

COMPARATIVE STUDY OF STEEL PLATE GIRDER AND PRESTRESSED
CONCRETE GIRDER

BAVANI A/P RENGARAJOO

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Structure)

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

FEBRUARY 2021

DEDICATION

I would like to dedicate this Master's Degree

*To my beloved parents and my siblings.
Thank you very much for your endless support.*

*To my supervisor, lecturer and classmates.
Thank you very much for your guidance and motivation.*

ACKNOWLEDGEMENT

I would like to take this opportunity to express my gratitude and appreciation to my supervisor Prof. Madya Dr. Arizu Sulaiman for providing valuable technical advice, encouragement, guidance and assistance that enable me to accomplish this Master Degree Project. Sincere appreciation also to lecturers and classmates at University of Technology Malaysia for their guidance and advice. I would also show my deepest gratitude to my parents and siblings for their support and encouragement.

ABSTRACT

Bridge structure has achieved a worldwide importance because they are key element of any road network. Girder bridges are structurally the simplest and the most commonly used on short to medium span bridges which typically constructed with construction material either steel or concrete. The aim of this project is to compare between steel plate girder and prestressed concrete girder in term of cost, dimension, capacity and environmental impact which include designing and analysis. The work involve in this study is to design bridges that provide light vehicle communication between residential areas using steel plate girder and prestressed concrete girder for five different span length which is 15 meter, 20 meter, 25 meter 30 meter and 35 meter. Comparative between steel plate girder and prestressed concrete girder shows that the estimated cost of prestressed concrete girder is more expensive than steel plate girder for span length 15 meter and 20 meter whereas for span length 25 meter, 30 meter and 35 meter the estimated cost for steel plate girder is more expensive than prestressed concrete girder. In term of impact on environment, the material consumption for steel plate girder is lesser than prestressed concrete girder for all span length meanwhile the amount of embodied energy for prestressed concrete is lesser than steel plate girder for all span length. Thus, steel plate girder is recommended for span length up to 20 meter and for span length beyond 35 meter prestressed concrete girder is more desirable.

ABSTRAK

Struktur jambatan telah mencapai kepentingan di seluruh dunia kerana ianya merupakan elemen yang penting di dalam rangkaian jalan raya. Jambatan struktur *Girder* merupakan jambatan yang paling ringkas dan yang paling umum digunakan bagi panjang rentang yang pendek sehingga ke sederhana panjang dengan menggunakan bahan binaan samada besi ataupun konkrit. Tujuan projek ini adalah untuk membandingkan di antara *Steel Plate Girder* dan *Prestressed Concrete Girder* dari segi kos, dimensi, kapasiti dan kesan ke atas persekitaran yang merangkumi rekabentuk dan analisis. Diantara kerja yang terlibat di dalam projek ini adalah merekebentuk jambatan bagi menampung kenderaan ringan untuk menghubungkan di antara kawasan kediaman dengan menggunakan *Steel Plate Girder* dan *Prestressed Concrete Girder* untuk lima panjang rentang yang berbeza iaitu 15 meter, 20 meter, 25 meter 30 meter dan 35 meter. Perbandingan antara *Steel Plate Girder* dan *Prestressed Concrete Girder* menunjukkan bahawa anggaran kos bagi *Prestressed Concrete Girder* adalah lebih mahal daripada *Steel Plate Girder* untuk panjang rentang 15 meter dan 20 meter manakala untuk panjang rentang 25 meter, 30 meter dan 35 meter anggaran kos untuk *Steel Plate Girder* adalah lebih mahal daripada *Prestressed Concrete Girder*. Dari segi kesan terhadap persekitaran, jumlah penggunaan bahan binaan untuk *Steel Plate Girder* lebih rendah daripada *Prestressed Concrete Girder* bagi semua panjang rentang namun jumlah *Embodied Energy* untuk *Prestressed Concrete Girder* adalah lebih rendah berbanding dengan *Steel Plate Girder* bagi semua panjang rentang. Oleh itu, *Steel Plate Girder* adalah disyorkan untuk panjang rentang hingga 20 meter dan bagi panjang rentang yang melebihi 35 meter *Prestressed Concrete Girder* lebih sesuai.

TABLE OF CONTENTS

	TITLE	PAGE
	DECLARATION	iii
	DEDICATION	iv
	ACKNOWLEDGEMENT	v
	ABSTRACT	vi
	ABSTRAK	vii
	TABLE OF CONTENTS	viii
	LIST OF TABLES	xi
	LIST OF FIGURES	xiii
	LIST OF APPENDICES	xv
CHAPTER 1	INTRODUCTION	1
1.1	Introduction	1
1.1.1	Component of bridge	2
1.1.2	Types of Bridges	3
1.1.3	Girder Bridge	5
1.2	Statement of the Problem	5
1.3	Objectives of the Study	6
1.4	Scope of the Study	6
1.5	Significance of the Study	7
CHAPTER 2	LITERATURE REVIEW	9
2.1	Introduction	9
2.2	Steel Plate Girder	10
2.3	Prestressed Concrete	12
2.3.1	Type of Prestressing	13
2.3.2	Materials for prestressed Concrete	13
2.3.3	Theory Of Prestressing	14
2.3.4	Prestressed Concrete I-Girder	15

2.4	Impact of Construction Material On Environment	16
CHAPTER 3	RESEARCH METHODOLOGY	19
3.1	Research Design and Procedure	19
3.2	Operational Framework	20
3.3	Structural Layout	21
3.4	Loading	22
3.5	Design of Steel Plate Girder	24
3.5.1	Section Properties	25
3.5.2	Minimum Web Thickness	26
3.5.3	Check For Shear Lag	26
3.5.4	Check For Moment Capacity	26
3.5.5	Web Design	27
3.5.6	Design of End Stiffener	27
3.5.6.1	Buckling Check	27
3.5.6.2	Resistance To Local Buckling Under Transverse Forces	28
3.5.6.3	Check Torsional Buckling Of Stiffener	28
3.5.7	Design Of Intermediate Stiffener	28
3.5.8	Serviceability Limit State (SLS)	29
3.6	Design of prestressed concrete girder	29
3.6.1	Section Properties	30
3.6.2	Required Section Modulus	31
3.6.3	Prestressing Force	32
3.6.4	Magnel Diagram	33
3.6.5	Tendon Profile	34
3.6.6	Prestress Losses	34
3.6.6.1	Short Term Losses	35
3.6.6.2	Long Term Losses	35
3.6.7	Deflection	35
3.7	Cost Comparison	36
3.8	Dimension properties and capacity	36

3.9	Environmental Impact	37
CHAPTER 4	RESULTS AND DISCUSSION	39
4.1	Introduction	39
4.2	Total Material Quantity for Steel Plate Girder	39
4.2.1	Size Of Steel Plate Girder Section For Each Span Length	40
4.2.2	Total Estimated Cost For Steel Plate Girders	42
4.3	Total Estimated Cost for Prestressed Concrete Girders	43
4.4	Differential Percentage of Total Cost	43
4.5	Cost Comparison between Steel Plate Girder and Prestressed Concrete Girder	44
4.6	Comparison On Dimension Properties and Capacity (Resistance) Of Steel Plate Girder and Prestressed Concrete Girder	46
4.7	Comparison Depth of Section For Steel Plate Girder and Prestressed Concrete Girder	47
4.8	Comparison Weight of Section For Steel Plate Girder and Prestressed Concrete Girder	49
4.9	Environmental Impact Calculation (EIC)	50
CHAPTER 5	CONCLUSION AND RECOMMENDATION	57
5.1	Conclusion	57
5.2	Recommendation	58
REFERENCES		59

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Concrete and Steel Characteristics for Construction (Johnson, 1996)	9
Table 2.2	Rule of thumb for main plate girder design (Azemi, 2014)	12
Table 3.1	Number and Width Of Notional Lane (Eurocode 1, 2003)	22
Table 3.2	Load Model 1 : Characteristic Value (Eurocode 1, 2003)	23
Table 3.3	Design of Steel Plate Girder procedures	25
Table 3.4	Design of prestressed concrete I-Girder procedures	29
Table 3.5	I-Girder section	31
Table 3.6	Embodied energy according to Alcorn & Wood and Hammond & Jones (Lee et.al, 2010)	38
Table 4.1	Total weight of steel plate girder for 15 meter length span	40
Table 4.2	Total weight of steel plate girder for 20 meter length span	40
Table 4.3	Total weight of steel plate girder for 25 meter length span	41
Table 4.4	Total weight of steel plate girder for 30 meter length span	41
Table 4.5	Total weight of steel plate girder for 35 meter length span	42
Table 4.6	Total Cost Of Steel Plate Girder For Each Span Length	42
Table 4.7	Total Cost of Prestressed Concrete Beam For Each Span	43
Table 4.8	Differential Percentage Of Total Cost	44
Table 4.9	Cost Comparison of Steel Plate and Prestressed Concrete Girder	44
Table 4.10	Dimension Properties and Capacity (Resistance) Of Steel Plate Girder and Prestressed Concrete Girder	47

Table 4.11	Depth of Steel Plate and Prestressed Concrete Girder	48
Table 4.12	Weight of Steel Plate and Prestressed Concrete Girder	49
Table 4.13	Material quantities and environmental impact calculation (EIC) for span length 15m.	51
Table 4.14	Material quantities and environmental impact calculation (EIC) for span length 20 m.	51
Table 4.15	Material quantities and environmental impact calculation (EIC) for span length 25 m.	52
Table 4.16	Material quantities and environmental impact calculation (EIC) for span length 30m	52
Table 4.17	Material quantities and environmental impact calculation (EIC) for span length 35m.	53
Table 4.18	Summary of material quantities and environmental impact calculation (EIC) for all span length.	53

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 1.1	Bridges components	2
Figure 1.2	Girder Bridge	3
Figure 1.3	Arch Bridge	3
Figure 1.4	Truss Bridge	4
Figure 1.5	Cantilever Bridge	4
Figure 1.6	Suspension Bridge	4
Figure 1.7	Cable Stayed Bridge	5
Figure 2.1	Steel Plate Girder	10
Figure 2.2	Tension-Field Action In a Stiffened Plate Girder (Dawood)	11
Figure 2.3	Stiffened and Unstiffened Plate Girder	11
Figure 2.4	Type of tendons	14
Figure 2.5	Prestressed I-Beam at Madrid-Guadalajara Railway	16
Figure 3.1	Flow Chart For Comparison Of Steel Plate Girder And Prestressed Concrete Girder	20
Figure 3.2	Plan and Longitudinal Section	21
Figure 3.3	Typical Cross Section	21
Figure 3.4	Application Of Load Model 1	23
Figure 3.5	Steel Plate Girder section (Azemi, 2014))	24
Figure 3.6	I-Girder section	30
Figure 4.1	Histogram of estimated cost of 8 girders of different type and span length	45
Figure 4.2	Plot of estimated cost of 8 girders of different type and span length	45
Figure 4.3	Percentage different of cost with span length	46
Figure 4.4	Histogram showing variation of depth of girder with span length	48

Figure 4.5	Plot showing variation of depth of girder with span length	48
Figure 4.6	Histogram showing variation of weight of girder with span length	49
Figure 4.7	Plot showing variation of weight of girder with span length	50
Figure 4.8	Comparison of steel plate girder and prestressed concrete girder for Material Consumption	54
Figure 4.9	Comparison of steel plate girder and prestressed concrete girder for Embodied Energy	54

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	Design of Steel Plate Girder and Prestressed Concrete Girder	61

CHAPTER 1

INTRODUCTION

1.1 Introduction

Bridges are constructed to cross obstacles such as water body or road to provide passage over the obstacle and connecting two inaccessible areas. Bridges are important in the infrastructure of a country because it can reduce distance to travel and enabling the transportation of goods and people. In the early days the bridges were built using stone and wooden.

Bridges have horizontal span between supports to cater vertical loading. Design of bridge is depends on many factors such as the function of the bridge, nature of terrain, construction material, cost of the bridge, safety, aesthetic and many others factors.

The cost for constructing major bridges is expensive and therefore the design of bridge must be efficient, economical and elegant. Efficient is to produce a better performance bridge with minimum usage of material. Economical bridge is when the cost of construction and maintenance can be reduced while the efficiency is maintained. Finally, elegant is the appearances of the bridge without compromising the performance and economy.

1.1.1 Component of bridge

Arrangement of bridge is shown in Figure 1.1 and the basic component parts of bridge structure are as following:

- i. Deck - Main part to access from one side to another side
- ii. Abutment - The support at the two end of bridge
- iii. Pier - Is a compression member to transfer vertical load from superstructure to foundation
- iv. Pile - Foundation support to transfer load from structure to soil and it is a fundamental component to bridge with pier
- v. Girder - It is a main horizontal beam to support vertical loads.
- vi. Bearing - Located in between the girder and pier cap to accommodate movement and displacement.

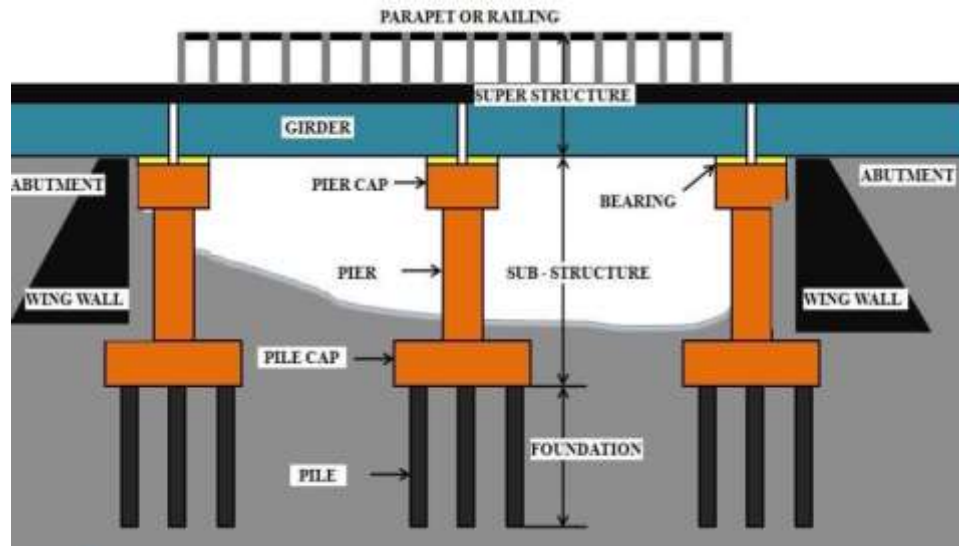


Figure 1.1 Bridges components

1.1.2 Types of Bridges

There are six basic types of bridges as shown in figures below accordingly, which are the girder bridge, arch bridge, truss bridge, cantilever bridge, suspension bridge and cable stayed bridge.



Figure 1.2 Girder Bridge



Figure 1.3 Arch Bridge



Figure 1.4 Truss Bridge



Figure 1.5 Cantilever Bridge



Figure 1.6 Suspension Bridge



Figure 1.7 Cable Stayed Bridge

1.1.3 Girder Bridge

Girder bridge is one of the most important bridge because they are used more frequently than any other type of bridge. Girder bridges have greater stiffness but less subject to vibrations according to (Barker and Puckett, 2013). Girder bridges are consist of deck slabs such as reinforced concrete deck slabs on which vehicles and pedestrian will access through. Decks will be placed on girder and the girder will be supported by pier, abutments and foundations.

1.2 Statement of the Problem

Bridges can be constructed using various type of material including steel, concrete and even timber. Steel plate girder had been used since late 1800s especially in constructions of railroad bridges and steel plate girder is famous because of ease of fabrication.

Since the development of prestressed concrete by Freyssinet in early 1930s, the application of prestressed concrete has evolved in the construction of bridges and gradually replace steel structures bridges which needs costly maintenance due to corrosion (Bhawar et.al, 2015).

In current trend, prestressed concrete bridges have been expanding the applicable and becoming a strong competitor to steel bridges and reinforced concrete bridges (Jagtap and Shahezad, 2016). Therefore, the objective of this proposal is to compare between steel plate girder and prestressed concrete girder in term of cost, environment impact and also the properties of girder in term of depth and weight for various span length.

1.3 Objectives of the Study

The objectives of this study are as follows : -

- i. To compare the differences of cost between steel plate girder and prestressed concrete girder for various span length.
- ii. To identify the differences of environment impact between steel plate girder and prestressed concrete girder in term of material consumption and embodied energy (EE).

1.4 Scope of the Study

The work involve in this project is designing bridge using steel plate girder and prestressed concrete girder for various span lengths. The bridge is to provide light vehicle communication between residential areas on either side of a carriageway road. The design is based on Eurocode with same loading for each span length ranging from 15 meter to 35 meter for both type of girder. Finally cost analysis, comparison on dimension, capacity and also environmental impact calculation is conducted between the two types of girder.

1.5 Significance of the Study

One of the main criteria of selecting a construction material for particular design is the cost of the material but nowadays construction industries is contributing large part in environmental problems due to extensive resource depletion and energy required for the construction. Therefore, comparative study between steel plate girder and prestressed concrete girder is needed to guide engineers to choose the suitable material of construction according to the requirement of a particular project or design. Through this study, the percentage differences in term of cost and environmental impact between steel plate girder and prestressed concrete girder is obtained for various span length.

REFERENCES

- Arpad Horvath and Chris Hendrickson. (1998) 'Steel Versus Steel-Reinforced Concrete Bridges: Environmental Assessment'.
- Bhagyashree C Jagtap, Prof. Mohd. Shahezad. (2016) 'Comparative Study of Prestressed Concrete Girder and Steel Plate Girder for Roadway Over Bridge', volume 2 (issue 1)
- Bhawar P.D, Wakchaure M.R and Nagare P.N. (2015) 'Optimization Of Prestressed Concrete Girder', volume 4 (issue: 03).
- Bruno Lee, Marija Trcka and Jan Hensen. (2010) 'Embodied energy of building materials and green building rating systems — a case study for industrial halls'. 9th International Conference on Sustainable Energy Technologies. 24- 27 August 2010. Shanghai, China.
- Dr. Abbas Oda Dawood. 'Steel Design Plate Girder'. Misan University Engineerin College Civil Department
- Eurocode 1 (1991) 'Action on structures'. BS EN 1991-2-1-2003, Part 2 : Traffic loads on bridges.
- Eurocode 2, (1992) 'Design Of Concrete Structures'. BS EN 1992-1-1-2004, Part 1-1: General rules and rules for buildings.
- Eurocode 3 (1993) Design of steel structure - BS EN 1993-1-1-2005, Part 1-1 : General rules and rules for buildings.
- Eurocode 3 (1993) Design of steel structure - BS EN 1993-1-5-2006, Part 1-5 : Plate structural elements
- Eurocode 3 (1993) Design of steel structure - BS EN 1993-1-8-2005, Part 1-8 : Design of joints
- Heera Lomite and Sridhar Kare. (2009) 'Impact of Construction Material on Environment (Steel & Concrete)' University College of Borås School of Engineering : Master Degree Project Report.
- Mohamad Salleh Yassin (2018). 'Bridge Design To Eurocodes', Universiti Teknologi Malaysia, Johor, Malaysia
- Mustafa Batikha , Osamah Al Ani1, and Taha Elhag. (2017) 'The effect of span length and girder type on bridge costs'. MATEC Web of Conferences.

- Naida Ademovic. (2018) 'Sustainable Development And Concrete Bridges'. XVII Anniversary International Scientific Conference By Construction And Architecture Vsus'.
- Nur Afifah binti Azemi. (2014) 'Steel Plate Girder Bridge Design Using Indian Standard Method And British Standard Method'. Universiti Teknologi Petronas : Bachelor Degree Project Report.
- Richard M. Barker, Jay A Puckett. (2013) 'Design of Highway Bridges' 3rd edn. New Jersey : JohnWiley & Sons, Inc, Hoboken
- Tierra Armada Sustainable Technology. (2012), 'Precast & Prestressed Beam Bridges'.
- Timothy Werner Johnson. (1996) 'Comparison of Environmental Impacts of Steel and Concrete as Building Materials Using the Life Cycle Assessment Method'. Master Of Science In Civil and Environmental Engineering At Massachusetts Institute Of Technology
- Yen Lei Voo and Stephen J. Foster. (2010) 'Characteristics of ultra-high performance 'ductile' concrete and its impact on sustainable construction', volume 3 (no.3)