at the lower floor.

- The change in the properties of the brick is small at the same frame properties especially in case of with outer columns but without outer columns, the vertical displacement increases with decreasing the stiffness of the brick.

The results obtained by Rahul et al., Nikhil et al. and Hanna et al. are in consistent with the results obtained in this study especially in terms of bending and the brick properties.

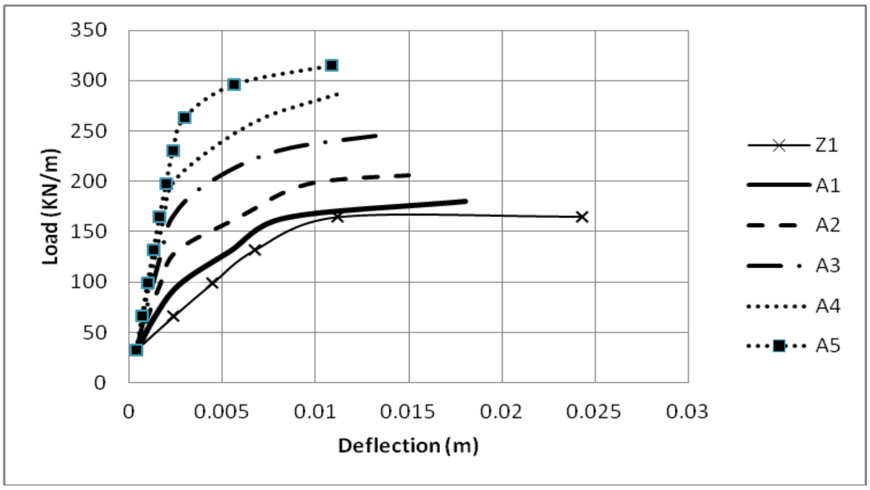

Figure 8. load – deflection at top beam for group (A)

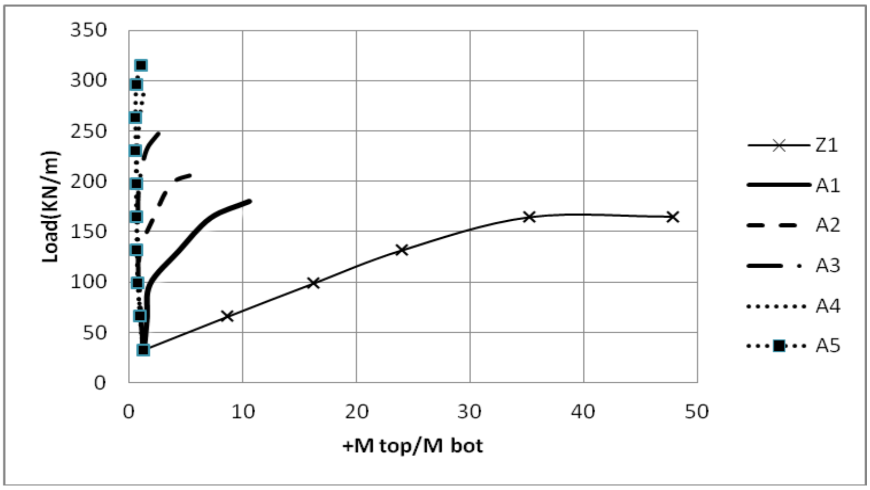

Figure 9. Maximum positive moments ratio between top & bottom beam for group (A)

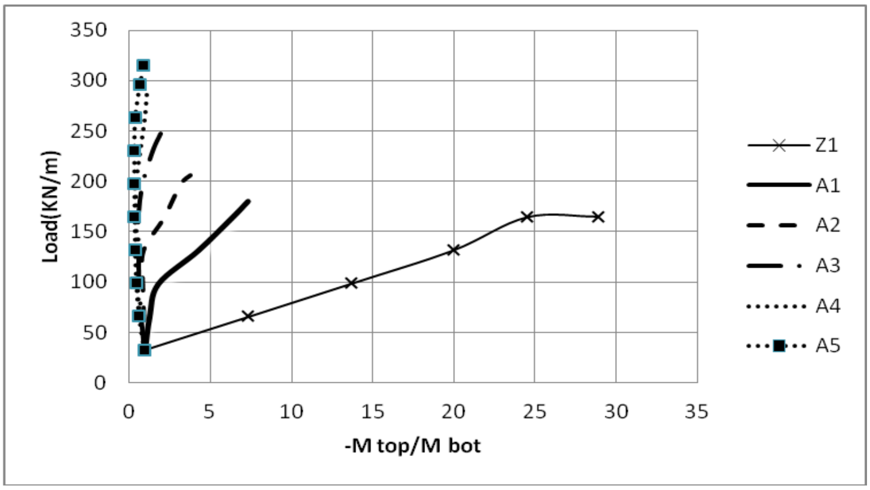

Figure 10. maximum negative moments ratio between top & bottom beam for group (A)

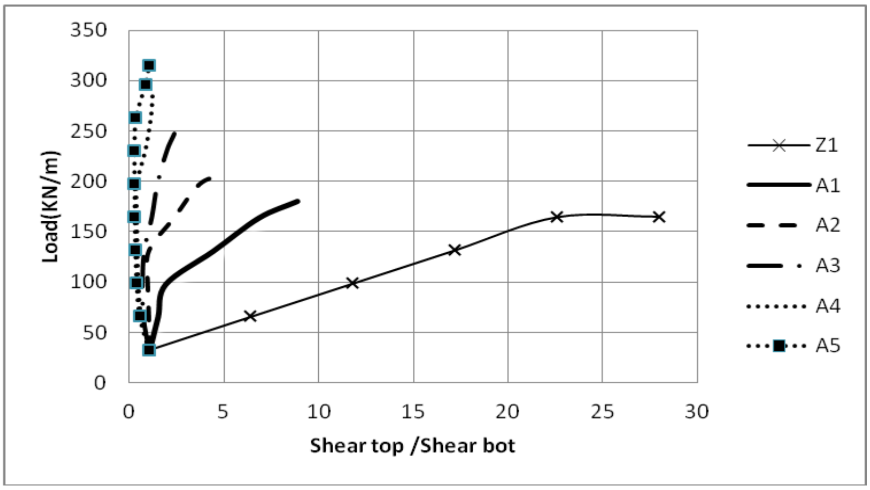

Figure 11. maximum shear ratio between top & bottom beam for group (A)

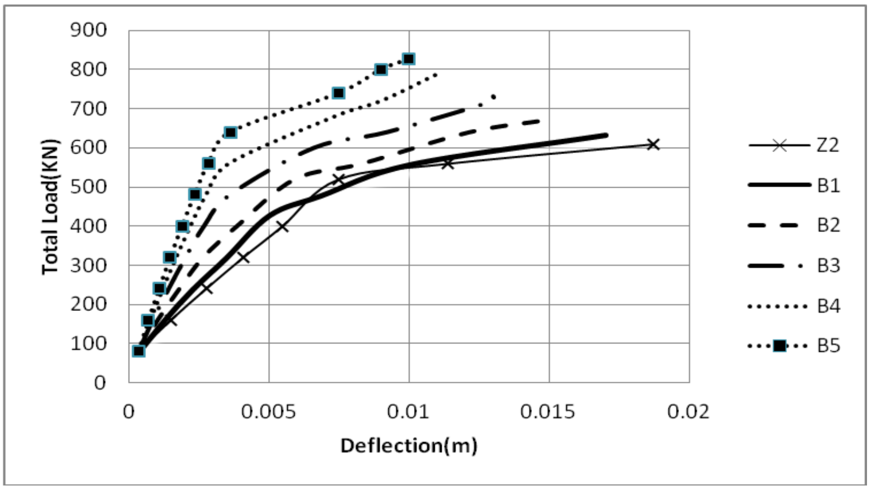

Figure 12. Load – deflection at top beam for group (B)

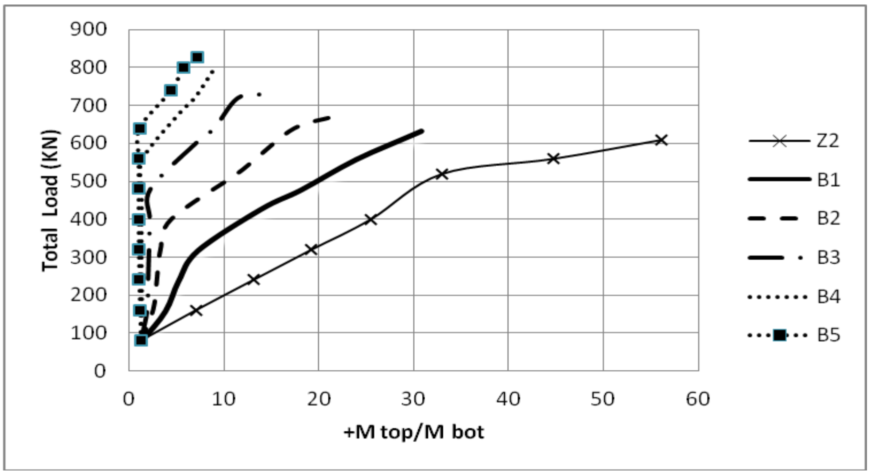

Figure 13. Maximum positive moments ratio between top and bottom beam for group (B)

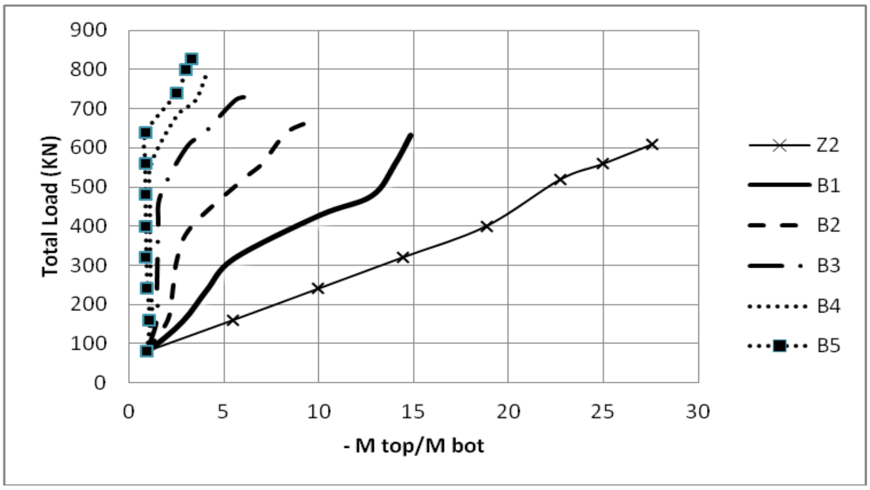

Figure 14. Maximum negative moments ratio between top and bottom beam for group (B)

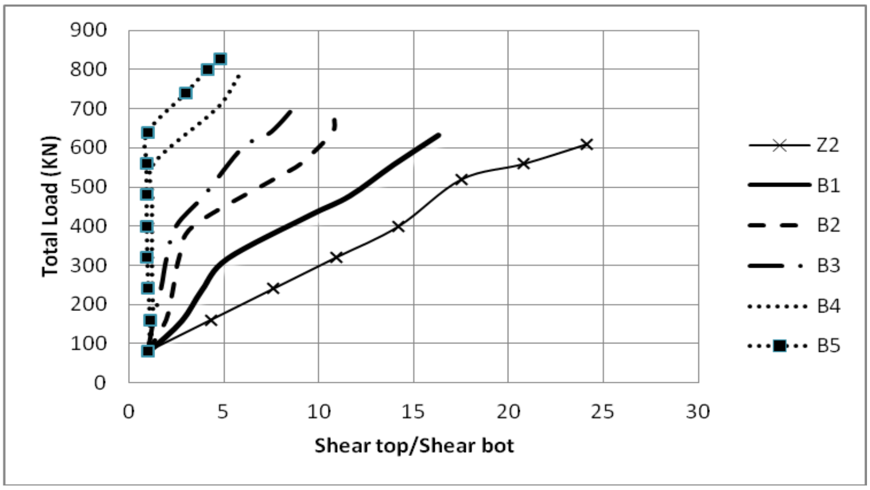

Figure 15. Maximum shear ratio between top and bottom beam for group (B)

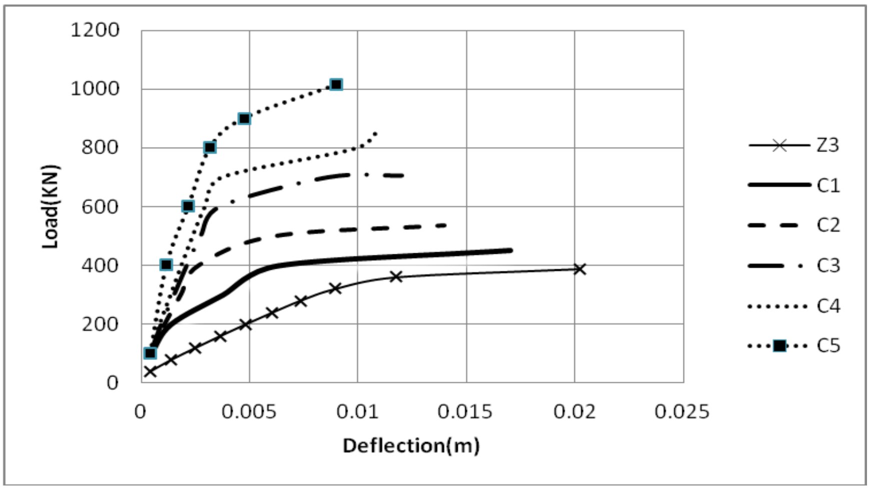

Figure 16. Load – deflection at top beam for group (C)

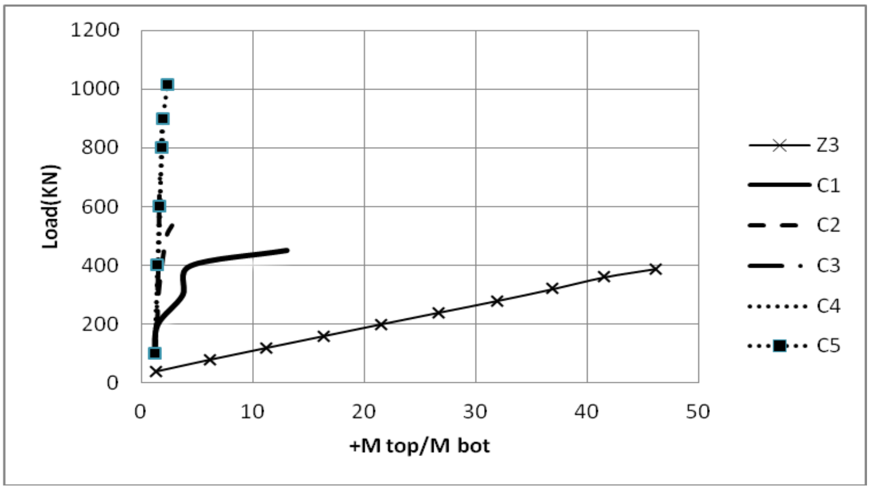

Figure 17. maximum positive moments ratio between top and bottom beam for group (C)

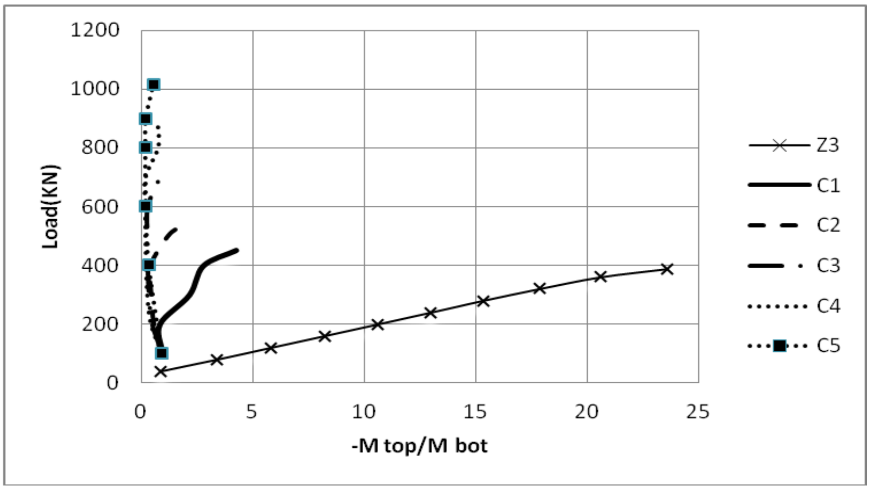

Figure 18. Maximum negative moments ratio between top and bottom beam for group (C)

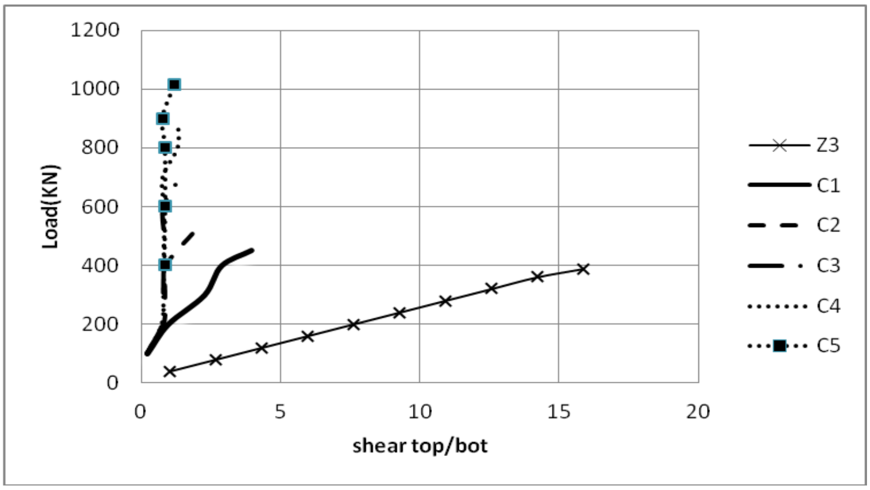

Figure 19. Maximum shear ratio between top and bottom beam for group (C)

5. Conclusions

This paper presents the outcome of nonlinear finite element analyses performed to study the behavior of infilled panels composed of lower and upper grade beams with different in-fill qualities between the beams. Eighteen models were analyzed and the results lead to the following conclusions: -

- Infilling between lower and upper grade beams reduces deflection, redistributes shear and moments favorably and increases ultimate carrying capacities under uniform loading, two concentrated loads and mid span concentrated load.
- The gain in ultimate load reached 35%under uniform loading.
- Efficiency of infilled grade beams in connecting rigidly foundation pads improved significantly compared to grade beams without infill.
- Quality of infill brick which is characterized by the $E_{fill}/E_{concrete}$ enhances the beneficial effects of infill markedly provided that $E_{fill}/E_{concrete}$ equals 0.5 or more.

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