COMPARATIVE STUDY OF BS8110 AND EUROCODE 2 STANDARDS FOR DESIGN OF A FACTORY REINFORCED CONCRETE FLAT SLAB

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By

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Projek ini menyediakan latar belakang asas Kod Struktural Eropah dan aspek pengenalan terutamanya mengenai prinsip reka bentuk dan perbezaan dengan Kod British Standard. Projek ini juga mengaji dan membandingkan penggunaan BS 8110 dan EC 2 dalam reka bentuk slab rata konkrit bertetulang untuk menentukan perbezaan antara dua kod. Skop penyelidikan ini adalah merancang prinsip untuk reka bentuk papak dengan menggunakan Kaedah Rangka Setara. Pemuatan dan analisis diambil dari struktur papak yang dimuatkan dengan parit trek, dianalisis dan memberi ulasan reka bentuk. Bangunan yang digunakan untuk projek ini adalah bangunan kilang; Kilang Komponen Bangunan Precast Scandinavian Industrialized Building System (SIBS). Bangunan itu adalah bangunan satu tingkat yang terdiri daripada lantai dasar dengan bumbung dek keluli. Lantai dasar terdiri daripada kawasan pengeluaran dan penyimpanan. Bangunan ini adalah kira-kira 5m tinggi yang mempunyai pelan dimensi 110m x 46m. Kekuatan bar tetulang dan berat unit konkrit bertetulang Reka Bentuk British Standard sedikit kurang daripada reka bentuk EC 2. Perlindungan konkrit yang diperlukan untuk Reka Bentuk Eurocode 2 lebih daripada Reka Bentuk Standard British kerana lebih banyak ciri rintangan kebakaran. Kawasan bertetulang untuk kedua-dua jalur tengah dan jalur lajur serta sokongan jalur tengah dan jalur lajur British Standard Design adalah kurang daripada reka bentuk EC 2. Walaubagaimanapun, Reka Bentuk Standard British yang menggunakan wayar mesh BRC A10 perlu menyediakan lapisan kekuatan hasil menyebabkan kawasan bertetulang disediakan meningkat ke 569.9 mm^2. Kos konkrit yang diperlukan untuk Reka Bentuk EC 2 adalah lebih tinggi daripada Reka Bentuk British Standard berdasarkan ketebalan lapisan konkrit yang telah direka. Kos bar tetulang keluli yang diperlukan untuk Reka Bentuk Eurocode 2 adalah lebih rendah daripada Reka Bentuk Standard British mengikut kawasan bar keluli yang direka bentuk.

ABSTRACT

This project provides some fundamental background of the European Structural Codes (Eurocodes) and some introductory aspects particularly on design principles and the differences with British Standard Codes brought about by the harmonised codes. This project also investigates and compares the use of BS 8110 and Eurocode 2 in the design of reinforced concrete flat slab to determine the differences between the two codes for this project. The scope of this research is designing principles for slab design by using the Equivalent Frame Method. The loading and analysis are taken from the slab structure that is loaded with track trench, analysed and detailed design results made based on the analysis results. The building adopted for this project is a factory building; the Scandinavian Industrialised Building System (SIBS) Precast Building Components Factory. The building is a one-storey building consisting of ground floor with steel deck roof. The ground floor consists of production and storage area. The building is about 5m high having an approximate plan dimension of 110m x 46m. The British Standard Design reinforcement bars strength and unit weight of reinforced concrete are slightly less than that of Eurocode 2 Design. The result of concrete cover needed for Eurocode 2 Design is more than that of British Standard Design due to more fire resistance characteristics. The reinforcement area for both span middle strip and column strip as well as support middle strip and column strip of British Standard Design is less than that of Eurocode 2 Design. However, the British Standard Design using BRC A10 wire mesh need to provide full yield strength lap length causing the reinforcement area provided increases to 569.9 mm^2. The cost of concrete needed for Eurocode 2 Design is higher than that of British Standard Design based on the designed concrete cover thickness. Lastly, the cost of steel reinforcement bars needed for Eurocode 2 Design is lower than that of British Standard Design according to the designed steel reinforcement bars area provided.

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LIST OF ABBREVIATIONS

BS 8110	British Standard 8110
EC 2	Eurocode 2
SIBS	Scandinavian Industrialized Building System
RC	Reinforced Concrete
CP	Codes of Practice
UBBL	Uniform Building by Law
EU	European Union
BS EN 1990	British Standard European Norm 1990
BSI	British Standard Institution
CSI	Computers & Structures Incorporation
DDM	Direct Design Method
EFM	Equivalent Frame Method
ACI	American Concrete Institution
XC	Exposure Class
BRC	British Reinforcement Company

NOMENCLATURES

$f_{ck,cube}$	Concrete Cube Strength
f_{ck}	Concrete Cylinder Strength
d	Effective Depth
f_{cu}	Ultimate Concrete Characteristic Strength
γ_m	Partial Safety Factor
A_{sv}	Cross-Sectional Area of Shear Reinforcement
S_v	Internal Forces and Moments
V	Shear Force
V_c	Concrete Shear Force
f_y	Yield Strength of Reinforcement
G_k	Dead Load (including Self-Weight)
Q_k	Imposed Load

CHAPTER 1

INTRODUCTION

1.1 Background

Reinforced concrete structure is a combination of two dissimilar but complimentary materials, namely concrete and steel reinforcement bars. Concrete is produced by mixing sand, cement, aggregates and water while steel reinforcement bars are metal alloy that constitute of iron and carbon. Concrete and steel reinforcement bars combined as reinforced concrete (RC) is a common material used widely in construction applications. This is done by embedding steel reinforcement bars in the concrete before the concrete sets.

Reinforced concrete slab is a flat element that is used in floors, roofs, walls of buildings and as the decks of bridges. The floor system of a structure can take many forms such as in-situ solid slabs, ribbed slabs or precast units. Slabs may span in one direction or in two directions and they may be supported on monolithic concrete beams, steel beams, walls or directly by the structure’s columns.

Design is the process made by engineers to determine the type, size and material used through a meticulous calculation until production of detailed drawings. The design work involves all structural elements of a building such as slabs, beams, columns, foundations and roofs. Slab design will consider all structural design aspects like bending moment, shear force, cracking and area of reinforcement.

In the context of the reinforced concrete design, the methods are formulated based on philosophies leading to design codes attendant to a particular design method. The usage of different design methods and codes will definitely bring about different results in structural analysis and design leading to varialibility in behaviour, costs and durability of structures. Structural engineers will provide designs that would lead to optimum performance and economy by employing the most efficient design method in accordance to a relevant design code available in order to satisfy client's requirements.

The building adopted for this project is a factory building; the Scandinavian Industrialised Building System (SIBS) Precast Building Components Factory.

1.2 Problem Statement

The problem statements in this project are:

1. Eurocodes have been the buildings design codes in European countries. In conjunction, Eurocodes are being adopted in Malaysia but there is lack of intention and knowledge to apply in buildings designs.
2. The determination of concrete cover thickness and steel reinforcement bars area that must refer to numerous tables could lead to mistakes and delay in design period.

1.3 Aim

This project aims to provide some fundamental background of the European Structural Codes (Eurocodes) and some introductory aspects particularly on design principles and the differences with British Standard Codes. This project will also investigates and compares the use of BS 8110 and Eurocode 2 in the design of reinforced concrete flat slab to determine the differences between the two codes in terms of loading analysis, ease of use and technological advancement by considering the loading and analysis of slabs which will be the representative structural element for this project. The use of a common code is also expected to lead to a standardisation of design to be updated for the latest design standards.

1.4 Objectives

The objectives in this project are:

1. To identify fundamental differences such as basis of structural design and actions on structures of reinforced concrete flat slab between British Standard and Eurocodes of the factory.
2. To compare structural characteristics and performances of flat slab with conventional two-way slab.
3. To compare the benefits and cost required of reinforced concrete flat slab design between British Standard and Eurocodes of the factory.
4. To produce a comprehensive detailed design calculations for reinforced concrete flat slab by using Eurocodes.

1.5 Scope of Work

The scope of work performed in this project consists of:

1. To analyse and design reinforced concrete slab of the factory using Eurocode 2 (EC 2) and then compare the design results with the existing design of British Standard code (BS 8110) used.
2. To produce a comprehensive detailed design calculations for the reinforced concrete flat slab based on Eurocode 2 (EC 2).

1.6 Dissertation Outline

This dissertation is presented starting from Chapter 1 that describes the problem statements, aims, besides objectives, scope of work and outcomes of this project. Chapter 2 describes the literature review mainly on British Standard Code (BS 8110) and Eurocode 2 (EC 2) with details reviews of researches reported on the design of stuctures and slab by other researchers and designers. Chapter 3 details the methodology of the study in the design of slab for case study using British Standard Code (BS 8110) and Eurocode 2 (EC 2). Description of the case study used for this project is also given. Chapter 4 describes the results of the design process and findings between British Standard code (BS 8110) and Eurocode 2 (EC 2). Chapter 5 gives the conclusion and future recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter discusses on the history and development of British Standard (BS 8110: Part 1:1997) and Eurocode 2- Design of Concrete Structures. The introduction and application of this code is a significant event in civil engineering, so this chapter will look closely on British Standard and Eurocode 2 as well as its applications.

The procedures and process of design based on Eurocode 2 does not change in adaptation where this section will point out the main outline in design procedures. Learning to use new codes will require time and effort, thus the development of this research is hoped to ease the transition of using Eurocode 2 as the new design standards.

2.2 British Standard

With effect from 2010, the British Standard Code (BS 8110) for the structural use of concrete will be withdrawn to give way for the full implementation of Eurocodes in the United Kingdom. The shifting to Eurocodes is the result of a long term effort to harmonise the structural design and construction practices throughout all countries in the European Union (EU) was first initiated in 1974 (Fong, 2006).

A long period of British colonisation resulted in Malaysia inheriting many aspects of engineering practices from the British. After almost 50 years of independence, Malaysia still very significantly relies on the British Standard Codes in design and construction practices. The earlier generations of Malaysian engineers had been very familiar with CP 114 and CP 110 while the present generation is comfortably using BS 8110. In bridge design, BS 153 and later BS 5400 are the main references used by local engineers. The dependency on British Standard Codes went to the extent that, it was stated in the Malaysian Uniform Building By Law (UBBL) that the design and construction of Malaysian buildings shall comply with Malaysian or equivalent British Standard Codes (Fong, 2006).

At the level of tertiary education in Malaysia, the teaching of design courses in the Civil Engineering programme based on British Standard Codes while for the design of structural concrete, BS 8110 (1997) is the main reference used. In design and construction practices, perhaps more than 80% of local engineers and consultants carry out their work based on BS 8110. Government agencies such as local authorities are more familiar with the British Standard Codes. The scenario presented above shows that there would be a huge impact in Malaysia for the withdrawal of BS 8110. There will be wide-ranging implications that will affect almost the whole segment of the design and construction industry (BS 8110, 1997).

The design of slabs covered in BS8110: Part 1, Section 3.7. General requirements given in Clause 3.7.1 such as design moments that are obtained by equivalent frame method, simplified method or finite element analysis (Bhatt et. al., 2006).

2.3 Eurocode 2

A new code named as Eurocode is now in use in the European Union (EU) countries for structural design. The code is revised and reissued as European Norm, EN which are mandatory in the sense that conflicting national standards must be withdrawn. This code is meant to unify design philosophies and make civil engineers productive across all of Europe. The steps brought about by the developments of Eurocodes have significant impacts on British Standard users as considerations must be made in keeping abreast with developments and technologies in current practices (Nwoji and Ugwu, 2017).

EC 2 are part of the whole range of structural Eurocodes that have been developed by European countries and are intended to harmonise the design and construction practices within Europe. The harmonisation provides equal opportunities to all engineers, consultants and contractors to practice within all the countries in the Europe. It took almost 30 years of development that claimed to be the most technically advanced in the world. There are many other parts of Eurocodes connected to EC 2 and may require cross-referencing during the process of design and construction. One example is BS EN 206, a standard for concrete materials. The existence of many parts makes the process of shifting to EC 2 look rather complicated, especially during the early stage of familiarisation. Only BS EN 1990: Basis of Structural Design is produced in a single part. This basic document (occasionally known as EC 0) contains principles and requirements for safety, serviceability and durability of structures (Implementation of the Structural Eurocodes, 2004).

A distinct feature of the Eurocodes is that it is concise, yet it describes the overall aims of design and provides specific guidance on how to achieve these aims in practice. For these purposes, the materials in Eurocodes were divided into principles and application rules. A further point to be noted in using the code is that a number of numerical values, e.g. partial safety factors, minimum concrete covers and coefficients in equations, are shown boxed. This signifies that the values are meant to be for guidance only and that other values may be adopted by individual member states (Faridah et al., 2001).

The publication of final version of Eurocode 2 (EC2) BS EN 1992-1-1: 2004 with a full title of Eurocode 2: Design of Concrete Structures, Part 1-1: General Rules for buildings in 2004 by the British Standard Instituition (BSI) and similar publications in other European countries signifies that the shifting to EC2 is now confirmed. Although many other parts of Eurocodes that are related to EC2 are still under the drafting stage and yet to be published in the final document, the development in the UK clearly indicates that there will be no turning back. The use of EC2 is mandatory in 2010 after a period of about 10 years of familiarisation in which EC2 is encouraged to be voluntarily in design work parallel (Moss, R. et al., 2004).

2.4 Eurocode 2 (National Annex)

EC 2 has a supplementary document known as National Annex which allows the use of alternative values that suit individual countries. Malaysia should take full advantage of this as there are many design parameters taken directly from foreign codes that are usually not very suitable to our environment. Concrete cover, which is related to durability and fire requirement; and time-dependent deformation of concrete, such as creep and shrinkage, for example, may require local design values. It is an opportunity for local researchers to carry out study on these topics and other areas (Wahid O., 2008).

This system of identifying certain parameters provides Eurocodes the flexibility to account for national differences in material properties, design and construction practices, climatic conditions and other significant factors. However, it is anticipated that the unification of manufacturing and construction practices throughout EC should see to the gradual disappearance of most of these boxed values from the Eurocodes. In general, Eurocodes are designed to be as user-friendly as possible. The material in the appendices and the 'normative' annexes has the same status as the rest of the Eurocode but appears in the appendices in order to produce a convenient referenced document. The material in the informative annexes, however, does not have any status but has been included merely for information (Eurocode 1, 1994).

In general, the applications of Eurocode allows flexibility for its adoption to local needs. The National Application Document plays a big role in the transferring of one national standard to another. Irrespective of the material properties or design conditions, Eurocode could be used reliably for the structural design of engineering materials in any country as long as it is used in conjunction with the national standard. It is this transfer of knowledge and standard which should be considered in deciding the future direction of Malaysian practices for codes of structural design (Faridah et al., 2001).

It is admitted that many more aspects should be discussed to assist Malaysian engineers to understand the EC 2, but this will be done in other publications. In short, EC 2 is simply a design guide and engineers have options to exercise their own engineering judgement based on their level of competency in engineering knowledge. The challenges are that engineers are expected to be more competent, have deep understanding of the subject and be fully prepared to acquire new knowledge in order to gain the maximum benefit of EC 2 (Narayanan et al., 2005).

It is crucial for Malaysia Standards Committee to decide its destiny in response to the withdrawal of BS 8110. The earlier the decision could be made, the better for engineers and other parties involved in construction. Experience in the UK has shown that the shifting to Eurocode requires tremendous effort and huge resources. It is important for the authorities to work closely with professional bodies as the withdrawal of BS 8110 may cause very significant impact not only to engineers but also to the whole economy (Fong, 2006).

2.5 Benefits of Eurocode 2

The benefits of structural Eurocodes, particularly to the construction industry, ensures standard workmanship to be achieved in a particular design therefore, enhancing quality control. To a considerable extent, the implementation of structural Eurocodes in Europe would have great implications on nations based on British practices. Eventually, a choice has to be made whether to accept the new approach or to remain unchanged. Undeniably, for the developing countries there is a need to keep abreast with new technologies at the international level. The selection of Eurocode is beneficial for this purpose however, requires effort in familiarising with the new requirements and additionally, the transfer of technology to conform to local design and structural requirements (Faridah et al., 2001).

2.6 Differences between BS and EC

The terminology used in the Eurocode is generally similar to that already used in the equivalent UK documents with some minor differences. For example, “loads” are now called “actions” while “dead” and ‘imposed” loads are now termed “permanent” and “variable” actions, respectively. Similarly, “bending moments” and “axial loads” are now called “internal moments” and “internal forces”, respectively. It is anticipated that these changes are unlikely to present any major problems, especially to UK engineers and those familiarised with British Standard Codes (Eurocode 1, 1994).

Table 2.1: Eurocode 2 Parts

Eurocode 2	Title	Standards superseded
BS EN 1992-1-1	General Rules for Buildings	BS 8110: Parts 1 and Part 2
BS EN 1992-1-2	Fire Resistance of Concrete Structures	BS 8110: Parts 1, Table 3.2 Part 2, Section 4
BS EN 1992-2	Bridges	BS 5400: Part 4
BS EN 1992-3	Liquid-retaining and Containment Structures	BS 8007

From the Table 2.1 above, EC 2 consists of different parts but the focus currently will only be on the principal part; Part 1.1 which is to supersede BS 8110 Part 1 and 2. Among the benefits outlined by the UK Concrete Centre (Nwofor et al., 2015) in using EC 2 are listed below:

1) The new Eurocodes are claimed to be the most technically advanced codes in the world.
2) Eurocode 2 should result in more economic structures than BS 8110.
3) The Eurocodes are logical and organised to avoid repetition.
4) Eurocode 2 is less restrictive than BS 8110.
5) Eurocode 2 is more extensive than BS 8110.

Puah (2014) highlighted some of the notable differences between EC 2 and BS 8110 as listed below:

1) The arrangement of chapters in EC 2 are generally laid out to give advice on the basis of phenomena (e.g.: bending and shear) rather than by member types as in BS 8110 (e.g.: beams, slabs and columns).

2) In EC 2 'load' is called 'action'. 'Dead' and 'live loads' will appear as 'permanent' and 'variable' actions respectively in EC 2.
3) Perhaps the most significant change that may affect the Malaysian designers is that EC 2 measures concrete strength based on cylinder and all design expressions are developed on cylinder strength. Hence, concrete cube strength, $f_{ck,cube}$ need to be converted to concrete cylinder strength, f_{ck} in EC2.
4) EC 2 adopts a traditional European approach in design where engineers are expected to refer to other documents such design guides or textbook in order to apply the design principles of the code. As a result, EC 2 does not provide derived formulae (e.g.: for bending, only the details of the stress block are expressed). For example, those familiar with Clause 3.4.4.4 of BS 8110: Part 1, would not find the same design expressions in EC 2.
5) Unlike BS8110 in which the guidelines provided are limited for normal strength concrete, higher strengths of concrete are covered by Eurocode 2, up to class C90/105. However, because the characteristics of higher strength concrete are different, some expressions in the code are adjusted for classes above C50/60.
6) In shear design of beams, the major difference is that EC 2 does not fix the angle of diagonal shear crack at 45° as proposed by BS 8110. The method used in EC 2 is known as the variable strut inclination method. The method allows engineers to choose the optimum angle in order to achieve the most economic design.
7) The punching shear checks are carried at 2*d* from the face of the column and for a rectangular column, the perimeter is rounded at the corners.
8) Serviceability checks could still be carried out using 'deemed to satisfy' span to effective depth rules similar to BS 8110. However, if a more detailed check is required, Eurocode 2 guidance varies from the rules in BS 8110 Part 2.

9) The rules for determining the anchorage and lap lengths are more complex than the simple tables in BS 8110. Eurocode 2 considers the effects of, amongst other things, the position of bars during concreting, the shape of the bar and cover.

In building design, commonly used parameters by local practicing engineers such as that for imposed loads on floors for office buildings, durability and fire resistance requirements were made uniform for both EC2 and BS8110. Varied parameters were mainly those based on theories or principles of the codes such as the equations governing flexure at the ultimate limit state and shear. Differences in these principles might result in differences for load a common member dimension could carry, be it at service or the ultimate limit state. Consequently, the amount of reinforcement required might also be affected. It has been opined that EC2, in common with other ECs, tends to be general in character and this might pose some difficulties in its initial use for design. Nevertheless, for the present purposes there is no loss or wrong application in applying uniform factors to both code provisions for the building design (Shodolapo and Kenneth, 2011).

As stated earlier some of the terms used in Eurocodes are different from British Standards, in that it tries to cover a wide variety of situations. Changes are made on the dead loads definition in EC2 where it draws a distinction between loads with small and large variations. If the variation between lower and upper loads is less than 20% of the mean value, then the mean value is used as the characteristic value. If the variation exceeds 20%, then both the lower and upper loads should be considered as characteristic values. BS 8110 does not make such an explicit distinction in the definition of the characteristic value of dead loads. Such considerations are relevant when dealing for example, with the weight of a slab and a wall cast against earth. Other modifications with regard to loads are made to the load combinations and the values of corresponding partial safety factors at both serviceability and ultimate limit states. The partial safety factor for reinforcement does not change. For concrete, EC2 adopt a single value of 1.5 throughout, as oppose to BS 8110 that is using different values for bending, shear and bond. With regard to durability considerations, EC2 does not permit the 'trade-off' between cover and concrete quality as BS 8110 does (Faridah *et al.*, 2001).

Both EC2 and BS 8110 permit redistribution of bending moments in continuous beams. The difference lie in the rules given to cover the ductility and detailing requirements in the two documents. For EC2, 30% redistribution is permitted for high ductility steel while 15% for normal ductility. EC2 does not permit any redistribution in sway frames whereas BS 8110 allows up to 10% redistribution. Flexural design of sections using EC2 is rather complicated as compared to BS 8110. EC2 permits the use of stress-strain curve for the reinforcement that is identical to that in BS 8110. EC2 also allows the use of a relationship with a sloping upper branch that considers strain hardening. For stress-strain curve of concrete, EC2 use the same basic diagram as BS 8110 but slightly simpler to use. EC2 allows the use of simplified stress block. It permits the use of both a rectangular and a bilinear diagram. The expression of shear strength of concrete in EC2 contains all the parameters as in BS 8110. There are some differences with regard to limitations. In BS 8110, f_{cu} should not be taken as greater than 40 N/mm^2. There is no limit on the concrete strength in EC2. The values for γ_m are 1.25 and 1.5 in BS 8110 and EC2, respectively. EC2 provides alternative in designing the shear links. It allows the use of the method as in BS 8110 that is based on 45° strut. EC2 also allows the use of variable strut inclination method leading to increased consumption in the requirement of shear links (Narayanan et al., 2005).

Meanwhile, the comparison between structural Eurocodes and British Standards Codes is generally where EC2: Part 1 is broadly comparable to the existing British

Standard Code, BS 8110 Part 1 and Part 2. BS 8110 is applicable to buildings whereas EC2 comprised of various parts and covers on the different types of structures. For example, building is generally covered by EC2: Part 1 that could be distinguished easily from BS 8110 in the way the chapters are described. The latter contained chapters dealing with beams, slabs and columns whereas EC2: Part 1 has chapters on bending, shear, torsion and buckling. The arrangement of chapters in EC2 is based on phenomena whilst BS 8110 uses element types (Faridah *et al.*, 2001).

The differences between BS 8110 and EC2 could also be seen in the serviceability limit state design. British Standard for the design and construction of reinforced and prestressed concrete structures is based on limit state design principles whereas the Eurocodes are a new set of European structural design codes for building and civil engineering works. For example, EC2 includes the provision to check the stress level in reinforced concrete, whilst BS 8110 does not require this. In contrast to BS 8110 that uses the characteristic loads for serviceability check, EC2 requires modification factors of loading, depending on the nature of the particular check being carried out (Krishna and Pranesh, 2001).

From the brief discussions above, certainly there need to be a clear understanding on the background of the new codes, particularly the differences before a designer could use it effectively in practice. Nevertheless, Eurocode are being introduced and applied for design concrete structures but still not yet widely use in Malaysia nowadays (Eurocode 1, 1994).

In general, EC2 provides only the basic information required, whereas BS 8110 gives considerably more detailed information. With BS 8110, one can use the coefficients given for various load effects such as bending moments and shear coefficients for continuous beams and slabs. EC2 expects the designer to obtain these from textbooks or manuals. In EC2, design formulae are generally related to the cylinder strength. This is one of important changes that must be noted. As an approximation, the cylinder strength could be taken as 80% of the cube strength (Arya, 2009).

2.7 Comparison of Flat Slab with Two-Way Slab

Flat slab is defined in BS8110: Part 1, Clause 1.2.2.1 as a slab with or without drop panels, supported generally without beams by columns with or without column heads. The code states that the slab may be solid or have recesses formed on the soffit to give a waffle slab. Flat slab is thicker than that required in T-beam floor slab but the omission of beams gives a smaller storey height for a given clear height and simplification in construction and formwork (Reynolds and Steedman, 1988).

The flat slabs could be considered as special type of two-way slabs. In the case of two-way slabs, the total load is carried in two directions jointly by slab and its supporting beams whereas in the case of flat slabs, beams are eliminated and broad strips of slab centred on column lines in each direction serve the same function as the combination of slab and beams. The presence of column head or drop does not change this requirement (Gambhir, 2008).

The main difference between flat slab & conventional slab-beam system is that the one is directly supported on the column while another system has a beam for support. The load is transferred directly from slab to column in the flat slab. In conventional slab-beam system, the load is transferred from slab to beam and ultimately beam to the column. The various differences between flat slab & conventional slab-beam system is shown in the Table 2.2 next page:

Table 2.2: Differences between Flat Slab & Conventional Slab-Beam System (Gharpedia.com, Differences between Flat Slab & Conventional Slab-Beam System, 2016)

No.	Flat Slab System	Slab-Beam System
1	The floor / roof consists of walls / slabs and there are no beams.	The floor / roof consists of beam and slab.
2	The thickness of slab is large.	The thickness of slab is small while depth of beam is large.
3	It provides greater clear ceiling heights.	It provides lesser clear ceiling heights.
4	Load(s) from slab is directly transferred to column.	Load(s) from slab is transferred to beam and from beam to column.
5	Less formwork is needed.	More formwork is needed.
6	Formwork is simple and hence not costly.	Formwork is complicated and hence costly.
7	Drop panel is provided above column.	Drop panel is not needed above column.
8	Floor system requires lesser depth and hence there will be reduction in storey height.	Floor system requires more depth and hence there will be increase in storey height.
9	Dead load of the structure is less.	Dead load of structure is more.
10	It is easy to install sprinkler and piping and other utilities as beams are absent.	It is tricky to install sprinkler, piping and other utilities as beams are present.
11	Flat ceiling is available which gives attractive appearance.	Flat ceiling is not available for flat attractive appearance, you may have to do false ceiling.
12	Illumination is better as beams are absent.	Illumination is not as effective as in flat slab as beams are present.
13	It is easier to provide acoustical treatment on underside of the slab.	It is difficult to provide acoustical treatment on underside of slab.
14	At least three continuous spans slab in each direction are needed for construction.	Construction of single span slab is possible.
15	Ratio of longer span to shorter span should not be more than 2.2.	Ratio of longer span to shorter span has no limitation.
16	Live load shall not exceed three times the design dead load.	Live load has no relation with design dead load.
17	The minimum thickness of the slab is 125 mm.	The minimum thickness of the slab is 100 mm.
18	Reinforcements are commonly provided in two layers.	Reinforcements are commonly provided in one layer.
19	It is less resistant to the earthquake as it is less flexible than slab beam system.	It is more resistant to the earthquake as it is flexible than flat slab system.

The two-way slabs possess a major structural advantage over the flat slab that it could be reinforced more effectively to resist torsion and shear. In the case of two-way slabs, much higher built-in factor of safety of the order of 3.5 is available as compared to that for flat slabs of the order of 2.0 (Gambhir, 2008).

In flat slab, the slab must carry 100 per cent of the load in each direction whereas in two-way slabs, the slab carries less than 50 per cent of the load in each direction and the supporting beams to the columns carry the remainder. As a result, the mid-span moments in middle strips in both systems are similar, but the moments in column strips for flat slabs are much higher than that in the column strips in the two-way slabs. In flat slabs, the ratio of negative to positive moments is 1.86 as compared with 2.0 for fixed ended condition and about 1.32 for two-way continuous slabs (Gambhir, 2008).

The main drawbacks with flat slabs are that they may deflect excessively and are vulnerable to punching failure. Excessive deflection could be avoided by deepening slabs or by thickening the slab near the columns using drop panels. Punching failure arises from the fact that high live loads results in high shear stresses at the supports that may allow the columns to punch through the slab unless appropriate steps are taken. Using deep slabs with large diameter columns providing drop panels and/or flaring column heads could avoid this problem (Gharpedia.com, Differences between Flat Slab & Conventional Slab-Beam System, 2016).

The major advantage of flat slab construction lies in the absence of supporting beams which results in plain ceiling surface giving better diffusion of light, easy constructability with economy in the formwork, larger headroom or shorter storey height, pleasing appearance and easy acoustical treatment. General flat slab construction is economical for spans up to 10m with relatively light loads (Gambhir, 2008).

However, the stiffness of flat slab construction is much less than the beam-slab-column construction. Due to reduced stiffness, flat slab construction is not very effective in carrying horizontal loads that result in significant bending moments in the slabs. Thus, the flat slab construction is used in low and medium rise buildings. They are also not suitable for multi-storeys office buildings having width less than the height. Serviceability problems also arise with excessive long-term deflection of such relatively thin slabs. Nevertheless, the problems are considerably reduced in the flat slabs with drops and column heads (Gambhir, 2008).

2.8 Comparative Study between BS 8110 and EC 2 of previous Work

This section discusses on previous work conducted concerning the comparison of reinforced concrete building structure element between British Standard Code (BS 8110) and Eurocode 2 (EC 2).

Nwoji and Ugwu (2017) did a comparative study of BS 8110 and Eurocode 2 in structural design and analysis. This project was undertaken to compare the use of BS 8110 and Eurocode 2 in the design of structures and focused on outlining the relative gains and/or shortcomings of Eurocode 2 and BS 8110 under certain criteria which are loading, analysis ease of use and technological advancement. To accomplish this, the analysis and design of the main structural elements in reinforced concrete building was undertaken using the two codes. A modest medium rise building was loaded using the two code and analysed. Analysis was done using CSI Start Tedds to obtain the shear force and bending moment envelopes. In summary, the comparative benefits of using Euroode 2 are that it is logical and organized, less restrictive and more extensive than the BS 8110. The new Eurocodes are claimed to be the most technically advanced code in the world and therefore should be adopted by engineers (Nwoji and Ugwu, 2017).

Besides that, a comparative study by Shodolapo and Kenneth (2011) of EC2 and BS8110 beam analysis and design of the main structural elements in a reinforced concrete four storey building was undertaken using the two codes namely EC2 and BS8110 with the aid of the Prokon 32 suite of programmes. In respect of the main beams, the emphasis was on examining the bending moment diagrams for the critical continuous beam span for both codes before moment redistribution and after 10%, 20% and 30% redistribution in that order. It was concluded that reliance should not be placed on the trend in shear variations with respect to both codes (Shodolapo and Kenneth, 2011).

Apart from that, Kamarul (2010) developed a program that is able to analyse and design reinforced concrete slabs using the application of spreadsheet Microsoft Excel. The analysis and design of slabs is in accordance with BS 8110 Part 1: 1997 and Eurocode 2 - Design of concrete structures. Thus, this research focused on the application of those design codes in the form of spreadsheets from Microsoft Excel for the purpose of analysing and designing of reinforced concrete slab. Basically, the procedures in designing this element require numerous calculations in order to reach the most desired and economical design. The spreadsheet had been developed with design procedures based on BS 8110 and Eurocode 2, which is the design of reinforced concrete slabs. Necessary checking such as deflection and crack control was also calculated by the spreadsheet which helps to improve the accuracy of the design. The calculations done by the spreadsheet was compared to manual calculation to ensure the reliability of the spreadsheet. Results and conclusions show that this spreadsheet fulfils the research objectives that are to develop spreadsheet to aid designers in the designing using BS 8110 and Eurocode 2 (Kamarul, 2010).

A research was conducted by Patil and Rupali (2014) on the analysis and design of flat slabs using various codes where “Flat Slab” is better understood as a slab without beams supporting directly instead supported by columns and/or shear walls. For instance, large bending moment and shear forces are developed close to the columns. These stresses brings about the cracks in concrete and may provoke the failure of slab, thus there is a need to provide a larger area at the top of column recognized as column head and/or drop panel. The analysis of flat slab is executed by Direct Design Method (DDM) & Equivalent Frame Method (EFM) as directed by different standard, however the Finite Element Analysis and Equivalent Frame Analysis is carried out by using software named "SAFE". The analysis and design is performed by Equivalent Frame Method with staggered column and without staggered column as prescribed in the different codes like IS 456-2000, ACI 318-08, BS 8110-1997, EC2 Part1 2004 to be compared. In this process, moments are distributed as column strip moments and middle strip moments. Equivalent Frame Analysis is also carried out for distribution of column strip moments and middle strip moments by using software "SAFE". Excel worksheets for analysis and design of flat slab using equivalent frame method for all standard codes are also prepared (Patil and Rupali, 2014).

A comparative study conducted by Nwofor *et al.* (2015) of BS 8110 and Eurocode 2 Standards for design of a continuous reinforced concrete beam was completed. In this paper, a comparative study of BS 8110-97 and Eurocode 2 for the design of reinforced concrete beam with a particular interest on the area of tension and shear reinforcements required, with the aim of determining which of the two codes provides the most economical design being carried out using Microsoft Excel spreadsheet. A six-span continuous beam from the roof of a three-storey shopping complex was selected and designed with the aid of a programmed Microsoft Excel spreadsheet, taking into account only dead and live loads and assuming all spans to be loaded equally for both dead and live load combination. The self-weight of the beam was taken as the dead load while the live load was assumed to be a unity. The result of the analysis was used to design the beams based on both codes with the aid of a programmed spreadsheet. The percentage difference between the areas of steel required by the two codes was calculated with the BS 8110 code results as the control values. The average percentage difference for all spans was found to be about -3.08%, indicating that the Eurocode2 requires less amount of reinforcement at the spans. The average percentage difference for all supports was found to be about -2.83%, indicating that the Eurocode2 requires lesser amounts of reinforcements at supports. The average percentage difference of the required ratio of area of shear reinforcement to spacing was about -61.90% indicating that the BS8110 requires more shear reinforcement than the Eurocode 2 (Nwofor *et al.*, 2015).

Finally yet importantly, another comparison work by Puah (2014) for Eurocode 2 and BS 8110 on reinforced concrete flexural and shear member design that was done based on 12 different cases generated by Microsoft Excel's spreadsheets. It aimed to discover the similarity and differences of these two codes, where investigation of code brings more benefits in designing and to familiarize engineers with EC2. Only main reinforcement and vertical shear link of continuous beams and slabs were designed at ultimate limit state, without considering lateral and notional load, axial load, torsional moment, earthquake, no pre-stressed concrete is used, column is not analysed and steel Grade 460 were used for BS 8110 and EC 2 (Puah, 2014).

The 12 cases vary from each other by span lengths and imposed load or variable actions. Generally, the imposed load stays within the range of 2.5 to 7.5kN/m^2, while the span length of beams varies from 8 to 9 metres. After obtaining the design results of 12 cases, tables and graphs are produced to compare the results of BS 8110 and EC2. The value of moment and shear are always lower for EC2 due to the partial safety factors that are lower than the one used by BS 8110 causing material safety factor for EC2 to be lower (Puah, 2014).

For flexural design, the required steel ratio of EC2 is slightly higher than that required by BS 8110. It was concluded that Grade 500 steel should be used for EC2, only then the steel ratio for both codes will be even more similar, with the steel ratio of EC2 being slightly lower than BS 8110. This agrees with the studies from literature review whereby design based on EC2 are supposed to be more economical (Puah, 2014).

For the design of shear, BS 8110 takes into account the concrete shear resistance but EC2 does not, while the strut angle of EC2 is 22° which is lower than BS 8110 strut angle of 45° as shown in the Table 2.3 below:

Table 2.3: Shear Design Formula for BS 8110 and EC 2

	EC 2	BS 8110
A_{sv}/S_v	$\frac{V}{0.78 f_y d cot 22°}$	$\frac{V - V_c}{0.95 f_y d cot 45°}$

It was realized that the design shear force of BS 8110 is lesser than EC2 for more than 50% where EC2 would be more conservative in providing A_{sv}/S_v. Additional research was carried out by adopting steel Grade 500 for EC2 which causes the percentage difference before EC2 becomes more conservative up to 52.5%. This means that BS 8110 will required a higher concrete shear resistance to be less conservative (Puah, 2014).

Cases whereby the shear force is lower than the concrete shear resistance, BS 8110 will provide a minimum links and assume a shear stress of 0.4 MPa, here BS 8110 will shows a more conservative A_{sv}/S_v ratio than EC2. When comparing the relationship between shear force and A_{sv}/Sv ratio for BS 8110 and EC2, the graph of EC2 is less steep, which indicates the shear link of EC2 increase lesser than BS 8110's when the shear increase. As a summary, the flexural and shear design results of EC2 was more economical than BS 8110 (Puah, 2014).

2.9 Research Gap with previous Work

Conclusively, the previous studies and researches do not compare and interpret the costs required from the results between the reinforced concrete slab designs of British Standard Code (BS 8110) and Eurocode 2 (EC 2) that depicts the research gap with this project.