STRENGTH BEHAVIOUR OF COLUMN STUDS IN PREFABRICATED WALL PANELS USING COLD-FORMED STEEL

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To my beloved family...
I am extremely grateful to my supervisor, Dr. Arizu Sulaiman for his enthusiastic and expertise guidance, constructive suggestions, encouragements and the valuable assistance in many ways. Also, I am very thankful to him for sharing his precious time to view this report. This study would not have been what it is without such assistance.

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ABSTRACT

A full-scale experimental study on the strength behaviour of individual studs and column studs in a prefabricated wall panel is presented in this report. The individual stud and the panel are made of cold-formed steel sections with a dimension of 3 m height, and 3.15 m height and 1.5 m width respectively. At the moment, the British Code has not provided adequate detail design to account the load capacity of a cold-formed steel column stud in a prefabricated wall panel. The structural performances of column stud therefore need to be obtained through the experimental investigation. A total of five specimens were tested in pure axial compression until failure. The specimens consist of three specimens with one type of lipped C-channel designated here as S350CT1, S350CT2 and S350CT3, one specimen of I-section, D350CT1 and one specimen of wall panel, W350CT1. Comparison between experimental values for column stud in the wall panel and experimental values for the individual studs were made. Experimental values for the individual studs were also compared with the theoretical values computed based on BS 5950-Part 5:1998 Code of practice. All individual studs which were subjected to pure axial compression, except the S350CT1, failed due to flexural buckling (FB) mode, with a substantial visible permanent deformation and without significant torsional buckling. S350CT1 failed due to shearing of the bolts in the bolted connection. From the investigation, it can be concluded that the selection of section geometries affect the failure stress capacity of individual studs dramatically. All individual stud failure loads obtained experimentally are in good agreement with the predicted values. As for the prefabricated wall panel, it was found that a flexural buckling and local buckling had occurred in the wall panel as the wall panel reaching the failure, and subsequently the ultimate load.
ABSTRAK

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DECLARATION</td>
<td>ii</td>
</tr>
<tr>
<td></td>
<td>DEDICATION</td>
<td>iii</td>
</tr>
<tr>
<td></td>
<td>ACKNOWLEDGEMENTS</td>
<td>iv</td>
</tr>
<tr>
<td></td>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td></td>
<td>ABSTRAK</td>
<td>vi</td>
</tr>
<tr>
<td></td>
<td>TABLE OF CONTENTS</td>
<td>vii</td>
</tr>
<tr>
<td></td>
<td>LIST OF TABLES</td>
<td>xi</td>
</tr>
<tr>
<td></td>
<td>LIST OF FIGURES</td>
<td>xiii</td>
</tr>
<tr>
<td></td>
<td>LIST OF SYMBOLS</td>
<td>xvii</td>
</tr>
<tr>
<td></td>
<td>LIST OF APPENDICES</td>
<td>xxi</td>
</tr>
<tr>
<td>1</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1.1 Background of the Study</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1.2 Problem Statement</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1.3 Aim and Objectives</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1.4 Scope</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>LITERATURE REVIEW</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>2.1 Introduction</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>2.2 Previous Researches on Cold-Formed Wall Panel</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>and Built-Up Section</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3 Wall Studs</td>
<td>10</td>
</tr>
</tbody>
</table>
2.4 Applications of Cold-Formed Steel 13
2.5 Types of Cold-Formed Steel 15
2.6 Manufacturing Processes of Cold-Formed Steel 17
2.7 Connection for Cold-Formed Steelwork 18
  2.7.1 Bolted Connections 20
  2.7.1.1 Bolt Spacing 22
  2.7.1.2 Bolt Capacity 22
  2.7.2 Screw Connections 24
  2.7.2.1 Screw Spacing 25
  2.7.2.2 Screw Capacity 25
2.8 Strength and Design Criteria for Cold-Formed Steel 26
  2.8.1 Stiffeners in Compression Elements 27
  2.8.2 Limit States for Cold-Formed Steel Compression Members 28
    2.8.2.1 Local Buckling of Individual Elements 29
    2.8.2.2 Yielding 30
    2.8.2.3 Distortional Buckling 31
    2.8.2.4 Flexural Buckling 31
    2.8.2.5 Torsional Buckling 32
    2.8.2.6 Torsional-Flexural Buckling 33
  2.8.3 Local Buckling and Postbuckling of Thin Compression Elements 34
  2.8.4 Web Crippling 37
  2.8.5 Mid-line Method for Computing Properties of Cold-Formed Steel Sections 38
  2.8.6 Shear Modulus, Modulus of Elasticity and Tangent Modulus 38
  2.8.7 Yield Point of Cold-Formed Steel 39
  2.8.8 Effective Length Factor, K 40
2.9 I-Section Compression Member 41
3 EXPERIMENTAL INVESTIGATION
3.1 Introduction 42
3.2 Material Properties 43
3.3 Coupon Test 43
  3.3.1 Specimens of Coupon Test 44
  3.3.2 Coupon Test Procedure 44
  3.3.3 Coupon Test Measurement and Calculation 45
3.4 Predicted Ultimate Load 47
3.5 Individual Stud Test 48
  3.5.1 Specimens of Individual Stud Test 48
  3.5.2 Individual Stud Test Procedure 50
3.6 Wall Panel Test 61
  3.6.1 Specimens of Wall Panel Test 61
  3.6.2 Wall Panel Test Procedure 68

4 RESULTS AND ANALYSIS
4.1 General 74
4.2 Tensile Coupon Tests 74
  4.2.1 Observation of Tensile Coupon Tests 75
  4.2.2 Results of Tensile Coupon Tests 75
4.3 Theoretical Approach for Axial Compression Capacities 78
  4.3.1 Singly Lipped C-Channel
    (250×75×20×2.05 mm) 78
  4.3.2 Doubly Lipped Channel (I-Section)
    (250×150×20×4.1/2.05 mm) 91
4.4 Individual Stud Tests 106
  4.4.1 Observation of Individual Stud Tests 107
    4.4.1.1 S350CT1: Type I 107
    4.4.1.2 S350CT2: Type II 108
    4.4.1.3 S350CT3: Type III 109
    4.4.1.4 D350CT1: Type III 110
  4.4.2 Results of Individual Stud Tests 112
4.4.2.1 S350CT1: Type I 112
4.4.2.2 S350CT2: Type II 114
4.4.2.3 S350CT3: Type III 117
4.4.2.4 D350CT1: Type III 119

4.5 Comparison and Discussion of Individual Stud Test Results 122

4.6 Wall Panel Test 124
4.6.1 Observation of Wall Panel Test 125
4.6.2 Results of Wall Panel Test 127

4.7 Comparison and Discussion of Individual Stud Test and Column Stud Test Results 129

5 CONCLUSIONS 131
5.1 Summary of study 131
5.2 Conclusions 132
5.3 Future Studies 133

REFERENCES 134
Appendices A - C 137-158
<table>
<thead>
<tr>
<th>TABLE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Typical applications and types of fasteners</td>
<td>20</td>
</tr>
<tr>
<td>2.2</td>
<td>Bearing capacity in bolted connections</td>
<td>23</td>
</tr>
<tr>
<td>2.3</td>
<td>Shear capacity in screw connections</td>
<td>25</td>
</tr>
<tr>
<td>2.4</td>
<td>Effective lengths for compression members</td>
<td>40</td>
</tr>
<tr>
<td>3.1</td>
<td>Parameter value for S1</td>
<td>45</td>
</tr>
<tr>
<td>3.2</td>
<td>Parameter value for S2</td>
<td>46</td>
</tr>
<tr>
<td>3.3</td>
<td>Parameter value for S2</td>
<td>46</td>
</tr>
<tr>
<td>3.4</td>
<td>Test piece dimension</td>
<td>46</td>
</tr>
<tr>
<td>3.5</td>
<td>Type of test method for each specimen</td>
<td>52</td>
</tr>
<tr>
<td>4.1</td>
<td>The ultimate and yield strength of material</td>
<td>77</td>
</tr>
<tr>
<td>4.2</td>
<td>Exact, mid-line and actual dimensions of a C-channel section</td>
<td>79</td>
</tr>
<tr>
<td>4.3</td>
<td>Mid-line and actual dimensions for the each C-channel element</td>
<td>79</td>
</tr>
<tr>
<td>4.4</td>
<td>Measurement of each element for the calculation of $Y_1, Y_2, \ X_1$ and $X_2$ of C-channel</td>
<td>80</td>
</tr>
<tr>
<td>4.5</td>
<td>Measurement of each element based on $x$ and $y$ axis for the calculation of $I_x$ and $I_y$ of C-channel</td>
<td>80</td>
</tr>
<tr>
<td>4.6</td>
<td>Calculation of $A$ and $\bar{X}$ using each element of a C-channel</td>
<td>85</td>
</tr>
<tr>
<td>4.7</td>
<td>Calculation of $A_{eff}$ and $\bar{X}$ using each element of a C-channel</td>
<td>85</td>
</tr>
<tr>
<td>4.8</td>
<td>Calculation of $A$ and $\bar{Y}$ using each element of a C-channel</td>
<td>86</td>
</tr>
<tr>
<td>Section</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>4.9</td>
<td>Calculation of $A_{eff}$ and $\overline{Y}$ using each element of a C-channel</td>
<td></td>
</tr>
<tr>
<td>4.10</td>
<td>Exact, mid-line and actual dimensions of an I-section</td>
<td></td>
</tr>
<tr>
<td>4.11</td>
<td>Mid-line and actual dimensions for the each I-section element</td>
<td></td>
</tr>
<tr>
<td>4.12</td>
<td>Measurement of each element for the calculation of $Y_1$, $Y_2$, $X_1$ and $X_2$ of I-section</td>
<td></td>
</tr>
<tr>
<td>4.13</td>
<td>Measurement of each element based on $x$ and $y$ axis for the calculation of $I_x$ and $I_y$ of I-section</td>
<td></td>
</tr>
<tr>
<td>4.14</td>
<td>Calculation of $A$ and $\overline{X}$ using each element of an I-section</td>
<td></td>
</tr>
<tr>
<td>4.15</td>
<td>Calculation of $A_{eff}$ and $\overline{X}$ using each element of an I-section</td>
<td></td>
</tr>
<tr>
<td>4.16</td>
<td>Calculation of $A$ and $\overline{Y}$ using each element of an I-section</td>
<td></td>
</tr>
<tr>
<td>4.17</td>
<td>Calculation of $A_{eff}$ and $\overline{Y}$ using each element of an I-section</td>
<td></td>
</tr>
<tr>
<td>4.18</td>
<td>Failure stress of individual studs</td>
<td></td>
</tr>
<tr>
<td>4.19</td>
<td>Test result for wall panel</td>
<td></td>
</tr>
<tr>
<td>4.20</td>
<td>Stud failure load in wall panel</td>
<td></td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Typical wall assemblies</td>
<td>3</td>
</tr>
<tr>
<td>2.1</td>
<td>Wall studs</td>
<td>11</td>
</tr>
<tr>
<td>2.2</td>
<td>Buckling of studs between screws</td>
<td>12</td>
</tr>
<tr>
<td>2.3</td>
<td>Overall column studs buckling</td>
<td>12</td>
</tr>
<tr>
<td>2.4</td>
<td>Steel sections used in building construction</td>
<td>14</td>
</tr>
<tr>
<td>2.5</td>
<td>Cold-formed steel cross-sections</td>
<td>15</td>
</tr>
<tr>
<td>2.6</td>
<td>C-channel cold-formed steel with $x$ and $y$ axis, and the depth, $D$</td>
<td>16</td>
</tr>
<tr>
<td>2.7</td>
<td>Profiled steel sheeting</td>
<td>16</td>
</tr>
<tr>
<td>2.8</td>
<td>Cold-roll forming tools</td>
<td>17</td>
</tr>
<tr>
<td>2.9</td>
<td>Manufacturing by press braking</td>
<td>18</td>
</tr>
<tr>
<td>2.10</td>
<td>Manufacturing by folding</td>
<td>18</td>
</tr>
<tr>
<td>2.11</td>
<td>Example of mechanical fasteners for thin wall elements</td>
<td>19</td>
</tr>
<tr>
<td>2.12</td>
<td>Tension failure</td>
<td>21</td>
</tr>
<tr>
<td>2.13</td>
<td>Various failure modes of bolted connection</td>
<td>21</td>
</tr>
<tr>
<td>2.14</td>
<td>Spacing of bolts, $S_e$ and edge distances, $e$</td>
<td>22</td>
</tr>
<tr>
<td>2.15</td>
<td>Failure modes of screwed connection</td>
<td>24</td>
</tr>
<tr>
<td>2.16</td>
<td>Types of compression elements</td>
<td>28</td>
</tr>
<tr>
<td>2.17</td>
<td>Buckling modes for a lipped C-channel in compression</td>
<td>28</td>
</tr>
<tr>
<td>2.18</td>
<td>Buckling modes of lipped C-channel using finite strip analysis</td>
<td>29</td>
</tr>
<tr>
<td>2.19</td>
<td>Local buckling of cold-formed steel plain channel column</td>
<td>30</td>
</tr>
</tbody>
</table>
2.20 Torsional-flexural buckling of a nonsymmetric section 34
2.21 Local buckling of compression elements of columns 34
2.22 Postbuckling strength model 35
2.23 Stress distribution stages in stiffened compression elements, where \( f_{cr} \) is the critical local buckling stress and \( F_y \) is the yield point 36
2.24 Effective width of stiffened compression element 36
2.25 Maximum stress for unstiffened compression elements 37
2.26 Mid-line of the cross-section 38
2.27 Gradual yielding of stress-strain curve 40
2.28 Effective lengths of various end conditions 41
3.1 Tensile coupon test 43
3.2 Coupon dimension 45
3.3 Dimensions of sections 49
3.4 Geometry of I-section 49
3.5 Actual I-section 49
3.6 Stiffener in the top and bottom ends of individual studs 52
3.7 Type of data logger and hand pump used in experiment 52
3.8 Individual stud test using type I for S350CT1 53
3.9 Actual setup test for S350CT1 54
3.10 Individual stud test using type II for S350CT2 55
3.11 Actual setup test for S350CT2 56
3.12 Individual stud test using type III for S350CT3 57
3.13 Actual setup test for S350CT3 58
3.14 Individual stud test using type III for D350CT1 59
3.15 Actual setup test for D350CT1 60
3.16 Geometry of wall panel with one middle stud 62
3.17 A complete prefabricated wall panel 63
3.18 Side view of W350CT1 64
3.19 Dimensions of sections in wall panel 64
3.20 C-channel bracing configuration 65
3.21 Prefabricated wall panel 66
3.22  Detail connections between top track and studs in wall panel
3.23  Actual bolted connections in wall panel
3.24  Installation of wood pieces at the top end of wall panel
3.25  A full scale wall panel test
3.26  Actual setup test for W350CT1
3.27  Arrangement of rods on both spreaders, S1 and S2
4.1   Failure modes of the specimens
4.2   Coupon test result for coupon specimen 1 (S1)
4.3   Coupon test result for coupon specimen 2 (S2)
4.4   Coupon test result for coupon specimen 3 (S3)
4.5   Singly C-channel section dimensions
4.6   Gross section and reduced section of a C-channel
4.7   I-section dimensions
4.8   Gross section and reduced section of an I-section
4.9   Specimen 1 (S350CT1) failure modes
4.10  Specimen 2 (S350CT2) failure modes
4.11  Specimen 3 (S350CT3) failure modes
4.12  Specimen 4 (D350CT1) failure modes
4.13  Load versus deflection chart for S350CT1
4.14  Some data from load versus deflection graph for S350CT1
4.15  Load versus deflection chart for S350CT2
4.16  Some data from load versus deflection graph for S350CT2
4.17  S350CT2
4.18  Load versus deflection chart for S350CT3
4.19  Some data from load versus deflection graph for S350CT3
4.20  S350CT3
4.21  Load versus deflection chart for D350CT1 in the range of deflection -4.0 to 4.0 mm
4.22  Load versus deflection chart for D350CT1
4.23 Some data from load versus deflection graph for D350CT1 121
4.24 D350CT3 122
4.25 Failure mode of W350CT3 126
4.26 Local buckling in the connection area 127
4.27 Load versus deflection chart for W350CT1 128
4.28 Some data from load versus deflection graph for W350CT1 128
4.29 Local buckling at middle stud 128
LIST OF SYMBOLS

\(a^b\) - Thickness of flat test piece (for coupon specimen)
\(A\) - Area of a cross-section or gross area
\(A_{eff}\) - Effective cross-sectional area
\(A_i\) - Area of each element
\(A_n\) - Net area of a section
\(A_t\) - Tensile stress area of the bolt or area at the bottom of the threads
\(\alpha\) - Coefficient of linear thermal expansion or
- Factors for member in compression
\(b\) - Flat width of an element or
- Width of the parallel length of a flat test piece (for coupon specimen)
\(b_{eff}\) - Effective width of a compression element
\(b_{eu}\) - Effective width of an unstiffened compression element
\(b_g\) - Gripped end width (for coupon specimen)
\(b_f\) - Width of flat elements (mid-line dimension)
\(b_1, b_2\) - Mid-line dimensions of the respective elements assuming rounded corners are replaced with intersections of the flat elements
\(B\) - Overall flange width
\(BL\) - Overall lipped depth
\(C_w\) - Warping constant of a section
\(d\) - Nominal diameter of the bolt or
- Diameter of the screw
\(d_e\) - Distance from the centre of a bolt to the end of the connected element in the direction of the bolt force
\(d_s\) - Head of screw or washer diameter
\( D \) - Overall web depth
\( D_c \) - Depth of the compression zone of the web, taken as the distance from the neutral axis of the gross cross-section to the compression element
\( D_w \) - Section depth or twice the depth of the compression zone
\( e \) - Distance between the centre of a bolt and any edge of the connected member or
- Shear centre position as shown in Table D.1 BS 5950-Part 5
\( e_s \) - Distance between the geometric neutral axis and the effective neutral axis of a section
\( E \) - Modulus of elasticity of steel
\( E_t \) - Tangent modulus
\( f \) - Local buckling stress
\( f_c \) - Compressive stress on the effective element
\( f_{cr} \) - Critical local buckling stress
\( f_{pr} \) - Proportional limit
\( F_s \) - Longitudinal shear force
\( F_y \) - Yield point
\( G \) - Shear modulus of steel
\( I_x, I_y \) - Second moment of area of a cross-section about the \( x \) and \( y \) axis respectively
\( J \) - St Venant torsion constant of a section
\( K \) - Buckling coefficient of an element
\( L_c \) - Parallel length (for coupon specimen)
\( L_E \) - Effective length of a member about the critical axis
\( L_g \) - Length between gripped area (for coupon specimen)
\( L_o \) - Original gauge length (for coupon specimen)
\( L_t \) - Total length of test piece (for coupon specimen)
\( m \) - Number of flat elements
\( M_c \) - Moment capacity of a cross-section
\( M_t \) - Distance from centre of each element to the bottom flange
\( n \) - Number of all 90° corners
\( N_l \) - Distance from centre of each element to the web
\( p_c \) - Compressive strength
$p_{cr}$ - Local buckling stress of an element
$p_o$ - Limiting compressive stress
$p_S$ - Shear strength obtained from Table 11; BS 5950-Part 5
$p_t$ - Tension strength obtained from Table 11; BS 5950-Part 5
$p_y$ - Design strength of steel
$P_{bb}$ - Bearing capacity of bolt
$P_{bs}$ - Bearing capacity of connected elements
$P_c$ - Buckling resistance under axial load
$P_{cs}$ - Short strut capacity
$P_E$ - Elastic flexural buckling load (Euler load) for a column
$P_{Ex}, P_{Ey}$ - Elastic flexural buckling load (Euler load) for a column about $x$ and $y$ axis respectively
$P_{fs}$ - Shear capacity of screw by testing
$P_{ft}$ - Tensile capacity of screw by testing
$P_S$ - Shear capacity of bolt or
- Shear capacity of screw
$P_t$ - Tension capacity of bolt or
- Tensile capacity of screw
$P_T$ - Torsional buckling load of a column
$P_{TF}$ - Torsional-flexural buckling load of a column
$p'_c$ - Buckling resistance after consider $M_c$ and $e_s$
$Q$ - Factor defining the effective cross-sectional area of a section
$r_{cy}$ - Radius of gyration of one channel
$r_i$ - Radius of corner (mid-line dimension)
$r_o$ - Polar radius of gyration of a section about the shear centre
$r_x, r_y$ - Radius of gyration of a section about the $x$ and $y$ axis respectively
$s$ - Longitudinal spacing of interconnections
$S_o$ - Original cross-sectional area of the parallel length
- Original cross-sectional area of the parallel length (for coupon specimen)
$S_{sv}$ - Spacing between bolts or screws
$S_{x}, S_{y}$ - Plastic modulus about the $x$ and $y$ axis respectively
\( t \) - Net material thickness or
- Minimum thickness of the connected material

\( t_1, t_2 \) - Thicknesses of element widths \( b_1 \) and \( b_2 \) respectively

\( t_3 \) - Thickness of the member in contact with the screw head

\( t_4 \) - Thickness of the member remote from the screw head

\( v \) - Poisson ratio

\( w \) - Width of the plate

\( x_0 \) - Distance from the shear centre to the centroid of a section measured along the \( x \) axis of symmetry

\( X_1, X_2 \) - Distance from centroid to left and right edge of the section measured along the \( x \) axis of symmetry respectively

\( \bar{x}, \bar{y} \) - Horizontal and vertical position of the neutral axis from the web or lipped and bottom flange respectively

\( X_i, Y_i \) - Distance from centre of each element to the centre of cross-section in horizontal and vertical direction respectively

\( Y_s \) - Material yield strength

\( Y_1, Y_2 \) - Distance from centroid to top and bottom edge of the section measured along the \( y \) axis of symmetry respectively

\( Z_x, Z_y \) - Section modulus about the \( x \) and \( y \) axis respectively

\( \lambda_x, \lambda_y \) - Slenderness ratio about the \( x \) and \( y \) axis respectively

\( \eta \) - Perry coefficient
## LIST OF APPENDICES

<table>
<thead>
<tr>
<th>APPENDIX</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Results from Individual Stud Test S350CT1</td>
<td>138</td>
</tr>
<tr>
<td>A2</td>
<td>Results from Individual Stud Test S350CT2</td>
<td>142</td>
</tr>
<tr>
<td>A3</td>
<td>Results from Individual Stud Test S350CT3</td>
<td>144</td>
</tr>
<tr>
<td>A4</td>
<td>Results from Individual Stud Test D350CT1</td>
<td>147</td>
</tr>
<tr>
<td>B1</td>
<td>Results from Wall Panel Test W350CT1</td>
<td>153</td>
</tr>
<tr>
<td>C1</td>
<td>Calculation of the Bolted Connection between Stud and Track</td>
<td>156</td>
</tr>
</tbody>
</table>
1.1 Background of the Study

A wall is a continuous vertical structure, which is thin relative to its length and height. External walls help to provide shelter against our environment such as wind, rain and the daily and seasonal variations of outside temperature to its location, for reasonable indoor comfort and internal walls divide buildings into rooms or compartments. To provide adequate shelter a wall must have sufficient strength and stability to be self-supporting and to resist the loads from roofs and upper floors. To differentiate the structural requirements of those walls that carry lateral and axial loadings (the loads from roof and upper floors in addition to their own weight) from those that are freestanding and carry only their own weight, the terms load bearing and non load bearing are used [1]. Other functions of walls are to enclose the space within it and to divide that space to provide privacy, security and equable conditions for storage and operations for occupants in the building. The commonly accepted specific requirements of a wall are stability, strength, resistance to weather and ground moisture, durability, fire safety, good thermal properties and resistance to airborne and impact sound, security and aesthetics [2].
Nowadays, the use of prefabricated wall panel in the construction industry has become a very common trend. The need to increase production efficiency, to save materials and to respond to the changing demands of building, users is leading to increase the use of prefabrication. Advantages of using prefabricated wall panel is to ensure consistency of quality as the wall frames have been properly engineered to meet specific load, wind bearing and bracing requirements, to include savings cost and time and easier site inspection as well as greatly improved in design details and during fabrication of the units. For instance, prefabricated and preassembled construction has been successfully applied to the standard public housing blocks throughout the 1990s. Prefabricated wall systems are manufactured in the factory, trucked to a construction site, lifted into position on a building using a crane, and anchored in place. The current market for prefabricated wall system is diverse and extensive, ranging from precast concrete wall panels to utilized glass and metal curtain wall systems [3].

Masonry, timber and reinforced concrete have traditionally been used for walls, but cold-formed steel continues to grow in popularity due to its structural and material advantages. In comparison with these conventional construction materials, steel is inherently recyclable and incurs much less cost to the environment (in terms of energy consumption and pollution) during its processing. The use of cold-formed steel has been more prevalent as well as in commercial or community applications because they are lighter than traditional concrete. A cold-formed steel wall panel internally or externally normally consists of top and bottom tracks, studs, braces (depending on the strength requirements) and the studs to track were connected together using bolts, welds, screws, pins or rivets (Figure 1.1). The studs were connected to horizontal tracks top and bottom, and sheathed on one or two side with board, which can be assembled together on site or manufactured in the factory. Steel frame should be fully integrated with both the external and internal wall panel systems as well as the floor systems so that they are mutual supporting. This lead naturally to consideration of stresses skin design [4].
Many companies involved in the construction industry are small or medium sized and so their ability to industrialise their methods may be limited. There is also increasing pressure to develop construction systems that are more sustainable. Buildings should be designed to use materials from renewable sources that minimise transportation costs, can be easily disassembled and reused. One area where there is an opportunity to develop system that may suit a variety of different sized organisations and improved the sustainability of construction is the use of cold-formed steel prefabricated wall panels as it is very cheap [5].

![Typical wall assemblies](image)

**Figure 1.1** Typical wall assemblies a) wall panel with bracing, b) wall panel with one side sheathing

### 1.2 Problem Statement

When the demand of low capital cost, easy and simple fabricated structure component, new techniques that suitable for both factory and site construction, erection that allows for deconstruction and recycling, and a very light structure component; is on the rise, prefabricated wall is one of the solution. The cheapest and suitable material is cold-formed steel that can be used as a main structure or column studs in a wall panel. Typically, the cold-formed steel cross-sections mostly used as
column studs are single C-channel and I-section made of back-to-back C-channel. The strength of the wall is depending on the overall buckling of main structure, column stud. At the moment, the British Code [6] has not provided adequate detail design to account the load capacity of a cold-formed steel column stud in a prefabricated wall panel. The structural performances of column stud therefore need to be obtained through the experimental investigation.

For these reason, an experimental study was carried out to evaluate the possibility behaviour of four individual stud specimens using two different section geometries (C-channel and I-section) and column studs using C-channel in one full-scale prefabricated wall panel. Then the relation between individual stud and column stud will be observed.

1.3 Aim and Objectives

The aim of this study is to determine the strength behaviour of the individual stud and column studs in prefabricated wall panel made by cold-formed steel. The main objectives of this study are:

a) To investigate the buckling behaviour by determining the ultimate load of both; the individual stud and column studs in a prefabricated wall panel subjected to compression.

b) To obtain the overall behaviour in terms of the failure modes of prefabricated wall panel.

c) To observe the insensitivity of the individual studs to the geometry of the sections.
d) To compare the individual stud test failure loads with the predicted load values, calculated based on BS5950-Part 5:1998 Code of practice for the design of cold-formed sections [6].

e) To correlate the results of the individual stud test to the results of the column stud in prefabricated wall panel test.

1.4 Scope

The scopes of this study will cover both the experimental and theoretical investigation of cold-formed steel section subject to compression;

1. The specimens for individual stud test were included three C-channel sections and one I-section, and were tested in simply supported condition for compression failure.

2. Determination of the design yield strength of cold-formed steel sections using tensile coupon test.

3. Determination of the axial compression capacity of cold-formed steel sections experimentally and theoretically.

4. The wall panel constructed with 3.15 m height and 1.5 m width.

5. Column studs will be the focus of the study for prefabricated wall panel experimental.