# Numerical Simulations of the Bond Stress-Slip Effect of Reinforced Concrete on the Pushover Behavior of Wall

*by* Sudarno P Tampubolon

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# Numerical Simulations of the Bond Stress-Slip Effect of Reinforced Concrete on the Pushover Behavior of Wall

Sudarno P Tampubolon[1], Chung-Yue Wang[2], Ren- ZuoWang[3)]
[1]*(Civil Engineering, Christian University of Indonesia, Indonesia)*
[2]*(Professor, Dept. ofCivil Engineering, National Central University, Taiwan)*[3]*(Associate Researcher, National Central for Research on Earthquake Engineering, Taiwan)*

***ABSTRACT :*** *Structure failure often occurs in the structure of wall. This failure can adversely affect the comfort level of the structure. Knowing the behavior of structure resulting from the load is important, as it can help to predict the strength of the structure and comfort of the structure being worked on. One way to find out and predict the strength and comfort of the structure as a result of the load received is experimental test and simulation. The simulation VecTor2 used to predict the shear force, crack, and displacement of reinforced concrete wall when applied the load. This simulation considered the effect of bond stress-slip effect of behavior reinforced concrete. Bonds stress-slip gives a great influence on the strength and hysteretic response of the reinforced concrete wall. That is why this study considers the influence of bond stress-slip on reinforced concrete wall. All the result of simulation VecTor2 using bond stress-slip effect would be compared with the result of the experimental test to see the accuracy of the simulation test.*

***KEYWORDS -****reinforced concrete, wall, bond stress-slip effect, perfect bond, reinforced concrete (RC), VecTor2 simulation.*

## I. INTRODUCTION

Some experiment test already doing the test to know the behavior and predict the strength of the wall for the loading applied. Generally, the failure occurs for the wall is crack. The crack occurs of the wall when getting load maximum. Actually, this condition often occurs for the structure when the natural disaster. In the real case for the structure wall usually found the crack position occurs in the longitudinal line.

This research doing experimental test in National Center for Research on Earthquake Engineering (NCREE) and compare with the simulation VecTor2 to predict the displacement and maximum shear of wall. For the loading test for the wall applied with the displacement loading control. The experiment test doing test for the one specimens. This specimen has size (150x150) cm for the wall, (43x250) cm for the foundation and top beam.

## II. LITERATURE REVIEW OF VECTOR2

The main focus of this study was to understand the modeling capabilities of VecTor2 under monotonic loading and also displacement loading control conditions for structure. Therefore, a variety of the types of connections, material properties and connection details examined was crucial for confirming the applicability of the program or identifying it is limitations. The specimens consisted of reinforced concrete wall and seismically and non-seismically designed wall that was analyzed under simulated seismic loading conditions similar to those followed during the experimental tests. The modeling efforts were utilized using the default behavior or constitutive model options in order to prove that the program successfully captures the necessary response parameters without any modifications to the structure details.

The study of the bond material behavior at the interface between reinforcement and concrete was one of the focus of this research. This research formulated "how to calculate the shear force, displacement, and crack prediction that occurs for interior beam-column joint, exterior beam-column joint, beam, column, and wall when applied the axial force and displacement loading control. To know the behavior of structure it's important to predict some failure which one occurred for structure or element.

The purpose of this study was to show the success using the program for default material constitutive modeling specimens. The results of this study will allow VecTor2 to be used as a modeling tool to know behavior of reinforced concrete wall, and will provide useful data for the designer. So the next future this program will be used to design some behavior for reinforced concrete wall because easier and not expensive comparing with the experimental study, also can give assessment data structure before and after retrofitting techniques are applied.

## III. CALCULATION OF BOND STRESS-SLIP MODELS WALL

Simulation VecTor2 consider the effect of bond stress-slip models for embedded bars. effect this model giving an impact on the behavior of reinforcement and concrete. This condition considers the behavior of friction between concrete and steel reinforcement of wall load. Before got value of confined reference bond stress and slip, the first doing try and eror to make sure the value. This value will be use to calculated and predicted behavior of bond-slip. This behavior determined by confinement pressure factor (β), which one of this condition determined by linear interpolating between the unconfined and confined reference bond stress and slip. This behavior can be calculated with:

$$\beta = \frac{\sigma}{7.5} \text{ (in Mpa) } 0 \leq \beta \leq 1 \qquad 3.1)$$

$$\sigma = \rho_t . f_y \qquad 3.2)$$

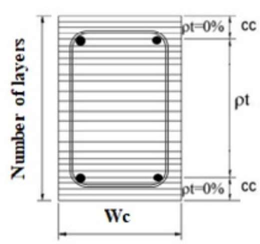


Figure 3.1Transverse reinforcement ratio position.

$f_y$ = yielding strength of the transverse reinforcement; $\rho_t$ = transverse reinforcement ratio.

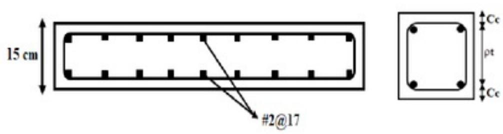


Figure 3.2Detail of transverse reinforcement ratio of wall

$$\rho t = \frac{2xAb}{stxwc} = \frac{2x32.2}{170x150} = 2.5x10^{-3} = 0.25\%$$

$$\beta = \frac{\sigma}{7.5}; \text{ (in MPa) } 0 \leq \beta \leq 1$$

$$\sigma = \rho_t \text{ x } f_y = 0.0025x377 = 0.9425MPa$$

$$\beta = \frac{\sigma}{7.5} = \frac{0.9425}{7.5} = 0.126$$

## IV. SIMULATION AND EXPERIMENTAL TEST

### IV.1 Setup Experimental Test Reinforced Concrete Wall and Simulation VecTor2

Test setup for the experimental test wall shows in Figure 4.1 As mentioned earlier, the experimental reinforced concrete wall using three kind type of concrete compressive strength. This condition caused, the experimental test would like to see the behavior of concrete wall with high concrete quality. The boundary condition of the experimental test uses the bolt for a foundation to make specimen rigid.

The load-displacement control was applied beside the top of the beam and also applied an axial load 1725 kN on the top of a beam. The loading would be applied until the wall can withstand the load given. Loading deflection and an axial load applied to the specimen test, it would give some behavior for the experimental test reinforced concrete wall like; crack, lateral force maximum, and displacement.

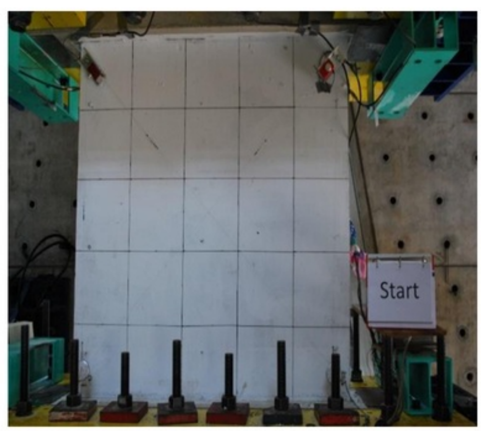


Figure 4. 1Test setup experiment test for the wall (Jyun-JieTsao, 2018)

The simulation Vector2 for the reinforced concrete wall require region type and element size to build-up specimen simulation. Simulation wall consists of three regions (foundation, wall, and top beam) and uses mesh size (50x50) mm for all regions. Table 4.1 shows the detail region and mesh size of simulation reinforced concrete wall. The boundary condition for the simulation wall applied pinned on the foundation and roller on the top beam. Figure 4.2 shows the modeling wall simulation VecTor2 and position of the boundary condition.

Table 4.1Region Type and Parameter Design Wall Simulation VecTor2

| Region Type | Member Type | Element Size (mm) | Vertices X | Vertices Y |
|---|---|---|---|---|
| Region I | Foundation | 50 x 50 | 0 | 430 |
| | | | 0 | 0 |
| | | | 2500 | 0 |
| | | | 2500 | 430 |
| Region II | Wall | 50 x 50 | 500 | 430 |
| | | | 2000 | 430 |
| | | | 2000 | 1930 |
| | | | 500 | 1930 |
| Region III | Top Beam | 50 x 50 | 0 | 2360 |
| | | | 0 | 1930 |
| | | | 2500 | 1930 |
| | | | 2500 | 2360 |

The same behavior with the experimental test, the load deflection for the simulation VecTor2 applied beside the top beam and on the top surface beam applied an axial load of 1725 kN. Axial load and load displacement control were applied together for the experimental test and simulation. This simulation also considering the bond-slip effect to predict the behavior of reinforced concrete wall.

Try and error simulation carried out to predict the value of bond-slip confinement pressure (β) and obtained value 0.002. This value would compare with bond-slip calculation as explained in chapter 5.3 to see the accuracy of the simulation. Obtained the value of bond-slip confinement pressure of 0.126 for calculation. Simulation try and error, less compatible and need more time to predict bond-slip confinement pressure. From this simulation, better using the calculation to predict the bond-slip effect.

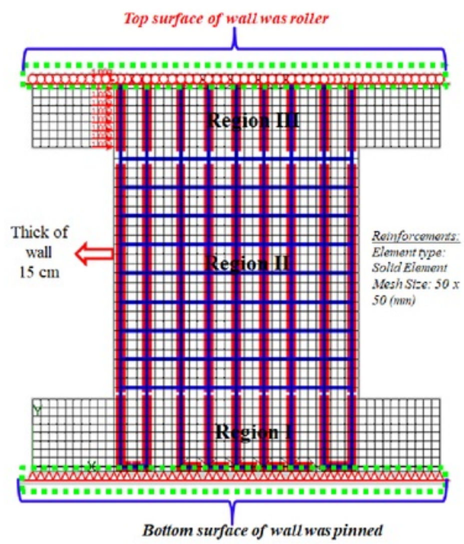


Figure 4.2Test setup Wall Simulation VecTor2 (VT2)

## IV.2 Simulation Reinforced Concrete Wall by the VecTor2 code

Simulation wall by the VecTor2 code using a mesh size of wall 50x50 mm, bond-slip confinement pressure (β) 0.126, applied load displacement control and axial force on the top of the surface wall 1725 kN. From the VecTor2 simulation obtained the total number of nodes for the simulation wall is 2263 nodes and number of elements 2426 elements. Basically, the crack of the wall occurs like the diagonal line when applied the load-displacement and axial load.

This simulation and experimental test want to know the strength of the lateral force and the crack position occurring. The results of experimental and simulation VecTor2 shown in Table 4.2 andFigure 4.3 shown the crack position, stress tension, and strain tension of simulation VecTor2 and experimental at drift ratio 0.25%.

Table 4.2 Comparison results experiment test and simulation VecTor2

| Wall I | Experimental Test | Simulation VecTor2 | Ratio = VT2 / Exprt |
|---|---|---|---|
| Load at (drift ratio 0.25%), kN | 816 | 937.1 | 1.14 |
| Displacement (mm) | 3.75 | 3.75 | 1 |
| Load at (drift ratio 0.375%), kN | 1002.52 | 1048.5 | 1.04 |
| Displacement (mm) | 5.625 | 5.625 | 1 |
| Bond slip calculation | - | 0.126 | - |
| Bond slip try and error | - | 0.002 | - |
| Axial Load | 1725 kN | | |

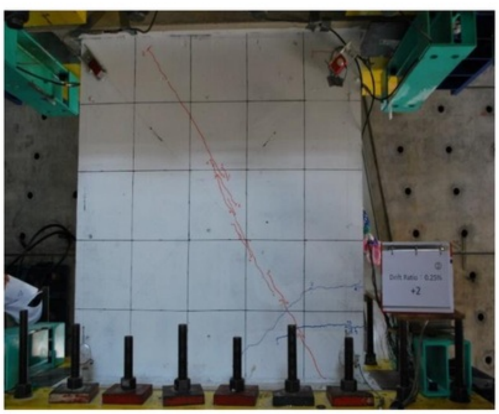

Figure 4.3.aCrack of position at drift ratio 0.25%, experimental wall

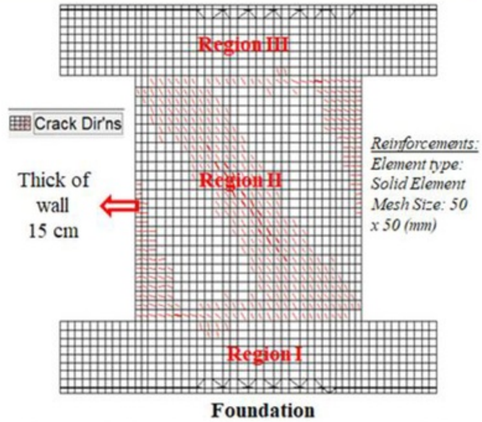


Figure 4.3.bCrack of position at drift ratio 0.25%, Simulation VecTor2

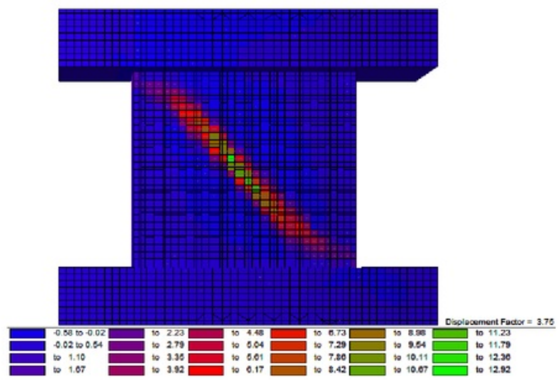

Figure 4.3. cStress tension ($\sigma_T$)at drift ratio 0.25%, Simulation VecTor2

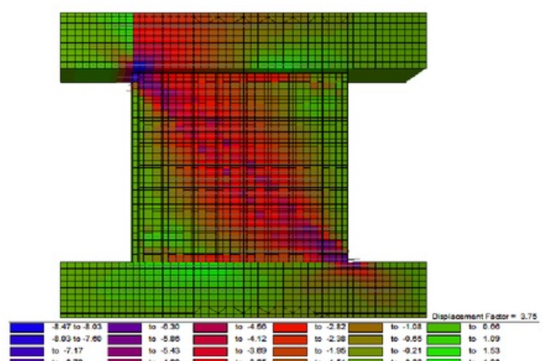

Figure 4.3.d Strain tension ($\varepsilon_T$)at drift ratio 0.25%, Simulation VecTor2

Simulation VecTor2 can predict the thickness of crack that occurs of that wall I. The position of thickness crack would be predicted same as the experimental test at drift ratio 0.25%. Figure 5.6 shows the graphics position of the crack thickness of simulation VecTor2 for drift ratio 0.25% and displacement 3.75 mm. The position of the crack thickness will be seen at different distances at the x-direction.

The crack maximum value obtained in this simulation is 1.16 mm. For the experimental test for the wall, the maximum value got at a drift ratio of 0.35% and displacement 5.625. Figure 4.4 shown the crack position, stress tension, and strain tension of simulation VecTor2 and compared with the experimental test at a drift ratio of 0.35%.

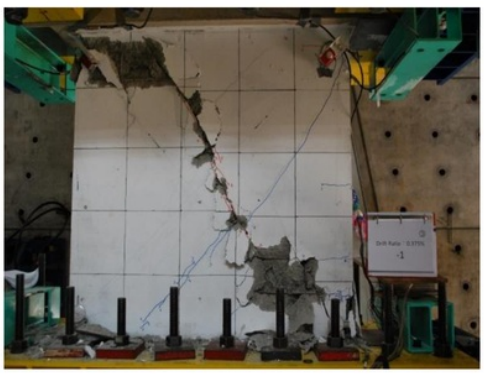

Figure 4.4.a Crack of position at drift ratio 0.35%, experimental wall

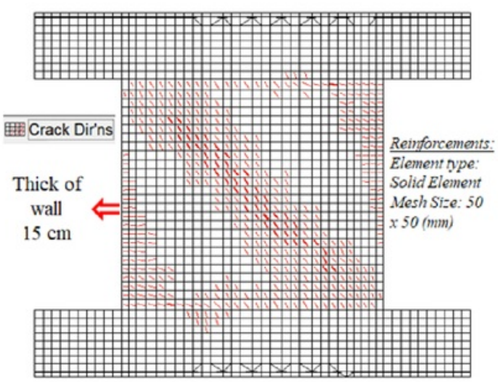


Figure 4.4.b Crack of position at drift ratio 0.35%, Simulation VecTor2

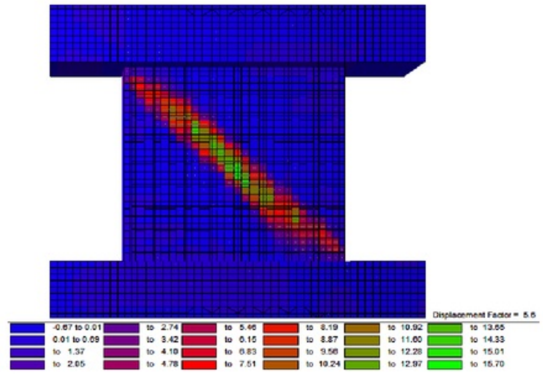

Figure 4.4.cStress tension ($\sigma_T$)at drift ratio 0.35%, Simulation VecTor2

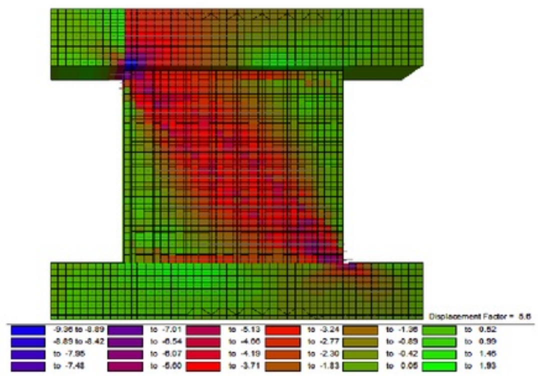

Figure 4.4.dStrain tension ($\varepsilon_T$)at drift ratio 0.35%, SimulationVecTor2

The position of thickness crack would be predicted same as the experimental test at drift ratio 0.25% and drift ratio 0.35%. The crack maximum value obtained in this simulation is 2.01 mm. When drift ratio 0.25%, the maximum value of the lateral force for the simulation VecTor2, 937.1 kN, experimental 816 kN, a ratio of peak load simulation and experiment 1.14, while for drift ratio 0.35%, the maximum value of the lateral force for simulation VecTor2 get the peak load 1048.5 kN, experimental 1002.52 kN and ratio peak load simulation and experimental is 1.05. Figure 4.10and Figure 4.11 shows the comparison hysteretic loop of experimental and simulation VecTor2 on drift ratio 0.25% and 0.35%.

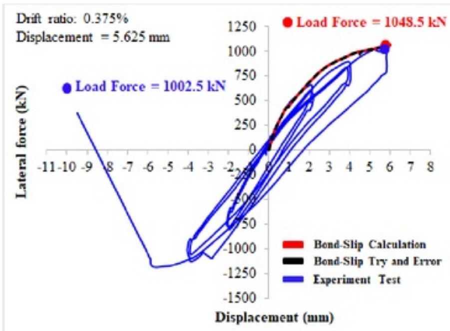


Figure 4.5Hysteretic loop combination experiment test and simulation VecTor2 at drift ratio 0.25%.

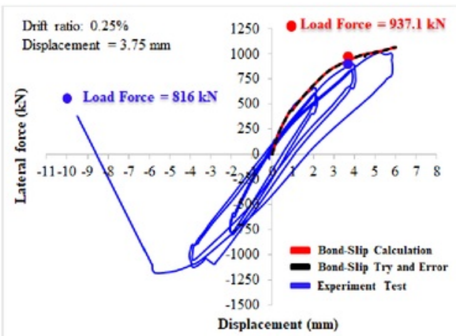


Figure 4.6Hysteretic loop combination experiment test and simulation VecTor2 at drift ratio 0.35%.

## V. CONCLUSION

Simulation Vector2 for reinforced concrete of wall give some conclusion to predict the behavior of reinforced concrete and the condition would be compare with the experimental test. Some of the conclusions that we can get from the results of this simulation are:

1. Simulation VecTor2 use the bond stress-slip embedded bars can predict the behavior of reinforced concrete of wall to see the crack, displacement and maximum shear force.
2. The value of lateral force depended of the tensile strength of reinforcement and yield strength of reinforcement, if tensile strength of reinforcement and yield strength of reinforcement high the lateral force would be high, vice versa.
3. Value of bond stress-slip embedded bars depended of transverse reinforcement ratio and confining pressure of reinforcement.
4. From the calculated the value of confinement pressure bond –slip got for wall (0.126).
5. From the result of simulation VecTor2, obtained the comparison ratio value for all peak load is between 0.9-1.5, it means the simulation VecTor2 can predict the behavior of reinforced concrete wall use the bond-slip stress effect.
6. The predicted failure mechanisms and crack patterns for the simulation VecTor2 use bond stress-slip also showed good correlation with the experimental test results.
7. From the calculation and simulation obtained the average confinement pressure bond –slip for post yielding rebar ranging from $0.025\sqrt{fc}$ to $0.04\sqrt{fc}$.

## VI. ACKNOWLEDGEMENTS

The following recommendations are made to further improve the simulation VecTor2 of the beam-column Joint and wall to extend the concept to other types, as for the recommended recommendations are:

1. To review the behavior of specimens that have been simulated with VecTor2 use monotonic loading, it is necessary to observe and simulate the effect of bond stress-slip and reversed cyclic loading for each specimen.
2. To improve the accuracy of this simulation, it is recommended to compare this simulation result by using other bond-slip type and modified the mesh size for every specimen from small size to big size.
3. This simulation is expected to be compared with LS- DYNA to see the accuracy of these two simulations and consider the value of bond-slip effect.
4. For modeling interior beam-column joint need developed and showed a method to calculate the spring constant.

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