Tension walls shear test simulation and study in LS_DYNA for IiA9844

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Arup International Consultants (Shanghai) Co Ltd Shenzhen Branch
6/F Duty Free Building
No. 6 Fuhua Yi Road
Futian Central Business District
Shenzhen 518048
China
www.arup.com

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			Prepared by	Checked by	Approved by
		Name	Zi-peng Xu, Yin-pei Xin Sheng-wei Zhen	Hai Lin	Y Wang
		Signature			
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Contents

1 Introduction

For most of the super tall buildings' concrete core walls, it is a normal situation that partial wall piers need to resist tension and shear simultaneously at the L3 earthquake or large wind cases. However, there are not test based guideline and specification for its design. In order to study the failure mechanism, hysteretic behaviour, load-carrying capacity, ductility, stiffness and energy dissipation of the shear wall, five specimen walls with different axial tensions were studied by test research under IiA funding 9844. The test research work finished at April 2015, and then funding team started numerical simulation work.

It is very important that the numerical model's material can simulate the mechanical behaviour in this condition correctly, which will help engineer to judge the accuracy of the calculation and analysis in special projects. The previous studies based on cases that the shear wall was at eccentric compression condition. And the properties of the material have not been tested exclusively in eccentric tension and shear condition. So, the simulate study was done to gain insight on modelling of reinforced concrete tension walls under lateral cyclic loading in LS-DYNA, with focusing on using MAT_172 CONCRETE_EC2.

2 Test program and LS-DYNA Model

2.1 Test specimens

The test specimens are composed with five shear walls. In order to study the influence of axial tension, different axial tension were applied to this five shear walls. The detail of specimens are shown as table1.

Table 1 the detail of specimens

Specimen number	**bars**	**The strength of concrete**	**Axial tension/(kN)**	**Tensile ratio**	**Loading style**
SW1			0	0	repeatedly
SW2			176	0.86	repeatedly
SW3	Shown as the figure 1	C40	380	1.85	repeatedly
SW4			578	2.82	repeatedly
SW5			578	2.82	repeatedly

Note:

- *The tensile ratio is defined as N/(ft*A).*
- *Compared with SW-4, there are shear resistant diagonal bars inside SW5.*
- *The section height/width ratio of walls are 1.5.*

The tested material properties of the reinforcement are summarized in Table 2. Steel reinforcement stress-strain curve is detailed in accordance with the current codes GB 50010-2010 and GB50011-2010.

Table 2 Material properties of bars

Diameter(mm)	**Yield stress of bar f_y(MPa)**	**Ultimate stress of bar f_u(MPa)**	**Youngs Modulus E_s(N/mm^2)**	**Calculated Yield strain**
Φ6	661.7	744.7	2.0×10^5	0.003309
Φ8	582.5	638.7	2.1×10^5	0.002774
Φ22	490.3	617.3	2.0×10^5	0.002452
Φ25	445.0	576.7	2.0×10^5	0.002225

According to test and GB50010-2010, the compression strength and tensile strength of concrete is 40MPa and 2.47MPa respectively.

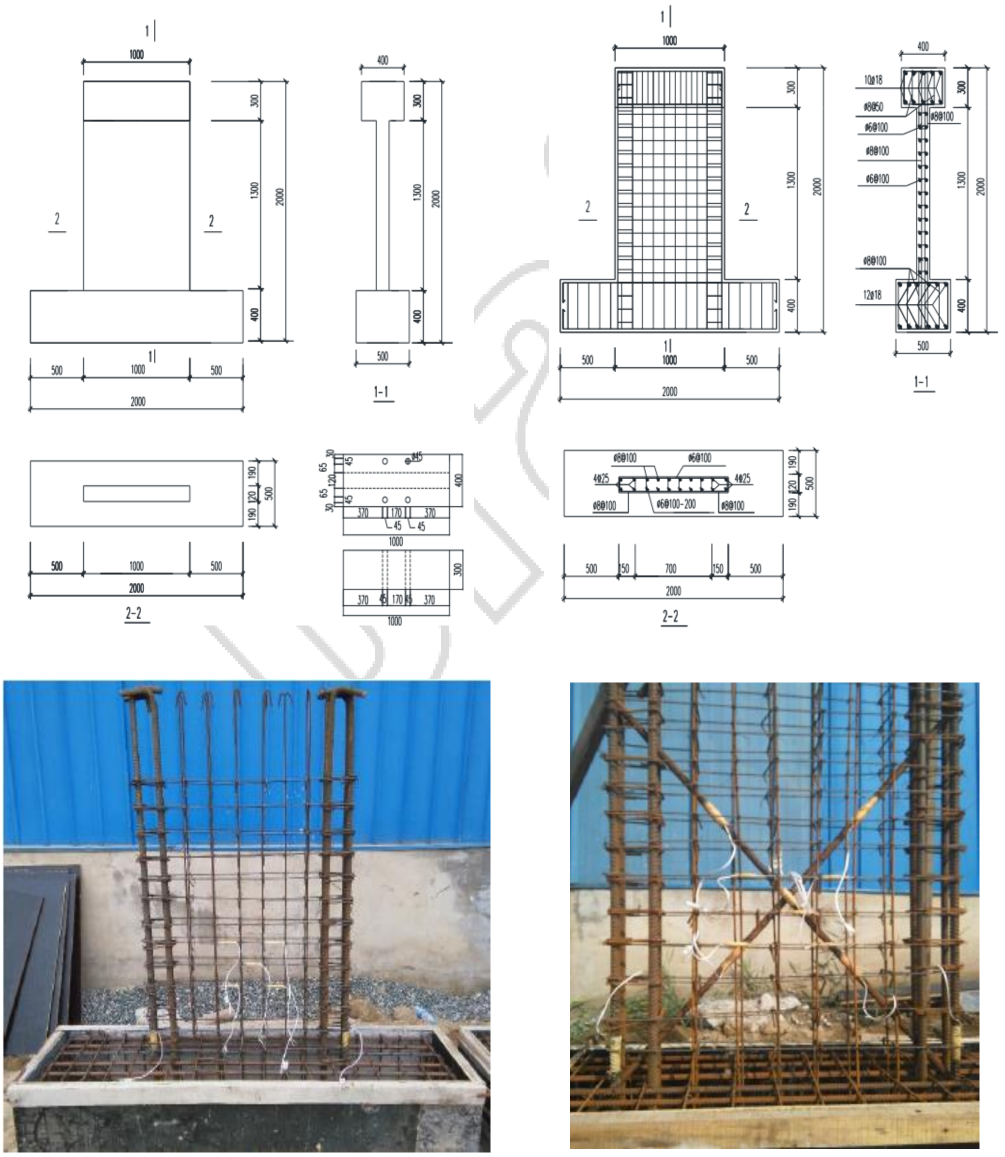


Figure 1 Specimens details

2.2 Loading history

All specimens were subjected to a similarly loading histories, which was shown as Figure 2. A two-phase cyclic loading scheme was used in the Test. Firstly, the cracking loading was calculated, then a certain percentage of the cracking loading was used, and increased the loading gradually till the wall crack. Secondly, after cracking, multiple displacement of cracking cyclically was exerted on and until the specimen's failures.

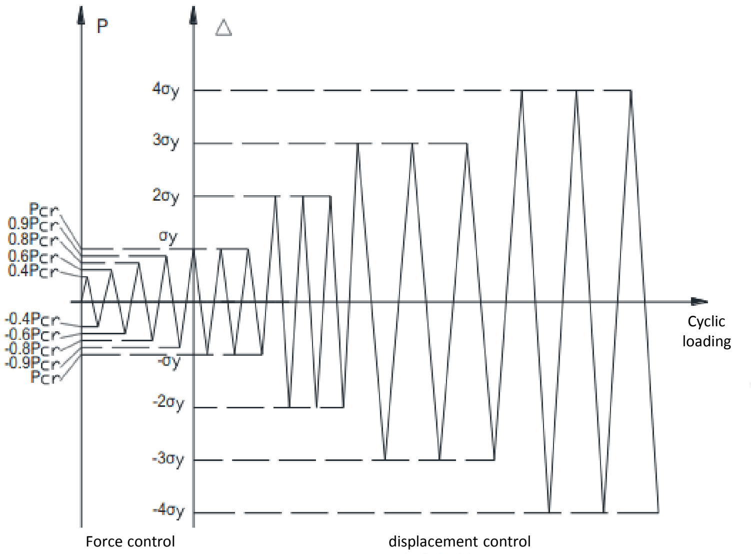


Figure 2 Loading history

2.3 LS-DYNA Model

2.3.1 Material

For both the unconfined and confined concrete, Mat_172 CONCRETE_EC2 was used.

2.3.2 Section

A shell model was created for each shear wall. The section of the shell contained 7layers- two outer layers, two layers of horizontal reinforcement, two layers of vertical reinforcement and one inner concrete layer, and the total thickness of the section is 120mm.

2.3.3 Boundary

The boundary condition was assumed according to the Test in order to simulate truly. The top nodes in relative area of bear beam were connected with the ground by two real stiffness screws, and the bottom nodes were connected with ground by springs that can only provide compressive stiffness. Besides, the translation of all the bottom nodes was constraint in global x-direction. The figure of LS-DYNA model are shown as below.

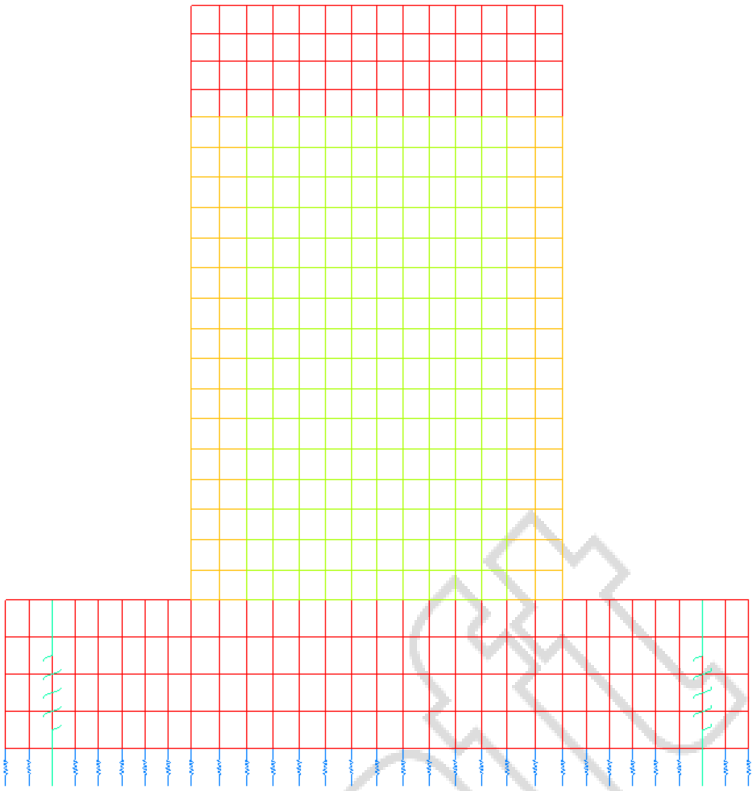


Figure 3 the Diagram of model in LS-DYNA

3 Test results

3.1 Failure mode from test observation

Figure 4 show the failure mode of different specimens. There are some test phenomena that summarized below.

The number of cracks about SW1 is relatively small and the cracks development slowly at the entire process. There is a main cracks with 45 degree angle and SW1 shear failure finally.

The cracks distribute discretely and intensive throughout the shear wall if there is a tension on the wall. There is some main cracks with 30 degree angle and which become to 45 degree angle finally with the shear failure mode.

There is some diagonal bars in the SW5, the cracks will concentrate around the diagonal bars, and the development of cracks will be controlled. The number of cracks is more than SW4. The diagonal bars can improve the shear capacity and energy consumption effectively.

Note,

There are not horizontal cross-section shear failure phenomenon been observed, although the specimens are short walls.

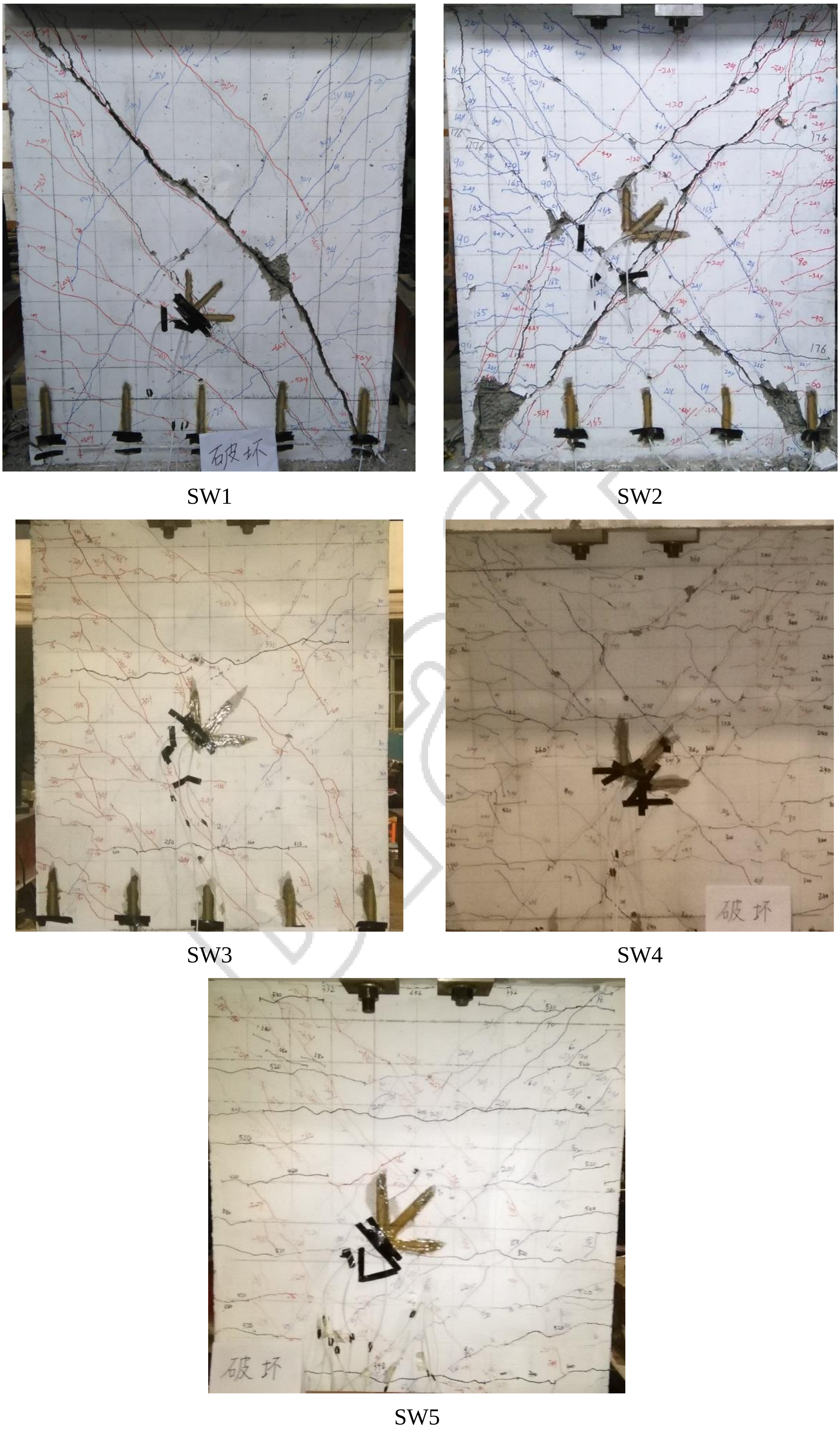


Figure 4 failure mode of specimens

3.2 hysteretic response

The lateral-displacement hysteretic response for the specimens with different tension is shown in Figure 5. Compared with SW1, the capacity of SW2 to SW4 will degrade, and that will degrade more as the tension increasing. Besides, the hysteresis loops showed an anti-S shape for the stiffness degradation and the phenomenon is known as pinching effect. And the phenomenon is more pronounced with the increase of tension. So the tension will degrade the ductility and energy dissipation capacity of shear wall.

While, the hysteretic response for SW3 and SW4 show that the capacity degrade limited. Although the tension is bigger than the tension capacity of concrete much more, and which will lead to the form of horizontal cross-section cracks, the shear wall still have certain capacity and ductility.

If the diagonal bars was added in SW5, the cracking load, the initial stiffness and the shear capacity will improve greatly. Besides, the ductility and energy dissipation capacity of shear wall were also improved greatly.

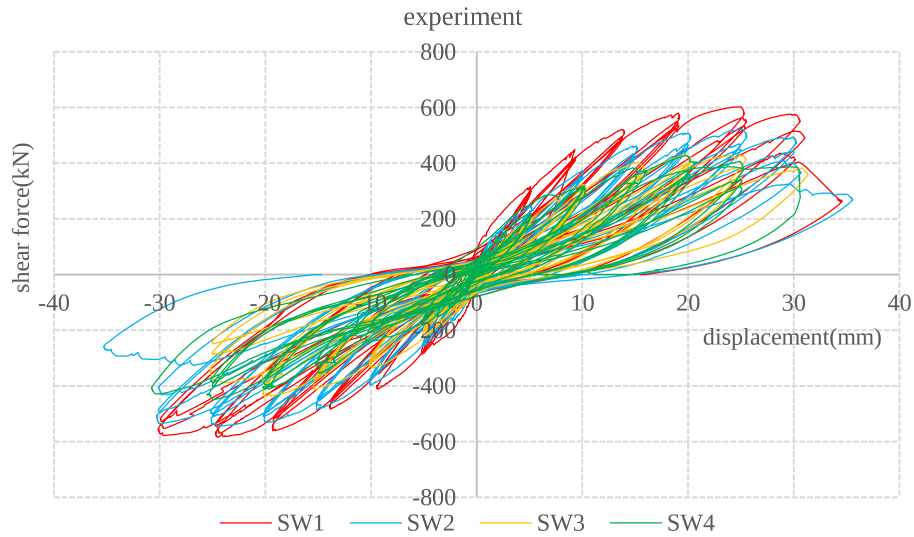


Figure 5 Comparison of test results for Shear walls with different tension

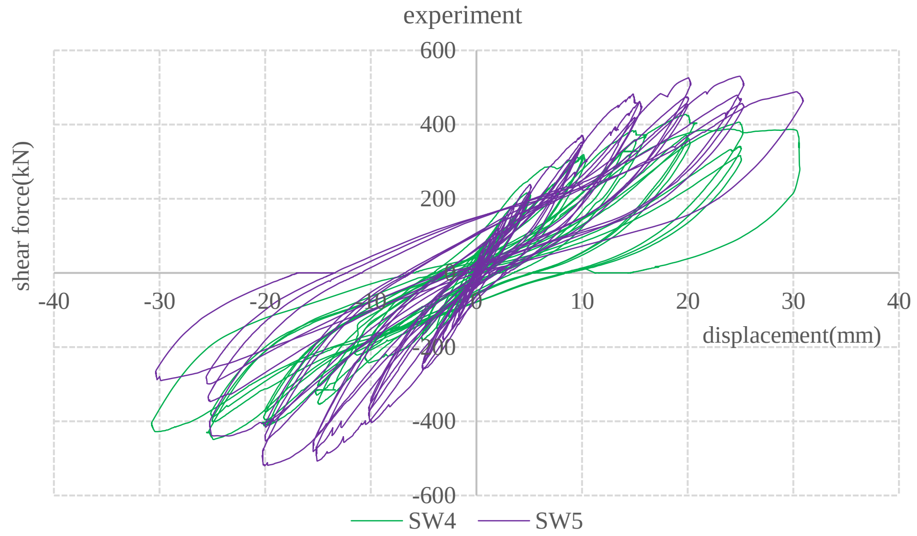


Figure 6 Comparison of test results for SW4 and SW5

4 Material

In this report, we focus on whether the material EC2 can simulate the shear behaviour about the tensioned RC wall correctly. The comparison about hysteretic behaviour will be an appropriate criteria.

After doing some simulation, there are deficiencies for EC2 to simulate the behaviour under the loading combined tension and shear, especially for the condition that the tension was applied first. The simulation results show as below.

4.1 Horizontal cross-section shear strength

Studies about the material of EC2 show that the friction on crack planes will not help the wall to resistant the shear force when there is no compression in the crack plane, and the transverse bars and longitude bars also will not help to resistant shear force when the cracks are parallel to the transverse bars. So, the only parameter that can help to simulate the shear behaviour of wall is TAUMXC. But, the Figure 7 to Figure 9 show that the parameter of TAUMXC can’t simulate the behaviour of wall accurately.

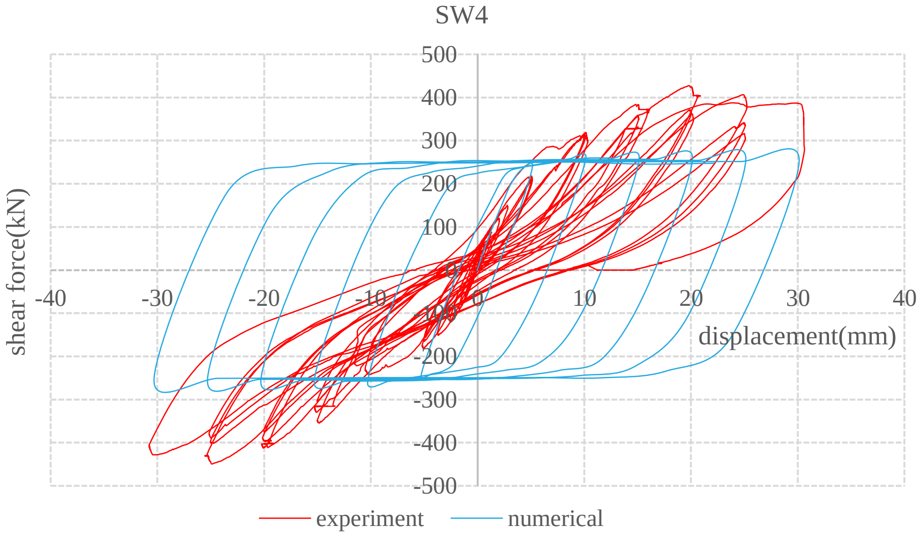


Figure 7 Hysteretic behavior about shear wall4

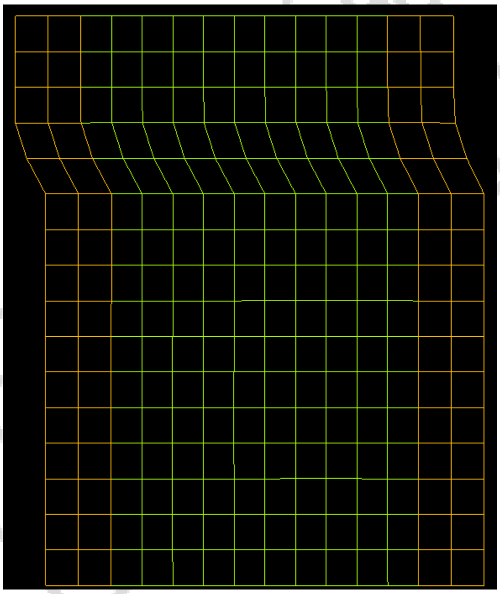


Figure 8 Diagram of the deformation about Shear wall4

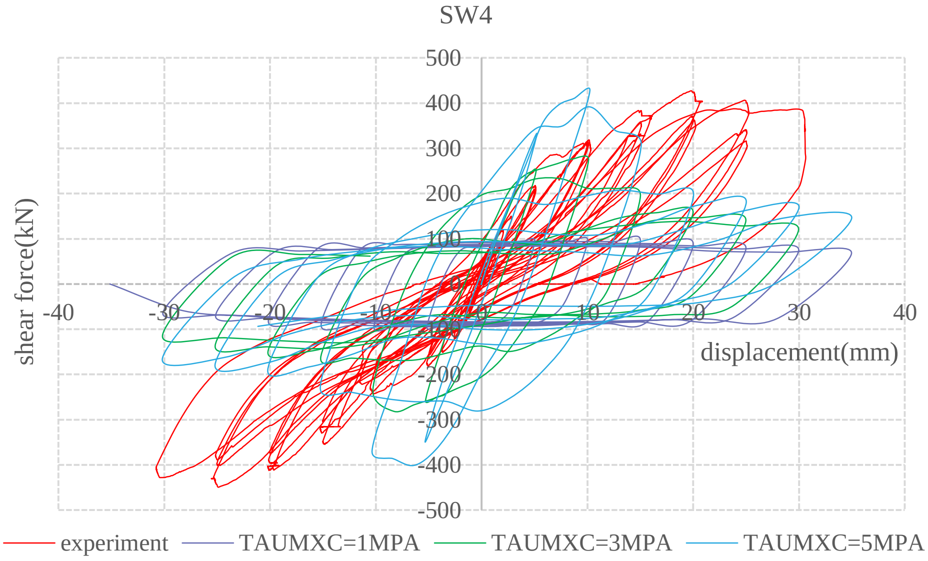


Figure 9 Comparison of hysteretic behaviour with different TAUMXC

Note: TAUMXC is the max through-thickness shear stress after cracking

In MC2, the concrete by default is assumed to crack in tension once the maximum in-plane principal stress reaches f_{tk}. Cracks can open and close repeatedly under hysteretic loading. But, the direction of the crack relative to the element coordinate system is stored when the crack first forms, and a second crack may form perpendicular to initial crack. So the initial crack is parallel to the transverse bars when there is a tension on the wall, and the second crack will perpendicular to the transverse bars. In this condition, transverse bars and longitude bars will not help to resistant the shear force.

In order to solve this problem, some attempts are adopted. A feasible suggestion is that the first crack and the second crack must be diagonal, and the intersecting reinforcement will help to resistant the lateral force, as shown in Figure 10. The analysis assumption that the tension and lateral force exert together was utilization. The analysis results are detailed in Chapter five.

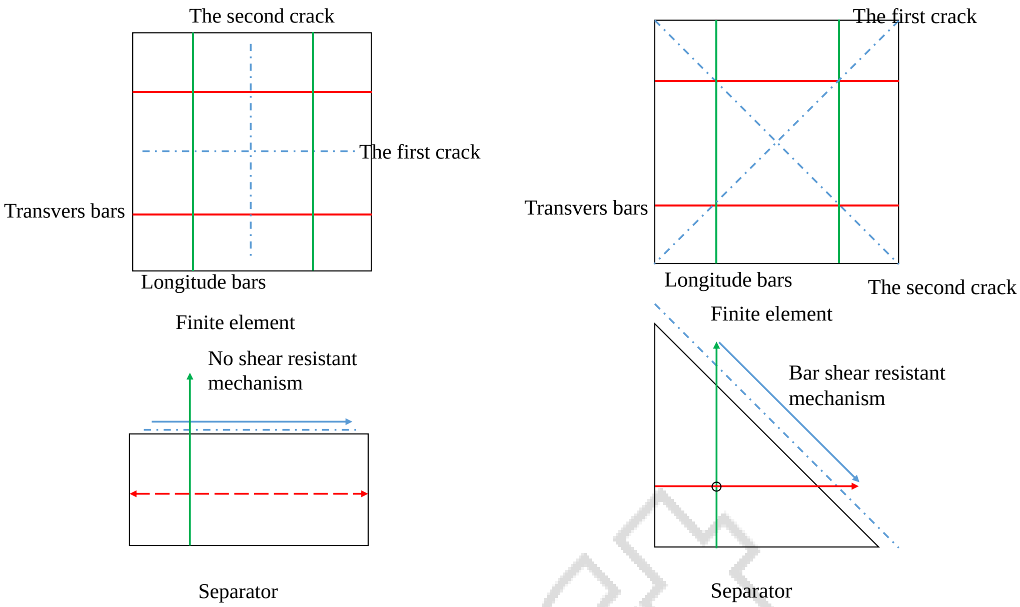
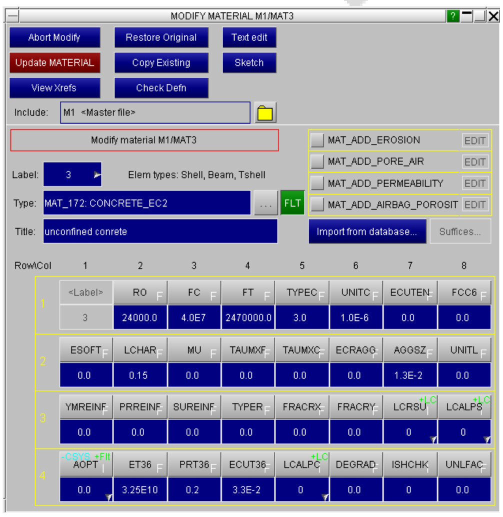


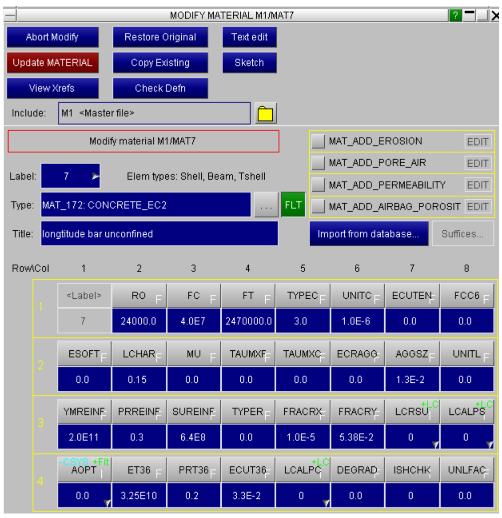
Figure 10 shear force mechanism

5 Comparison with numerical model

Based on the analysis of Chapter four, one attempt is adopted so as to simulate the failure mode and hysteretic behaviour about the SW3 to SW5 which withstand greater tension. The relate results are shown as below.

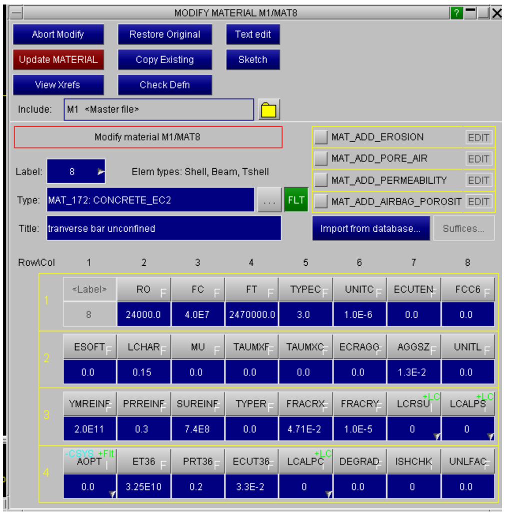
Figure 11 shows the relate parameter values for SW1 and SW2. The mass density magnify 10 times so as the calculation time will reduce, and the effect of gravity is limited compared the tension. So, all model don't consider the gravity. The strength of the material and young’s modulus are adopted based on the Chinese code. According to the experimental phenomenon, five shear wall is be in shear failure mode that the transverse bar is pulled off. So, the ultimate strain of concrete are design large relatively to avoid the failure of concrete crushed.





The layer of concret

The layer of longitude bar

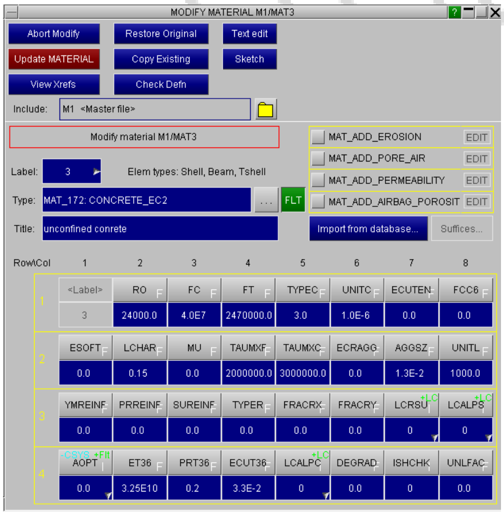


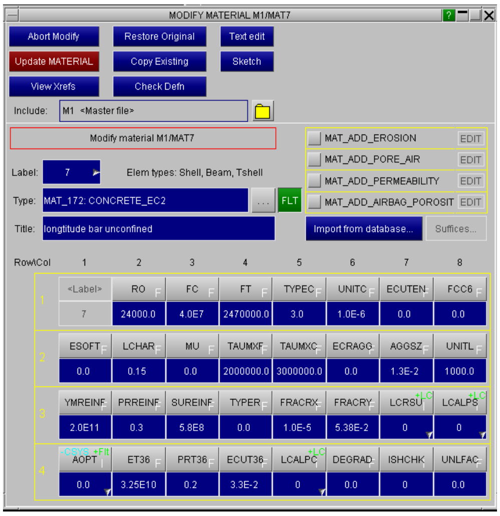
The layer of tranverse bar

Figure 11 The relate material parameter value for SW1 and SW2

For SW3, SW4 and SW5, the relate parameter values will be same different. In order to simulate the horizontal cross-section shear capacity, the parameter of TAUMAF (Maximum friction shear stress on crack planes) and TAUMXC (Maximum through-thickness shear stress after cracking) are introduced, shows as Figure 12.

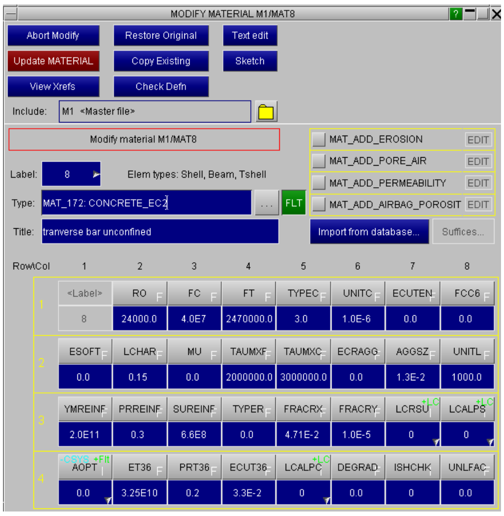
While, the judgement based on the concept and analysis results show that the TAUMAF will not effect for there will not compression stress when the wall was exerted tension.





The layer of concret

The layer of longitude bar



The layer of tranverse bar

Figure 12 The relate material parameter value for SW3, SW4 and SW5

5.1 Shear Wall1

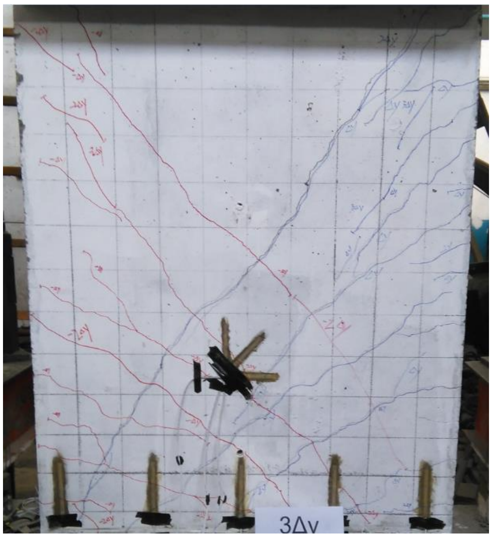
According to the Assumption, there is no axial tension on the SW1 (shear wall1), the failure mode and hysteretic behaviour are shown as below.

5.1.1 Failure mode

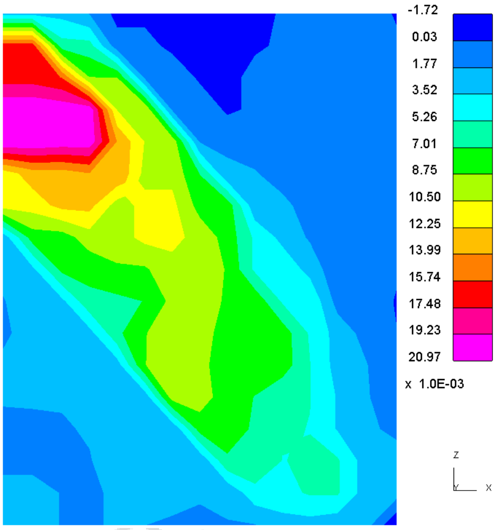
When the first crack appears, the lateral displacement in this status is defined as the yield displacement status. And in the phase of displacement control, multiplied yield displacement was exerted on the wall. There are two states including two or three times of the yield displacement status and the damage status respectively that the test focus on mainly.

1) In the status of two or three times of the yield displacement, cracks appear entirely and the main diagnose crack was formation. The strain about transvers bars shows the results, most of the wall in the middle part area were over the yield strain.

2) In the status of damage, some transvers bas were pulled off, the width of diagnose crack was very large, which can also be observed at the transverse bar's strain.

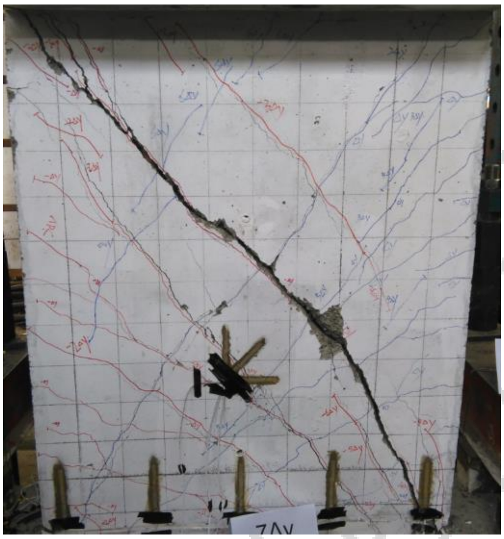


Test

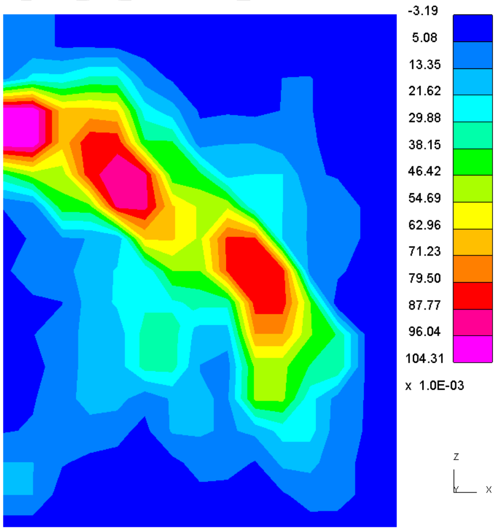


The strain about the tranverse bars

The status of three times of the yield displacement



Test



The strain about the transverse bars

Damage state

Figure 13 The comparison about the damage between test and numerical model

5.1.2 Hysteretic behaviour

Figure 14 shows the lateral-displacement hysteretic behaviour of SW1.

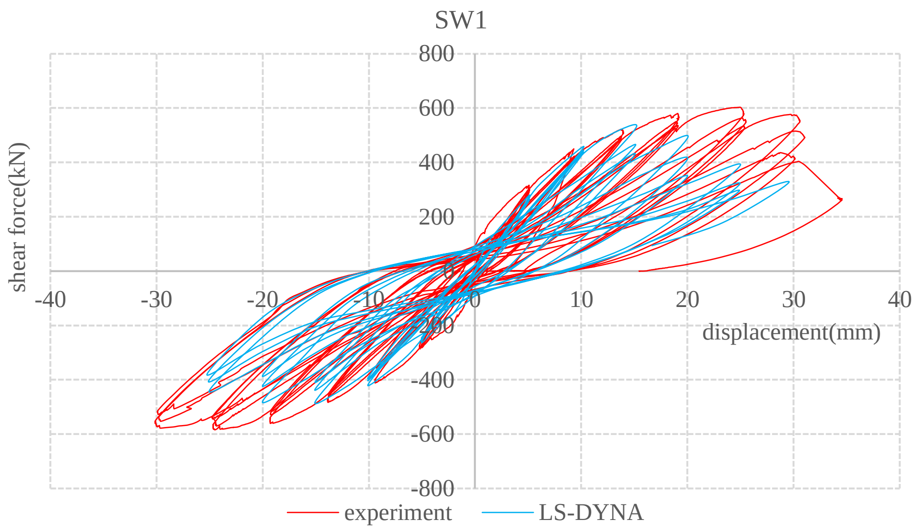


Figure 14 Comparison of DYNA results and test data for SW1

The results show that the material can well simulate the behaviour of shear wall without accurate tension. But the shear capacity will be smaller than in the Test.

5.2 Shear Wall2

The tension force about SW2 is 176kN on the top and the calculated average stress is 0.83f_t. If there is tension, the element is easy to damage under the action of lateral loading for the hourglass can't be controlled. So the model can't simulate the behaviour of wall completely. In order to solve the problem, the element must be changed to full integration element.

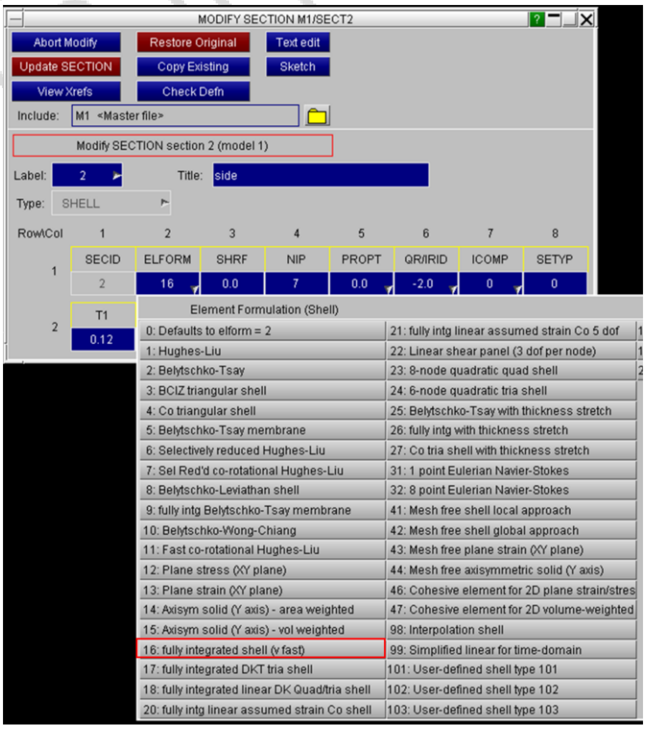
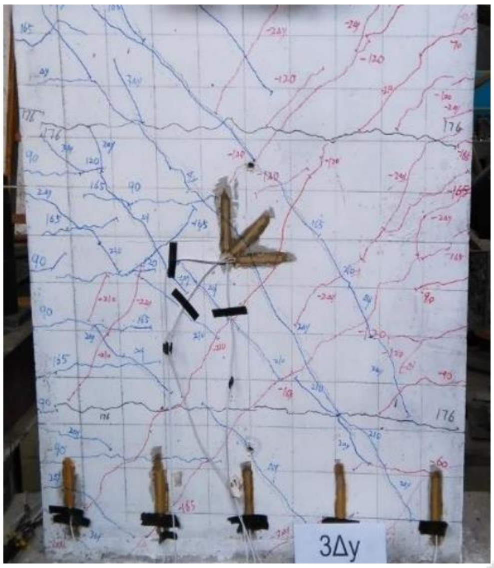
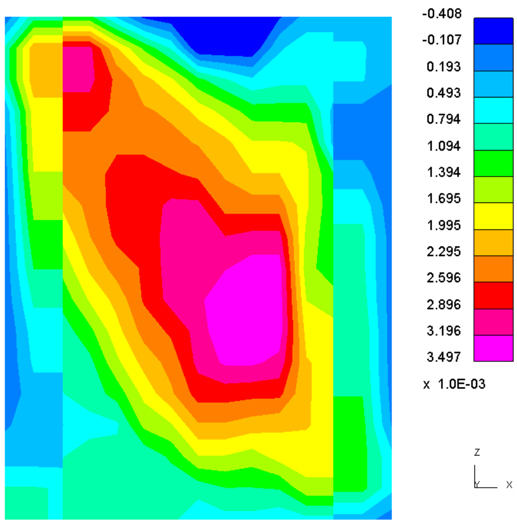


Figure 15 Fully integration section category

5.2.1 Failure mode

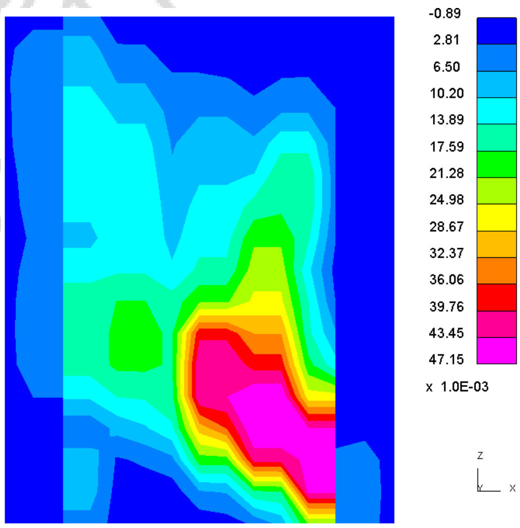
Like shear wall1, there were also two states of behaviour need to be studied about the SW2. And the analysis results are similar with that of SW1





Test The strain about the transverse bars

The status of three times of the yield displacement



Test The strain about the transverse bars

Damage state

Figure 16 The comparison about the damage between test and numerical model

5.2.2 Hysteretic behaviour

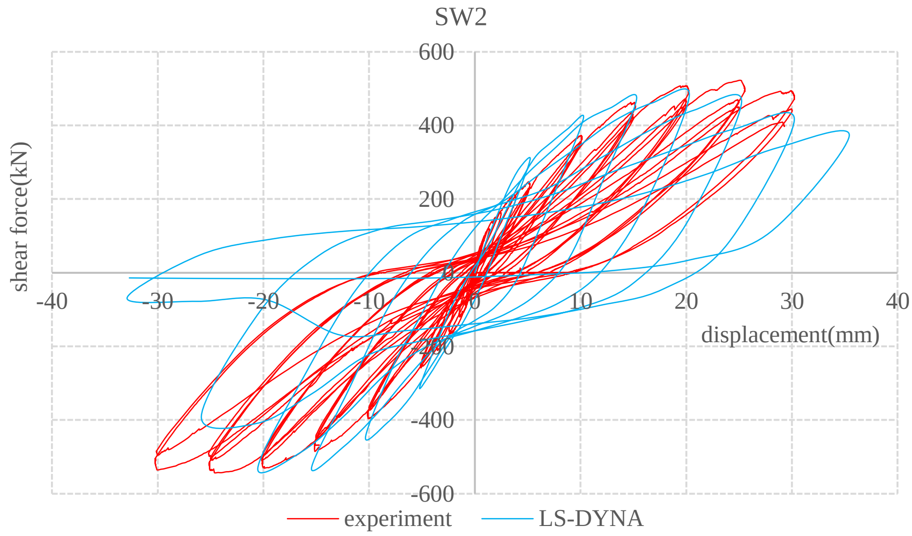


Figure 17 Comparison of DYNA results and test data for SW2

Figure 17 show that the initial stiffness and capacity of the wall can be simulated accurately, but the pinching effect is not serious than the Test.

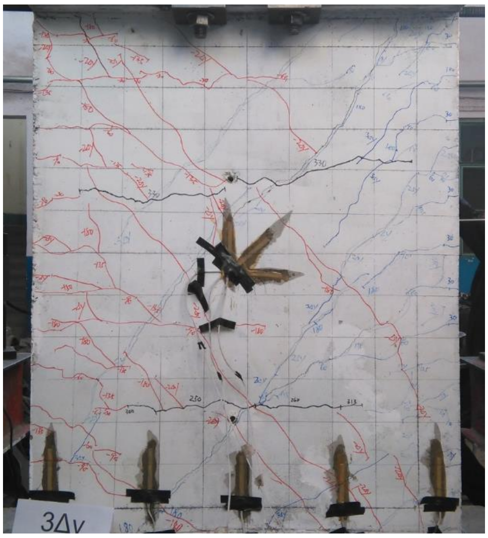
5.3 Shear Wall3

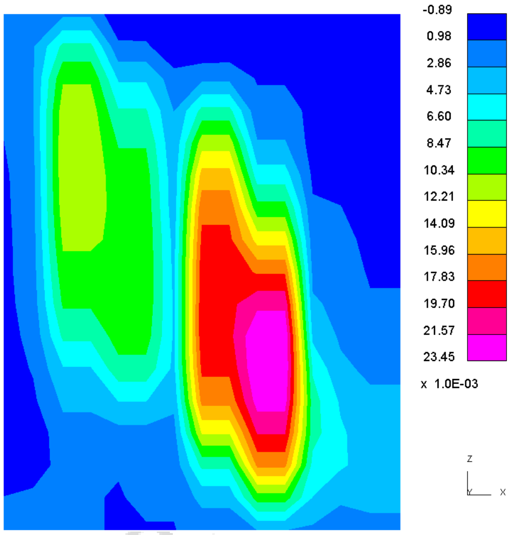
The tension force about SW3 is 380kN on the top and the calculated stress is 1.85f_t.The tension was over the strength of concrete, and there will be some through cracks in the wall. In this condition, the shear capacity of SW3 will be break greatly.

As mentioned above, the material EC2 can't simulate the behaviour of shear wall if there are some horizontal cross-section cracks that parallel to the transverse bars. So, the assumption that the tension and lateral force exert together. The analysis results show as below.

5.3.1 Failure mode

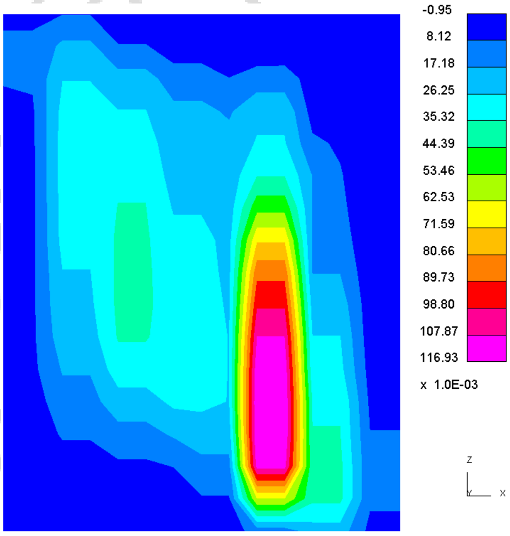
The failure mode was also similar with the sw1 and sw2. But, the number of diagnose cracks was more than SW1 and SW2. Except that the diagnose crack's width was not so wide.





Test The strain about the transverse bars

The status of three times of the yield displacement



Test The strain about the transverse bars

Damage state

Figure 18 The comparison about the damage between test and numerical model

5.3.2 Hysteretic behaviour

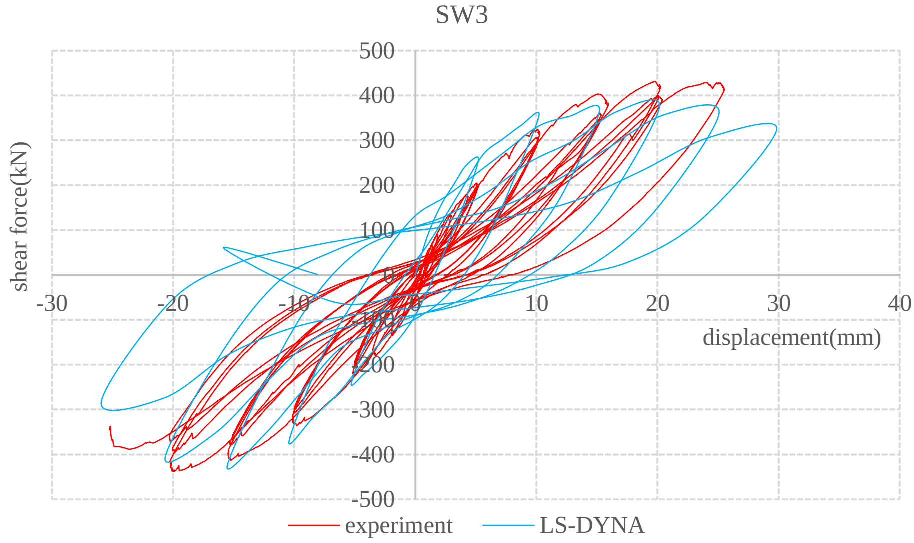


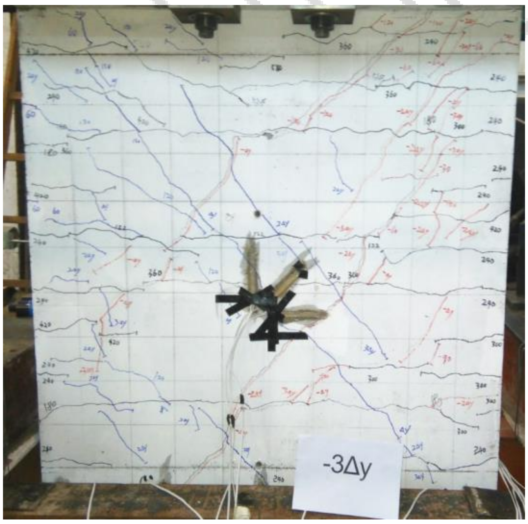
Figure 19 Comparison of DYNA results and test data for SW3

Figure 19 show that the simulation results is similar with SW2.

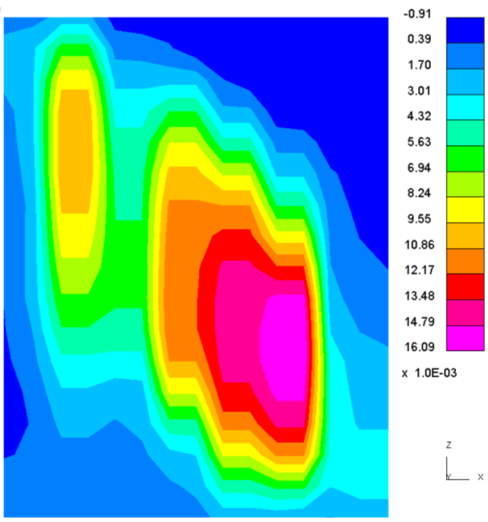
5.4 Shear Wall4

The tension force about SW4 on the top is 578kN and the calculated average stress is 2.82f_t. The tension was many times over than the tension strength of concrete, and there will be more horizontal cracks in the wall.

5.4.1 Failure mode

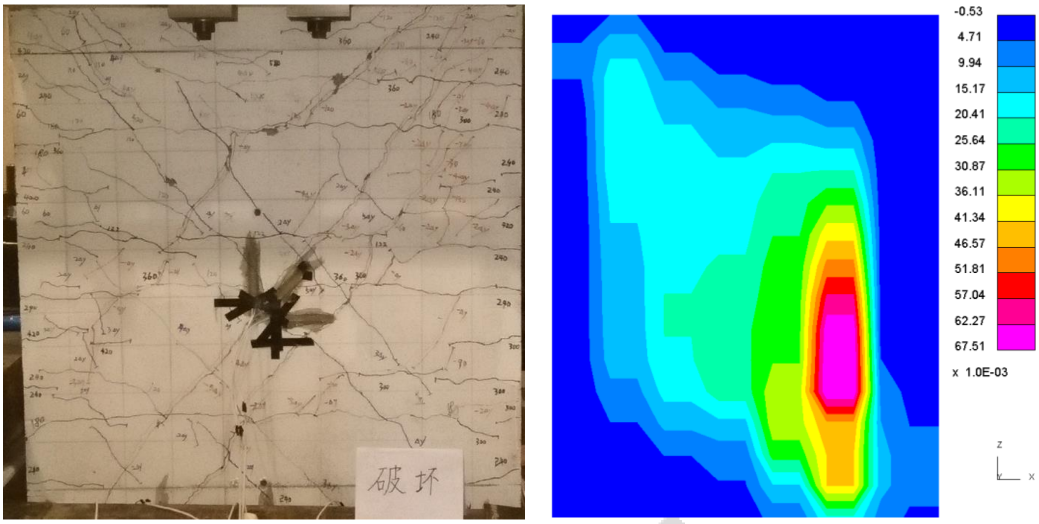


Test



The strain about the transverse bars

The status of three times of the yield displacement



Test The strain about the transverse bars

Damage state

Figure 20 The comparison about the damage between test and numerical model

5.4.2 hysteretic behaviour

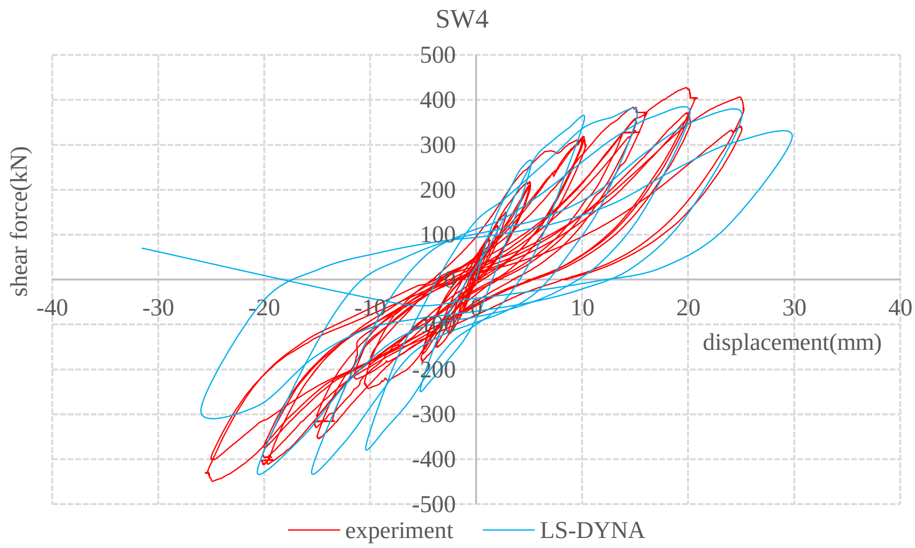


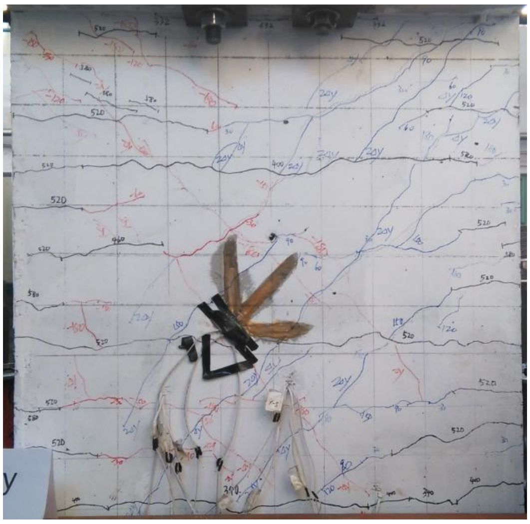
Figure 21 Comparison of DYNA results and test data for SW4

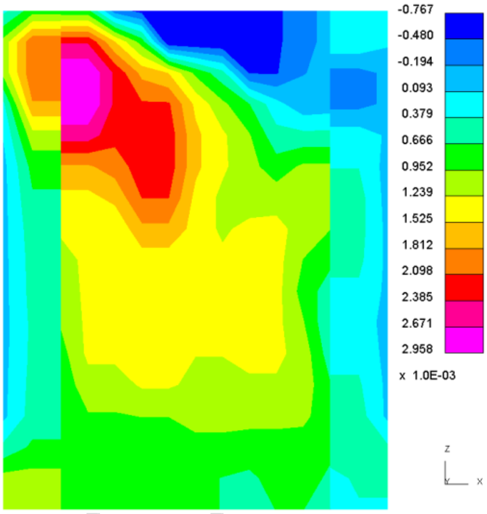
Figure 21 show that the simulation results is similar as SW2 and SW3.

5.5 Shear Wall5

Compared with SW4, there are two shear resistant diagonal bars inside SW5 and the tension force is equal. The diagonal bars is simulate by Mat_003 PLASTIC_KINEMATIC.

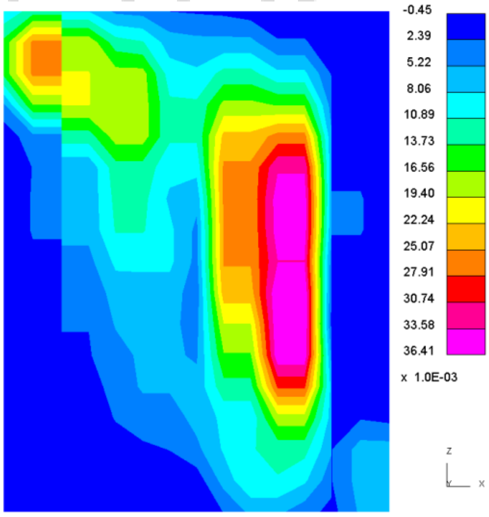
5.5.1 Failure mode





Test The strain about the transverse bars

The status of two times of the yield displacement



Test The strain about the transverse bars

Damage state

Figure 22 The comparison about the damage between test and numerical model

5.5.2 hysteretic behaviour

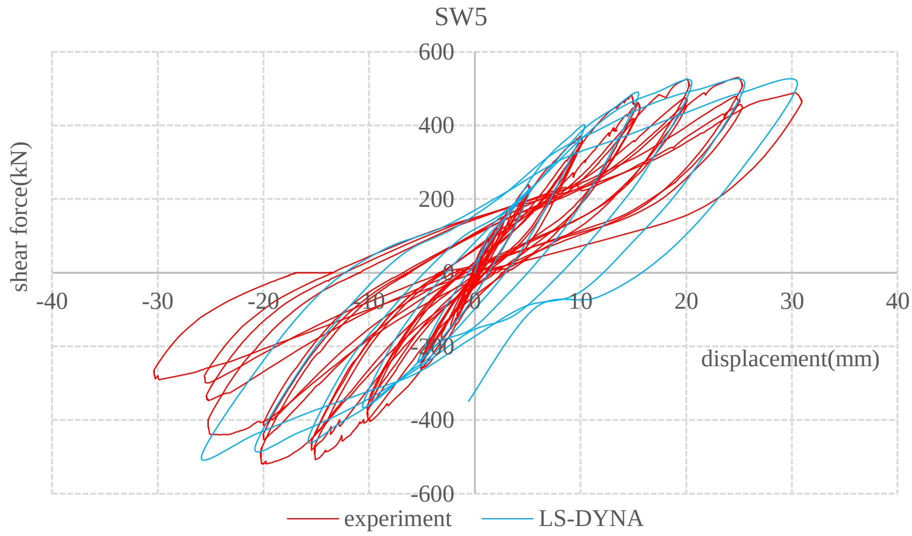


Figure 23 Comparison of DYNA results and test data for SW5

6 Conclusion and suggestion

Through the above analysis, the following conclusion and suggestion can be obtained.

1. The crack loading and ultimate loading of shear wall will drop if there is a tension on the wall, besides, the shear capacity, stiffness and ductility will degrade as well. So, structure design and analysis need to consider the effect of tension in the walls.

2. It is an effective method to add the diagonal bars in the shear wall to help to improve the shear resistant performance of shear wall under large tension forces.

3. A attempt that the first crack and the second crack are controlled to be diagonal is adopted in this study, and the simulation results are similar with the experiments

4. It is difficult for EC2 to simulate the shear behaviour if there initial crack is parallel to the transverse bars. So, maybe some parameters that can help to improve EC2 capability would be added.

5. The simulation of pinching effect for tension wall is not accurate according to this study, so the relate parameter could be considered to refine.

7 Reference

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