MINISTRY OF EDUCATION AND TRAINING
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PUNCHING SHEAR BEHAVIOR OF FLAT SLAB - CONCRETE FILLED TUBULAR (CFT) COLUMN CONNECTIONS

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DOCTORAL THESIS SUMMARY

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INTRODUCTION

1. The significance of this research

In the past decades, Steel-Concrete composite structures have been used more and more widely in civil and industrial buildings in many countries all over the world because of the outstanding advantages of the combination between concrete and steel materials in both structural and constructional aspect. The buildings using a combination of this structural solution illustrated high strength, stiffness and toughness, which satisfies the utility, economic efficiency, aesthetics as well as fire resistance compared to traditional steel structure.

In high-rise buildings, the height of the floor, the size of column and span of the structural components are important factors affecting the economic efficiency and utility of the buildings. Therefore, the demand for a new structure which can reduce the height of the floor, the size of the column and increase the structural span, shorten the construction time and save construction costs is a very necessary issue. The structural systems using Concrete Filled Steel Tube (CFT) column and reinforced concrete flat slab are relatively new structure in accordance with the above criteria, and they are expected to be widely applied in the world in near future. However, the effective connections between CFT column and flat slabs and their punching shear behaviors, which are vital factors in ensuring the strength of the structural system, have not yet been investigated adequately and are attracting much attention from numerous researchers.

This thesis proposes a new type of the connection between the RC flat slab and the CFT column with simplified details, easy fabrication and suitable construction conditions in Vietnam. Through calculations and preliminary simulations, the size and composition of the CFT column-flat slab connections will be proposed. The shear resistant and punching shear behavior of full-scale specimens will be investigated through empirical experiment. In addition, the analytical model will be simulated by using three-dimensional finite element software (ABAQUS) and the reliability of the simulation technique will be verified by comparison with the experimental results.

2. Objectives of the study
- The thesis proposed a unique connection between the reinforced concrete flat slab and CFT columns with simplified details, easy fabrication and suitable for Vietnam construction conditions.
- Investigate the punching shear behavior of RC flat slab-interior CFT column connection by experiments and numerical analysis.
- Propose an analytical model to predict the punching shear capacity of RC flat slab-interior CFT column connection.

3. Scientific and empirical significance of research

Scientific significance

In Vietnam, the application of CFT columns in buildings is relatively new and not yet popular. The results obtained from the experiments and simulations in this study will contribute to the new arguments and knowledge as well as useful data for future research in this field.

Empirical significance

Presently, the connections between the reinforced concrete flat slabs and the CFT columns have been proposed and investigated by numerous authors to investigate the structural behavior and efficiency for practical application. The proposal of a new the connection between the reinforced concrete flat slabs and the CFT columns, which contains a simplified detail and is efficient as well as suitable for the construction conditions in Vietnam, will be the prerequisite for further research on other types of connections to develop structural solution for CFT column - reinforced concrete flat slab in construction. In particular, the introduction of a numerical model to predict the load-carrying-capacity of the connection in accordance with the experimental results is essential to obtain reliable results in the structural design of this type of connections in practice without any costly and time-consuming experiments.

4. Content of Research
- Provide an overview of the research project.
- Propose a unique connection between the reinforced concrete flat slabs and the CFT column.
- Full scale test specimen fabrication.
- Test setup and Experimental program.
- Process, analyze data and evaluate the results.
- Simulate the behavior of the connections by using ABAQUS three-dimensional finite element software with considering the nonlinear geometrical effects and nonlinear material effects.
- Verify the reliability of the simulation technique by comparing the test results with the experimental results.
- Draw the conclusions and recommendations.

5. Research Methodology
Use experimental research methods in combination with numerical simulation by using ABAQUS three-dimensional finite element software

6. Object and scope of the study

Research subjects:
Experimental investigation and simulation of the behavior of CFT column-reinforced concrete flat slab connections subjected to punching shear load.

Research scope:
- Conventional Flat slab system, no pre-stress effect, no-hole near the connection, interior CFT column
- Not consider the combination action of moment cause by horizontal loading and the column axis;
- Only use increased static load, not cyclic or dynamic load.

7. The composition of the thesis
The thesis contains 125 A4 pages with following composition:
Introduction.
Chapter 1: Overview of CFT column-reinforced concrete flat slab connections.
Chapter 2: Experimental Program of CFT column-flat slab connections
Chapter 3: Investigation the Behavior of CFT Colum-RC Flat Slab Connections by Numerical Method.
Conclusion and development direction.

8. Contribution of the thesis
- The thesis proposed a unique connection between reinforced concrete flat slab and CFT columns with simplified details, easy fabrication and suitable for domestic construction conditions.
- Establish experimental procedures and conduct experiments to investigate the punching shear behavior of the proposed RC flat slab-CFT column connection.

- Simulate the behavior of the connection by using ABAQUS three-dimensional finite element software and verify with the experimental results.


CHAPTER 1: OVERVIEW OF CFT COLUMN-REINFORCED CONCRETE FLAT SLAB CONNECTIONS

1.1 Concrete Filled Tubular (CFT) Columns
1.2 Reinforced Concrete Flat Slabs
1.3 The Connections between Reinforced Concrete Flat Slabs and CFT Columns

1.3.1 The Study of Satoh and Shimazaki (2004)
Satoh and Shimazaki (2004) [37] experimentally investigated the punching shear behavior of square CFT column-RC flat slab joints

Figure 1.22 and Figure 1.23: The Connection Details and Experimental Setups of Satoh and Shimazaki

1.3.2 The Study of Su and Tian (2010)
Su and Tian (2010) [40] investigated the punching shear behavior of interior circular CFT column – RC Flat slab connection subjected to earthquake load. The test results showed this type of connection can sustain
a larger value of drift ratio than the conventional column-reinforced concrete flat slab connections.

1.3.3 The Study of Yan (2011)

Yan (2011) [44] has proposed two types of CFT column-flat slab connections. The interior CFT column contains I-type shear reinforcement detail (type 1) and box type shear reinforcement detail (type 2). Two specimens were tested under punching shear until failure. The experimental results show that the ultimate load carrying capacity of the type-1 specimen was 417 kN while the type-2 one was 569 kN.

1.3.4 The Study of Kim et al. (2014)

Kim et al. (2014) [23] proposed a rigid shear resistance details for CFT column-RC flat slab connections by using steel shearheads. The test results showed that the punching shear capacity of the connections using steel shearheads was higher than that of conventional details.

1.3.5 Local researchers

1.4 Pros and Cons of existing CFT column-flat slab connections

1.4.1 Pros: Ensure the require strength and ductility

1.4.2 Cons: The connections proposed by Satoh and Shimazak, Yan, and Kim et al. have complicated details and were embedded in slab causing a difficulty construction and installation of steel reinforcement. Moreover, the forces were transmitted from the Slabs to the CFT columns only through steel tubular shell by shear reinforcement details, not through the concrete core.

1.5 Punching shear capacity of RC Column-Flat Slab Connection in existing Building Design Code
1.5.1 Vietnam Building Code 5574:2012
1.5.2 EC-2 Building Code
1.5.3 ACI 318-11 Building Code

1.6 Conclusions

Chapter 1 presented the advantages of the CFT columns, the reinforced concrete flat slabs as well as the CFT column-RC flat slabs connection and the overview of this type of components. Through that, the thesis also suggested the necessity of proposing a new connection between reinforced concrete flat slabs and the CFT column and following by the empirical research and simulating research to clarify the behavior and the effectiveness of the proposed connection.

CHAPTER 2. EXPERIMENTAL PROGRAM OF CFT COLUMN-FLAT SLAB CONNECTIONS

2.1 Experimental specimens

2.1.1 Introduction

The proposed connection is denoted as S-02-M-V and the conventional RC column-flat slab connection with the same column diameter and slab thickness is denoted as S-C-V.

2.1.2 Characteristic and details of proposed connections

2.1.2.2 The details of proposed connection

The details of proposed connection include (Figure 2.1 and Figure 2.2):

✓ Pros
Steel reinforcement has a continuous detail.

- The stiffener and the supporter system transfer the vertical loads from flat slab system to both steel tubular shell and concrete core and increase the integrity of the connections.
- Moreover, because the stiffener and the supporter system are located beneath the slab, the installation of longitudinal reinforcement is as convenient as conventional RC flat-slab system.

**Cons**

Because the stiffener and the supporter system are located beneath the slab, aesthetics is not guaranteed.

### 2.1.3 Geometric characteristics and details of specimens

#### 2.1.3.1 S-C-V specimen

![Figure 2.3: The layout of upper longitudinal reinforcement of S-C-V](image)

![Figure 2.4: The layout of lower longitudinal reinforcement of S-C-V](image)

![Figure 2.5: A-A Section of S-C-V](image)

#### 2.1.3.2 S-02-M-V specimen

![Figure 2.6: The layout of upper longitudinal reinforcement of -02-M-V](image)

![Figure 2.7: The layout of lower longitudinal reinforcement of -02-M-V](image)

![Figure 2.8: A-A Section of -02-M-V](image)

### 2.1.4 Experimental setup

- The experimental process is divided into 2 stages as follows:
2.2 Experimental apparatus

2.2.1 Loading frame

2.2.2 LVDT system, straingauge and measuring devices

2.3 Experimental process and test result analysis

2.3.1 Material

2.3.1.1 Concrete

Figure 2.13: Compressive Splitting tensile strength tests

The average compressive strength of specimens, $f_{cm}$, was 40.4 MPa and the average splitting tensile strength of specimens $f_{ctm} = 0.9f_{sp} = 3.16$ MPa. The test results were illustrated in Table 2.4 và Table 2.5.

2.3.1.2 Steel plate

Steel plates and steel cover of the CFT of S-02-M-V specimen used Q345B steel. Tensile tests showed that the plate has the yield strength of 351 MPa, and the ultimate strength of 489 MPa.
2.3.1.3 Longitudinal reinforcement

Longitudinal reinforcement used in this experiment is Vietnamese-Japanese steel with the diameter of 14mm-SD390. Tensile tests showed that the longitudinal reinforcement has the yield strenght of 532.5 MPa, and the ultimate strength of 614.0 MPa.

2.3.2 Installation of LVDTs and strain gauges

2.3.2.1 The LVDTs installation of S-C-V and S-02-M-V:

The LVDTs were attached above the slab after the specimen has been mounted into the loading system and denoted as D1, D2, D3, D4, D5, D6 (Figure 2.16 and Figure 2.17).
2.3.2.2 The strain gauge installation of S-C-V and S-02-M-V

The steel strain gauges were denoted as S1, S2, S3, S4, S5, S6 (Figure 2.18 and Figure 2.20). The concrete strain gauges were denoted as C1, C2, C3, C4, C5 (Figure 2.5 and Figure 2.6).

![Figure 2.18: Strain gauge installation of the upper layer of longitudinal reinforcement (S-C-V specimen)](image1)

![Figure 2.19: Strain gauge installation of concrete (S-C-V specimen)](image2)

![Figure 2.20: The concrete strain gauge and upper layer steel strain gauge S-02-M-V](image3)

2.3.3 Experimental process

2.3.3.1 Specimen casting

![Figure 2.21. Formwork and reinforcement installation of S-C-V](image4)

![Figure 2.22: Concrete pouring of S-C-V](image5)

![Figure 2.23: Formwork and reinforcement installation of S-02-M-V](image6)

![Figure 2.24: Concrete pouring of S-02-M-V](image7)

2.3.3.2 Transpostation, assembly and installation of specimen
2.3.3.3 Load cell installation

Figure 2.27: Load cell erection for S-C-V and S-02-M-V

2.3.3.4 Measurement device installation

Figure 2.28: LVDT installation for S-C-V

Figure 2.29: LVDT installation for S-02-M-V

Figure 2.30: Steel and Concrete strain gauge installation for S-C-V and S-02-M-V
2.3.4 Experimental process and test results of S-C-V

2.3.4.1 Experimental process

The initial load was about 5% of the total calculated failed force, about 30 kN / load segment.

2.3.4.2 Test results of S-C-V

Punching shear force: 827.3 kN

2.3.4.3 Punching cone characteristics of S-C-V

The test results showed that the slab was damaged totally due to the punching shear force. The value of punching shear force was recorded at 827.3 kN (Figure 2.36).
2.3.5 Experimental process and test results of S-02-M-V

2.3.5.1 Stage 1

The horizontal force was loaded by using a hydraulic actuator with a displacement-controlled method. The maximum load with respect to 17mm displacement was 74 kN.

![Image](image1.png)

*Figure 2.38: Force-Horizontal displacement at column head*

2.3.5.2 Stage 2

The CFT column-RC flat slab was subjected to vertical load until failure and the ultimate punching shear load reached 1024.00 kN.

![Image](image2.png)

*Figure 2.39: Force-displacement relationship of S-02-M-V*

![Image](image3.png)

*Figure 2.40: Force-strain relationship of steel re-bar of S-02-M-V*

![Image](image4.png)

*Figure 2.41: Force-strain curve for concrete of S-02-M-V*

![Image](image5.png)

*Figure 2.42: The shape of punching cone of S-02-M-V*
2.3.5.4 Punching cone characteristics of S-02-M-V

Stage 1: Horizontal displacement at column head reached 17 mm with respect to a Force of 74 kN, there is no cracks appeared on the surface of slab.

Stage 2: The test results showed that the structural system was destructive by punching shear. The ultimate punching shear load reached 1024.00 kN (Figure 2.42).

2.4 Conclusions

Chapter 2 presents the proposed flat concrete joint - reinforced concrete and reinforced concrete reinforced concrete floor - CFT column, experimental results of concrete materials, flat steel and reinforced concrete floor and real process. Determine the punctured behavior of the sample SCV and sample S-02-MV. The results of the experiments are shown in diagrams of the relationship between puncture force and quantities such as displacement, stress, strain in concrete and reinforcement of samples S-C-V and S-02-M-V. The shape of the puncture tower and the force-bearing behavior are similar to those of other authors in the world.

CHAPTER 3 INVESTIGATE THE BEHAVIOR OF CFT COLUM-RC FLAT SLAB CONNECTIONS BY NUMERICAL METHOD

3.1 Introduction

3.2 Overview of ABAQUS Software

3.2.1 Components in ABAQUS

3.2.2 Types of components used in simulation

3.2.3 Concrete material model

3.2.3.1 Concrete material modeling in Compression

3.2.3.2 Concrete material modeling in Tension

3.2.3.3 Modeling of plastic behavior of Concrete material

3.2.3.4 Concept of yield surface in plastic model

3.2.4 Contact interaction between surfaces of the components

3.2.4.1 “Tie” interaction

3.2.4.2 “Embedded elements” interaction

3.2.4.3 “Coupling” interaction
3.2.4.4 “Hard contact” interaction

3.3 Numerical simulation method in this Study

3.3.1 Material modeling

![Figure 3.16: Compressive stress-strain curve](image)

![Figure 3.17: Tensile stress-crack width curve](image)

The typical tensile stress-strain curve of steel plates and steel rebars (d=14mm) of S-C-V and S-02-M-V were illustrated in Figure 2.14 and Figure 2.15

3.3.2 Punching shear behavior simulation of RC interior Flat slab-column connection (S-C-V Specimen)

3.3.2.1 The components of S-C-V

![Figure 3.18: Geometrical modeling](image)

![Figure 3.19: Concrete material modeling](image)

![Figure 3.20: Steel reinforcement modeling](image)

![Figure 3.21: Upper and lower support modeling](image)

3.3.2.2 Contact interaction of S-C-V

<table>
<thead>
<tr>
<th>Components</th>
<th>Form of interactions</th>
<th>Interacted components</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC Flat slab</td>
<td>Hard contact</td>
<td>– Upper and lower boundary steel-support plate</td>
</tr>
<tr>
<td>Steel rebars d=14mm</td>
<td>Embedded element</td>
<td>– RC Flat slab – RC Column</td>
</tr>
</tbody>
</table>

3.3.2.3 The boundary condition of S-C-V
The boundary conditions used in simulation is similar to those in experiment, the 4 upper and lower boundaries are pinned connections $u_1=u_2=u_3=0$ (Figure 3.24 and 3.25)

![Figure 3.24: Simulation for the boundary condition of upper surface in S-C-V](image1)

![Figure 3.25: Simulation for the boundary condition of lower surface in S-C-V](image2)

![Figure 3.26: Meshing for S-C-V](image3)

3.3.2.4 Creating meshes for S-C-V specimen

The size of meshes for concrete element, steel plate support element and steel rebars is 50mm. The result was presented in Figure 3.26.

3.3.2.5 The comparison between the numerical simulation results and experimental results (specimen S-C-V)

![Figure 3.27: Force-displacement D1 curve for S-C-V](image4)

![Figure 3.29: Force-strain S1 curve for S-C-V](image5)

3.3.2.6 The formation of cracks and punching cone in the simulation of S-C-V

Along with the development of radial cracks, tangent cracks outside the perimeter of the column are formed, then these tangent cracks are joined together to form the punching cone at a rate of loading of 759.58 kN (Figure 3.34).
3.3.2.7 Conclusion

The results show that the punching shear force of the simulation is 8.19% lower than that of the experiment and this value observed in the case of D1 displacement is 6.82% lower. The cracking loading and area of punching cone in the simulation are also close to the experimental results.

3.3.3 Punching shear behavior simulation of interior RC Flat slab-CFT column connection (S-02-M-V Specimen)

3.3.3.1 The components of S-02-M-V
3.3.3.2 Contact interaction of S-02-M-V

<table>
<thead>
<tr>
<th>Components</th>
<th>Form of interactions</th>
<th>Interacted components</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC Flat slab</td>
<td>Hard contact</td>
<td>– Steel column</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Steel-plate support</td>
</tr>
<tr>
<td>Concrete core in CFT column</td>
<td>Hard contact</td>
<td>– Steel column</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Stiffener</td>
</tr>
<tr>
<td>Steel column</td>
<td>Hard contact</td>
<td>– Concrete core</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Flat slab</td>
</tr>
<tr>
<td>Steel column</td>
<td>Tie</td>
<td>– Steel-plate support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Stiffener</td>
</tr>
<tr>
<td>Stiffener</td>
<td>Hard contact</td>
<td>– Concrete core</td>
</tr>
<tr>
<td>Stiffener</td>
<td>Tie</td>
<td>– Steel column</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Steel-plate support</td>
</tr>
<tr>
<td>Steel plate-support</td>
<td>Hard contact</td>
<td>– Flat slab</td>
</tr>
<tr>
<td>Steel rebar in slab d=14mm</td>
<td>Embedded element</td>
<td>– Flat slab</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Concrete core</td>
</tr>
</tbody>
</table>

3.3.3.3 The boundary condition of S-02-M-V

The boundary conditions used in simulation is similar to those in experiment, the 4 upper and lower boundaries are pinned connections \( u_1 = u_2 = u_3 = 0 \) (Figure 3.43 and 3.44).

3.3.3.4 Creating meshes for S-02-M-V specimen

The size of meshes for concrete element, steel plate support element and steel rebars is 50mm. The result was presented in Figure 3.45.

![Figure 3.43: Simulation for the boundary condition of upper surface in S-02-M-V](image1)

![Figure 3.45: Meshing for S-02-M-V](image2)

3.3.3.5 The comparison between the numerical simulation results and experimental results (specimen S-02-M-V)
**Stage 1:**

The connection is subjected to increasing cyclic load up to drift ratio of H/140.

*Figure 3.46: Deformed shape of S-02-M-V with respect to 17 mm displacement at the column head*

*Figure 3.47: Force-displacement at column head in S-02-M-V*

*Figure 3.48: Mises stress in slab with respect to 17 mm displacement at the column head*

**Conclusion:** During the simulation, the horizontal load does not cause cracks in the Slab (Figure 3.48).

**Stage 2**

Applying the vertical load using displacement-controlled method until completely failure.

*Table 3.6: The comparison between the numerical simulation results and experimental results (S-02-M-V)*

<table>
<thead>
<tr>
<th></th>
<th>Punching shear force (kN)</th>
<th>Displacement D1 (mm)</th>
<th>Displacement D3 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-02-M-V (experiment)</td>
<td>1024.00</td>
<td>23.43</td>
<td>17.56</td>
</tr>
<tr>
<td>S-02-M-V (simulation)</td>
<td>925.15</td>
<td>22.38</td>
<td>15.25</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>9.65%</td>
<td>4.48%</td>
<td>13.15%</td>
</tr>
</tbody>
</table>
3.3.3.6 The formation of cracks and punching cone in the simulation of S-02-M-V
Along with the development of radial cracks, tangent cracks outside the perimeter of the column are formed, then these tangent cracks are joined together to form the punching cone at a rate of loading of 943.65 kN (Figure 3.56 and Figure 3.57).

Figure 3.49: Force-displacement D1 curve for S-02-M-V
Figure 3.50: Force-strain C1 curve for S-02-M-V

Figure 3.54: The first tangent cracks appear in S-02-M-V
Figure 3.55: Cracks appear in the direction of the four corners of the slab in S-02-M-V
Figure 3.56: Shape of punching cone in S-02-M-V
Figure 3.57: Shape of punching cone in S-02-M-V by experiment and numerical simulation

3.3.3.7 Conclusion

The experimental and numerical results of S-C-V and S-02-M-V showed that the punching shear capacity of proposed connection S-02-M-V is over 20% higher than that of S-C-V and the stiffness of S-02-M-V is also higher than S-C-V (Figure 3.58).
Figure 3.58: Force-displacement relationship of S-C-V and S-02-M-V

Table 3.7: The comparison between the numerical simulation results and experimental results of S-C-V and S-02-M-V

<table>
<thead>
<tr>
<th></th>
<th>Punching shear force (kN)</th>
<th>Displacement D1 (mm)</th>
<th>Displacement D3 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-C-V</td>
<td>827.3</td>
<td>759.58</td>
<td>20.65</td>
</tr>
<tr>
<td>S-02-M-V</td>
<td>1024</td>
<td>925.15</td>
<td>23.43</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>23.78%</td>
<td>21.79%</td>
<td>13.46%</td>
</tr>
</tbody>
</table>

The numerical simulation results are relatively close to the experimental ones, but the initial slope of the "force-displacement" curve or "force-strain" curve from the numerical analysis is greater than the corresponding results in experiment. This indicates that the initial stiffness of the connection subjected to punching shear force from the numerical
analysis is greater than the corresponding results from the experimental one. It is also possible to realize the similarity of the other studies simulating the behavior of reinforce concrete components subjected to shear force. This is due to the limited simulation-capacity of the concrete model available in the library of ABQUS software and should be clarified in future studies.

3.4 A calculation process to predict the punching shear capacity of specimen S-02-M-V based on TCVN 5574: 2012, EC 2 and ACI 318-11.

3.5 Conclusion

The simulation results are shown in diagrams of the relationship between punching shear force and various mechanical factors such as displacement, stress strain in concrete and steel reinforcement of specimens S-C-V and S-02-M-V. The simulation results show that the variation is in the range of 1.5-10.0%. The shape of punching cone in numerical simulation using ABAQUS software is quite similar to the experimental results.

CONCLUSION AND DEVELOPMENT DIRECTION

1. Conclusion

  — The study proposes a unique connection between the reinforced concrete flat slab and the CFT column with simplified details, easy fabrication and incline the ability of punching shear than those from other published studies.

  — The research has designed the process and perform the study of punching shear capability of the connection. Imitated of some experimental models by specialized software – ABAQUS, the following conclusions can be withdrawn: Experimental results demonstrate that the value of the punching shear capacity of the proposed connection (P = 1024.00 kN) is 24% higher than that of conventinal RC column-flat slab connection (P = 827.3 kN), which has the same cross-section and
longitudinal reinforcement ratio. This experiment indicated the connection, which is proposed, is able to bear the force. These results illustrated that the punching shear force, displacement and deformation are different from experimental results with values less than 10%. This proves that numerical models can be used as a method to predict the behavior of RC column-flat slab connection and CFT column-flat slab connection.

Based on Vietnamese Standard TCVN 5574: 2012, Euro Code 2 and American Standard ACI 318-11, the research has put forward how the punching shear of the new connection can be calculated. The outcome of the extreme punching shear capability for the brand new S-02-M-V connection demonstrated that maximum punching shear force value by the standards are all lower than the punching shear capability by the empirical study of the connection. This shows that propose a calculation is suitable and safe for the S-02-M-V connection.

2. Development orientation
- The research results of this topic can be developed to propose a connection details and investigate by empirical and numerical method for edge column and corner column.
- Based on the results of the thesis, it is possible to propose some more CFT column-flat slab connections which have the advantage in creating an optimal solution in the CFT column-flat slab connection design.
- The numerical simulation of the behavior of shear structural components, especially the punching shear capacity, by using finite element software is relatively complicated and not appropriate for the pre-failure stage of test specimen due to the incomplete concrete material model. Thus, it is necessary to investigate the additional model from various FE software, or to develop an appropriate material model to obtain the expected numerical results.
DECLARATION

Some of the work presented in this thesis has previously been published in the following papers:


