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The Developed Analytical Model of Composite Steel Plate Shear Walls (C-SPSW)

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□ ABSTRACT □

Composite shear walls are important construction elements in terms of their use in high-rise buildings and nuclear installations. It consists generally of a steel plate and concrete wall, which are connected by bolts or shear connectors as well as boundary elements.
Several researchers have used the Finite Element Method to investigate the behavior of composite shear wall using structural analysis programs as ANSYS or ABAQUS.Many of these studies were based on either modeling each element alone or three-dimensional modeling one or two stories of a single wall. This modeling is very effective in predicting the performance of the wall under lateral loads. This three-dimensional modeling requires a lot of time, effort and good experience and cannot be easily used for design purposes. In this research, a simplified mathematical model is developed using ABAQUS finite element software to predict the nonlinear response of composite steel plate shear walls. The developed model is validated using results from tests reported in the literature of composite walls. The accuracy and simplicity of the proposed model make it suitable for further numerical studies and designing of composite steel shear wall using available engineering programs such as SAP and ETABS programs.

Keywords: composite steel plate shear wall- Finite Element Method-simplified model

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النموذج التحليلي المطور لجدران القص المعدنية الصفائحية المختلطة

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□ ملخّص □

تعتبر جدران القص المعدنية المختلطة من العناصر الانشائية الهامة من حيث استخدامها في الأبنية العالية والمنشآت النووية. تتألف بشكل عام من صفيحة معدنية تمثل جدار القص الفولاذي وجدار بيتوني يتم الوصل بينهما من خلال براغي تثبيت أو روابط قص بالإضافة الى العناصر المحيطية من الاعمدة والجوائز. تطرق عدد من الباحثين لدراسة سلوكها باستخدام طريقة العناصر المنتهية وبمساعدة برامج هندسية متقدمة مثل ANSYSوABAQUS، ومعظم هذه الدراسات كانت إما بنمذجة كل عنصر لوحده أو بنمذجة ثلاثية الأبعاد لطابق أو طابقين من الجدار لوحده، وهذه النمذجة فعالة جدا في التنبؤ بالأداء المتوقع للجدار تحت تأثير الحمولات الجانبية الخارجية، إنما تستلزم الكثير من الوقت والجهد والخبرة الجيدة في مبادئ النمذجة الصحيحة والتمثيل الحقيقي للعنصر، وهذا ما يجعل التصميم باستخدام هذه الطرق غير مُجدي. قمنا من خلال هذا البحث بصياغة نموذج رياضي مبسط باستخدام طريقة العناصر المنتهية وبمساعدة برنامج التحليل الانشائي ABAQUS يمكنه التنبؤ بالسلوك اللاخطي لجدار القص المختلط. وتم التحقق من هذا النموذج المطور بالمقارنة مع نتائج لجدران مختلطة وموثقة من خلال تجربة مخبرية. يعتبر هذا النموذج المطور والمبسط مناسب جداً لدراسة وتصميم جدران القص المعدنية المختلطة باستخدام البرامج الهندسية المتاحة مثل برامج SAP وETABS.

الكلمات المفتاحية: جدران القص المعدنية المختلطة، طريقة العناصر المنتهية، نموذج تحليلي مبسط.

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1-Introduction:

Composite Structural elements are of great importance, especially in high buildings such as in composite shear walls, which consist of steel plate within frame elements of beams, columns and reinforced concrete walls that work together with steel plates through shear stud or bolts, and used as effective and good systems to resist lateral loads on the building. This model of shear walls offers good resistance, lightweight and low cost compared to traditional reinforced concrete shear walls when used in high-rise buildings.

The concrete panel provides out-of-plane restraint preventing premature failure of the steel plate due to buckling. Both shear resistance and energy dissipation capacity of the steel plate are thus significantly improved.[1]

Research summarized analytical studies on the in-plane shear behavior of **CSPS** walls and proposed analytical models to predict the shear resistance and deformation capacities of **CSPS** walls and to validate the accuracy of the proposed model for the purpose of appropriate design procedures included the development of suitable mini-models taken from the primary one.

The simplified model of composite shear wall should be able to represent the expected real structural behavior in terms of stiffness and strength. Therefore, simplified model should be validated by comparison with numerical results obtained from finite element micro-models of the shear wall.[2]

The macro-models based on the equivalent strut and tie strip method are often used to model infill wall. The basic parameter of these struts and strip is their equivalent width, which affects the stiffness and strength [3]

Previous studies indicate that the steel plate in steel shear walls can be modeled with inclined strips (strip model). The angle of inclination represents the direction of the principal tension stresses. In the case of composite steel shear walls, the studies suggested to represent steel plate with strips in tow direction .The material used for strips shall be the same as the steel plate, so that the number of strips in each direction shall not be less than ten, with the concrete being neglected.[4].

2- Research Scope:

The study presented here aims to develop a simplified mathematical model to predict the nonlinear response of composite shear wall; this simplified model will be easy to use in common structural engineering programs such as SAP200 or ETABS, saving a lot of time and effort to study the complex behavior of these walls when using an advanced research program.

3-Research Methodology and Materials:

3-1 Analytical study using Finite Element Method (FEM):

ABAQUS-V14.2 was used to create numerical models to study the behavior of composite steel plate shear walls. Initially, a three-dimensional 3D model was developed that takes into account geometric and material nonlinearity. In the second stage, the results of the analysis using the validated numerical 3D model were used to develop and validate a simplified analytical model of composite steel plate shear walls.

3-1-1: 3D numerical model for composite steel plate shear wall.

In order to validate the developed numerical model, the specimen tested by Qiuhong ZHAO1 and Abolhassan ASTANEH-A [5] is modeled using the same geometrical dimensions, materials properties and boundary conditions of the tested specimen.

3-1-2: Experimental test used in Modeling:

Qihuhong ZHAO1 and Abolhassan ASTANEH-A [5] carried out experimental test on a composite shear wall located in a building within frame elements for three stories at 1/2 scale as shown in Fig. 1. The experimental specimen is a lateral-load resisting system in which the composite shear wall is the main resisting system.

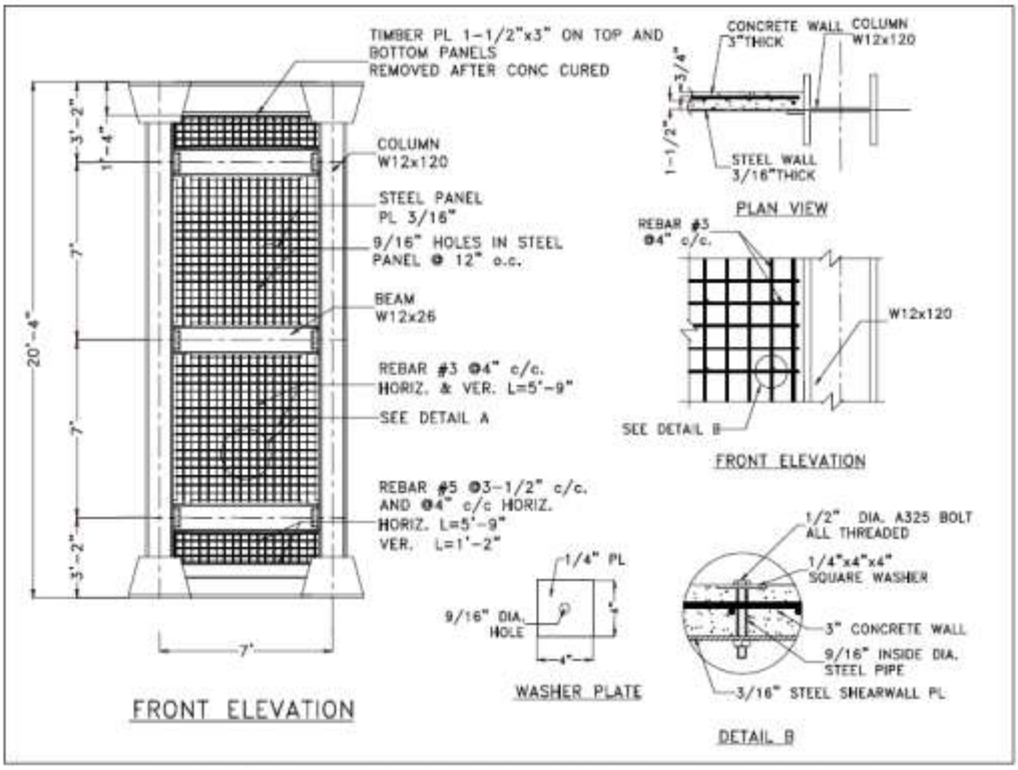

Figure 1. A Specimen with Details of Concrete Shear Wall [5]

3-1-3: Materials properties of tested specimen:

In the specimens, the steel wall plate was made of A36 with specified yield stress of 248 MPa (36 ksi).The steel boundary frame was made of A572 Grade 50 steel, with specified yield stress of 345 MPa (50ksi). The reinforced concrete (R/C) shear wall was made of concrete with a specified f'c of 28 MPa (4000psi) and one layer of reinforcement with a grid of #3 rebar and #5 rebar at perimeter(fy = 420MPa), fu = 630MPa). The R/C walls in the specimen were pre-cast and bolted to the steel walls by 13 mm (½ inch) diameter A325 bolts, see Table 1.

Table 1. Components of Test specimens

Steel wall Plate thickness	Pre-cast R/c wall				Wall bolts Dia.	Beam section	Column section
	thickness	Rebar Dia.	Rebar spacing	Reinf. Ratio			
4.8 mm	76 mm	10 mm	102 mm	0.92%	13 mm	W12*26	W12*120

*Properties of cross sections refer to the AISC Manuals

The beam-column connection in the steel frame was cover plate plus shear tab moment connection designed according to FEMA 350[6] recommendations to make sure that the shear and plastic moment capacity of the beam will be fully developed.
The test set-up is shown in Figure 2. Main components of the test set-up are: Actuator, Top Loading Beam, Bottom Reaction Beam, R/C Reaction Blocks, and Bracings. The test set-up was designed so that lateral displacements and forces could be applied to the specimen and sufficient factor of safety could be provided under the large forces generated. The test set-up also provided the boundary conditions for the specimen that resembled the actual boundary conditions for a typical floor in a generic structure.
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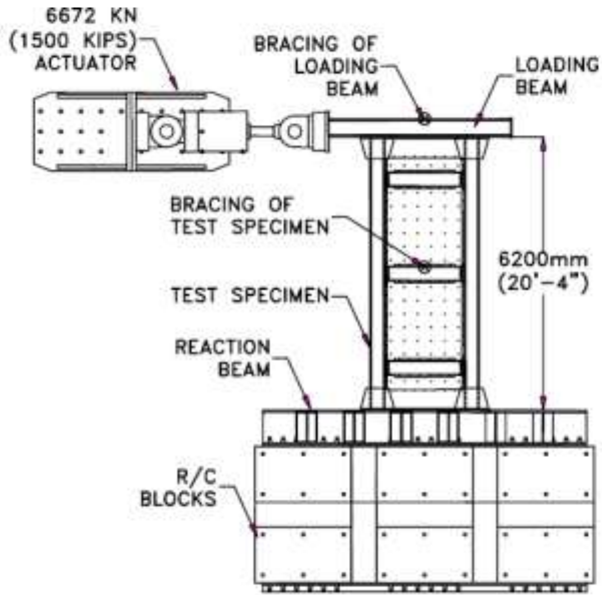


Figure 2. Test Specimen and Test Set-up[5]

Figure (3) shows the numerical model (3D, reinforcing -bolts) developed using ABAQUS to simulate the tested specimen shown above [5].

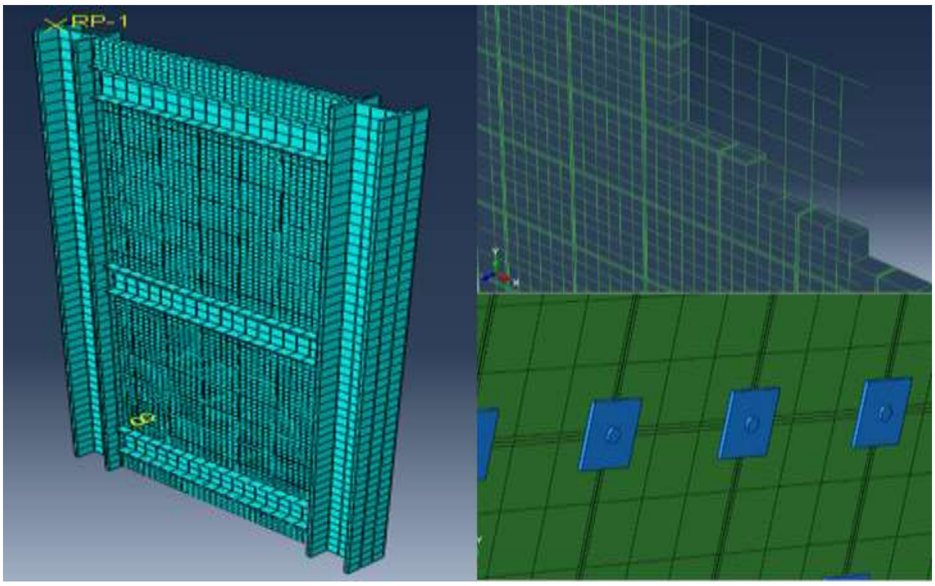


Figure 3. ABAQUS Model

3-1-4: Finite element types used in the model:

Eight-node solid elements C3D8 were used to model frame elements, concrete wall panels and bolts (Figure 4a), each node has three degrees of freedom (3 transitions). 4-node shell elements S4R were used to model the steel plate, each node has six degrees of freedom (3 transitions and 3 rotation) ,(Figure 4b).

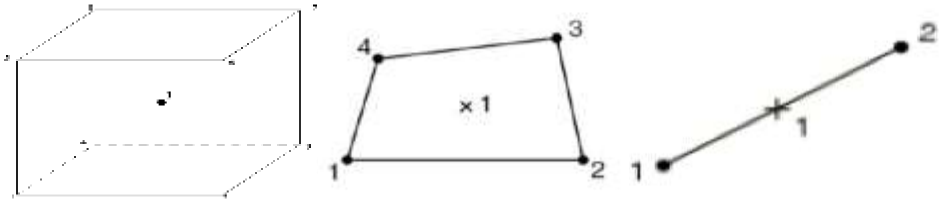


Figure 4. ABAQUSE Element Type [ABAQUS 6.14 Documentation][7]

2-node 3-D truss T3D2 elements were used to model reinforcing rebar, (Fig. 4c), each node has three degrees of freedom (3 transitions).

3-1-5: Materials properties:

3-1-5-1: Concrete Material properties:

Concrete Damaged Plasticity model (CDP) available in ABAQUS is used to model the behavior of concrete.

There are various parameters related to the definition of the concrete damage plasticity model. Mathematical relationships of complete stress-strain curves in tension and compression associated with the respective damage curves are required to be provided. In the concrete damaged plasticity model, the concrete under uniaxial tension follows a linear elastic relationship initially until the peak tensile stress is reached. After this point, micro cracking starts to form in the concrete, which is resembled in the macroscopic level with a softening stress-strain relation. This extends until the point where the stress reaches very low values close to zero; where, the concrete can be considered to be failed. Under uniaxial compression, the concrete follows a linear elastic relationship until the initial yield stress 'σ_{c0}'. This is followed by the plastic region where the relationship is characterized by stress hardening followed by strain softening beyond the ultimate stress 'σ_{cu}'. In order to simulate the tensile behavior of reinforced concrete in concrete damaged plasticity model, the input provided were that of the young's modulus $\mathbf{E_t}$, the tensile stress 'σ_t' vs cracking strain ε_t^{ck} relationship and the damage parameter value 'd_t ' vs cracking strain 'ε_t^{ck}' relationship for the relevant grade and constitutive model of concrete chosen.

$$\varepsilon_t^{ck} = \varepsilon_t - \varepsilon_{el} \qquad : \varepsilon_{el} = \frac{\sigma_t}{E_t}$$

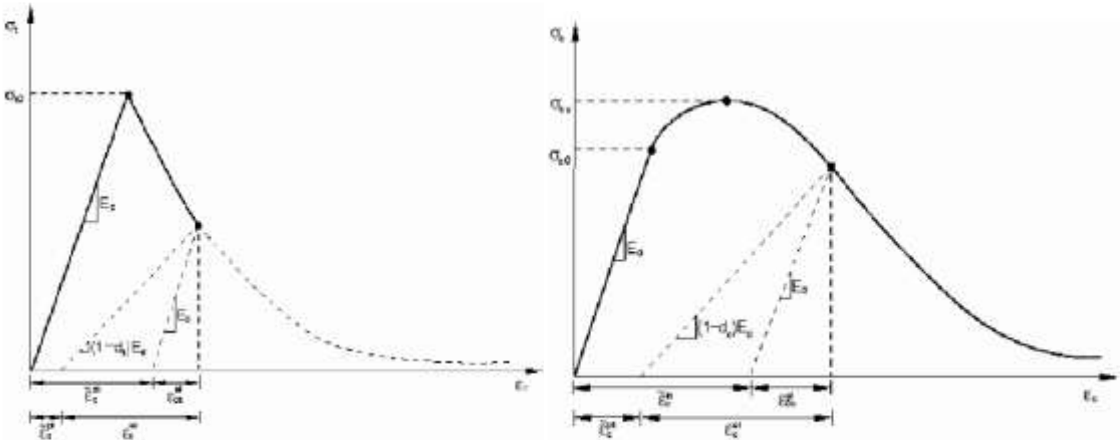
Where,ε_t^{ck} is the cracking strain, 'ε_t ' is the total concrete tensile strain, 'ε_{el} ' is the elastic strain corresponding to undamaged concrete material, 'σ_t ' is the concrete tensile stress. The damage parameter 'd_t ' is found out as the ratio of degraded strength to the peak strength.

In the concrete damage plasticity model, the strain 'ε ' is comprised of the elastic strain 'ε_e 'and the plastic strain ε_p.

$$\varepsilon = \varepsilon_e + \varepsilon_p$$

The stress-strain relationship is as follows: $\sigma = (1 - D)E_0\,(\varepsilon - \varepsilon_p)$
Where, 'D' is a scalar degradation variable, 'E_0' is the initial elastic stiffness.
ABAQUS checks for the accuracy of the damage curve using the plastic strain values ε_t^{pl} It is to be noted that Fig. 5 depicts'Et' as 'E_0 '. Negative and/or decreasing tensile plastic strain values are indicative of incorrect damage curves, which may lead to generate error message before the analysis is performed [6]. All these inputs were provided in tandem with the concrete constitutive model chosen to provide a tensile stress-strain relationship similar to Fig.-5 accounting for tension stiffening, strain-softening and reinforcement interaction with concrete.

In order to simulate the compressive behavior of reinforced concrete in concrete damaged plasticity model, the input provided were that of the young's modulus Ec the compressive stress'σc ' vs inelastic strain ε_c^{in} relationship and the damage parameter value ***dc*** vs inelastic strain ε_c^{in} relationship for the relevant grade and constitutive model of concrete chosen.

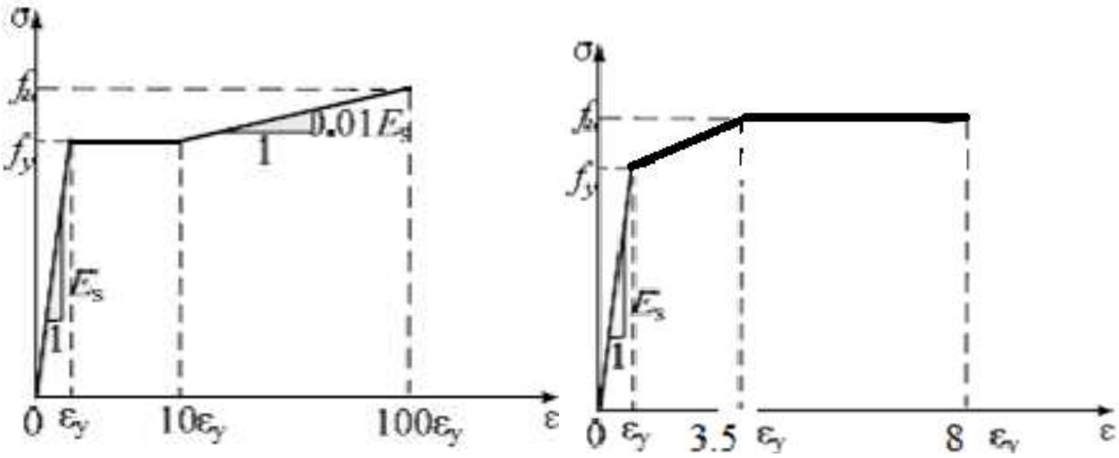


a Parameters for tension model of concrete **b-Parameters for compression model of concrete**
Figure 5. [ABAQUS V6.14 Documentation] [7]

E_0 :Initial young's modulus, $Ec = 5000\sqrt{f_c'}$

3-1-5-2: Steel material properties:

Steel is a ductile material with non-linear behavior due to yielding and strain hardening of the material. The behavior of steel is modeled by tri-linear stress-strain curve as shown in Figure (6a) for beams, columns, steel plate and reinforcement bars and in Figure (6-b) for bolts.



(a) plate, beam, column, and reinforcing **(b) Bolt**

Figure (6): Steel Stress-Strain curves

3-1-6: Loading and Boundary Condition:

The boundary conditions are modeled in accordance with the adopted experimental study:
The columns and plate are fixed at the bottom end.
- The side transitions of the center beam have been restricted in accordance with the experimental test.
- The steel plate was connected directly to the boundary elements in the numerical model.
Lateral-imposed displacement is applied at the top of the frame and increased gradually to reach an average drift of 2.5%, which corresponds to the maximum value in the ASCE7-05 code [8], and the Syrian Arab Code Appendix - II for the case of a vibration time less than 0.7sec [9].

4-Model validation:

The numerical model is validated by comparing the numerical results with the results of the experimental study adopted in the modeling procedure. The comparison has two main aspects: the first relates to observed failure modes, and the second relates to the response of the model represented by Force-Displacement curve. As shown in Figure (7) and Figure (8), the model can predict, with good accuracy, the concrete carking and steel plate buckling observed in the tested specimen.
Figure (9) shows the comparison of the experimental force-displacement curve with the numerical force-displacement curve obtained by the model. The carrying capacity of the test specimen was 2969 kN, while the numerical capacity was 2925 kN. Thus, the model can predict the maximum resistance of the composite shear wall with an accuracy of 90%.

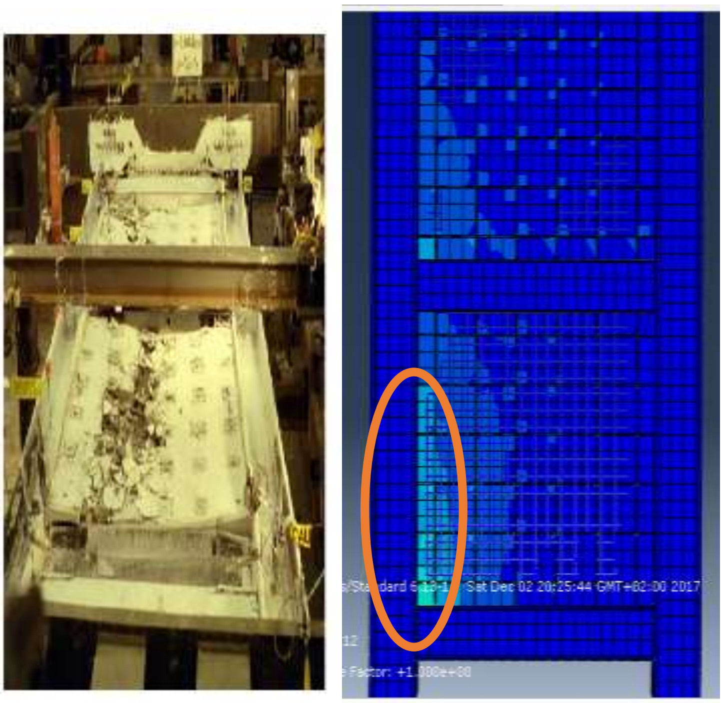


Figure (7) cracking places in experimental and analytical model

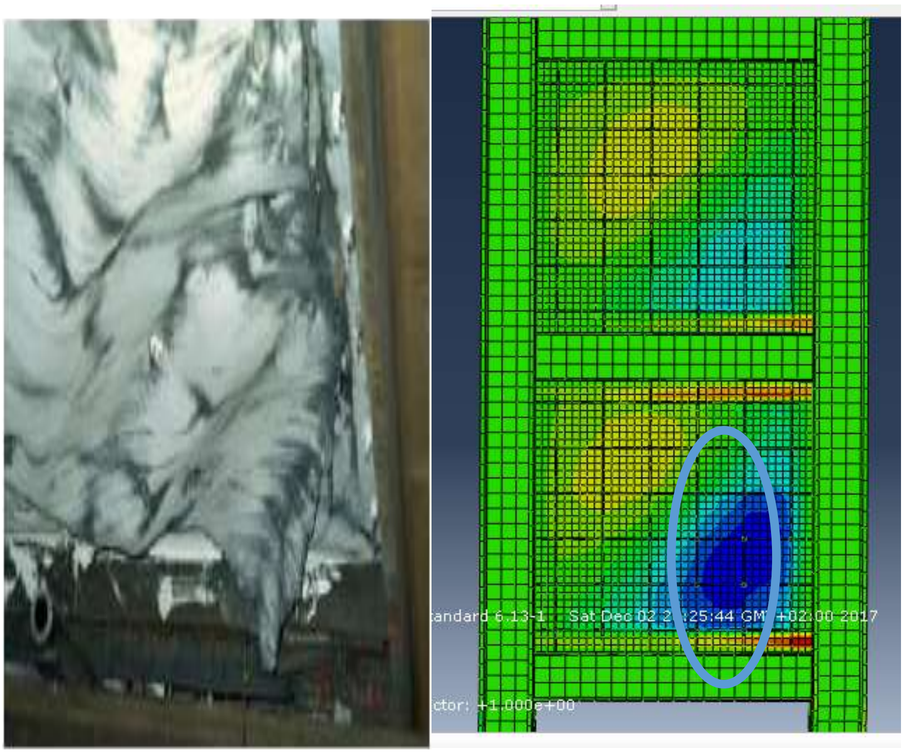


Figure (8) Buckling steel plate in experimental and analytical model

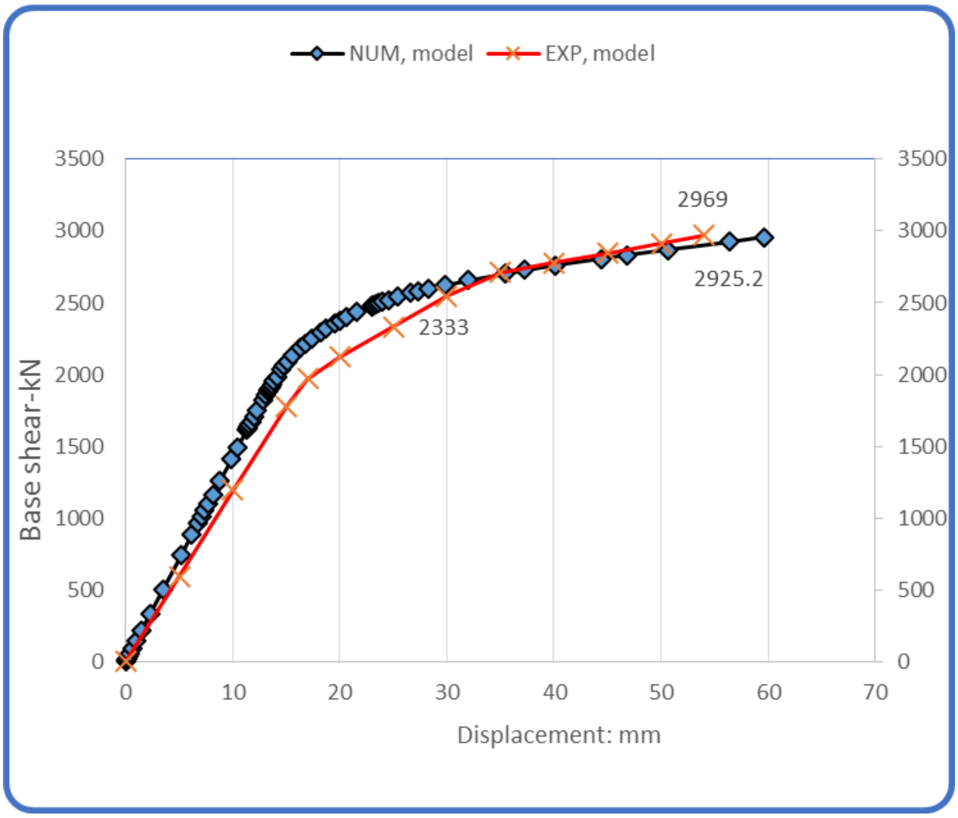


Figure (9) Force- Displacement in experimental and analytical model

5- Simplified analytical model for composite steel shear walls.

In this paragraph, a simplified analytical model is developed to predict the non-linear behavior of C-SPSW. This simplified analytical model takes into account the contribution of both steel and concrete to the(C-SPSW) resistance. This model is developed based on the strip model, which is commonly used to model SPSW [10] and steel plate in composite walls (C-SPSW).[11]

This model is also based on the equivalent diagonal compression strut model commonly used to model non-reinforced fill walls [4, 12, 13, and 14]. In addition to these models, the simplified analytical model is developed based on the experimental observations as well as the numerical results obtained using the 3D model developed in paragraph 3.1.1.

5-1: Steel plate modeling.

In the SPSW strip model, a single set of parallel inclined pin-ended strips is used as in figure (10).these pin-ended strips act as tension element to simulate the diagonal tensile fields formed in the steel plate after buckling. While no strips are placed in the other diagonal compression direction which is neglected due to the steel plate buckling. The number of strips must be at least ten. [10,15].

Fig (10) SPSW strip model

In C-SPSW walls, the presence of the concrete wall prevents the out-of-plane buckling of steel plate and hence the compression stress cannot be ignored. In this case, two sets of parallel inclined pin-ended strips are used to model the steel plate (Fig. 11). One of the two sets was placed in the diagonal tension direction while the other was placed in the compression one.

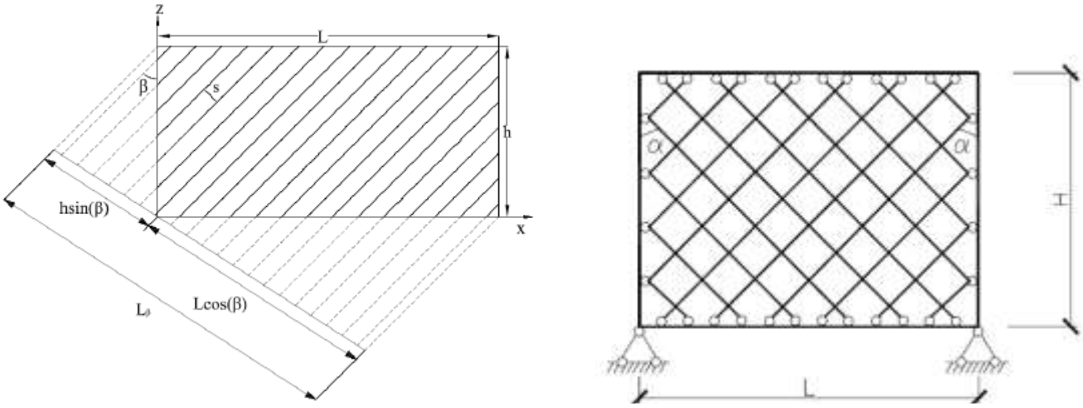


Fig (11) C-SPSW strip model

The angle of inclination α between the strip and the vertical line can be calculated by equation (1).[16].

$$tan^4\alpha = \frac{1+t.L/2Ac}{1+t.h(\frac{1}{Ab}+\frac{h^3}{360\, Ic\, L})} \qquad (1)$$

Where *h* is story height; *Ac* and *Ab* are cross-sectional area of boundary columns and boundary beams, respectively; *Ic* is the cross-sectional moment of inertia of boundary columns.

The cross-sectional area of each strip, A_s, can be determined according to the spacing as follows:

$$A_s = \frac{t(L\, cos\propto + H\, sin\propto)}{n} \qquad (2)$$

Where: *t* , *L*, *H* are the thickness, width and height of the steel plate, respectively; *n* is the number of strips in one diagonal direction.

In the strip model for SPSW, the strip is a tension-only element. When extended to the cross-strip model for C-SPSW, the strips in two diagonal groups are in tension and compression respectively. In order to determine the compressive strength, we assume both the tensile and compressive behavior are elasto-plastic, and based on the equivalence

between the resistance of the composite steel shear wall (C-SPSW) calculated according to the American code [15] and the resistance obtained by the strip model [17].
It is assumed that the tension strips contribute to a part of the (C-SPSW) shear resistance. this part is calculated as:

$$V_T = 0.5\, F_y Lt \sin 2 \propto \qquad (3)$$

While the compressed strips contribute to the remaining part of the(C-SPSW) resistance. this part is calculated as:

$$Vc = 0.5\, F'_y Lt \sin 2 \propto \qquad (4)$$

Where *fy* and *f'y* are tensile and compressive strength of the strips, respectively. Thus, the total capacity of the above system is obtained by:

$$V = V_T + Vc = 0.5\,(F_y + F'y) Lt \sin 2 \propto \qquad (5)$$

According to AISC Seismic Provisions (2010) [15], the capacity of C-SPSW can be evaluated as:

$$V = 0.6\, F_y Lt \qquad (6)$$

Comparing Eqs. (5) and (6) gives

$$F'_y = \left(\frac{1.2}{sin2\propto} - 1\right) F_y \qquad (7)$$

5-2: Concrete Wall Modeling:

The strip models currently used to model the (C-SPSWs) [1], neglect the contribution of concrete resistance, its role is limited to preventing the buckling of the steel plate. However, the results obtained using the 3D model developed in paragraph (3.1.1) confirmed that there is a non-negligible contribution of the concrete wall to the horizontal shear resistance of the (C-SPSWs). This contribution is greater than 20% for composite walls with aspect ratio not less than one, (Fig. 12).
To study the effectiveness of each component of the shear wall in the shear resistance, Fig. 13 shows the variation of percentage contribution (F_{cont} %) for each component of the composite wall (steel plate, concrete board and frame) to the shear resistance by aspect ratio (Ar=L/H) (Fig. 12).
Figure (12) shows that the concrete panel is effective in shear resistance when (Ar ≥1).

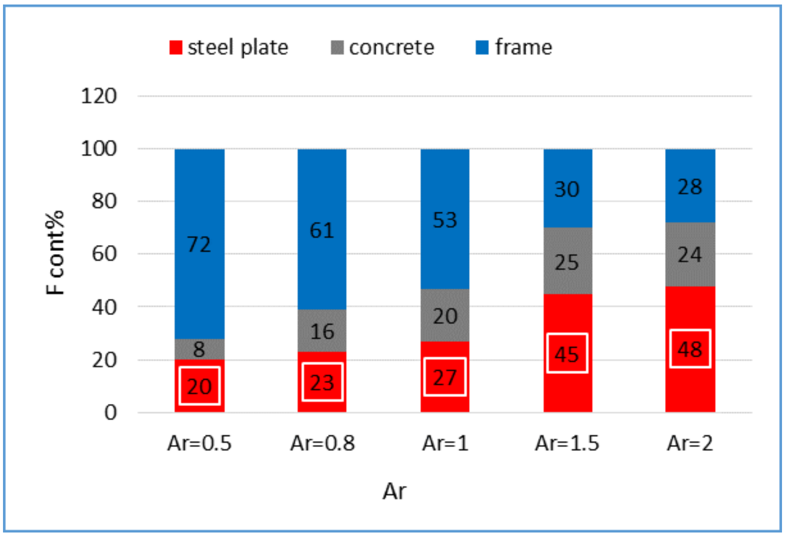


Fig (12) shear force contribution of component C- SPSW with different aspect ratio (Ar)

We will model the concrete wall using the Equivalent Concrete strut concept [4,18,19]This concept is based on put diagonal strut in the direction of the compression field formed in the concrete wall and is often placed diagonally between the two corners of the wall. However, the results obtained from the 3D model developed in paragraph 3.1.1 show us that the use of one strut between the two opposite wall angles may not be entirely appropriate. Figure (13) shows that the compression field in the concrete wall is partially supported by the beam and column.

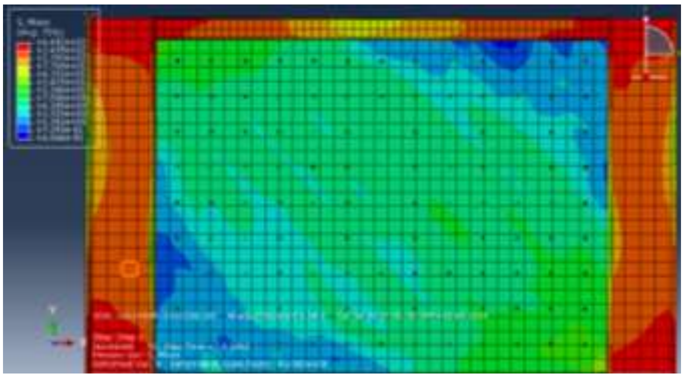


Fig (13) Diagonal compression filed in concrete wall

Based on this result, the concrete wall modeled using three concrete diagonal struts as shown in (Fig-14).

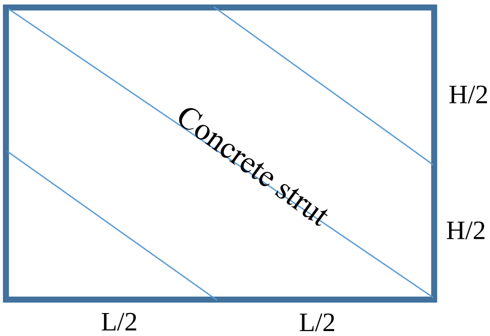


Fig (14) Diagonal compression strut for concrete wall model

The thickness of the equivalent strut is equal to the thickness of the concrete wall, but the problem lies in determining a suitable width for this strut. There are many researches that have been interested in identifying this width for infill walls without reinforcement [12,13,14,18,19]. Several relations were suggested to determine this width, all of which take into account the dimensions and stiffness of the wall, as well as the dimensions and stiffness of the boundary elements (beams and columns).

Mainstone and Weeks [19], gave equivalent diagonal strut concept based on experimental and analytical data, and proposed an empirical equation for the calculation of the equivalent strut width. This equation was adopted by FEMA 356[4].

$$a = 0.175(\lambda\, h_{col})^{-0.4}\, r_{inf} \qquad \textbf{(8)}$$

$$\lambda = \left[\frac{E_{inf} t_{inf} \sin 2\theta}{4 E_{fe} Ic\, h_{inf}}\right]^{1/4} \qquad r_{inf} = \sqrt{{h_{inf}}^2 + {L_{inf}}^2}$$

Where: t_{inf}, h_{inf}, and E_{inf} are the thickness, the height and the modulus of the infill panel respectively, θ is the angle between diagonal of the infill and the horizontal, Ec is the modulus of elasticity of the column, Ic is the moment of inertia of the columns, H is the total frame height, and λ is a dimensionless parameter.

r_{inf} : Diagonal length of infill panel, L_{inf} : Length of infill panel. h_{col}: Column height between centerlines of beams.

We will adopt the relations (8), but it needs some modifications to be appropriate for the concrete infill wall used in the composite shear wall (C-SPSW). For the behavior of materials of the steel frame, steel plate strips, and the three concrete strut representing the concrete wall, the same behavior used in the numerical model 3D has been adopted.and recommended in reference studies and in the FEMA code.

6- Results and its discussion:

6-1: Simplified Model Validation: To create the simplified model, the width of a single concrete strut is calculated by dividing the value obtained by equation (8) evenly over the three struts used for modeling the concrete wall. Figure 16 shows a comparison between the base shear-displacement curves from the basic numerical model 3D and the simplified model for a composite, single-story, shear wall (Ar = L / H = 1).

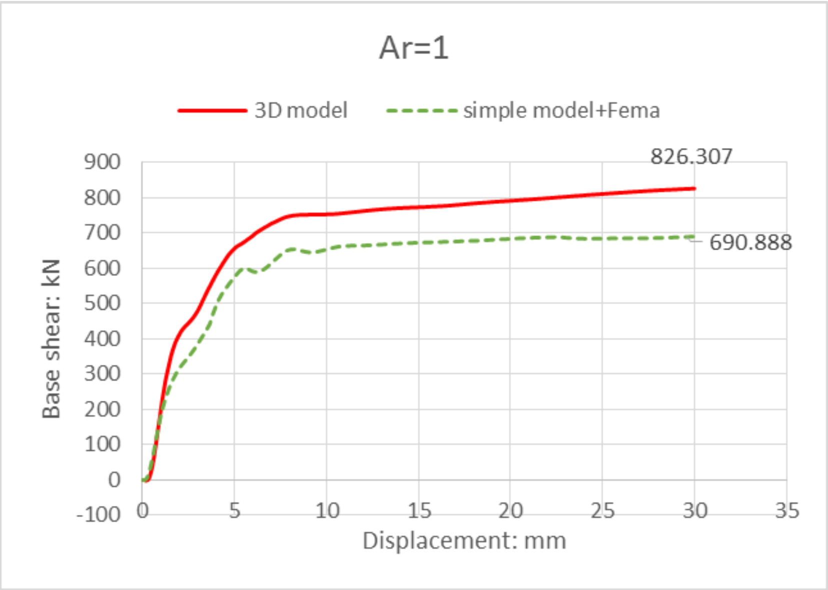


Fig (15) C-SPSW force-displacement in case 3D and simple model by Eq(8)

Table (2) summarized the wall specification

Table (2) Wall design parameter: Dim:mm

a	t_{inf}	r_{inf}	L_{inf}	I_C	E_{con}	E_{inf}	h_{inf}	h_{col}
192.22	40	1548.12	1008	8.2972E7	25000	200000	1175	1250

Figure (15) shows that the simplified model gives lower values than the actual values (in the basic model 3D) where the difference in maximum resistance is 16.5%.This difference is mainly due to the fact that the resistance of the concrete strut used in the simplified model is less than the actual contribution of the concrete wall. we consider that relations (8) originally adopted for non-concrete infill walls is not fully appropriate for reinforced concrete infill walls used in the composite shear wall (C-SPSW).

By examining the distribution of stresses within the 3D wall in (Fig.13), we observe that the concrete stresses were mainly concentrated in a compression region diagonally formed between the two corners of the wall. In addition, the diagonal compression region is partially supported by the beam and column

Based on these observations, the wall can be replaced by a diagonal equivalent strut with the same thickness of the concrete wall. Then, we need to determine the equivalent width of this strut. For this, we have relied on the following calibration method: The maximum diagonal resultant force (Rc) in the concrete wall was calculated as shown in Fig-16.

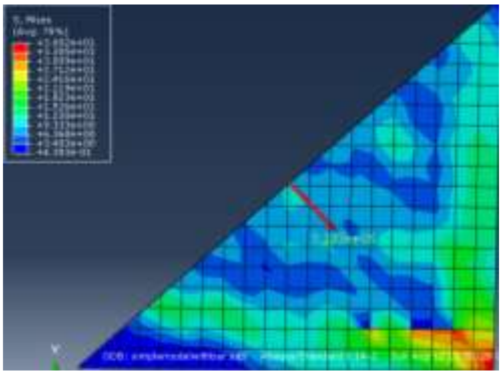


Fig (16) maximum diagonal resultant force (Rc) in the concrete wall

For a composite wall with aspect ratio of 1 (Ar=1), the maximum diagonal resultant force (Rc) is equal to 3.5E + 5 N as shown in Fig-17. Then, the equivalent width of the diagonal strut is calculated by equation (9).

$$a_{new} = \frac{Rc}{0.85F'c*t} = \frac{3.5E+5}{0.85*28*40} = 368mm \qquad \textbf{(9)}$$

In equation (9), the compression stress is supposed to be uniformly distributed over the concrete wall thickness (tc = 40mm), and the concrete strength is equal to (0.85f'c).

Based on this result, the relationship (8) can be modified to obtain the relationship (10) which is adequate to calculate the total width of the equivalent strut for concrete infill walls:

$$a_{new} = 0.35(\lambda\, h_{col})^{-0.4}\, r_{inf} \qquad (10)$$

The relationship (10) gives values equal to twice the value obtained using the relationship (8). This indicates that the concrete material and the reinforcement increase the efficiency of the infill wall to resist diagonal compression. We calculate the width of the concrete strut according to relation (10) for the same composite wall studied in this paragraph (Ar = 1) and we analyze again using the simplified analytical model.

Figure (17) shows that the wall capacity calculated by the numerical model 3D reached 826 kN, while the calculated wall capacity using the simplified model reached (760 kN). Thus, the simplified model can predict the maximum resistance with accuracy of more than 90%.

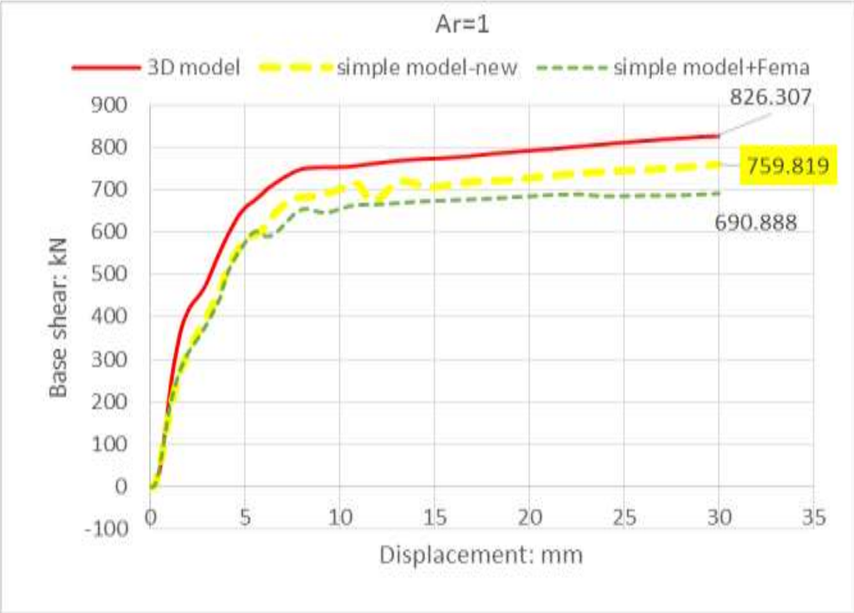


Fig (17) C-SPSW force-displacement in case 3D and simple model by Eq(8) and modify Eq(10)

To validate the modified relation (10) we will test it on a set of composite shear walls with different aspect ratio through the subsequent parametric study.

6-2: Parametric Study:

The relations (1), (2) and (10) are used to define the properties of the steel plate strips and the strut of the concrete wall in the simplified model show that these properties depend on the dimensions of the steel plate and the concrete wall. In this paragraph, a parametric study is carried out on a single-bay single-story (C-SPSW) with different aspect ratios. Table (3) summarizes the geometric characteristics and aspect ratio of the studied composite shear walls. The thickness of the steel plate is (ts =1.6mm), the thickness of the concrete wall is (tc =40mm). the beam and column sections were fixed for all the studied models. The section (IPE240) was used for the columns and section (M3, 2.9) for the beams.

Table (3) C-SPSW design parameter

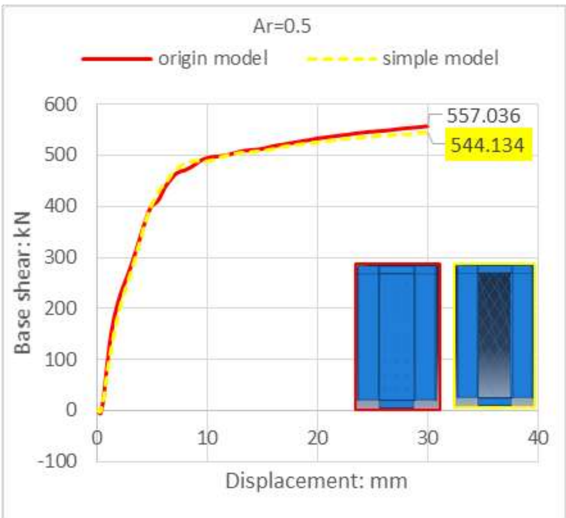
Wall type	H(mm)	B(mm) width	Ar	H_{inf}(mm)	L_{inf}(mm)
W1	1250	625	0.5	1175	383
W2	1250	1000	0.8	1175	758
W3	1250	1250	1	1175	1008
W4	1250	1900	1.5	1175	1658
W5	1250	2500	2	1175	2258

The parameters of the simplified analytical model (properties of the strips and the struts) are summarized in Table (4).Ten steel strip and three concrete strut were used, the angle of inclination of the steel strip (α) is calculated with the vertical direction, but the angle of the concrete strut is calculated with the horizon [1].

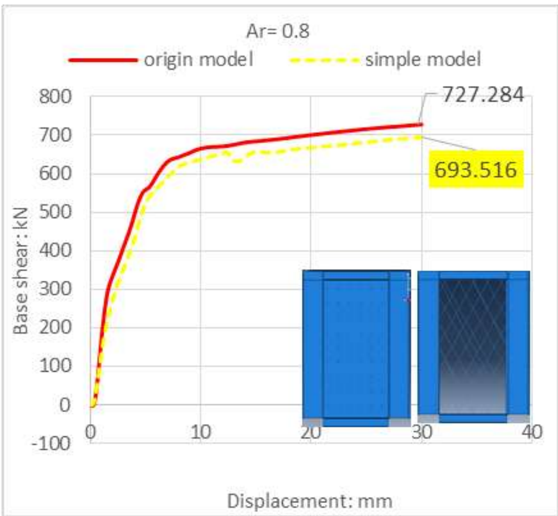
Table (4) simplify C-SPSW model design parameter (strip and strut)

$a_{new}/3$	B_{strip}	θ	α	Wall type
107.7	97.64	72	34.11	W1
150	129.25	52.2	34.7	W2
128.15	149.96	49.39	35	W3
169	202.77	35.34	35.7	W4
215	251.47	27.50	36.36	W5

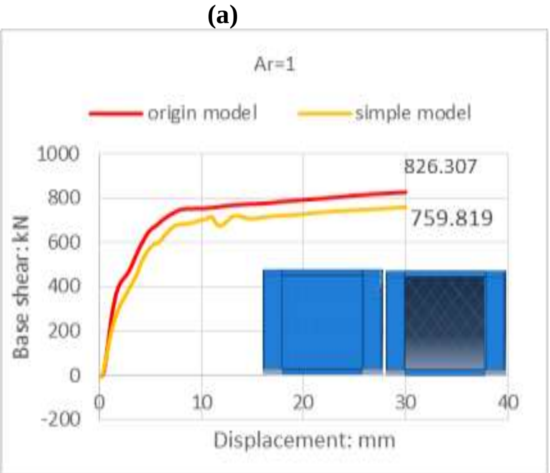
Figure (18: a ~ e) shows a comparison between the base shear-displacement curves resulting from (3D) model and those resulting using the simplified analytical model for all studied composite shear walls. Table (5) summarizes the maximum resistance of the studied composite shear walls for the two previous models as well as the differences between the two models



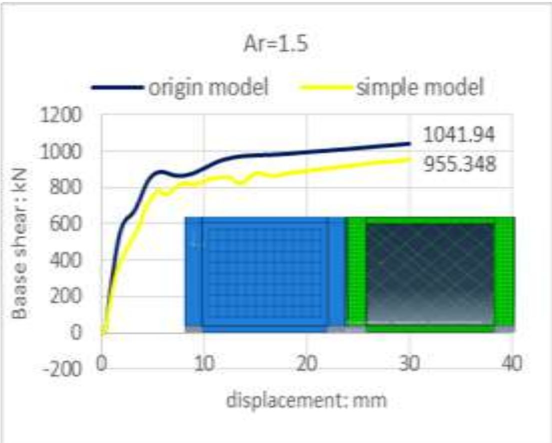
(a)



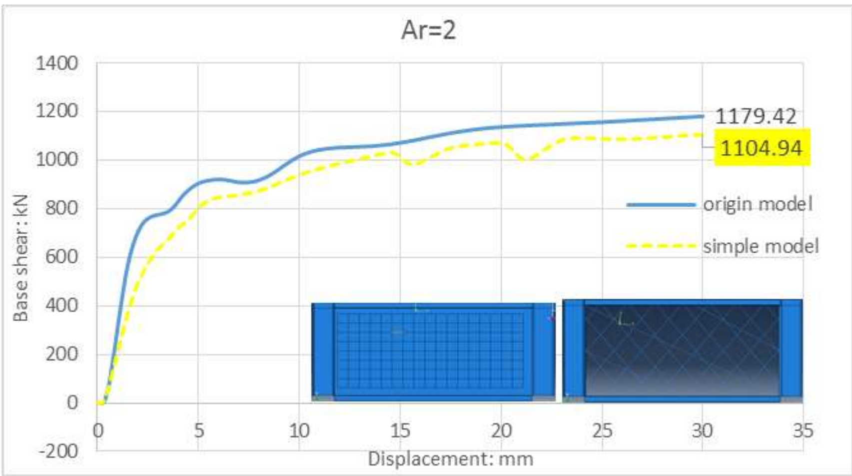
(b)



(c)



(d)



(e)

Fig (18) C-SPSW force-displacement in case 3D and simple model by modify Eq(10)

Table (5) Maximum force resistance in case 3D and simple model by modify Eq(10)

Difference %	Simple model(kN)	3D origin wall(kN)	Aspect ratio
2.316	544.134	557.036	Ar=0.5
4.64	693.516	727.284	Ar=0.8
8	759.819	826.307	Ar=1
8.31	955.348	1041.94	Ar=1.5
6.31	1104.94	1179.42	Ar=2

The curves shown in (Fig. 18) and the values of (Table 5) show that the simplified analytical model can predict the total nonlinear behavior of composite steel plate shear wall with good accuracy of more than 92%. It is worth mentioning that the simplified analytical model developed in this study is valid for composite steel plate shear wall with aspect ratio in the range of (0.5 - 2).

7-Conclusions and commendations:

A 3D numerical model of C-SPSW was created using ABAQUS finite element software and validated according to experimental results. Simplified analytical model for C-SPSW was developed based on the steel plate strip model and the concrete diagonal compression strut model. The following conclusions can be mentioned:

1. for composite shear walls with aspect ratio not less than one, The concrete wall contribution to the shear resistance of composite shear wall (C-SPSW) is more than 20%.

2. A diagonal compression field is formed in the concrete wall, which is partially supported by the beam and column in the corner area of the wall.

3. The steel plate was modeled using two group of inclined strips with angle of inclination (α), calculated using equation (1). Each group contains at least 10 strips placed in opposite directions.

4. The concrete wall was modeled using three concrete struts; a diagonal one between the two opposite wall corners and two parallel struts, each one connects the middle of the beam and column. The width of the concrete strut is calculated using relation (10).

5. The results showed that the width of the concrete strut equivalent to the diagonal compression field formed in the concrete wall is approximately two times greater than that calculated by FEMA356 for infill walls of block or cement brick.

6. The simplified analytical model developed in this study is valid for composite steel plate shear wall with aspect ratio in the range of (0.5 - 2). It is able to predict the overall lateral response with good accuracy of more than 92%.

Recommendations:

We recommend carrying out a parametric study to assess the effect of changing the number and angle of the strip on the overall nonlinear behavior of the simplified analytical model**.**

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