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Numerical Analysis for Double Skin Profiled Steel-Concrete Shear Wall

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***Abstract*— This paper presents a symmetric finite element model to simulate the behavior of a composite profiled steel-concrete shear wall. The objective of this research paper is to gain more understanding of the behavior of the double skin profiled steel-concrete shear wall. The new model was validated with Rafiei experimental tests [1]. Extensive parametric study on steel and concrete grades, profiled steel thicknesses with ECC [2] and SCC [3] concrete, the effect of changing concrete thickness with the same profiling shape, using embossment with the steel sheet and also using steel sheet and concrete as alone was performed. A comparison between this model and Rafiei finite element model shows that the symmetric model able to simulate the behavior of composite profiled composite shear wall with high accuracy and more faster in computational run time after using adequate mass scaling**

***Keywords*—double skin, profiled steel-concrete, composite wall, shear wall, mass scaling, SCC Concrte, ECC Concrete symmetric, finite element model, Numerical analysis, ABAQUS**

I. INTRODUCTION

Double skin profiled steel concrete shear wall system consists of profiled steel sheet connected to sandwiches concrete core. The use of composite shear wall is a natural development of composite flooring system. The using of profiled steel plate in concrete slab as permanent form work and reinforcement was first developed in USA in the early 1950s. Following its introduction into the United Kingdom in the 1970 s it has become the most common form of floor system for steel framed office buildings [4, 5]. Using composite steel concrete shear wall has many advantages such as it doesn't need shuttering and it can be pre-cast or cast in place [6, 7].

Wright [5] study this new type of construction for vertical load bearing system. The results suggesting that only the concrete capacity may be considered when designing for axial resistance of the walls with commercially-available decking and the steel acting as a permanent form and was not contributing to the service strength. The axial load capacity depends on the local buckling of the steel sheeting and by the profiled shape of the concrete cross-section [8].

Hossain [9] investigate the analytical, numerical, and experimental study on the behavior of profiled concrete shear panels that may be used as core walls in framed construction. This study suggested that the profiled shape had a significant effect on the shear resistance. Profiled concrete panel based on an equivalent plain concrete panel can be used for design purposes.

Hossain and wright [10] study the shear behavior of composite shear wall. The investigation had concentrated upon the individual behavior of component parts before considering the composite wall as a whole. The composite wall showed much higher strength, stiffness, ductility, than its component.

Rafiei [1, 11] Study the in-plane shear strength, ductility, energy absorbing capacity, stress-strain characteristics and failure modes of double skin composite walls consisting of a pair of profiled steel sheets with an infill concrete. The performance of composite wall was investigated through experimental investigations using two types of concretes (self-consolidating concrete 'SCC' [3] and highly ductile engineered cementitious composite 'ECC' [2]) and profiled steel sheets (mild and high strength). Rafiei made reasonable finite element model to simulate the behavior of composite wall after validated with experimental results.

This paper presents a symmetric finite element model which give acceptable result after validated with Rafiei experimental and numerical model.

II. SYMMETRIC FINITE ELEMENT MODEL

This model is proposed to simulate Rafiei experimental tests [1]. The model runtime is 15 minutes under high performance computers and can take one hour with normal performance. The total number of elements in this model were 10112 nearly 24 % from the Total number of elements used in Rafiei model [12]. The ABAQUS explicit [13] procedure used for the analysis.

A. Model description

The model consists of ten parts (concrete - profiled steel sheet - top beam - column - support -top 30 mm bolts - bottom beam - bottom 30 mm bolts - load plate - base plate).

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By using these ten parts fourteen instances were generated to assemble the symmetric model as shown in figure1. The element used for meshing profile sheet (S4R) element. And for other parts the element (C3D8R) is used

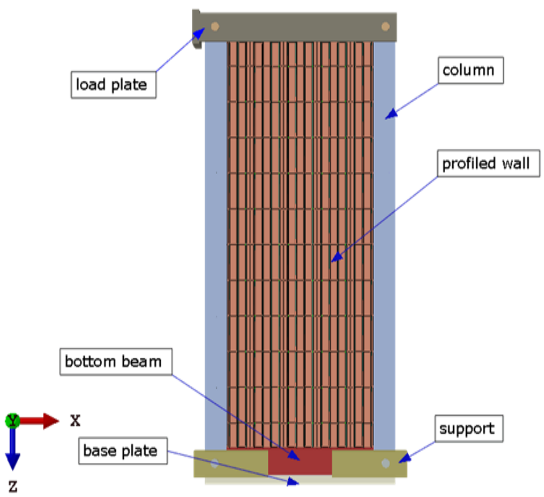

Figure 1: the parts assembly for symmetric model

B. *Constraint and interaction*

1) *Contact*

The general explicit contact was used to connect the surfaces. The tangent and normal properties for contact were assigned as below. The surface smoothing was assigned the area of the bolts and surfaces around it. In The tangent contact behavior. The friction formula was penalty method with 0.1 friction coefficient. In normal contact behavior, the pressure Overclosure was linear. The appropriate contact stiffness after more trials was found to equal 50 which give the best simulation to the inter action between concrete and profile sheets.

2) *Tie constraint*

In order to take in to account the effect of 12 mm bolts, surface to surface tie constraint was used and to take in to account the effect of intermediate fastener, node to surface tie constraint was used (44 nodes were tied) [11].

3) *Coupling*

The coupling between a reference point at which the load is applied as displacement and the load plate area as in figure. (2).

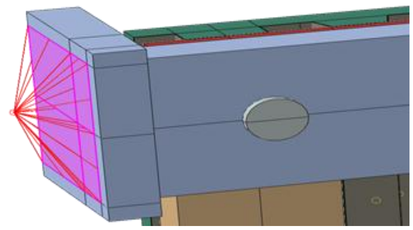

Figure 2: the kinematic coupling between reference point and load plate

The coupling type: kinematic coupling and the constraint degree of freedom in X direction was chosen.

C. *Boundary Condition and Loads*

All displacement degrees of freedom of the support and base plate were restrained. The load plate was restrained in y direction. The symmetric boundary condition was used to the plane of symmetry. The reference point restraint in all directions except the x- direction. The load applied as displacement boundary condition with value 80 mm at a reference point in x direction. All degrees of freedom at this point were restrained except the x direction as shown in fig. (5). A smooth step amplitude function was used with applied load to make the analysis quasi-static.

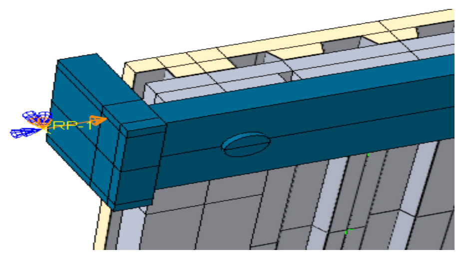

Figure 3: the load applied to the reference point

D. *Steps of Solution*

The monotonic load applied in two steps. First step was the default initial step. And the second step was dynamic explicit step with nonlinear geometric and one second time period with automatic increment. The mass scaling [13] applied to the wall model scaled by scale factor equal 100 at beginning of step.

E. *Steel and Concrete Model*

As Rafiei [12] model. For compressive stress-strain relationship in concrete, the model proposed by Popovics[14, 15] was incorporated to simulate the concrete behavior.

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$$\frac{f c}{f' c} = \frac{n\,(\frac{\varepsilon_c}{\varepsilon_0})}{n-1+(\frac{\varepsilon_c}{\varepsilon_0})^{nk}}$$

Where

$f'c$: ultimate compressive strength of concrete

$\mathbf{n}$: a curve -fitting factor (can be taken as $n = 0.8 + \frac{f'c}{17}$ $\;or\;$ $n = \frac{Ec}{Ec - E'c}$)

Ec : initial tangent modulus for concrete ($Ec = 6900 + 3300\sqrt{f'c}$)

ε_0 : strain when fc reaches $f'c$,$\varepsilon_0 = \frac{f'c}{Ec}\,(\frac{n}{n-1})$

$E'c$: tangent modulus of concrete at $f'c$,$E'c = f'c / \varepsilon_0$

K : a factor to control the slope of the stress-strain curve:

If $\left(\frac{\varepsilon_c}{\varepsilon_0}\right) \le 1 \rightarrow K = 1$

If $\left(\frac{\varepsilon_c}{\varepsilon_0}\right) > 1 \rightarrow K = 0.67 + \frac{f'c}{62} \ge 1$

For stress-strain relationship for concrete in tension. For SCC concrete a bi-linear strain-softening model [16] and for ECC a linear strain-softening model [17] were used to simulate the concrete behavior in tension. The bi-linear strain-softening model decreases from point (E_{Cr} , F'_T) to ($5E_{Cr}$, $F'_T/3$) with the slop of ($\frac{F'_T}{6E_{Cr}}$) and from point ($5E_{Cr}$, $F'_T/3$) to ($16E_{Cr}$, 0) with the slop of ($\frac{F'_T}{33E_{Cr}}$) as shown in figure (4).

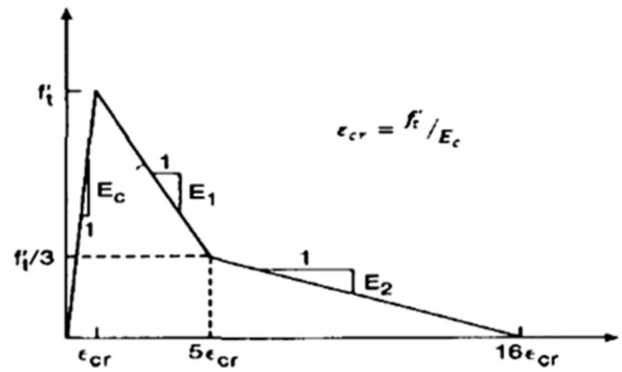

Figure 4: the Bi-linear model for strain-softening [16]

The linear strain -softening model for normal concrete assumes that the strain softening after failure reduces the stress linearly to zero at a total strain of about 10 times the strain at failure. The strain at failure (f_t / E_c) in concrete is typically, the order of 10 −4. It was suggested the tension stiffening that reduces the stress to zero at a total strain of about 10 (f_t / E_c) is of the order of 10 −3. For the ECC, due to its ductility, the total strain was magnified by 100 (f_t / E_c) [11]. The concrete damage plasticity model [13] used for concrete with default option expect the deletion angle = 30 for SCC concrete and 20 for ECC concrete. This value gives agree result with Rafiei experimental test. For Steel model the isotropic hardening model was defined in ABAQUS [13]. The steel proprieties obtained from Rafiei test [1]. TABLE I shows Rafiei test matrix

TABLE I
Rafiei test matrix for monotonic shear loading [11]

Test sets	Wall	Concrete				Profiled steel sheet		
	Dimensions height × width (mm × mm)	Type	f'_c (MPa)	f'_t (MPa)	E_c (MPa)	(F_y) (MPa)	(F_u) (MPa)	E_s (MPa)
CSW-1	1626 × 720	SCC	51.9	4.9	30,670	552	577	202,940
CSW-3	1626 × 720	ECC	40.2	4.8	24,500	552	577	202,940
CSW-5	1626 × 720	SCC	35.7	3.3	26,620	354	420	206,980

f'_c: Compressive strength of concrete; f'_t: tensile strength of concrete; E_c, E_s = modulus of elasticity of concrete and steel sheet, respectively; F_y, F_u = yield and ultimate strength of profiled steel sheet, respectively.
SCC: Self-consolidating concrete; and ECC: engineered cementitious composites.

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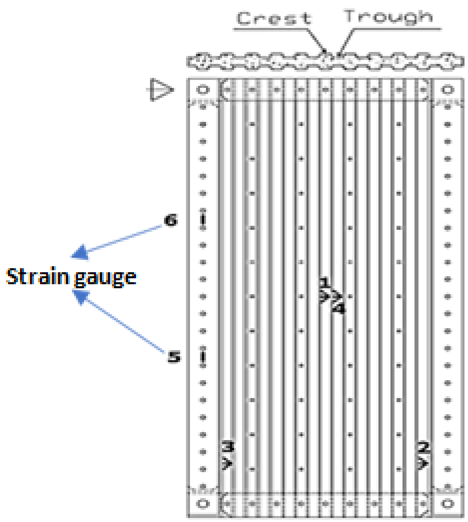

Figure 5: The Location of four rosettes and two single strain gauges used in Rafiei test [1].

III. Symmetric Model Validation

This model used to validate the experimental composite wall tested by Rafiei [1] and compared also with Rafiei finite element model [11]. The result showed that the new model can simulate the behavior of composite wall for the tests specimens.

Using amass scaling [13] of value = 100 can improve the computational efficiency while retaining the necessary degree of accuracy for the model as shown in fig (6). The applied load was 80 mm for all models.

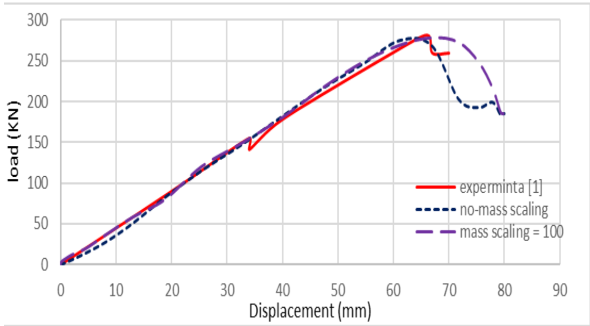

Figure 6: the effect of mass scaling on the result for the third test [1]

A. *FE modeling of test set 3 (ECC concrete) [1]*

1) *Load displacement*

The symmetric finite element model was able to simulate the behavior of the wall.

The maximum load capacity of the wall was 278.9 KN compared with 281 KN for experimental results [1] and 246 KN Rafiei FEM [11]. The difference between the new model and experimental was less than 1 % as shown in fig. (7).

2) *Shear stress*

The maximum shear stress from experimental [1] was 310 Mpa compared with 325 Mpa from the present symmetric finite element model. Which is about 5 % more than experimental as given in fig. (8).

The maximum Shear stress in rosette 3 from FEM was 316 Mpa. The difference between this value and experimental was 2 %.

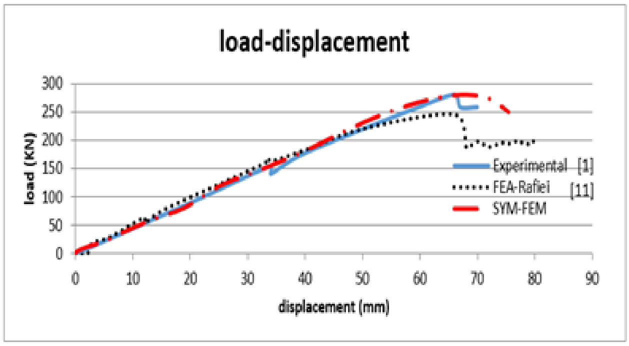

Figure 7: comparison between load versus displacement for test 3 [1]

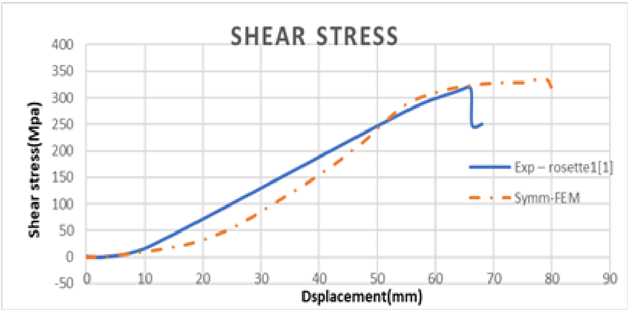

Figure 8: shear stress versus displacement rosette 1 [1]

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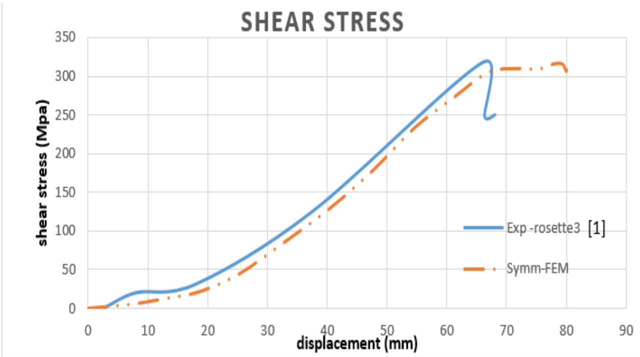

Figure 9: shear stress versus displacement rosette 3 [1]

3) Axial Stress in Column

The two curves close to each other as shown in figure below.

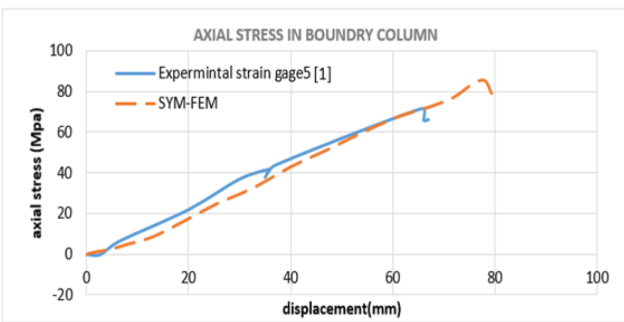

Figure 10: The axial stress versus displacement at strain gauge 5 [1]

4) Principle stress

Fig. (11) shows the comparison between max and min principle stress at the centre of the wall in steel sheet rosette 1 [1].

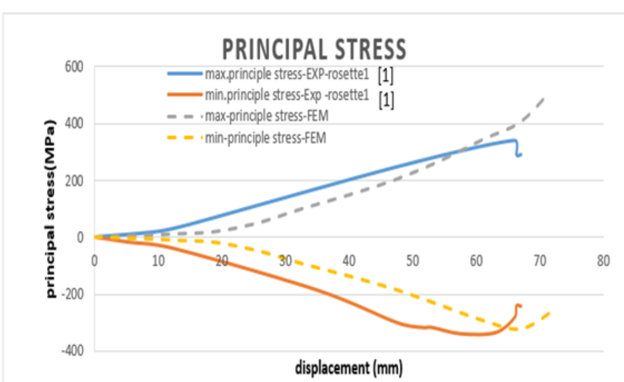

Figure 11: comparison between FEM and experimental principle stress in steel sheet rosette 1[1]

B. FE modeling test set 5 (SCC concrete) [1]

The maximum load capacity of the wall for the present analysis equals 183.4 KN while for experimental [1] equals 212 KN and for Rafiei FE model [11] equals 179 KN. The present symmetric FE result is less than the experimental one by about 8.7 % as shown in fig. (12).

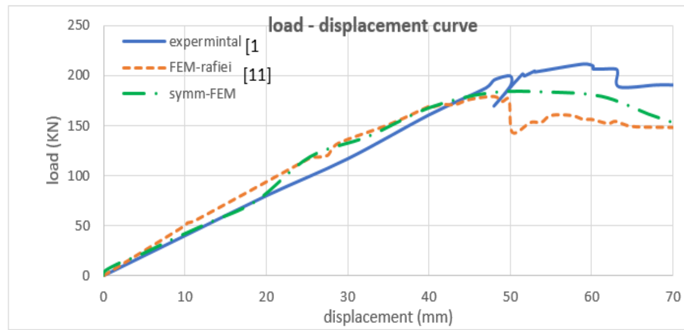

Figure 12: comparison between load versus displacement curves for test

IV. PARAMETRIC STUDY

A. using individual wall parts

Two different models made to find the effect of using each individual parameter (concrete only and profiled steel only) before considering the composite action produced by the fastener. The mild steel grade uses for profiled sheet with thickness 0.61 mm. Other two composite walls with SCC concrete (40.2 Mpa) were used. The first one has 44 fasteners but the second has no fasteners.

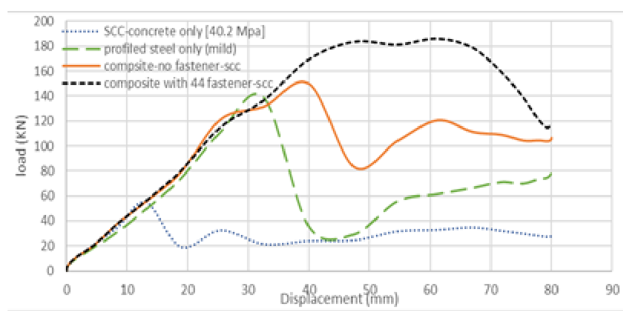

Figure 13: Displacement versus shear load relation

TABLE II
SHOWS THE FAILURE LOAD FOR VARIOUS WALL COMPONENTS

Model name	SCC Concrete only	Profiled steel only model	Composite wall-no fastener	Composite wall-44 fastener
Max load	54.80 KN (13mm)	138.9 KN (32.55mm)	149.7 KN (40 mm)	186.16 KN (61.2 mm)

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The shear resistance for SCC concrete only is very low where no ductility and failure occurs at 13 mm displacement. When using profiled sheet only the shear resistance equals about 2.5 times that of concrete only. When using sheet and concrete the shear resistance for composite wall without fastener is increased by about 7.7 % compared with using steel sheet only and when using 44 fasteners the shear load increased by 34 %.

B. Sheet thickness with ECC concrete

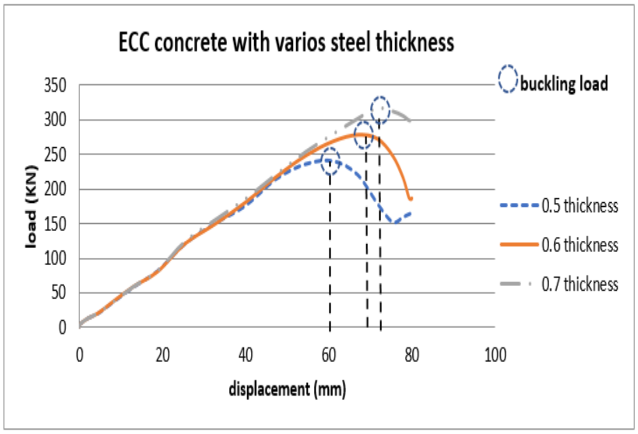

Figure 14: Displacement versus shear load relation with different steel thickness (ECC 40.2 Mpa)

Three different sheet thickness have been modelled (0.5, 0.6, and 0.7 mm) with ECC (40.2 Mpa), high strength steel (552 Mpa) and 44 intermediate fasteners. The results are shown in fig. (14) and table. (3).

TABLE III
THE BUCKLING LOAD AND DISPLACEMENT WITH DIFFERENT STEEL THICKNESS (ECC CONCRETE)

Sheet thickness	0.5 mm	0.6 mm	0.7 mm
Buckling load (displacement)	240.76 KN (61.18 m)	276.4 KN (67 mm)	311.8 KN (75.37mm)

Increasing the sheet thickness by 20 % (from 0.5 to 0.6) increase the buckling load by 14.8 % and the displacement by 9.5 %. Increasing the sheet thickness by 40 % (from 0.5 to 0.7 mm) increase the buckling load by 29.5 % and the displacement by 23 %.

C. Sheet thickness with SCC concrete

Three different sheet thickness have been modeled (0.5, 0.6, and 0.7 mm). The other parameter is SCC concrete (40.2 Mpa) high steel (552 Mpa) and 44 intermediate fasteners.

The results. Showed that increasing steel sheet thickness increase shear resistance by 15 to 19 % and displacement from 10 to 12 %.

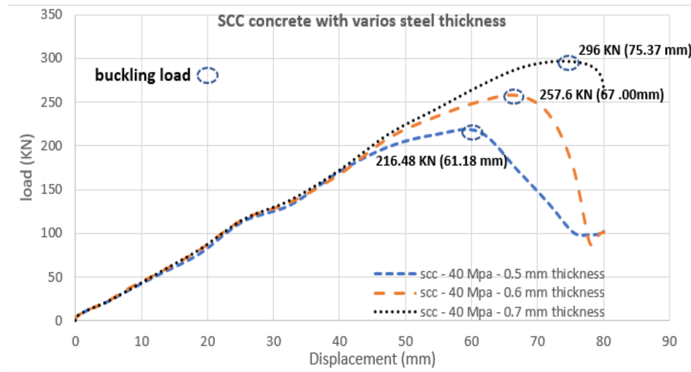

Figure 15: Displacement versus shear load relation (thickness change)

Using ECC concrete (40.2 Mpa) gives shear load more than SCC concrete (40.2 Mpa) for the sheet thickness by about (11 % for 0.5 mm, 7.3 % for 0.6 mm and 5.3 % for 0.7 mm).

D. Steel grade

Two steel grades high (552 Mpa) and mild (354 Mpa) steel used with ECC concrete (40.2 Mpa). The number of intermediate fastener used to tie the sheet were 44 fasteners. The result showed that increasing steel grade by 56 % (from 354 to 552 Mpa) increasing the shearing load by 29 % and displacement by 41.2 %.

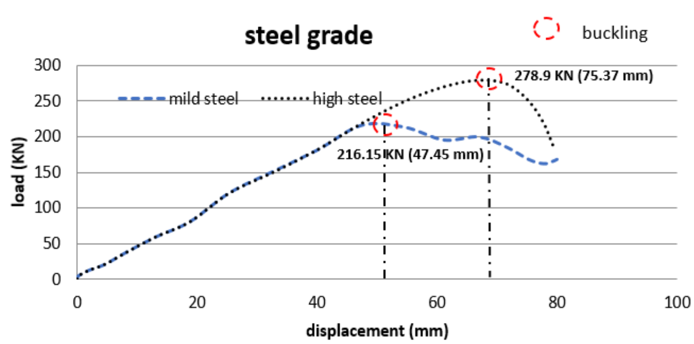

Figure 16: load -displacement curves with different steel grades

E. Concrete grade change

1) Using 44 intermediate fasteners

Three models with different SCC concrete grades have been used 20 Mpa, 40 Mpa and 60 Mpa.

The other fixed parameter used profiled sheet with mild steel grade 354 Mpa,0.61 thickness and 44 intermediate fasteners. The results showed in the table (4).

TABLE IV
THE VALUES OF BUCKLING LOAD AND DISPLACEMENT WITH DIFFERENT CONCRETER GRADE

SCC-Concrete grade	20 Mpa	40 Mpa	60 Mpa
Max load	176.56 KN	185.3 KN	200.14 KN
Buckling load	176565 N (54.6 mm)	182450 N (54.6 mm)	200137 N (54.6 mm)

Increasing concrete grade with composite wall with 44 fasteners have a small effect on the result the first increase from 20 to 40 Mpa the shearing load increase by 5 % and from 40 to 60 Mpa the shearing load increase by 8 % at the same displacement.

2) No intermediate fastener

Three models with different SCC concrete grades 20 Mpa ,40 Mpa and 60 Mpa have been used with two profiled sheets with 0.61 mm thickness from mild steel grade 354 Mpa, and there is no intermediate fastener. The results showed that increasing concrete grade have a small effect on the results as shown in the TABLE V below.

TABLE V
THE VALUE OF BUCKLING LOAD AND DISPLACEMENT WITH DIFFERENT CONCRETER GRADE

SCC-Concrete grade	20 Mpa	40 Mpa	60 Mpa
Max load	133.4 KN	157.71 KN	163.64 KN
Buckling load	133.4 KN (32.55 mm)	157.71 KN (40 mm)	163.64 KN (40 mm)

Increasing concrete grade with composite wall with no fastener have a small effect on the result the first increase from 20 to 40 Mpa the shearing load increase with 18.24 % and displacement with 22.88 % but the second increase in grade has the minimum effect on the results. Where the shearing load increase with 3.7% at the same displacement.

F. Concrete core change

The smallest thickness (t flat) of ECC profiled concrete core (40.2 Mpa) has been changed, three models with different thickness 20 mm, 30 mm and 40 mm have been submitted. The other parameter was high strength steel sheet (552 Mpa) with 0.61 thickness and 44 intermediate fasteners.

The results showed that increasing core thickness using the same profile shape have a small effect as shown in figure. (20).

Table VI
The Values Of Buckling Load And Displacement With Different Concreter Thickness

T flat thickness	Sheet thickness	Buckling load
20 mm	0.61 mm	272216 N (71.71 mm)
30 mm	0.61 mm	278892 N (66.95 mm)
40 mm	0.61 mm	297446 N (75.36 mm)

Figure 17: Cross section for concrete shows the parameter t flat

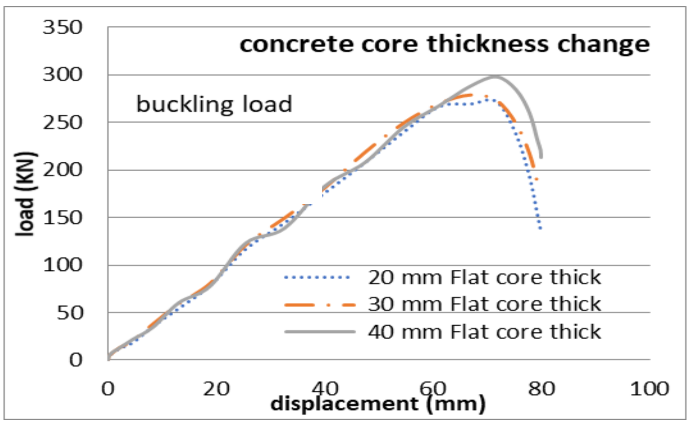

Figure 18: load – displacement curves for concrete core parameter

G. Embossment

Anew part added to the model and merged with profiled sheet as shown in figure. (22) the new part repeated every 64 mm in horizontal and 128 mm in vertical. The 44 fasteners placed between embossments to tie the mild steel sheet (35.7 Mpa) with SCC concrete.

The results showed that the embossment and intermediate fasteners together can prevent buckling the failure is due to steel yielding only up to 80 mm displacement.

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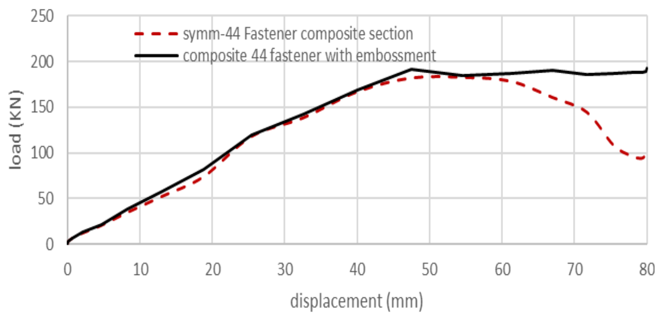

Figure 19: load – displacement curves for composite wall with and without embossment

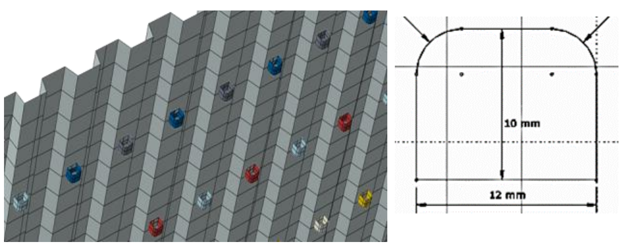

Figure 20: steel sheet with embossment

A comparison between some similarity in parametric study for symmetric finite element model and Rafiei model showed in table below. The variance in result appear in the model that has no fasteners. This may be due to the contact between sheet and concrete is friction less in tangent behavior in Rafiei model [11] (but the friction already exists) and hard contact in normal behavior .in this model a small amount of friction (friction coefficient =0.1) between sheet and concrete introduced in tangent behavior and linear contact in normal behavior.

TABLE VIII
THE COMPARISON BETWEEN THE SYMM- FE MODEL AND RAFIEI FE MODEL [11]

N of fastener	Concrete grade	Steel grade/thick	Max load Rafiei FE model(KN)	Max load symm-FE model(KN)
44 -fastener	20	350 /0.61mm	178	176.5
44 -fastener	40	350/0.61 mm	185.9	185.3
44 -fastener	60	350/0.61 mm	208.6	200.14
No fastener	20	350/0.61 mm	108.2	133.39
No fastener	40	350 /0.61 mm	126.7	157.7
No fastener	60	350/0.61 mm	144.5	163.64

V. CONCLUSION

This paper describes a symmetric finite element model used to simulate the behavior of profiled steel- concrete composite shear wall.

The model validated with Rafiei experimental tests and compared with Rafiei finite element model and was found to be the best simulation with respect to accuracy and computational efficiency. The model runtime takes from (15 minutes to 1 hour) depending on computer performance after using adequate mass scaling compared with 44 hours in Rafiei finite element model.

A mass scaling of value =100 was found the best value with respect to accuracy and computational efficiency. An extensive parametric study on symmetric finite element model to assess the effect of different parameter on the behavior of composite shear wall, as listed below.

- A composite wall with 44 intermediate fasteners provides higher shear load capacity than its individual components. And compared with composite wall without fasteners, the shearing load increase by 24.4 % and displacement by 53 %.
- Steel sheet thickness has a bigger effect on shearing load capacity for SCC concrete than ECC concrete.
- Using high strength steel (552 Mpa) rather than mild steel (354 Mpa) increasing shearing load capacity by 29 % and displacement by 41.2 %.
- Concrete grade and concrete core thickness have a small effect on the results.
- Adding embossments to the profiled steel sheets made the model more ductile and can prevent buckling to occurs before yielding.

Finally, when the composite action between steel sheets and concrete increase, the effect of concrete grade, concrete thickness on the results disappear. This study recommended that using intermediate fasteners and embossment together to improve ductility and prevent the sheet buckling before its yielding.

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