Finite Element Analysis of Cold-formed Steel Connections

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Abstract

This paper presents a study on the structural performance of column-base and beam-column connections of cold-formed steel with the use of single-lipped C-sections with bolted moment connections. Experiments were done on two specimens; a column-base connection and a beam-column connection and the results showed that section failure caused by flexural buckling was always critical. Managing to attain moment resistances which are close to the results of connected sections, it was proven that the proposed connections were structurally efficient. Finite element models were established with the use of shell elements to model the sections while bar elements were used to model the bolted fastenings for the purpose of examining the structural behaviour of both the column-base and the beam-column connections. Incorporation of material non-linearity and comparison between the experimental and numerical results were presented. The proposed analysis method for predicting structural behaviour of column-base and beam-column connections with similar connection configuration proved to be adequate.

Key Words: Column Bases, Beam Column, Bolted Moment Connections, Finite Element Modeling.

1. INTRODUCTION

Being lightweight and able to provide high performance structurally, cold-formed steel sections are suitable for building construction. With thickness ranging between 1.2mm to 3.2mm and yielding strength of from 250 to 450 N/mm^2, the most commonly available steel sections are lipped C and Z-sections. Connected onto primary structural members through web cleats as pinned or moment connections, cold-formed steel sections usually depend on the connection configurations as they act as secondary members. There are many design recommendations of cold-formed steel sections available for application in building construction such as AISI [1], BS5950 [2] and Euro code 3: Part 1.3 [3]. Moreover, there are also many design guides and commentaries available to assist structural engineers to design cold-formed steel structures [4, 5, 6, 7].

Since the last decade, there has been a widely growing trend in the construction of low to medium rise houses and modest span of portal frames where cold-formed steel sections are used as primary structural members. Therefore, in order to ensure practically and efficiency in terms of the framing, it is important to develop simple and effective moment connections between cold-formed steel members. Despite being commonly used throughout the years, little research has been done on the use of cold-formed steel members especially among single cold-formed steel sections. Various studies by Chung and Lau [8] and Wong and Chung [9] presented the experimental results for the use of bolted moment connections between cold-formed steel members which were typically applied in building construction where the bolted moment connections between the cold-formed steel members showed high structural efficiency. Furthermore, another study by Ho and Chung [10] provided extended experimental investigation on the use of bolted moment connections between lapped Z-sections.

2. SCOPE OF STUDY

This paper presents a study on the structural performance of column-base and beam-column connections of cold-formed steel with the use of single-lipped C-sections with bolted moment connections. Connection tests were done of two specimens; column base and beam column connections in order to study their structural behaviour as well as the moment resistances. Moreover, this paper shows the establishment of a finite element model through the modelling of the sections and the bolted fastenings with the use of shell and bar elements. Incorporation of material non-linearity and comparison between the experimental and numerical results will be presented more detailed in the following sections.

3. EXPERIMENTAL TESTS ON CONNECTIONS

Tests on a column base and a beam column using single cold-formed lipped channel sections with bolted moment connections were carried out, and Figure 1 illustrates the details of the connection configurations.

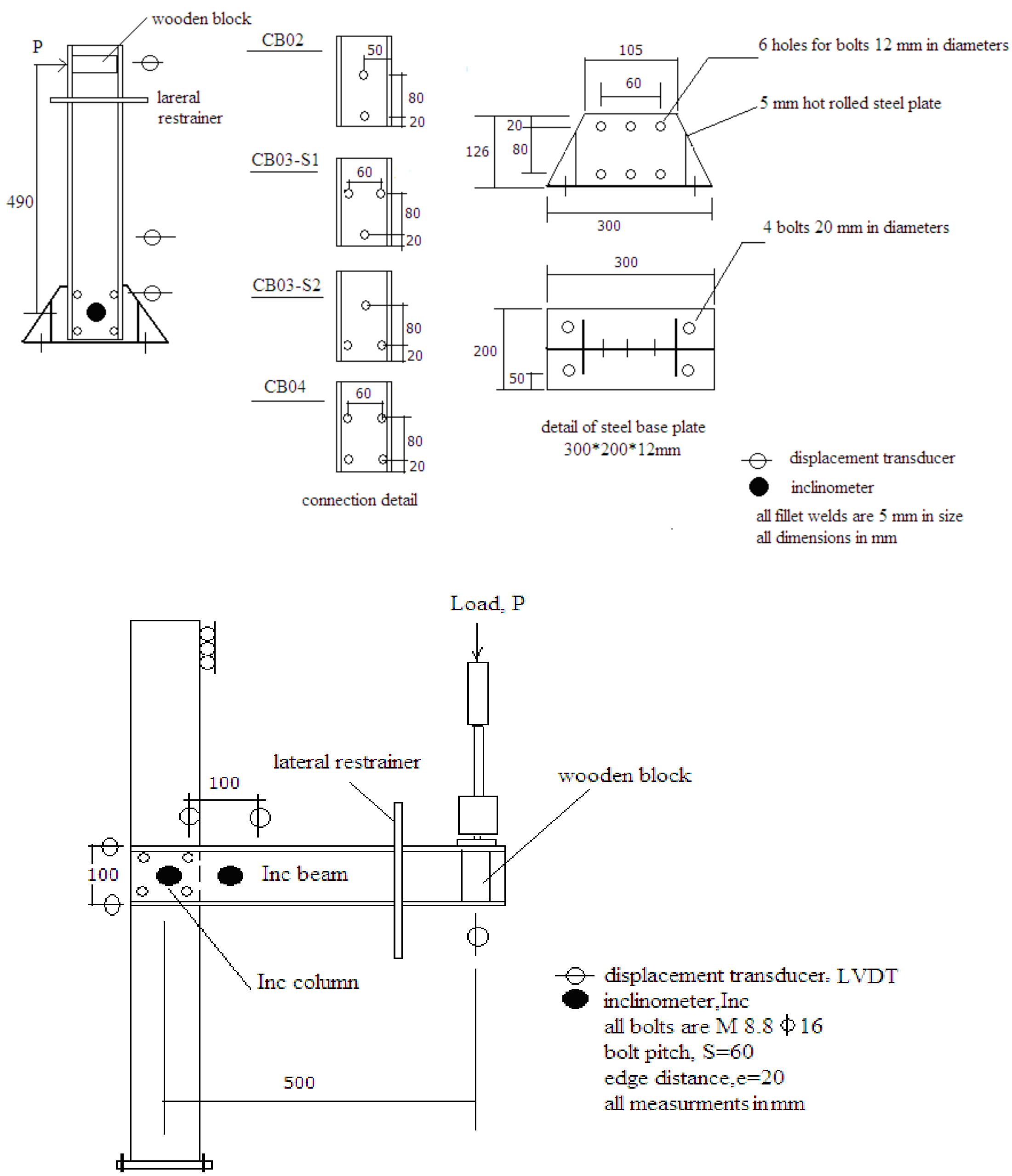


FIGURE 1: Detail of cold-formed steel column base and beam column connections

The beam and column members are formed from single cold-formed lipped channel sections. The flange width, web and lip depth of the cold-formed section are 50,100 and 14 mm respectively, with 1.6 mm thick section. The test specimens were designated as CB and BC for column base and beam column connections respectively as shown in Table 1. The measured yield strength was found to be 490 N/mm^2 and 572N/mm^2 for 1.6 mm thick section and bolt grade 8.8 of 12 mm diameter respectively. In all tests, loads were applied near the top of the test specimens and the applied load increased gradually until unloading occurred where continuous measurements were taken for the applied loads, the deflections of the loaded points including the rotation of the members throughout the test. The failure of both test specimens occurred due to flexural buckling of section web near connections, as shown in Figure 2. The load-deflection and moment rotation curves of the tests for both the column base and beam column connections were plotted in Figure 3 and Figure 4 respectively. The results from both the experiment as well as the analysis of the finite element were plotted in same graph for easy comparison. It was shown that all the connections rotated linearly under low applied loads, and then exhibited non-linear deformation characteristics when the applied loads increased. The restriction of the moment resistances of the connections to be the applied moment is at the connection rotation of 0.05 rad [8]. The results of all the tests are as summarized in Table 1.

TABLE 1: Summarization of the test program and test results

Test	Bolt pitch (mm)	Eccentricity (mm)	Mr_{EXP} @0.05rad (kNm)	Failure mode
CB	80	490	3.6	FF_{cs}
BC	60	500	2.1	FF_{cs}

Mr_{EXP}: denotes calculated moment resistance from experimental; FF_{cs}: denotes Flexural failure of connected section.

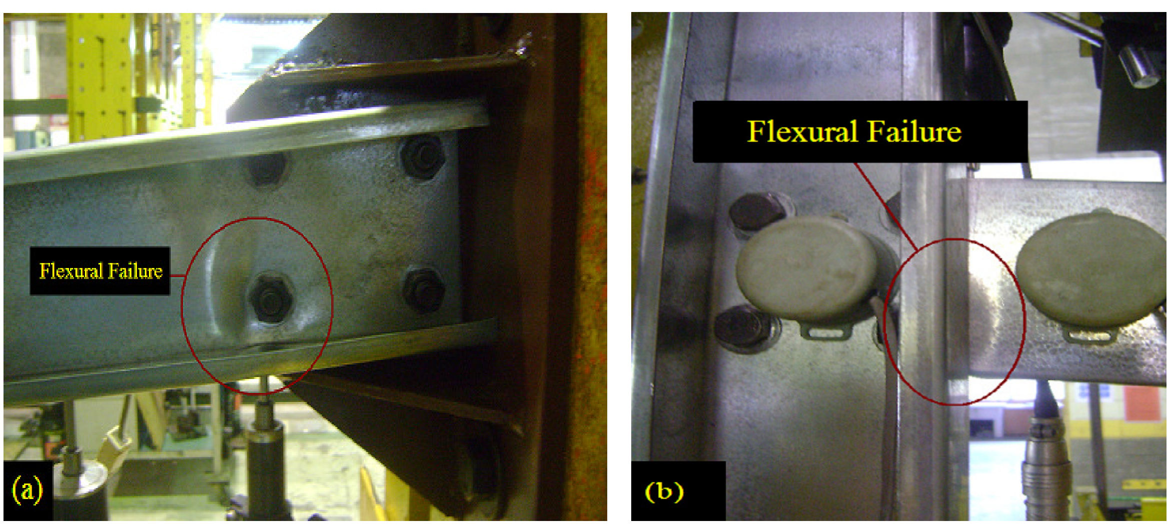
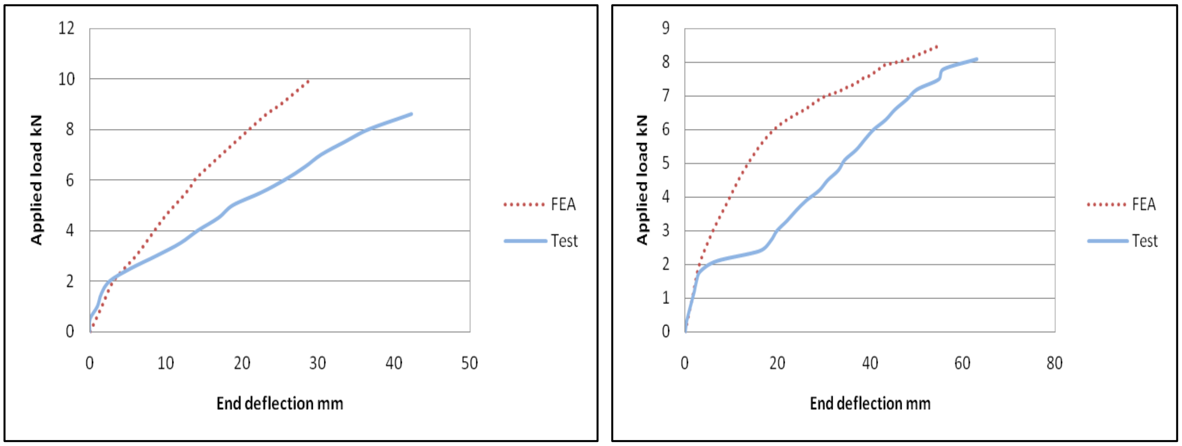


FIGURE 2: Flexural failure of connected section (a) column base connection (b) beam column connection.



(a) (b)

FIGURE 3: Load-deflection curves of cold-formed steel connections (a) column base (b) beam column

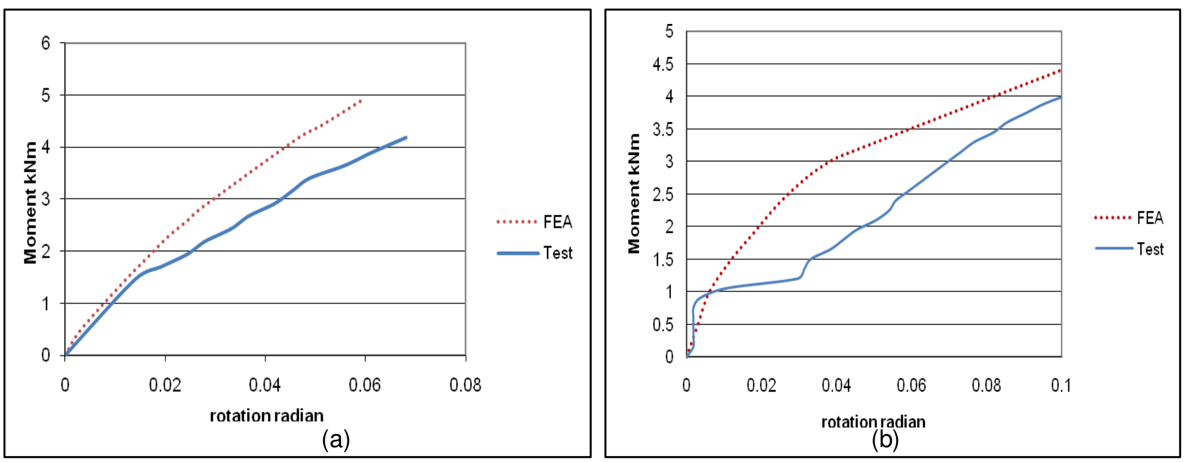


FIGURE 4: Moment-rotation curves of cold-formed steel connections (a) column base (b) beam column

4. NUMERICAL INVESTGATION

Compared to the typical hot-rolled steel sections, cold-formed steel sections are usually much more slender and can be notably deformed. Experiments on the connections between cold-formed steel sections and non-linear finite element modelling are considered to be particularly useful in tackling such problems. Moreover, finite element modeling can also provide important information of the structural responses of the cold-formed steel structures, such as the deformation of the shapes, initial stiffness, moment resistance and stress distributions. Numerical investigations [11] using commercial finite element packages were reported to study and assess the structural behaviour of bolted moment connections in which one of the most significant was a study by Chung et al. [12] which examined the load deformation characteristics of bolted fastenings under combined bending and shear through the application of advanced finite element modelling and with the use of three-dimensional solid elements with material and geometrical non-linearities.

4.1. Finite Element Model

In this study, the purpose finite element package LUSAS, Version 13.5 [13] was adopted for the numerical simulation of the cold-formed steel column base and beam column connections, as shown in Figure 5. To increase the accuracy of the research, the LUSAS modeling process used the connection dimensions, boundary conditions and material properties as similar as possible to that of the experimental set-up model. However, to obtain better and accurate results, many models need to be generated before the most suitable element discretisation can be found. The finite element models were incorporated with the following features:

- Four-node three dimensional shell elements, QTS4, were used to model the C sections.
- Two-node three dimensional elements, BRS2, were used to model the bolt fasteners.
- The measured stress-strain curves obtained from the coupon tests were used for the material models of the C sections with the von Mises yielding criteria as an addition.

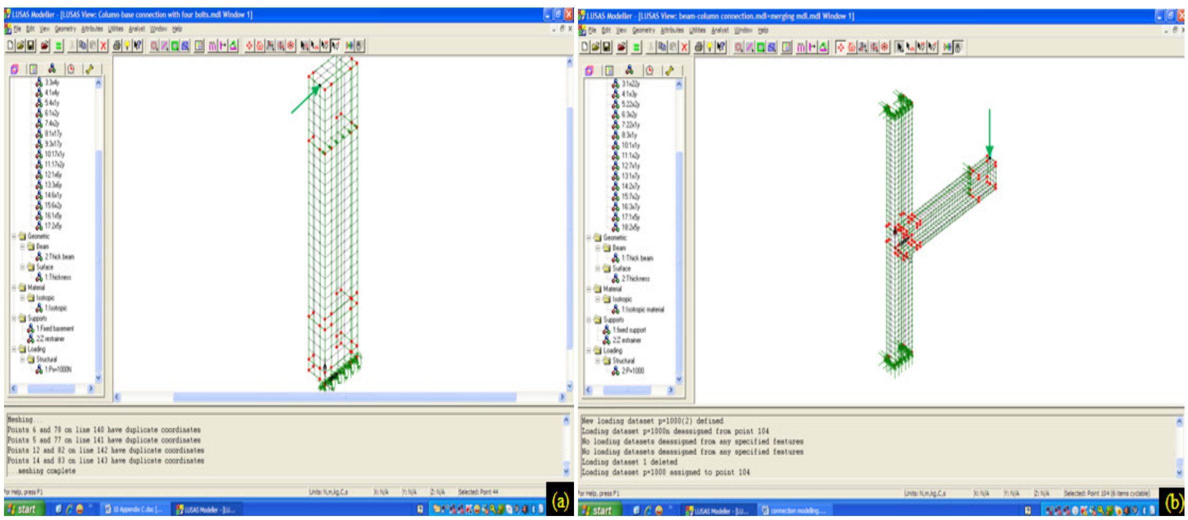


FIGURE 5: Finite element models of connections (a) column base (b) beam column

4.2. Numerical Results

The load-deflection and moment-rotation curves of the connections provided by the established finite element models were plotted onto the same graphs of the measured curves in Figure 3 and Figure 4 respectively for direct comparison. Load-deflection curve can be obtained directly from the model result file while calculations are needed to be done by extracting the data from loadings and nodal displacements for the moment-rotation curve. Both the numerical and the curves which were measured in the experiment agreed very well over the linear stage while accuracy of the analysis decreased for the rest deformation ranges. Figure 6 illustrates the deformed shapes of the column base and beam column connections. According to the applied point load, larger deflection was expected and the prediction was proven true. Comparison of the moment resistances obtained with the use of the finite element models with the measured value are summarized in Table 2 to allow comparison. Establishing a model factor, Ψ_{FEM}, the finite element models were assessed structurally to ensure their adequacy. The model factor is defined as:

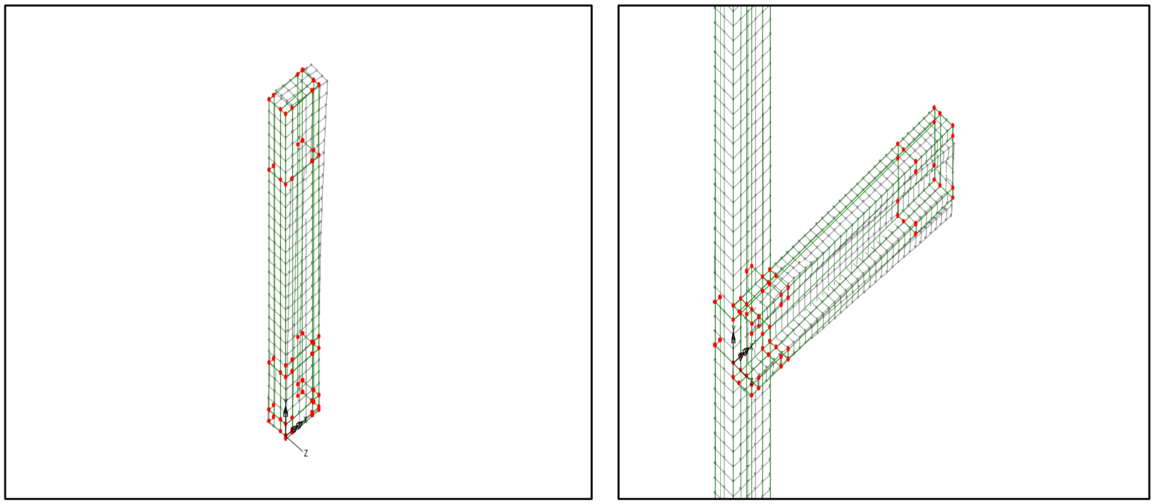
$$\Psi_{FEM} = \frac{\text{Predicted moment resistance obtained from finite element analysis, } Mr\ FEM}{\text{Mesured moment resistance, } Mr\ Test} \quad (1)$$

The model factor for the finite element model of the column base connection was 1.2 while the factor for the beam column connection was 1.5 which shows the accuracy of the finite element models in the prediction of the moment resistance of the proposed connections. However, the values of the model factors and the output results can be improved to be more accurate, by doing further advanced finite element analysis investigation that incorporate affect of material, geometrical and boundary non-linearities.

TABLE 2: Summary of moment resistances

Mr_{EXP}: denotes calculated moment resistance from experimental; Mr_{FEM}: denotes moment resistance from finite element models; Ψ_{FEM} : is defined as Mr_{FEM} / Mr_{EXP}

Test	Mr_{EXP} (kNm)	Mr_{FEM} (kNm)	Model factor Ψ_{FEM}
CB	3.6	4.4	1.2
BC	2.1	3.2	1.5



(a) (b)

FIGURE 6: Deformed mesh for the connections (a) column base (b) beam column

5. CONCLUSIONS

Tests were done on a column base and a beam column connection with bolted moment connections where lateral loads were placed and the results of the experiment showed the structural behaviour of the connections. In the tests, the flexural failure of the connected C-sections proved to be always critical and through establishing finite element models, the structural behaviour of the connections were able to be predicted. Comparison on the moment resistances obtained from both the tests as well as the models showed that the results were satisfactory.

The established finite element models proved to be effective in assessing the moment resistances of typical column base connection and beam column connection and can be readily offered to be used by engineers in designing moment connections of cold-formed steel sections. The proposed method however, can be used only in bolted connections that have similar configurations to the ones investigated in the study.

6. REFERENCES

[1] American Iron and Steel Institute. *"AISI Specification for the design of cold-formed steel structural members*", Washington (DC), 1996.

[2] British Standards Institution. BS5950. "*Structural use of steelwork in buildings: Part 5: Code of practice for the design of cold-formed sections*", London,1998.

[3] Eurocode 3. "*Design of steel structures*". Part 1.3: General rules – Supplementary rules for cold-formed thin gauge members and sheeting, ENV 1993-1-3. Brussels: European Committee for Standardization, 1996.

[4] Chung, K.F. "*Building design using cold-formed steel sections*". Worked examples to BS5950: Part 5: 1987. The Steel Construction Institute, 1993.

[5] Hancock, G.J. "*Design of Cold-Formed Steel Structures*". 3rd ed. Australian Institute of Steel Construction, 1998.

[6] Lawson, R.M., Chung, K.F. and Popo-Ola, S.O. "*Building Design using Cold-formed Steel Sections*". Structural Design to BS5950-5:1998 - Section properties and load tables, The Steel Construction Institute, SCI-P276, 1-234, 2002.

[7] Yu, W.W. "*Cold-Formed Steel Design*". 3rd ed. New York: John Wiley and Sons Inc, 2000.

[8] Chung, K.F. and Lau, L. "*Experimental investigation on bolted moment connections among cold-formed steel members"*. Engineering Structure, 21(10), 898-911, 1999.

[9] Wong, M.F. and Chung, K.F. "*Structural behaviour of bolted moment connections in beam-column sub- frames*". Journal of Constructional Steel Research, 58(2), 253-274, 2002.

[10] Ho, H.C. and Chung, K.F. "*Experimental investigation into the structural behaviour of lapped connections between cold-formed steel Z sections*". Thin-Walled Structures, 42(7), 10 13-1033, 2004.

[11] Lim, J.B.P. and Nethercot, D.A. "*Ultimate strength of bolted moment-connections between cold-formed steel members*". Thin-Walled Structures, 41(11), 1019-1039, 2003.

[12] Chung, K.F.,Yu, W.K. and Wang a.J. "*Structural performance of cold-formed steel column bases with bolted moment connections*". Steel and Composite Structures. 5(4):289-304, 2005.

[13] LUSAS. *"Modeler User's Manual*". Version 13.5, United Kindom.