COMPARISON BETWEEN BS 5950 AND EUROCODE 3 FOR THE DESIGN OF PRE-ENGINEERED STEEL STRUCTURE OF A FACTORY

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ABSTRACT

The aim of this project dissertation is to design selected pre-engineered steel structural members including rafter and column with non-typical section by using two different design standards which are British Standard 5950 (BS 5950-1-1: 2000 "Code of Practice for Design – Rolled and Welded sections") and Eurocode 3 (MS EN 1993-1-1: 2010 "General rules and rules for buildings". The advantages and disadvantages of design using Eurocode 3 including cost effectiveness of the design compared with BS 5950 are determined in this project dissertation. The findings show that design using Eurocode 3 experienced lower structural performance in initial analysis but higher in final analysis compared to design using BS 5950 for critical combination. The structural capacities of Eurocode 3 design including shear capacity, axial capacity and moment capacity for the section used in this analysis are higher than BS 5950 design. Although the stable length for haunch in Eurocode 3 design is longer than BS 5950 design, the structural stability of Eurocode 3 design including the resistance of lateral torsional buckling and resistance of buckling due to interaction of axial and bending moment are lower compared to BS 5950 design. Lastly, Eurocode 3 design consumes 0.88% more still weight than BS 5950 design. This is because larger section sizes are required for Eurocode 3 to fulfill all requirements. Therefore, it can be concluded that BS 5950 design is cheaper than Eurocode 3 design.

ABSTRAK

Matlamat projek ini adalah untuk merekabentuk anggota-anggota keluli termasuk kasau dan tiang bagi struktur pra-kejuruteraan dengan menggunakan dua piawaian reka bentuk yang berbeza iaitu British Standard 5950 (*BS 5950-1-1: 2000 "Code of Practice for Design – Rolled and Welded sections"*) and Eurocode 3 (*MS EN 1993-1-1: 2010 "General rules and rules for buildings"*). Selain itu, kelebihan dan kelemahan penggunaan Eurocode 3 dalam reka bentuk keluli berbanding dengan BS 5950 juga dikaji dalam projek. Hasil projek ini menunjukkan bahawa reka bentuk menggunakan Eurocode 3 mengalami prestasi struktur yang lebih rendah dalam analisis awal tetapi lebih tinggi dalam analisis akhir berbanding dengan reka bentuk yang menggunakan BS 5950 bagi gabungan kritikal. Keupayaan struktur untuk reka bentuk Eurocode 3 termasuk keupayaan ricih, keupayaan paksi dan keupayaan momen untuk bahagian yang digunakan dalam analisis ini adalah lebih tinggi daripada reka bentuk BS 5950. Kestabilan panjang untuk *haunch* dalam reka bentuk Eurocode 3 lebih panjang berbanding dengan reka bentuk BS 5950. Namun, kestabilan struktur reka bentuk Eurocode 3 termasuk rintangan lengkorkan kilasan sisi dan rintangan lengkokan disebabkan oleh interaksi masa paksi dan lentur adalah lebih rendah berbanding dengan reka bentuk BS 5950. Berat keluli yang diperlukan bagi reka bentuk Eurocode 3 adalah 0.88% lebih banyak berbanding dengan reka bentuk BS 5950. Perkara ini adalah disebabkan oleh saiz keratan yang lebih besar diperlukan dalam reka bentuk Eurocode 3 bagi memenuhi semua keperluan. Secara kesimpulan, penggunaan BS 5950 dalam reka bentuk adalah lebih murah daripada reka bentuk Eurocode 3.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Steel is one of the common materials used in construction industry because it has lot of advantages such as adaptability, beauty, cost-effectively, durability and ductility. A steel standard code is required to serve as a reference document with important guidance. In this dissertation, British Standards and Eurocodes are used.

British Standard used in this research is BS 5950 -1: 2000, "Structural Use of Steelwork in Building". It is a standard combining codes of practice that covers the design, construction and fire protection of steel structures and specifications for materials, workmanship and erection. BS 5950 - 1: 2000 is the structural code used to supersede BS 5950 - 1:1990, "Structural Use of Steelwork in Building" and is widely used in Malaysia. The standard consists of nine parts and Part 1 of the standard, BS 5950-1-1: 2000 "Code of Practice for Design – Rolled and Welded sections" is used in this research work.

The Eurocode 3 is a set of European Standards produced by the European Committee for Standardization of the steel design. Eurocode 3 consists of 6 parts and part 1, EN 1993 - 1: 2005, "Design of Steel Structures" which gives the basic rules for design of buildings in steel is used. EN 1993 - 1: 2005 is largely similar in scope to BS 5950 – 1: 2000 which was replaced by about 2010. It consists of twelve subparts and Part 1.1: General rules and rules for buildings (EN 1993-1-1) is used in this dissertation.

Starting from March 2010, the British Standards have been withdrawn and replaced with implementation of Eurocodes in the United Kingdom (UK) including

British Standard 5950, the design code for the structural use of steel to Eurocode 3 (Eng, 2010). The Institution of Engineers Malaysia (IEM) has been taking initiative and lead to replace the existing British Standard which is the main source of structural design code in Malaysia since 2002. It is important to replace the current applied British Standards to new Eurocodes as the British Standard will no longer be revised. By 2010, five of the Eurocode parts have been drafted into Malaysian National Annexes relating structure design in concrete and steel design i.e. ME EN 1990, ME EN 1991-1-1, MS EN 1992-1-1 and MS EN 1993-1-1 and MS EN 1997-1-1.

1.2 Problem Statement

Although the steel design standard, EN 1993-1-1 had successfully drafted into Malaysian National Annexes MS EN 1993-1-1 at 2010, the survey conducted by BEM since mid-2014 shows that a high number of engineers have given negative responses to the questions posed on their awareness and confidence level in use and adaption of structural Eurocodes in place of British Standards (Jeffrey, 2015). The results indicated that more than half of the respondents are not ready to submit their design based on Eurocodes. One of the problems faced by the practicing engineers in adopting Eurocodes are lack of initiative in learning a new design standard because the learning process is tedious and time-consuming. Therefore, this research is required to enhance the understanding of the engineers towards Eurocode 3 design by comparing it with BS 5950 design and produce a Eurocode 3 design procedure manual for selected pre-engineered structural members. The design procedure manual is able to act as a reference for the engineers to design steel structure by using Eurocode 3.

On top of that, the past studies show the different results in determining the cost effectiveness of Eurocode 3 compare with BS 5950. Han (2006) had carried out a study comparing between BS 5950 and Eurocode 3 for the design of multi-storey braced steel frame to testify a claim from the Steel Construction Institute (SCI) which claimed that a steel structural design by using Eurocode 3 is 6 – 8% more cost-saving than using BS 5950 (Steel Construction Institute, cited in Han, 2006). The research shows that Eurocode 3 consumes 1.60% to 17.96% more steel weight than the design using BS 5950. The result has contradicted with the claim by Steel Construction Institute (Steel Construction Institute, cited in Han, 2006). Besides, Franky (2006) finding shows that the steel structure is more economical by using BS 5950 compare to Eurocode 3. The research carried out by Mugil and Hirol (2013) shows different results as compared to Franky (2006) and Han (2006) where the research had proven that the steel structural design based on Eurocode 3 more economical design compare to BS 5950. As the findings differ a lot, this study is carried out to determine the cost effectiveness of using Eurocode 3 compared with BS 5950.

1.3 Aim

The aim of this project dissertation is to design selected pre-engineered steel structural members with non-typical section by using two different design standards which are British Standard (BS 5950-1-1: 2000 "Code of Practice for Design – Rolled and Welded sections") and Eurocode (MS EN 1993-1-1: 2010 "General rules and rules for buildings". The results of the designs are compared to determine the advantages and disadvantages of adoption of Eurocode 3 in design compared with BS 5950.

1.4 Objective

The objectives of this project dissertation research are listed below:

i. To determine the fundamental differences in steel design between Eurocode 3 and BS 5950
ii. To manually design and using a design software for selected pre-engineered steel structural element with Eurocode 3 and BS 5950

iii. To produce a design procedure manual for pre-engineered steel structure member using Eurocode 3

iv. To evaluate the advantages and disadvantages of Eurocode 3 comparing with BS 5950 by using an example of pre-engineered steel structural member of a factory as a case study

1.5 Scope of Work

The scope of work of the project dissertation research are:

i. Carry out literature review to study the concept of steel deign by using BS 5950 and Eurocode 3

ii. Modeling of factory pre-engineered steel structure via Staad.Pro V8i

iii. Design selected pre-engineered steel structural members based on BS 5950 and Eurocode 3

iv. Produce a design procedure manual for selected pre-engineered steel structural members

v. Comparison of the designs between BS 5950 and Eurocode 3

1.6 Outcomes

The main outcome of the dissertation is to enhance the understanding of the engineers in Eurocode 3 design. This is achieved by producing the designs of the selected steel structural members for both Eurocode 3 and BS 5950 and obtaining the advantages and disadvantages of using Eurocode 3 from the result comparison. Besides, the design procedure manual for selected pre-engineered steel structural member produced is able to improve the understanding of the engineers in design procedures of steel structure by using Eurocode 3.

1.7 Project Dissertation Organization

The project dissertation is divided into five main chapters. Chapter 1 presents an introduction to the study. Chapter 2 presents the literature review regarding the background of BS 5950 and Eurocode 3 and the work done by previous researchers in the area of steel design. Chapter 3 shows the summary and description of the research methodology used for this study, including site visits, manual calculations and design software application. Chapter 4 presents the results and discussion of the design work for both Eurocode 3 and BS 5950. Lastly, conclusions and recommendations for further studies are presented in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Pre-engineered Steel Structure

Pre-engineered steel structure (Pre-engineered Building)'s origin can be traced back to 1960's from the revolution of the technological improvement over the year to enhance the quality of life (Singh, 2007). Pre-engineered steel structure is a structural system which is predesigned and prefabricated. The system involves pre-engineering of structural elements using a predetermined registry of building materials and manufacturing techniques that can be proficiently complied with a wide range of structural and aesthetic design requirements (Meera, 2013).

Pre-engineered steel structure is formed by more than three members including primary members, secondary members, roof and wall sheeting connected to each other and other building components (Frontline Rolls Forms Pvt. Ltd., 2018). Primary members consist of column and rafter whereas secondary members consist of purlin, girt and eave strut. The entire primary members and secondary members are designed and fully fabricated including cut-to-length, punching, drilling, welding and performing in the factory before sent to the site. At site, all the elements will be assembled and jointed by using bolt and nut connections thereby reduced the costs and assembly times (Frontline Rolls Forms Pvt. Ltd., 2018).

The basic concept of the pre-engineered steel structure is by providing the section at the required location only. The size of the section is varying throughout the length according to bending moment diagram (Goswami and Sharma, 2017). The use of optimal least section leads to reduction in steel requirement and cost reduction.

Only the selected primary members are designed by using BS 5950 and Eurocode 3. The selected primary members of the pre-engineered steel structure include column, rafter and the connections.

Figure 2. 1 Typical Pre-Engineered Steel Structure (Metal Tech Constructions Pvt. Ltd., 2016)

2.2 BS 5950

The background, scope and basis of design for BS 5950 are described below.

2.2.1 Background of BS 5950

British Standard 5950 (BS 5950): "Structural Use of Steelwork in Building" is a code of practice for steel design that introduced in 1985. BS 5950 is a limit state code used to supersede the older permissible stress code BS 449 (Arya, 2009). It is a standard combining code of practice which covers the design, construction and fire protection for steel structures, specifications for materials, workmanship and erection (BS 5950-1: 2000). In other words, the purpose of BS 5950 is to define common criteria in the design process of the steelwork in building and function as a guideline for designer on methods of assessing compliance with those criteria. BS 5950 is subdivided into nine parts and each part is published separately. The parts included in the standard are shown in the Table 2.1:

Table 2.1: Overall Scope of BS 5950 (BS 5950-1: 2000)

Part 1	Code of practice for design – Rolled and welded sections
Part 2	Specification for materials, fabrication and erection – Rolled and welded sections
Part 3	Design in composite construction – Section 3.1: Code of practice for design of simple and continuous composite beams
Part 4	Code of practice for design of composite slabs with profiled steel sheeting
Part 5	Code of practice for design of cold formed thin gauge profiled steel sheeting
Part 6	Code of practice for design of light gauge profiled steel sheeting
Part 7	Specification for materials, fabrication and erection – Cold formed sections and sheeting
Part 8	Code of practice for fire resistant design
Part 9	Code of practice for stressed skin design.

Part 1 of BS 5950 which is BS 5950-1:2000, Code of Practice for Design – Rolled and Welded Sections is used. BS 5950-1:2000 is introduced in May 2001 to supersede BS 5950-1:1990 (Way and Salter, 2003). BS 5950 is prepared by Technical Committee B/525, Building and Civil Engineering Structure, to Subcommittee B/525/31, Structure Use of Steel. The clauses that have been updated technically including sway stability, avoidance of disproportionate collapse, resistance to brittle fracture, local buckling, lateral-torsional buckling, shear resistance, stiffeners, members subject to combine axial force and bending moment, joints, connections and testing.

2.2.2 Scope of BS 5950-1:2000

BS 5950-1:2000 includes the recommendations for the design of simple and continuous steel structures using rolled and welded sections. It provides guideline for the design structural steelwork using hot rolled steel sections, flats, plates, hot finished structural hollow section and cold formed structural hollow section (BS 5950-1: 2000).

This standard is for building and allied structures that are not specifically covered by other standards.

2.2.3 Basis of Design

According to BS 5950-1:2000, structures should be designed using four methods including simple design, continuous design, semi-continuous design and experimental verification. In each case, the details of the joints should fulfill the assumptions made in the relevant design method without adversely affecting any other part of the structure. For each method, the limit state approach must be adopted where the designer needs to select a number of criteria to assess the proper functioning of the structure. Checking of the criteria must be done and each criterion must satisfy the requirement. The criteria are divided into two main groups which are ultimate limit states and serviceability limit states.

Ultimate limit states concern the safety of the whole part of the structure which is applied for the assessment that is made of the collapse condition. Service limit states are applied for limits beyond which specified service criteria are no longer met (Handbook of Structural Steelwork, 2007). The example of the limit states are listed in the Table 2.2.

Table 2. 2: Limit States (Table 1, BS 5950-1: 2000)

Ultimate Limit States (ULS)	Serviceability Limit States (SLS)
Strength (including general yielding, rupture, buckling and forming a mechanism)	Deflection
Stability against overturning and sway stability	Vibration
Fracture due to fatigue	Wind induced oscillation
Brittle fracture	Durability

2.2.4 Loading

Type and magnitude of the load experienced by the structure during its design life need to be determined before any checking of limit states being carried out. BS 5950 has classified the loading into three basic groups which are dead, imposed and wind load; loads from overhead travelling cranes; earth and ground-water loading. All the relevant loads should be considered separately and combine to obtain the most critical effects on the structural members and the structure as a whole (Morris and Plum, 1996). In this research, the loadings acted on the structure are dead, live and wind load. The loading can be categorized as characteristic load, F_k and multiplied with partial factor of safety, γ_f to obtain their respective design load.

$$Design\ Load = \gamma_f F_k \qquad \text{(Clause 2.4.1.1)}$$

2.2.5 Partial Factor

Appropriate partial factors, γ_f should be applied to provide adequate degrees of reliability for both limit states. The typical values of γ_f for ultimate limit state used in this research are shown in the Table 2.3. The relevant γ_f should be multiplied with the specific load when the checking of ultimate limit state is carried out. For serviceability limit state, the loads should be taken as the unfactored specific values except snow load (Arya, 2009).

Table 2. 3: Typical Partial Factor of BS 5950 (Table 2, BS 5950-1: 2000)

Loading	Load Factor, γ_f
Dead Load, G_k	1.4
Imposed Load, Q_k	1.6
Wind Load, W_k	1.4
Combined Loads $(G_k + Q_k + W_k)$	1.2

After referring to the values of partial factor stated in the Table 2.3, the load combinations to be used in this research is tabulated in the Table 2.4.

Table 2. 4: Typical Partial Factor of Different Load Combination of BS590

Load Combination	Load Type				
	Dead, G_k		Imposed, Q_k		Wind, W_k
	Adverse	Beneficial	Adverse	Beneficial	
1. Dead and Imposed	1.4	-	1.6	-	
2. Dead and Wind	1.4	-	-	-	1.4
3. Dead (Restraining Uplift) and Wind	-	1.0	-	-	1.4
4. Dead, Imposed and Wind	1.2	-	1.2	-	1.2

2.3 Eurocode 3

The background, scope and basis of design for Eurocode 3 are described below.

2.3.1 Background of Eurocode 3

Eurocodes are a series of 10 European standards from EN 1990 (Eurocode) to EN 1999 (Eurocode 9) to function as a common approach for the design of buildings and other civil engineering works. The standards are developed by CEN (European Committee for Standardization) to cover the design of all types of structures in concrete, steel, composite steel and concrete, timber, masonry and aluminium (Mckenzie, 2013). Eurocode covers the basic of structural design and Eurocode 1 covers the actions on structure. Besides, Eurocode 7 and Eurocode 8 cover geotechnical design and design for earthquake resistance. For Eurocode 2 to Eurocode 6 and Eurocode 9, the standards cover the design of structure with different materials.

In 30th March 2010, 57 parts of British Standards were withdrawn and superseded by 58 parts of Eurocodes in United Kingdom including BS 5950 to Eurocode 3 (Wescott, 2010). Eurocode 3 with full name of “Design of Steel Structures” is the standard for steel construction which is prepared by Technical Committee

CEN/TC250. It consists of 6 parts and part 1 will be used in this research. Part 1 of Eurocode is subdivided into 12 parts which are listed in the Table 2.5.

Table 2. 5: Scope of Part 1 of Eurocode 3 (EN 1993: Design of steel structures, 2018)

EN 1993-1-1:2005	Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings
EN 1993-1-2:2005	Eurocode 3: Design of steel structures - Part 1-2: General rules - Structural fire design
EN 1993-1-3:2006	Eurocode 3: Design of steel structures - Part 1-3: General rules - Supplementary rules for cold-formed members and sheeting
EN 1993-1-4:2006	Eurocode 3: Design of steel structures - Part 1-4: General rules - Supplementary rules for stainless steels
EN 1993-1-5:2006	Eurocode 3: Design of steel structures - Part 1-5: General rules - Plated structural elements
EN 1993-1-6:2007	Eurocode 3: Design of steel structures - Part 1-6: Strength and stability of shell structures
EN 1993-1-7:2007	Eurocode 3: Design of steel structures - Part 1-7: Strength and stability of planar plated structures subject to out of plane loading
EN 1993-1-8:2005	Eurocode 3: Design of steel structures - Part 1-8: Design of joints
EN 1993-1-9:2005	Eurocode 3: Design of steel structures - Part 1-9: Fatigue
EN 1993-1-10:2005	Eurocode 3: Design of steel structures - Part 1-10: Material toughness and through-thickness properties
EN 1993-1-11:2006	Eurocode 3: Design of steel structures - Part 1-11: Design of structures with tension components
EN 1993-1-12:2007	Eurocode 3: Design of steel structures - Part 1-12: General - High strength steels

The sub-parts used in this research are EN 1993-1-1:2005 “General Rules and Rules for Buildings”.

2.3.2 Scope of Eurocode 3

Eurocode 3 is the standard for design of buildings and civil engineering works in steel. It complies with the principles and requirements for the safety and serviceability of structure, the basis of their design and verification that are given in EN 1990 – Basis of structural design. Besides, the standard is focused on the requirements of resistance, durability and fire resistance of steel structures. Other requirements e.g. concerning thermal or sound insulation are not covered in Eurocode 3. (EN 1993: Design of Steel Structures, 2018)

2.3.2.1 Scope of Part 1.1 of Eurocode 3

Part 1.1 of Eurocode 3 which is EN1993-1-1:2005 "General Rules and Rules for Building" provides basic design rules for steel structures with material thickness t $\geq$ 3mm. It also provides supplementary provisions for the structural design of steel buildings which are indicated by the letter "B" after the paragraph number (EN 1993-1-1: 2005).

2.3.3 Basis of Design

The basic requirements of Eurocode 3 is the same as BS 5950 where the designs must satisfied limit state used in conjunction with the partial factor method and load combinations. The partial factor method and load combination are given in Eurocode (EN 1990) together with the actions given in Eurocode 1 (EN 1991). The limit state concept in Eurocode is the same with BS 5950 which consist of ultimate limit states and serviceability limit states. Eurocode explained that ultimate limit states apply for the safety of people, the safety of structure, protection of the contents and states prior to structural collapse. Serviceability limit states concern the deformations that affect the appearance, comfort of users, the functioning of the structure (including the functioning of machines or services) or that cause damage to finishes or non-structural members; vibrations that cause discomfort to people or limit the functional effectiveness of the structure; damage that is likely to adversely affect the appearance, the durability, or the functioning of the structure (Silva et al., 2012).

2.3.4 Actions

"Action", *F* in Eurocode carries the same meaning with "load" in BS 5950. "Permanent actions", *G* are the fixed load acting on the structure including self-weight, finishes and immovable partitions. It has the same meaning with "dead load" in BS 5950 (Shafii et al., 2001) . Besides, variable actions, *Q* are imposed, wind and snow load that acting on the structure. According to Eurocode 3, the actions should be taken from relevant part of Eurocode 1 and the guidance regarding the combination of actions is given in Eurocode (EN 1990).

Generally, the design value of an action, F_d is obtained by multiplying the representative value, F_{rep} by the relevant partial safety factor, γ_f. The F_{rep} may be the characteristic value, F_k of a permanent or variable action multiply with ψ (either 1.00 or ψ_0, ψ_1 or ψ_2).

$$F_d = \gamma_f F_{rep}$$ Clause 6.3.1(1): 6.1a

with:

$$F_{rep} = \psi F_k$$ Clause 6.3.1(1): 6.1b

2.3.5 Partial Factor

Similar to the BS 5950, an appropriate partial factor (γ_f) should be applied to provide adequate degrees of reliability for both limit states. The partial factors applied for Eurocode are different with BS 5950. For the structures in Malaysia, the following partial factors and combination factors are taken from Table NA2 and Table NA3a from Malaysia's Annex for MS EN1990: 2010.

$\gamma_{Gj,sup}$	= 1.35	Partial factor for unfavourable permanent actions
$\gamma_{Gj,inf}$	= 1.0	Partial factor for favourable permanent actions
$\gamma_{Q,i}$	= 1.5	Partial factor for variable actions *i*
$\gamma_{Q,1}$	= 1.5	Partial factor for variable actions *1*

ψ_0	= 0.5	Combine factor for wind actions
ψ_0	= 0.7	Combine factor for imposed roof loads
ξ	= 0.85	Reduction Factor

After considering the actions experienced by the structure in this research, the typical partial factor for different combination of actions of Eurocode (EN 1990) are shown in Table 2.6.

Table 2. 6: Typical Partial Factor of Different Load Combination of EN 1990

Limit State/ Load Combination	Load Type		
	Permanent, G_k	Variable, Q_k	
	Partial Factor, γ_G	Leading Action	
		Action	Partial Factor, γ_Q
1. Permanent and Imposed	1.35	Imposed	1.5
2. Permanent and Wind	1.35	Wind	1.5
3. Permanent (Restraining Uplift) and Wind	1.0	Wind	1.5

There are three load combinations used for design using Eurocode 3 in this project which are less than load combinations used in design using BS5950. The combination of permanent, imposed and wind actions are excluded as imposed loads and wind actions should not be applied together simultaneously according to Clause 3.3.2(1) in EN 1991.

2.4 Differences between Eurocode 3 and BS 5950

2.4.1 General Differences

The main difference of Eurocode 3 compared with BS5950 is that Eurocode 3 brings new methods into the scope (BSI Shop: British Standards Institution, 2018). For example, the design of semi-rigid joints in buildings is explained, and more advanced methods of design for cold formed steelwork are included. Furthermore, the rules for shell, piles, sheet piling, silos and stainless steel are new and not included in the BS 5950.

A study regarding the comparison between British Standards and Eurocodes has been carried out by Shafii et al. (2001). The research discussed briefly the differences between the two approaches. The research commended that the main differences between Eurocode 3 and BS5950 are only the symbols, terms, safety factors and limits adopted. The principles of design, concept and formulation are generally the same. The results from the comparison are summarized in the Table 2.7 below.

Table 2. 7: Summarization of Differences between Eurocode 3 and BS 5950 Stated in Shafii et al. (2001)

BS 5950		**Eurocode 3**
-	Organization of The Content	Contains numerous comprehensive rules and information and exceeds twice in length than BS 5950
• Z_x, Z_y • S_x, S_y • F • r_x, r_y	Symbols Used : • Elastic Section Modulus • Plastic Section Modulus • Axial Load • Radius of Gyration.	• $W_{el,y}$, $W_{el,z}$ • $W_{pl,y}$, $W_{pl,z}$ • F • i_y, i_z
• zz • xx • yy	Notation Used In Reference To Member Axes. • Longitudinal Member • Major Axis • Minor Axis	• xx • yy • zz
Reference to Material Strength	Partial Safety Factor	Apply to Structures and Components and take account of both material ad modeling uncertaintis
Load • Dead Load • Imposed Load	Term Used For Loading	Action • Permanent Action • Variable Action
• Plastic • Compact • Semi-compact • Slender	Section Classification	• Class 1 • Class 2 • Class 3 • Class 4
NO	Permits The Use of Alternative Methods Of Analysis And Design	YES

The research carried out by Han (2006) had tabulated the criteria to be considered in structural beam and column design for BS 5950 and Eurocode 3. The tabulations show that most of the factors that considered in each criterion are the same for both standards except the symbols used in design. For example, the formula used to check the compression resistance of the cross section for Class 1, 2 and 3 in BS 5950 is $P_c = A_g p_c$ (Clause 4.7.4(a)) whereas Eurocode 3 is $N_{c,Rd} = Af_y/\gamma_{m0}$ (Clause 6.2.4(2)). Both have considered the area of cross section and the design strength of the steel. Although most of the factors considered in each criterion are the same, the limit or constant used in each formula are different. For instance, the compression resistance formula for Eurocode needs to divide by the partial factor, γ_M whereas BS 590 does not consider this in its formula.

A research carried out by NSC (2009) showed the expressions that are used to calculate the resistance of a bolt connection in tension, shear and bending by using BS 5950 and Eurocode 3. The results show that there are no significant changes to the basic capacities of the components. The result for Eurocode 3 are slightly more conservative than BS 5950 due to the higher partial safety factor (γ_{M2} = 1.25). The article mentioned that the tensile resistance according to Eurocode 3 is equivalent to the BS 5950 capacity according to the “more exact method” of Clause 6.3.4.3 but there is no equivalent to the “simple method” in BS 5950 which means that prying must be allowed if bolts are subjected to tension. The article commended that the bearing resistance has changed in Eurocode 3 for S275 material, where the bearing will not govern if the material is at least half the diameter of the bolt. According to BS 5950, the bearing resistance in 10mm S275 material is equal to the shear resistance but according Eurocode 3, it is possible to obtain a much higher bearing resistance (NSC, 2009.

Cobb (2014) also summarized the differences of Eurocode 3 compared to BS 5950. Other than the points mentioned above, the steel properties of Eurocode 3 are different with BS 5950. According to BS 5950, the steel properties are referred to BS EN 10025-2. The steel properties for Eurocode 3 are required to refer to the values quoted in main code as BS EN 10025-2 proposed lower values than the core standard document. Besides, the buckling factor (ε) of Eurocode 3 is lower than BS 5950 which is $\sqrt{(235/f_y)}$ and $\sqrt{(275/f_y)}$ respectively. In addition, some parameters are not given directly from the Eurocode 3 for example critical elastic buckling moment (M_{CR}) and critical buckling length (L_{CR}). In Eurocode 3, M_{CR} is required and calculated for lateral torsional buckling but it is not provided in the code. It is required to refer to Non-Contradictory Complementary Information (NCCI) document published by Access Steel. However, buckling curve and formulae are provided in the methodology of BS 5950. In the calculation of buckling length, BS 5950 uses effective length, L_E whereas Eurocode 3 uses L_{CR} but provides no guidance on its calculation. Lastly, the combined bending and compression calculation formulae for Eurocode3 are very cumbersome methods if doing hand calculation but formulae used in BS 5950 are much more simplified.

2.4.2 Differences between Eurocode 3 and BS 5950 in Designing Portal Frame

There a number of differences between Eurocode 3 and BS 5950 in designing portal frames. The critical differences affecting the frame designing are stated in King (2001) and listed as below.

- **Load Factors of Load Combination**

As stated in the previous sections, the load factors used by BS 5950 are different with Eurocode 3. BS 5950 applies one set of higher load factor for a combination of (dead + live) loads compare to Eurocode 3. However, a lower partial factor for combination of (dead + live + wind) loads is used for BS 5950. Eurocode 3 requires all variable actions are considered in same partial factors but included a reduction factor on all variable actions except the most unfavorable condition.

- **Consideration of Second-Order Effect**

According to Eurocode 3, the significant of the second-order effects must always be considered in analysis either by second-order analysis or by modification to classic first-order analysis. However, sway check method in BS 5950 uses deflection check to assess the stiffness and if the stiffness is above certain value, second order can be ignored.

- **Base fixity**

The column bases are normally assumed to be truly pinned for ultimate limit state bending moment diagrams with BS 5950. In Eurocode 3, the assumption of a truly pinned base is acceptable but the actual flexibility of the fixed bases must be considers.

- **Separate Checks for Cross-Section and Buckling**

Eurocode 3 has entirely separate checks for cross-section resistance and buckling resistance which is helpful for checking element varying section along the frame.

2.5 Past Studies on Comparison between BS 5950 and Eurocode 3 for Design of Steel Structure

Han (2006) had carried out a study on comparison between BS 5950 and Eurocode 3 for the design of multi-storey braced steel frame. The design is carried out to testify a claim from the Steel Construction Institute (SCI) which claimed that a steel structural design by using Eurocode 3 is 6 – 8% more cost-saving than using BS 5950. The study involves the comparisons of finding on a series of two-bay, four-storey braced steel frames with spans of 6m and 9m with steel grade S275 and S355 designed using BS 5950 and Eurocode 3. The research proven that the design using Eurocode 3 is able to reduce the requirement of beam shear capacity by up to 4.06%, moment capacity by up to 6.43%, compression capacity between 5.27% to 9.34% and deflection value due to unfactored imposed load up to 3.63% comparison with BS 5950. However, the research shows that the serviceability limit check has govern the design of Eurocode 3 as the permanent load have to be considered in deflection checking which consume 1.60% to 17.96% more steel weight than the design using BS 5950. A further study is extended for the application of partial strength connection for beam-to-column connections in Eurocode 3 design for this research. Although the further study has proven that it is able to reduce the percentage of difference between the requirements of steel weight for Eurocode 3 and BS 5950 to 0.11% - 10.95%, the requirement of steel weight for Eurocode 3 is still higher than BS 5950. The result has contradicted with the claim by Steel Construction Institute mentioned at the early section.

Franky (2006) also carried out a research to compare between Eurocode 3 and BS 5950 for flexural member design. The findings of the research are similar to the research carried out by Han (2006) as mentioned early where the design of steel structure is more economical by using BS 5950 compare to Eurocode 3.

The research carried out by Mugil and Hirol (2013) shows different result with Franky (2006) and Han (2006) where the research had proven that the steel structural design based on Eurocode 3 more conservative and economical design compare to BS 5950. Few parameters such as different loading types, beam lengths and steel grades (S275 and S355) were used to observe their influences in design. The final result in the research shows that the design by BS 5950 required greater size beam compared with Eurocode 3.

Since the previous studies show the different results in the comparison of BS 5950 and Eurocode 3 in economical aspect, this study is carried out to determine the cost effectiveness of using Eurocode 3 compared with BS 5950. The type of steel structure studied in this research is pre-engineered steel structure which is different with the previous studies. The difference in load combination and checking process such as frame stability may cause in different results with previous studies.

2.6 Eurocode in Malaysia

According to Pforden (2014), the Institution of Engineers Malaysia (IEM) has been taking initiative and lead to replace the existing British Standard which is the main source of structural design code in Malaysia since 2002. By 2010, five of the Eurocode parts have been drafted into Malaysian National Annexes relating structure design in concrete and steel design i.e. ME EN 1990, ME EN 1991-1-1, MS EN 1992-1-1 and MS EN 1993-1-1 and MS EN 1997-1-1.

In April 2014, the three main engineering bodies in Malaysia which are IEM, the Board of Engineers Malaysia (BEM) and the Association of Consulting Engineers Malaysia (ACEM) had met and drafted a letter which was addressed to the Ministry of Housing and Local Government to seek for agreement in commencing a transition period for replacement of British Standard to Eurocode. They suggested that the three years of transition period starting from 1st June 2014 and ending in May 2017. Ir. Prof Jeffrey Chiang, who is part of the IEM technical committee in charged with developing the Eurocode had commented that he felt that three years should be long enough for the local authorities to push enforcement for local engineers to learn up on the Eurocode.

However, the Ministry is not agreeable to the proposed transition period and the Uniform Building By-Laws (UBBL) 2012 still stipulates the use of British Standards as the facto approved standards for submission purposes for some states. According to Jeffrey (2014), not all of the local authorities have started to implement the revised UBBL that used Eurocode standard, named as MS EN standards for submission purposes.

According to the survey conducted by BEM since mid-2014 shows that a high number of engineers have given negative responses to the questions posed on their awareness and confidence level in use and adaption of Structural Eurocodes in place of British Standards (Jeffrey, 2015). The likely problems faces by the practicing engineers in adopting Eurocodes are lack of initiative in learning a new design standard because the learning process is tedious and time-consuming. Besides, there is insufficient in-depth awareness of the Eurocodes among practicing engineers and other users of codes of practice in the design of structure. The article written by Pforden (2014) also mentioned that the main challenge in the adoption of new code is changing the mindset. The article stated that the engineers need to do more work to adopt a new code as the document of Eurocode is thicker and it is greatly differ with British Standard although the fundamentals are basically the same.

Therefore, this study is carried out to improve the understanding of the differences between BS 5950 and Eurocode 3. The design procedure manual is produced to ease the learning process of the engineers and enhance their confidence level in adoption of Eurocode 3 for steel design.

2.7 Summary of Literature Review

The literature review started with the review regarding the background of pre-engineered steel structure and followed by the review of the background of BS 5950 and Eurocode 3. Besides, the literature review regarding the past studies for the comparison between the differences of BS 5950 and Eurocode 3 was carried out. Most of the findings commended that the main differences between Eurocode 3 and BS5950 are only the symbols, terms, safety factors and limits adopted. The results of past studies by other researches in determining the cost effectiveness of design using Eurocode 3 show that the design using Eurocode 3 consumes more steel weight than the design using BS 5950 (Han (2006) and Franky (2006)). However, Steel Construction Institute (Steel Construction Institute, cited in Han, 2006) and finding from Mugil and Hirol (2013) show that the steel structural design based on BS 5950 is more economical compared to Eurocode 3. However, the designs for all cases are not similar in structural design. As the findings contradict each other, this study is carried out to determine the cost effectiveness of using Eurocode 3 compared with BS 5950.

The literature review on the adoption and application of Eurocode 3 in Malaysia was carried out. According to the survey conducted by BEM since mid-2014, the result indicated that high number of engineers have given negative responses to the questions posed on their awareness and confidence level in use and adaption of structural Eurocodes in place of British Standards (Jeffrey, 2015). Therefore, this research is required to enhance the understanding of the engineers towards Eurocode 3 design by comparing it with BS 5950 design and produce a Eurocode 3 design procedure manual for selected pre-engineered structural members.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The procedures of the research must first be known to ensure the analysis of this research can carry out properly. Basically, this research is carried out on three phases to understand the concept of design based on Eurocode 3 and comparing the design concept with BS 5950. The summary and the details of the steps involved in this research will be discussed in the following section.

3.2 Summary of Research Methodology

This dissertation is carried out on three phases, initiated with the desk study to understand the concept of steel design based on Eurocode 3 and comparing the design concept with BS 5950. The second phase is design and analysis of typical selected pre-engineered steel structure of a factory based on Eurocode 3 and BS5950. Phase 3 is to carry out taking off for both designs and compare the results. Lastly, a site visit to the pre-engineered steel structure consultant office, Hitec Metal Sdn Bhd in Kuala Lumpur.

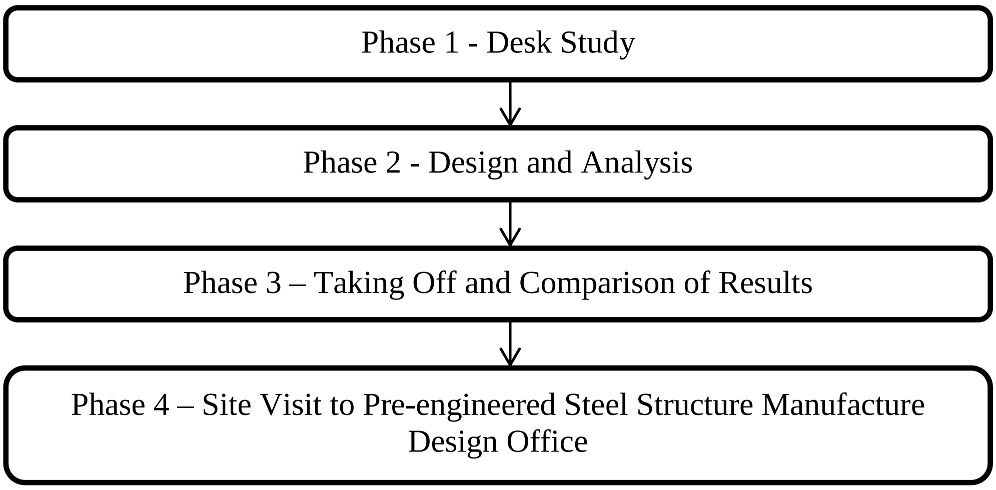

Figure 3. 1: Flow Chart of Research Methodology