GIRDER DEFLECTION FOR LIFTING LOAD

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DEPARTMENT OF MECHANICAL ENGINEERING
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KUALA LUMPUR

2017

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RESEARCH REPORT SUBMITTED IN FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER OF MECHANICAL ENGINEERING

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2017

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Name of Master: Mechanical Engineering

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Field of Study: Mechanics

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ABSTRACT

This study aim is to investigate the maximum girder deflection and propose methods to reduce the deflection based on the simulation and calculation conducted on the crane girder. The crane girder deflection studies by previous researchers have not used an actual crane deflection as a guideline. Furthermore, the crane deflection is being control by modeling a dynamic control system integrated on the cane functionality. Thus, to investigate the maximum girder deflection, an equation was derived based on principle of deflection on simply supported beam. Besides that, a 3D crane girder was modeled by the used of Solid Work software and run a finite element analysis by using Ansys software. Based on the observation of girder deflection, a relationship between calculated girder deflections, simulated girder deflections and actual girder deflection are built on the basis of error percentage among these results. As results, the crane girder deflection can be reduced by more than 10% if reinforcement added inside the girder structure. The reinforcement must cover and being layout throughout the crane structure to work at its best regardless of horizontal or vertical direction. The difference between the actual crane deflections with the calculated girder deflection is more than 10% which indicate that girder deflection does not represent the crane deflection in absolute term. However, form the observation of the stress behavior analysis on the crane girder, the areas which are affected once the girder deflected now can be identified. These areas are bottom flange, top flange and girder edge which can be modified or improvised to reduce the crane as well as girder deflection further. The implications of this study contribute to achieve better crane girder design in the industrial market as well as able to prolong the crane operation life span.

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ABSTRAK

Tujuan kajian ini ialah untuk memahami pesongan yang berlaku pada struktur jambatan kren dan mengemukan kaedah-kaedah yang sesuai bagi mengurangkan kesan pesongan tersebut. Berdasarkan kepada kajian sarjana terdahulu, penggunaan pesongan sebenar pada kren tidak digunakan sebagai garis panduan dalam menganalisis pesongan jambatan kren. Selain itu, penggunaan sistem kawalan dinamik lebih digunakan untuk mengawal pesongan kren. Sehubungan dengan itu, satu persamaan telah dibangkitkan melalui prinsip pesongan rasuk. Satu model 3D jambatan kren juga telah direka melalui aplikasi Solid Work dan dalam masa yang sama model ini telah analisis melalui keadah analisis unsur terhingga menggunakan applikasi Ansys. Satu persamaan teleh dibina diantra keputusan pesongan melalui persamaan yang telah dibangkitkan, keputusan pesongan melalui analisis model 3D dan pesongan sebenar kren. Persamaan tersebut ialah peratus kesalahan diantara hasil keputusan. Hasilnya, pesongan jambatan kren dapat dikurangkan melebihi 10% sekiranya struktur pengukuhan berada di dalam struktur jambatan kren. Struktur pengukuhan ini mesti meliputi seluruh struktur jambatan kren sama ada pada arah melintang mahupun menegak. Selain itu, beza diantara pesongan sebenar kren dan pesongan jambatan kren juga melebihi 10%. Ini menunjukkakan bahawa pesongan pada jambatan kren tidak dapat mewakili pesongan kren yang sebenar. Namun, melalui pemerhatian terhadap analisis tekanan pada struktur jambatan kren, kawasan yang paling terjejas apabila jambatan dipesongkan dapat dikenalpasti. Kawasan yang dimaksudkan ialah, struktur atas dan bawah jambatan kren termasuk bahagian hujung jambatan kren. Kawasan-kawasan ini dapat diubahasuai bagi mengurangkan pesongan pada jambatan kren. Implikasi kajian ini dapat membantu untuk medapatkan rekaan jambatan kren yang lebih baik disamping mampu memanjangkan jangka hayat operasi sesuatu kren.

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ACKNOWLEDGEMENTS

Alhamdullillah, the progress report is now completed. Thanks to God for giving me strength and his belssing to complete it. Without His mercy and blessing, its will be diffcult for me and once again thank you Allah.

My greatest appreciation to my supervisor Dr. Edzrol Niza bin Mohamad for his guidance and teaching. Dr. was very helpful and understanding. Besides that, to my employer MHE-Demag Malaysia Sdn. Bhd, thank you for allowing me to use all the materials and resources to complete this report.

Lastly, thanks to all my family members and friends. This report is specially didacted for you.

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TABLE OF CONTENTS

University of Malaya

University of Malaya

University of Malaya

LIST OF FIGURES

University of Malaya

LIST OF TABLES

University of Malaya

LIST OF SYMBOLS AND ABBREVIATIONS

B	:	Dumping coefficient
E	:	Material elastic modulus
F	:	Concentrated load of crane
f_w	:	Deflection due to the girder bending
f_o	:	Bending strain from the gantry leg
g	:	Gravitational
h	:	Geometry properties
I	:	Moment of inertia
$\bar{I}_n$	:	Theoretical moment of inertia
I_{Girder}	:	Moment of inertia of the crane sectional structure
K_r	:	Torque constant
K_E	:	Electric constant
L	:	Crane span
l	:	Cable length
M	:	Moment as specific distance
M_n	:	Moment by gantry leg
m_1	:	Payload mass
m_2	:	Trolley mass
p	:	Concentrated load
R	:	Resistance
R_o	:	Reference axis
r_p	:	Radius of pulley
$\bar{y}$	:	Centroidal axis
y_{max}	:	Total maximum girder deflection

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$y_{Girder\ weight}$: Girder deflection due to girder weight

$y_{Load\ at\ mid\ span}$: Girder deflection due to load acting at mid span

Z : Gear ratio

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LIST OF APPENDICES

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CHAPTER 1: INTRODUCTION

This chapter will introduce the issued needed to be discussed in this research. This research will focus on the girder deflection during the load is lifted. Basically the crane deflection is already being taken into design consideration before the start of manufacturing. The deflection is unavoidable since is a natural phenomenon happens due to force or load that acting on a particular structure. This deflection will eventually lead to the structure failure and will bring a bad reputation to the manufacturer. In recent years, the studies of crane deflection have become for condense and intense in order to achieved better performance and the life span of crane (Kopnov, 1998).

The crane design can be further optimize by observing the girder deflection phenomena. This was seen in previous research by (C. Alkin, 2005) where crane was modeled into three dimensional and finite element analysis was conducted to observed deformation on the crane structure mostly on the crane girder or bridge, the result was compared between different type of design which enable researcher to select better design for optimization. However, the focus was on varies of design instead of focusing on the deflection itself. Nevertheless, this indication shows the reliability of using finite element analysis for observing changes on the crane structure.

Crane manufacturers are often facing the issues of compression and bending o the crane structure which can cause the stability to loosen up. This compression and bending is also affected from the deflection of crane girder during load is lifted. The crane girder change it shape when the load is lifted and revert to its original shape when the loads is released. (Niezgodziński & Kubiak, 2005) able to propose contingency plan by indentifying the crane structure are that will face a high stress area and controlling the manufacturing process to minimize the stress affected during deflection. This is also showing the necessity of studying girder deflection further since it does not only enable

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researcher and manufacturer to understand the phenomena, this will also lead to a better improvement on the design and fabrication principle itself.

Therefore, this research will continue the studied in the crane girder deflection especially during the lifted of load or operation. Thus, this chapter will further elaborate the problem focus in this research as well as the objective from this study. To ensure the reliability of research, research scope will be clearly defined. For contribution towards industrials and academic, the research importance will be briefly discussed.

1.1 Research Problem

Girder deflection has been intensely studies for better crane optimization in the industries. According (Machacek & Tuma, 2006), the crane deflection studies was performed based on standard applied to the crane manufacturer which in the research specify in Central Europe. The research focuses on the deformation of girder web and proposes the better web geometry to be used in order to optimum the design. The optimization of crane design which aim of reducing the girder deflection is still lacking while most research are using the deflection to evaluated the stress point which affecting the crane structure stability. The same was also mention in (Muhammad Abid, 2008) where the research different approach of reducing the deflection however lacking information of comparison with actual crane deflection especially during load is lifted.

The studies of girder deflection have become more advance where (Jaafar et al., 2013) has shifted the focus on the design rather put more effort on controlling the dynamic behavior of the crane. The sole purpose of controlling the dynamic behavior is to ensure the crane are programmed to minimize vibration during operation which controlling the deflection to its minimum. The whole concept is to ensure the deflection duration is shorter. This is also supported by (He & Ge, 2016) studies the deflection for understanding to control the phenomena. This research has made a great advancement

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from the previous research, but the crane will eventually deflected at maximum and design was not further optimized. With this research the full behavior of girder deflection can be clearly observed and the ways of minimizing it in the design can be understand since the actual deflection of crane will be referred to. In the next subtopic will indicate clearly the objective for this research.

1.2 Research Objective

This research is involving the studies of girder deflection under influence of lifted load during operation.

The following are the research objective:

1. Understand the maximum girder deflection based on measurement by calculation method and simulation through finite element analysis
2. Propose the ways and method of minimizing the crane girder deflection.

1.3 Research Scope

This research will used the girder design from MHE-Demag electric overhead double girder crane of capacity 30 tons with the crane span of 12.05 m. The girder design will be used to derive the equation for maximum deflection under the influence of safe working load of 30 tons. The same design consideration will be used for finite element analysis. Furthermore, the simulation will only use the crane girder structure since this is the largest part of crane which will be affected by the deflection during the lifting of loads. Thus, the girder deflection measurements will be compared to each other to understand the maximum deflection phenomena as well as to investigate and propose the ways of minimizing the girder deflection. This research will also compare the girder deflection measurement results with the actual crane deflection to observe the possible ways of minimize the crane deflection as total.

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1.4 Research Importance

Girder deflection is un-avoidable phenomena for crane operation. Studies on the girder deflection will enable manufacture to optimize the crane design and pro long it life span during operation. It will also help researcher and manufacturer to see the crane structural condition first hand before the carne is delivered to end user for operation. This can be done by doing a finite element analysis of the crane where all the maximum stress and displacement can be see and enhance for the crane structural optimization (Abhinay Suratkar, 2013). This is important since the stress and displacement during crane operation will eventually lead to the structure failure as well as operation failure. Basically, the studies will better equip researcher and manufacture the best solution to be design for the crane operation condition

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CHAPTER 2: LITERATURE REVIEW

In this chapter, the previous research regarding the crane girder deflection will be discussed. The discussion will be divided in to three major subtopics. Firstly, the crane design overview will be highlighted. In this topic, the fundamental of crane design used by most manufacturers will be discussed and the design consideration of the crane fabricated by those manufacturers will be used as a reference model for this research. The crane design mostly similar for most manufacturers the only different will be how the crane design and operate according to the end user requirement or customer purpose. Secondly, subtopic regarding deflection will be highlighted as this research is interested on minimizing the girder deflection during load operation. In this subtopic, the calculation method of acquiring the deflection to performed and understands the factor contributed to it will be highly discussed. The calculation method will be used as a reference of calculating the deflection as well as modeling the crane structure for further understanding of the crane girder deflection phenomena. The last subtopic will be the discussion on method of reducing the crane girder deflection. The method that has been proposed by research if optimizing and improving the crane design will be highlighted. Besides that, recent technology used in crane application will also be discussed. Throughout the literature review, it will help us to relate towards the purpose of the research in reducing the girder deflection when load is lifted.

2.1 Girder Structure Design Overview

This subtopic will discussed two major points that are introduction of the girder structure design and the design consideration for girder structure. These two subtopics are important to understand how girder will works at its best condition to support crane during operation. This will also help us to know major factors that contribute to the girder design stability, rigidity and strength to take care of the deflection phenomena.

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This subtopic will also help us to indentify the grey areas that were not considered for deflection occurrence through the girder design itself.

2.1.1 Introduction to the Girder Design

Overhead crane have been used in verity of industries for a very long time (Niezgodziński & Kubiak, 2005). In carne, there are several parts that are important to ensure its can operate properly. According to (V.V. Arun Sankar, 2015) this parts are known as girder (bridge), trolley and end carriages (end trucks). Figure 2.1 showing the basic design on an overhead crane.

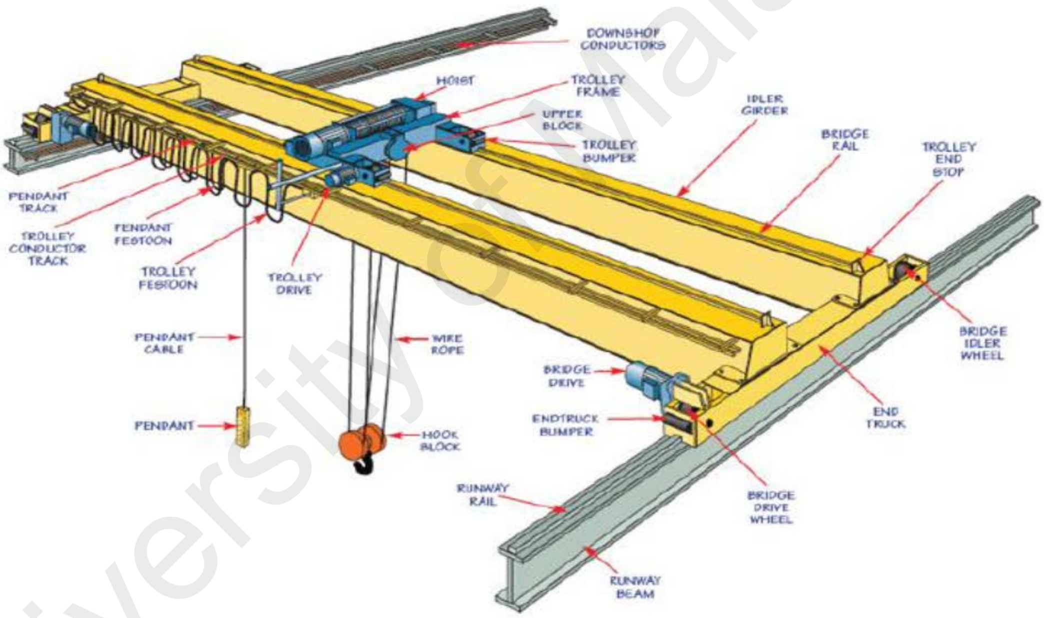

Figure 2.1: Overhead Crane Basic Layout

(V.V. Arun Sankar, 2015)

Through a simple observation, we found that most of the crane structure supported by the girders. The girder carrying the weight of the trolley and these loads will be carried by the wheels in the runway beam of a particular building. Based on (Abhinay Suratkar, 2013) the girder play major role in carrying load and due to this girder subject to the phenomena of deflection, stress concentration and failure. It is also proven that, by optimizing the girder design itself will help manufacturer to reduce the cost and pro-

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long the crane operation (Abhinay Suratkar, 2013). Therefore, to study girder design is necessary to improve the overall quality of an overhead crane. Girder design came in many different shapes that give different strength and functionality. The major parts that needed in the girder are girder webs that cut form mill steel plate of varies grade and quality. These webs then will be stiffed by a channel. Beside this there will be to flanges top and bottom respectively. This basically the medium parts that must be made to make a box girder for overhead travelling crane.

According to (Caglayan, Ozakgul, Tezer, & Uzgider, 2010), there basically 6 types of crane box type. This type usually made from steel mill structure with grade S235. As per the girder dimension come from 1500 mm to 3000 mm in term of height and 400 mm to 550 mm for the flanges width. Figure 2.2 shows the common type of girder box.

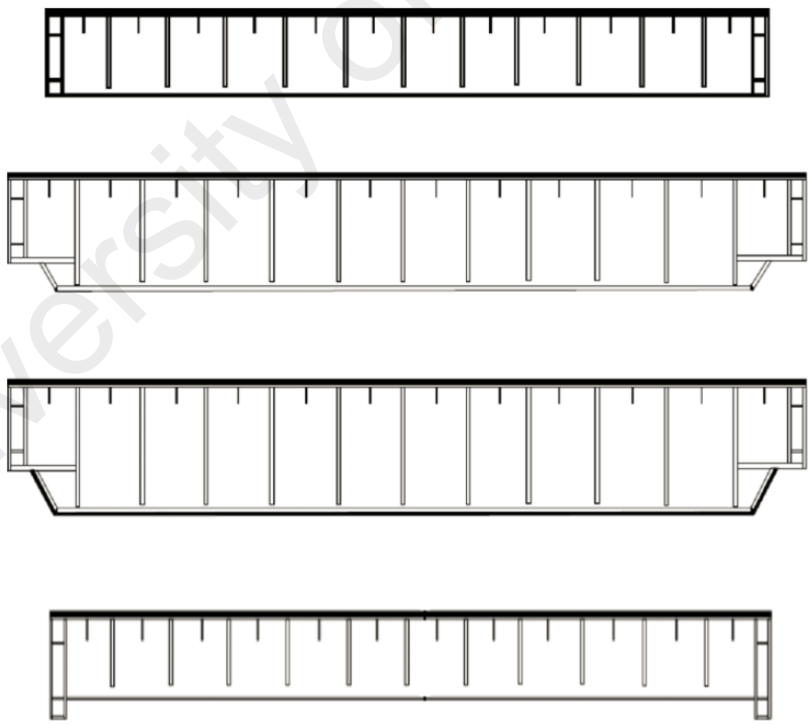

Figure 2.2: Common Type of Girder Box Design

(Caglayan et al., 2010)

Still mill are predeformed web plate that enable crane manufacturer to used thin webs to fabricate a girder. According to (Machacek & Tuma, 2006) the technology of using predeformed web plate enable crane manufacture to have a light crane with good mechanical properties. These mechanical properties are known as resistance in shear buckling with improves resistance for local loading. Using web plate also enables crane manufacture saving up to 30% of steel structure. The girder design is influence by the functionality of the crane itself. Based on the research by (Muhammad Abid, 2008) the design of a girder different based on type of carne motion, type of lifted load, geometric such us location and last but not least the environmental condition of the crane. These will determine the characteristics of the girder either to be long or short, the girder profile to be high or compact and whether the web plate need to be thick or regular thin. It is important to note that each parts of the girder are essential as a loading distributer. According to (C. Graciano & Ayestarán, 2013) if a girder was design with high web and thin plate, the overall weight will become lighter. However, it will results a high compressive load in the girder flanges. Hence, the girder design will expose to failure from the effect of buckling phenomena.

Therefore, this subtopic has clearly introduced the functionality of girder in crane operation. It is mention that girder type is varies based on the purpose or requirement of the crane. Girders mostly made from mill steel and each design factors such us height and width will reflect the girders mechanical properties and performance. Thus in the next subtopic design consideration that affecting the girder design will be discussed further to explain the overall view in girder fabrication.

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2.1.2 Design Consideration in Crane Girder Fabrication

Design consideration will provide the required information of how the crane will be fabricate to meet its best performance during operation. This consideration varies from structural point of view or functional point of view. Is best to describe from the structural point of view as this will educates us what will be the best design for girder structure. Based on the research by (Muhammad Abid, 2008), stiffener on the girder would play a major factor in the designing process. Stiffer will control the crane weight and resistance towards stress and deflection by only changing the quantity and its feature without changing the thickness of the steel plate used. There are both vertical and horizontal stiffeners in a particular girder structure. Changing the feature of horizontal stiffener would help to reduce the maximum deflection and stress accordingly. This is because the load will be equally distributed to the whole structure. Besides that, with the aid of vertical stiffener, the girder buckling in longitudinal and lateral direction is much more manageable. Figure 2.3 show the different orientation of the stiffener inside the girder.

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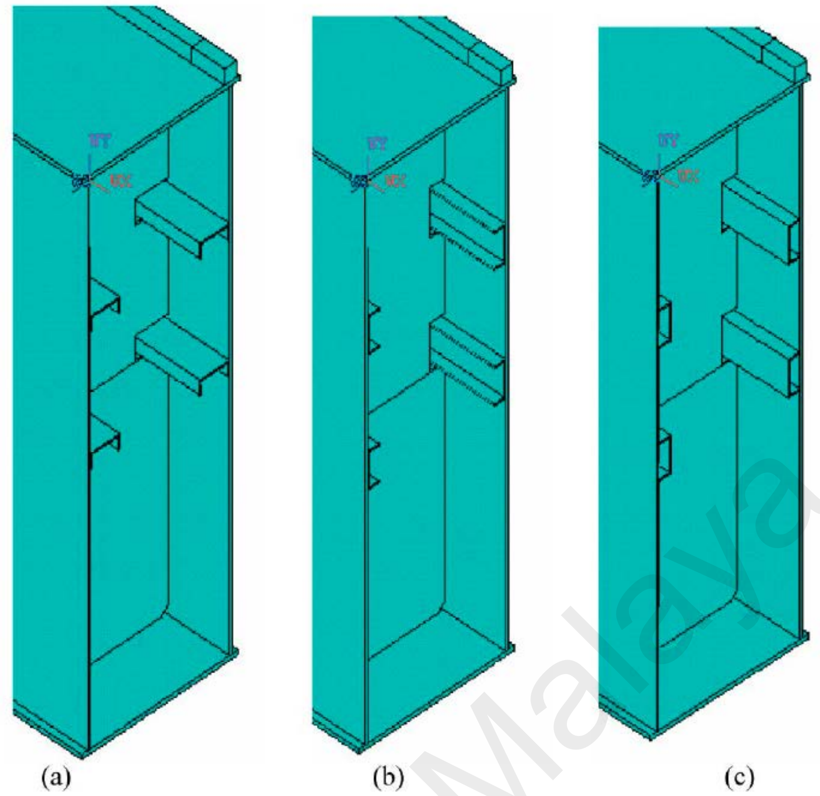

Figure 2.3: Different Orientation of the Stiffener inside the Girder

(Muhammad Abid, 2008)

The stiffener effects was further elaborate by (Niezgodziński & Kubiak, 2005). The research was focusing on the stability of the girder. It can be achieved through proper fabrication sequence. The joining method for girder is welding therefore deformation is most likely to occur if it is not conducted properly. Therefore, to achieve good fabrication quality and less prone to failure structure, the stiffener need to be weld on the web plate first before to the bottom flange of the girder. It was also understood that the buckling effect will also be reduced if this sequence was followed.

Crane loading through the crane structure and specifically the crane girder will also consider as major design factor in the fabrication process. Based on (Kopnov, 1998) loading on the crane will cause large effect of dynamic load that will eventually lead to the failure of the crane structure. This failure was known as fatigue failure. It was

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further describe as a failure that potentially occurs during the crane operation. Crane will lift a load and under this condition the structure will experience compression stress throughout the interior web sheet. Due to this reason vertical load is being experienced by the girder and rise of the maximum stress will be significant (Kopnov, 1998). The girder wills also response to the skew load that lead to the fatigue failure. The design considerations mostly take into account the stress and failure occurrence. On that basis, the crane load is important indication to indentify the suitable loading in the crane. This as further verify by (Zrnić, Gašić, & Bošnjak, 2015) where loading distribution on the crane structure will amplify the deflection in the vertical direction. This was possible since loading distribution change once the crane trolley that carrying the load move along the crane bridge. Dynamics of the lifting loads ignite the vibration problems on the crane system(Zrnić et al., 2015). Therefore, in order for the crane to functioning properly, the speed of trolley carrying the load need to be consider during design stage. The speed will affect the distribution of load during operation that affected the carne structure integrity. In term of functionality consideration, earthquake factor give a major contribution to the crane design. According to (Feau et al., 2015) earthquake contribute to the safety requirement and life span of the equipment on the crane. It is observe that from the experiment to analyze the response of crane girder with earthquake factor through experimental and modeling shows similar result. The response of friction force between the trolley and the girder was compared and pattern for deformation is similar. This acknowledged that the earthquake is an essential factor to be considered in designing to ensure better quality and integrity of crane structure. The important of earthquake factor was further explain by (Akihito Otani, 2002) by studying the vertical seismic response on the vertical direction of the crane. The two important factors that observe was acceleration of the trolley and the wheel reaction that will contribute the vertical displacement on the girder body. It is observe the

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displacement on the girder significantly changes accordingly with the seismic factor. This seismic factor is represented by the acceleration of the gravity. Acceleration experiences by the girder changes as the trolley reaction to the gravity changes. Therefore the significant of earthquake factor is important to ensure the crane achieved the best design.

This subtopic successfully indentifies the consideration to be taken care during deigning of crane. From the geometry of girder boxes and functionality of crane was detailed in order to produce best quality of design. The consequence of neglecting these considerations will eventually lead to crane structure failure and failed to meet the operation expectation.

2.1.3 Summary

From this topic the design overview of crane was discuss which can be a guide line as the preference of design for analysis. Besides that, consideration needed in designing a crane was further explained to highlight the factor need to achieve better quality in crane design. The next topic will discuss the measurement used to determine the deflection on the girder structure. This will complement the points discussed in the topic and to see the correlation between design and deflection phenomena.

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2.2 Deflection Phenomena in Crane Girder

This topic will mainly discuss two important topics related to the deflection phenomena. The first discussion will focus mainly on the deflection calculation method whereas the second topic will highlight factors that contribute to the girder deflection. From this discussion, the methodology used by international standards and manufactures in determining girder deflection can be understand. Besides that, further understanding of this deflection can be explored by case study from previous research based on actual crane condition and operation.

2.2.1 Girder Deflection Calculation Method

The most common concept to calculate the girder deflection is stated by the British Standard (BS 466:1984) where the vertical deflection shall not exceed 1/750 of the crane girder span measured from the central position which is cause by the weight of the trolley and safe working load. This has been used widely in the industries for most of cranes manufacturer. Due to the growing awareness of crane safety, the deflection calculation has been further studied to improve the crane performance and life span. The manufacture will always runs a deflection test on the actual crane body and according to (Ri, Muramatsu, Saka, Nanbara, & Kobayashi, 2011), the deflection of actual large structure can be estimated by the using of moir'e sampling method. The used of charge-coupled device is essential to record the deflection from the structure. This method was observed to me more accurate since it required high order interpolation and reducing the error during measurement is taken. However, this research will focus more on simulation to calculate the deflection which can be divided mostly in two which are conventional calculation and simulation through finite element analysis (FEM).

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Conventional calculation can be easily derived from Saint-Venant's principle which correlated the transverse loading with the deflection on a beam section. Sain-Venant's principle can be represented by the following formula.

$$\frac{\mathbf{1}}{\boldsymbol{p}} = \frac{\boldsymbol{M(x)}}{\boldsymbol{EI}} \qquad \mathbf{2.1}$$

Where,

p = Concentrated load

M = Moment as specific distance

E = Material elastic modulus

I = Moment of inertia

The above relation will help to develop vertical deflection of a beam through series of integration. The equation would be developed differently for each known length in the horizontal direction. Every section of known length will help to know the vertical deflection at certain point. The maximum deflection on the vertical axis will be known on the mid span of the total horizontal length of the beam or structure. The advancement of Saint-Venant's principle was proposed by researcher to enhance the assessment of deflection in various geometries. As highlighted earlier, crane structure came in different type and geometry according to the manufacturer and customer requirement. In view of this particular reasons (Dapeng Zhnag 2014) has derived an equation of girder deflection with effect from the leg bending moment. The leg bending moment required due to the fact that his research used gantry crane as a model reference. Although this is an added element to the equation derivation, the calculation method used in the research is significant in order to determine the deflection of a crane

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girder. There are two equation to be considered to obtain the deflection for a crane know as f_w and f_o respectively. These both equations will help to indentify the deflection under rated lifting weight. f_w And f_o equations are as follow.

$$\boldsymbol{f_w} = \frac{FL^3}{48E\overline{I_1}}\left[1 - \frac{3}{8}\cdot\frac{6(\overline{I_1 I_2}\,hL + \overline{I_2 I_3}\,L^3 + \overline{I_1 I_3}\,hL)}{4\overline{I_1 I_2}\,hL + 3\,\overline{I_2 I_3}\,L^2 + 4\overline{I_2}^2 h^2 + 4\overline{I_1 I_3}\,hL}\right] \qquad \textbf{2.2}$$

$$\boldsymbol{f_o} = \frac{M_2^2 h}{3E\overline{I_2}F} + \frac{M_2^2 h^3}{18\sqrt{3}E^2\overline{I_2}^2} + \frac{M_2^2 h^5 F}{972E^3\overline{I_2}^3} + \frac{M_3^2 h}{3E\overline{I_3}F} + \frac{M_3^2 h^3}{18\sqrt{3}E^2\overline{I_3}^2} + \frac{M_2^2 h^5 F}{972E^3\overline{I_3}^3} \qquad \textbf{2.3}$$

Where,

F = Concentrated load of crane

$\overline{I}_n$ = Theoretical moment of inertia

M_n = Moment by gantry leg

L = Crane span

h = Geometry properties

Based on the above equation, the rated deflection of crane can be determine by the equation below

$$\boldsymbol{f} = \boldsymbol{f_w} + \boldsymbol{f_o} \qquad \textbf{2.4}$$

(Dapeng Zhnag 2014) argue that crane deflection need to be measured from the deflection cause by the deflection due to the girder bending, f_w and deflection due to the bending strain from the gantry leg, f_o. However, the deflection due to the gantry crane for small leg will only contribute marginal effect to the total deflection of crane. This consideration will be neglected based on crane characteristic. Deflection by the girder bending is according to most standards in related to crane design. The consideration will take the crane deflection under static condition.

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Beside this conventional method, the deflection its self can be observed and calculated through finite element method analysis. finite element method able to analyzed specimen of complex geometries and contribute to the determination of deflection and stress of the analyzed specimen. (C. Alkin, 2005). In the basis of finite element method analysis, 4-node tetrahedral elements and 4-node quadrilateral shell elements have been used widely to do the modeling of the crane geometry. Using this method, the horizontal force will be ignored and only take into account of mass experience by the girder. Besides that, axial displacement was also considered to be zero which lead to the consideration of the trolley mass on the crane girder as another mass experience by the crane girder (C. Alkin, 2005).

The crane structure will be design accordingly inside software and the input based on observation of actual crane operation will be used to see the crane deflection. All of this information will be indicated by the software. This approach was further supported by (Muhammad Abid, 2008), where the structural geometry of the girder was develop first. Then, the geometry will be given complete properties of a girder structure such as the material properties and mechanical properties. The model will be analyzed by given boundary related to the loading experienced by the girder structure. Once again there will no horizontal force consider acting on the girder. Basically, finite element method analysis required the development of geometry model to begin with. Moreover, the boundary or initial input need to be predetermines to perform the required analysis in the finite element method software. This boundaries need to be fully understand, based on (Farooq & Myler, 2015) research, the performed and pre assume condition toward the girder structure before run its analysis to know the damage happens when loading was induce on the model. From the observation made by (Chen & Wang, 2012), the effective modeling of large structure can be made from configuring firstly the solid element to represent the joining between structure. Therefore, for crane is to identify the

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connection of each plate. Secondly, the model shall clearly represent all joining and parts that make the crane girder as a whole. Lastly, the model can be simplified enough to understand the behavior. All three configurations will lead to different result, however with this configuration the desire results from the modeling can be obtain. Figure 2.4 shows a crane structure undergone analysis by finite element method under gravitational influence.

Figure 2.4: Crane Structure Undergone Analysis In FEM Software

(Haniszewski, 2014)

Therefore, this subtopic has successfully pointed out the calculation method of deflection on girder. The fundamental method will be from conventional method where derivation of equation from single relation of loading and deflection on a beam. Furthermore, the usage of integration or derivation are needed to estimate the deflection on varies points. Besides that, girder deflection can be easily determined by FEM software. However, this method required geometry modeling and initial input to estimate the deflection. Thus, the next subtopic will further discuss the factors that affecting the deflection on girder.

2.2.2 Factors Contribute to Girder Deflection

Girder deflection occurs mainly due to the load experienced by it. From equation 2, the weight of the girder, the crane span or the girder length itself already contributes to the deflection. However, it is important to understand other since different design and functionality of girder will contribute to the structure strength and life span.

According to (Kopnov, 1998) the crane bridge mainly experience vertical load that caused by hoisting loads and skewing load from the crane operation. The hoisting of load contributes to the vertical load since the lowering, lifting and braking movement involves acceleration and deceleration. Therefore, oscillation of stress is being experience by the crane bridge then eventually leads to the deflection phenomena. This is further supported by (Akihito Otani, 2002), where the displacement on the vertical direction of crane girder are related to the acceleration experience by the body as well as the hoisting operation. The movement will create an oscillation that continuously affected the vertical displacement of the crane girder. This oscillation eventually will reach to a critical time which leads to the failure of the structure. This relation can be further improvised by the existence of seismic loading.

In the calculation of girder deflection through finite element analysis, the stress experience by the side plate and bottom plate of the crane girder was taking into consideration. Based (C. Alkin, 2005), the deflection reading will be different based on the method of calculation also the extra factor that used in the analysis. For example, the deflection on the girder increases if the safety factor was considered inside the analysis. This is further supported by (Muhammad Abid, 2008) since the stress on the side plate contribute to the maximum deflection of the crane girder. In the research, stress on the side plate was control by the changing the horizontal support geometry and orientation. The results show that, less stress on the plate will make the crane deflection minimize.

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The stress factor on the structure was further emphasis by (Abhinay Suratkar, 2013) where the maximum displacement of the crane girder occur in the mid span. This was concluded based on the maximum bending moment activities that happen on the girder span that accumulate from the stress of the girder box which being develop from the crane support.

As for conclusion, this subtopic highlighted two most important factors contribute to the girder deflection which agreed by most researcher. The main reason of the deflection is from the load experienced by the crane girder. The loads can be affected by the crane operation especially during the lifting and lowering of the crane hoist. The loads also affected by the stress experience by the girder wall. The greater the stress the deflection will become larger.

2.2.3 Summary

This topic, the calculation method of calculating the crane girder deflection was highlighted which can divide in two parts. The first part would be conventional method which using the application of integration and derivation whereas the second part is using finite element analysis. This method required a geometry modeling to be developed and boundary condition to be pre-determined to perform the analysis inside the software. Furthermore, the factors contribute to the deflection was also successfully discussed. Crane girder deflection mainly came from the loads experience by the structure. This load is affected by the crane operation related to acceleration and deceleration especially on the lifting and lowering movement. Moreover, stress on the crane box will also influence the deflection of crane girder. The next topic will discuss the method of reducing the crane deflection as well as modern crane design currently exists in the market.

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2.3 Improvement of Girder Deflection

There will be two subtopic will be discussed from this section where firstly the method of reducing the girder deflection will be highlighted and followed by the second discussion which is to understand modern design of the crane. This two topic will highlighted the existing technologies researcher used to reduce the girder deflection. The discussion of the technologies application and efficiency will be also highlighted to understand the gap in reducing the girder deflection. Furthermore, modern crane design will also be highlighted since modern designs are more sophisticated and compact. It is equipped with safety functionality to avoid failure of its operation and structural design. Therefore, this topic will help to develop further understanding the purpose of this research.

2.3.1 Reduction of Girder Deflection

The method of reducing the girder deflection can be determined form the analysis conducted to rectify the cause of deflection itself. Often deflection related to the structural failure and many researchers used design and structural element to improve and reduce the girder deflection.

According to (Niezgodziński & Kubiak, 2005) show positive result shows from the experimenting on reinforce girder box towards its structural failure by buckling. This reinforcement is referring to the lateral and longitudinal ribs which will be welded on the inner part of the girder box. It will act as pressing and bending allowance for the girder to become in straight condition. Besides that, this method was effective to increase the girder wall stiffness and ensure the girder box can prevent buckling due to loading. Another modification of the structural to reduce the girder deflection is by using predeformed web plate. This type of web plate will help to help to reduce the girder deflection since its provide support to buckling and shearing effect (Machacek &

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Tuma, 2006). Its help by prevailing the cyclic shear experience from the girder boxes from the crane movement and loading.

The structural modification was further observed by (Muhammad Abid, 2008). The research conducted in a way of understanding there most efficient way of reducing the deflection in a girder box. Three methods were proposed namely optimization by using horizontal stiffeners, optimization by using vertical stiffeners and optimization using both horizontal and vertical stiffeners (Muhammad Abid, 2008). The research concludes that, the alteration of using horizontal stiffener in the form of C-channel is more beneficial in reducing the girder deflection whereas the vertical stiffeners do not show any significant effects. To achieved better reduction of the girder deflection, is by arranging the horizontal stiffeners equally along the girder web plate which need to be arrange according to the web height. This observation shared together with (Carlos Graciano & Uribe-Henao, 2014). They ratio between the web and flange need to be assign carefully. This is also known as eccentricities. Large eccentricities will cause the crane to be prone to failure whereas limited eccentricities would contribute to the crane strength. Besides that, the girder weight can be control form the reducing the material thickness selected. This is essential since the weight of the girder itself will lead to the deflection of the girder. Thus, having less heavier girder will help to further minimize the deflection.

The important thing to realize about girder deflection would be to acknowledge that the maximum deflection will always occurs in the mid span of the crane. (Abhinay Suratkar, 2013) has indentified that crane will be easily optimize by analyzing the behavior using finite element analysis. The analysis is focusing on the maximum stress and maximum displacement on the y-axis. Result shows that when load is applied to the girder structure stress experience by the girder fall below the allowable stress according

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to India Standard and this is the same as for the displacement on the y-axis or commonly known as vertical deflection. Besides that, the overall mass of the structure have been reduces by 29% compare to initial design (Abhinay Suratkar, 2013). However, the safety factor consideration inside the finite element analysis has been set at high. Indirectly, uses of the analysis significantly improvise the design and help to understand of minimizing the girder box deflection.

The analysis through finite element is further supported by (Haniszewski, 2014) where in the research successfully run a simulation of the vertical deflection and stiffness properties of the crane girder. The simulation results were then compared with standard formulae related to crane deflection, stiffness and stress. According to (Haniszewski, 2014) the deflection is in the range of acceptable limits whereas the stiffness is improve since there is significant reduction of stress experience by the crane girder box. This is the result of effective crane deign have been model by the correct knowledge of finite element analysis. Each element of the crane was carefully design to be suited such us material, plate thickness and the load distribution itself. The model is generated from a shell elements and section was properly layout to ensure calculation are accurate and precise.

As for conclusion this subtopic has clearly highlighted the reduction of girder deflection by means of structural alteration of its reinforcement or stiffeners. In this regards, researchers agreed that alteration on the horizontal stiffeners give the greatest impact on reducing the vertical girder deflection. Besides that, appropriate design modeling can also help to understand to reduce the deflection on the girder. Both cases will relate the stress experience by the girder web where smaller the stress experience by the girder box, the smaller the effect of the vertical deflection experience by the girder box. Thus, the next subtopic will highlight the modern crane design exist in the

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market and will point out its contribution in optimization of the crane operation and design mechanism.

2.3.2 Modern Crane Design

In this subtopic, the modern crane design will be highlighted. The fundamental consideration of a modern crane will be discussed and the different between conventional design will also pointed out. Most of modern crane designs are more sophisticated equip with technologies to help preventing failure during operation. These technologies will also enable engineer to determine structural performance to the crane.

Based on (Tang & Huang, 2016) to effectively control the crane form load oscillations during operation, a controller shall be design accordingly. This controller will also able to ensure the crane operation under external disturbances especially wind. The controller was design to detect two cause of vibration which contributes from the crane operation by the operator and external factors such as wind. This controller will create a response that will make the crane react accordingly once oscillation is experience by the crane. The oscillation is related to the dynamic behavior of the crane. As discussed previously, reduction of movement on the crane girder will help to reduce the stress and eventually minimize the crane deflection. According to (Tang & Huang, 2016), the controller effectively provide the desired result of crane dynamic response that can be used for further improvement. The controller itself has been improved to be become smoother and high sensitivity towards disturbances especially wind. Control of crane dynamic behavior is further discussed by (He & Ge, 2016) where the research indentify that large vibration can be cause by the crane movement during transport of load from one point to another point. Thus, the research proposes a control system that can easily overcome the vibration that came from the crane leg or carriages. Without the control it, the vibration can cause the loads swinging and also cause poor crane

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operation. The idea of the control system is to regulate the crane to its most equilibrium position. The control system was also provided a boundary condition based on integral-barrier Lynapunov function (He & Ge, 2016). This condition will eventually lead the crane to become stable and reduce the vibration effect. The vibration measured is from the flexible cable or wire rope of the crane. During crane motion, this rope tends to move and cause vibration which also make the crane structure vibrate and resulting vertical deflection of the crane girder on short term period. However, by this proposed control the wire roper vibration was supersede and cause the crane dynamic movement achieved stability.

The discussion on crane dynamic behavior is further carried out by (Jaafar et al., 2013). The main focus of the research is to observe the crane dynamic behavior response. This response will influence the performance of the crane in term of crane total mass and load lifting. The problem that happens is during crane travel and lifting of load, swinging of the wire rope will occur. This will also make the structure oscillate that cause the girder structure vibrate and cause deflection on the vertical direction. Therefore to represent the relations, a mathematical model was derived as follow

$$\boldsymbol{V = \left[\frac{RBr_p}{K_r z} + \frac{K_E z}{r_P}\right] + \left[\frac{Rr_P}{K_r z}\right](m_1 l)\left[\ddot{\theta}\cos\theta - \dot{\theta}^2 \sin\theta\right] + \left[\frac{Rr_P}{K_r z}\right](m_1 + m_2)\ddot{x}} \quad \textbf{2.5}$$

$$\boldsymbol{m_1 l^2 \ddot{\theta} + m_1 l\,\ddot{x}\cos\theta + m_1 g l \sin\theta = 0} \quad \textbf{2.6}$$

This modeling is based on the following table input

Table 2.1: System Parameters

Parameters	Value (Unit)	Parameters	Value (Unit)
Payload mass (m_1)	0.5 kg	Resistance (R)	2.6 Ω
Trolley mass (m_2)	2.0 kg	Torque constant (K_r)	0.007 Nm/A
Cable length (l)	0.5 m	Electric constant (K_E)	0.007 Vs/rad
Gravitational (g)	9.81 m/s^2	Radius of pulley (r_p)	0.02 m
Dumping coefficient (B)	0.001 Ns/m	Gear ratio (z)	0.15

(Jaafar et al., 2013)

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The two relations were used as a base observation of crane behavior where V is the power supply voltage to the crane. This is acceptable since crane is power by electrical supply. From the analysis, its shows that with a bigger trolley mass it will help to reduce the oscillation of load and also vibration of the girder when load was move from one place to another. This research, believe that this information will lead to a better understanding of controlling the crane during operation. Better control system can me incorporated inside the crane design can be achieved. This is different form controlling the crane in static condition which more on the structural and design itself. As for the application of the control system, (Cao, Lee, & Meng, 2008) propose are control system of controlling the movement of gantry crane system used in handling port. Crane application is to mobilize load from one location to another location without failed. There a chances of operation failure and structural failure. Based on the research, type of load and time taken for operation is essential in order to ensure the crane safely controlled.

The most important modern crane design is based on the risk analysis performed to a previous crane failure (Dong, Xu, & Ren, 2015). The research takes a subject on jib arm crane remanufacturing process from making a risk analysis of predecessor cranes. The predecessor crane has been run through a test to evaluate the common failure during the crane operation. Six group of testing was formed against five different failure tests. The first test was to understand the physical appearance of the crane. In this category the external dimension of the crane jib was measure. Besides that, failure caused were then investigate from notch crack, deformation on the structure, strength of stress from the structural perspective and lastly, the stress from the welding between plate or web. The analysis provides a very efficient way of understanding in improvising the remanufacturing of the crane jib arm. The risk analysis perhaps not a contribution of

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direct design improvement but its help a new process in developing a better and more effective design of crane (Dong et al., 2015).

As for conclusion, this subtopic describe the modern crane design is focus on more about the dynamic control and improvising the failure of predecessor crane by performing risk analysis. This is not a conventional method of improving crane design which is focus more on the structural and mechanical design. However, the attribute toward the crane modern design does improve the crane functionality performance. It is also proven that the crane become more stable towards vibration and load oscillation that indirectly reduce the deflection occurrence.

2.3.3 Summary

In this topic, the reduction of girder deflection was successfully described. The researcher agreed that, to reduce the girder deflection, the stiffener or support on the horizontal axis on the girder web itself, this improve the structure resistance towards stress and minimize the effect of deflection. Besides that through crane modeling and analysis using finite element, the structure resistance towards deflection can be better understand. This topic also highlighted the modern crane design used in the industries, surprisingly controlling the crane dynamic behavior was frequently discuss by researcher compared to the factors related to structural and mechanical design. By controlling the dynamic behavior of crane, the operation with load become more stable and leads to less vibration that can cause deflection on the girder structure. Thus, the next topic will conclude the general overview over crane deflation during lifting of load.

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2.4 Summary of Literature Review

This chapter have been successfully highlighted the fundamental layout and design of crane. The crane structure that will be discussed about the deflection will be its girder. The girder is basically manufactured from pair of web plate, top plate and bottom plate. The girder is being reinforce with a vertical and horizontal stiffener to ensure it can withstand the load and operate at optimum level. In this topic, the calculation of girder deflection narrowed down in two different principles where firstly by using conventional calculation method and the second one will be modeling and conducting deflection analysis from the application of finite element method. The factors that are contribute towards the girder deflection also being discussed in this topic. Girder deflection is mainly from cause by the increasing stress activities in the girder web structure. These stresses are coming from the load that applied to the crane girder. Thus, to reduce the deflection the application of vertical stiffener along the girder structure is essential. Furthermore, application of modeling can be used in predetermine the suitable design by knowing the potential deflation of a particular design. Now days, crane are more sophisticated and equipped with a controller to ensure its stability during operation especially when moving load from one location to a different location. The stability achieved by the controller enable the crane to be operated with less oscillation and vibration which indirectly reducing the effect of vertical deflection on the crane girder. The next chapter will discuss the methodology used in this research of analyzing the crane girder deflection phenomena. Calculation and modeling method will be highlighted. The methodology will reflect all predecessor research and will help to understand the best application of minimizing the girder deflection.

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CHAPTER 3: METHODOLOGY

This chapter will highlight the methodology used for this research. The purpose of this research is to study the girder deflection during load is lifted and propose method to reduce the girder deflection based on the differences of observation from the calculated deflection. The previous research methodology calculations are based on calculation and simulation itself. The data will be observed and analyzed without actual input from the actual girder deflection. Therefore, in this chapter two main girder deflections will be discussed. The first method would be the deflection based on calculation of simply supported point. This calculation will be based on derivation from the structure relation and input related to the load, material properties will be used to get the desired result. The second method is based on the finite element analysis of deflection calculation on Ansys software. Boundary information for the design will be incorporated inside the analysis to observe the deflection. The extension for this research observation will be comparing the result to the actual deflection measured during factory acceptance test conducted in the manufacture factory. Thus, three reading of deflection will be compared and observed to understand the deflection phenomena. From the observation, the reduction method of deflection will be highlighted for future references.

3.1 Crane Girder Deflection Calculation Methodology

In this subtopic, the research methodology for calculating the girder deflection and deflection analysis will be covered. There will be two calculation methods that will be used. The first method is a calculation based on the simply supported structure at a point. The second method will be finite element analysis based on a model develop using solid work. Figure 3.1 will show the general step to conduct the research

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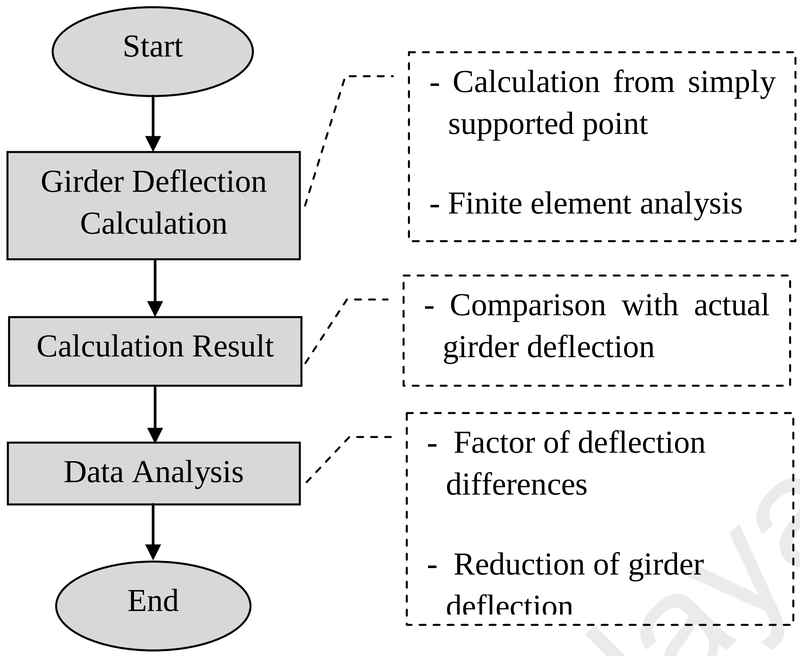

Figure 3.1: General Research Methodology for Girder Deflection Analysis

Figure 3.1 shows the general analysis towards girder deflection that will be carried down throughout this research. The analysis will of the girder deflection will be focus on two main parts which are the factors that contribute to the girder deflection. This can be concluding based on the differences of the calculated deflection with the actual deflection. Thus, it will lead to the understanding of reducing the girder deflection methods which can be applied on the crane design and manufacturing process

3.2 Girder Deflection from Calculation of Simply Supported Structure

In this subtopic the derivation for the girder deflection will be shown, as discussed previously in Chapter 2, when considering the deflection of girder deflection, deflection from the girder weight and from the load acting on the mid span is required. Thus the relation of these two factors is shown below.

$$y_{max} = y_{Girder\ weight} + y_{Load\ at\ mid\ span} \quad \mathbf{3.1}$$

The maximum deflection acting on the crane girder on y-axis is represented by $y_{max.}$ The sum of deflection from the girder and load acting on the mid span is essential to accurately calculate the deflection. The derivation of both deflections will be shown below for understanding.

3.2.1 Derivation for Deflection Due To Girder Weight and Load at Mid Span

The girder structure can be illustrated as follow to easily understand the girder weight acting on the structure and its support

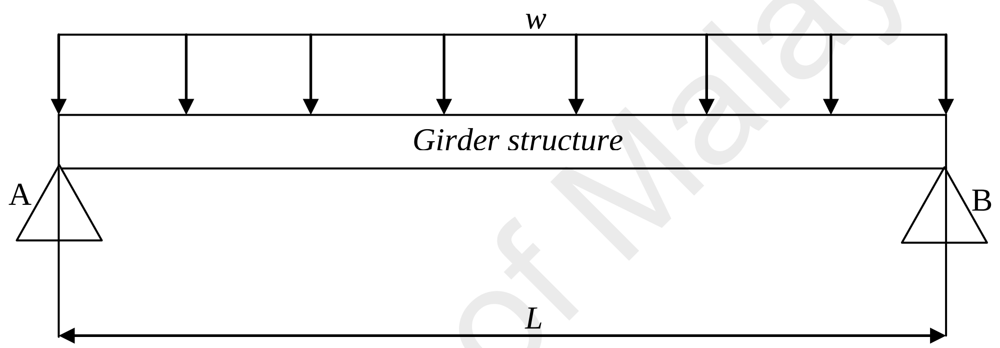

Figure 3.2: Illustration of Girder Weight Acting On Its Structure

Figure 3.2 indicate that the weight of the girder is distributed uniformly across the girder structure. To develop the equation of deflection we need to cut the structure at mid span at point D as illustrated below.

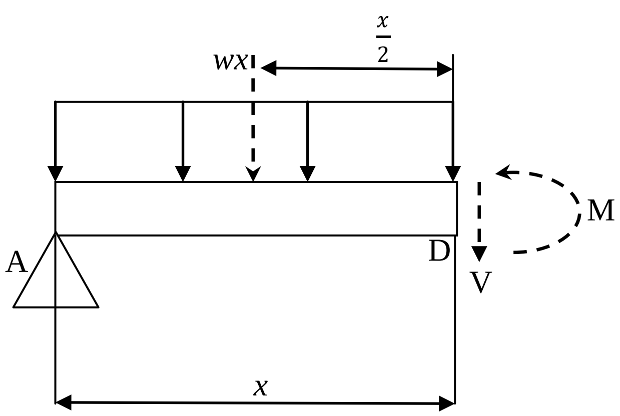

Figure 3.3: Illustration of Girder Weight Reaction Acting On Its Structure on Mid Span

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From figure 3.3 the relation of reaction force *wx*, R_A, V and moment at point D, M_D can be derives as follow.

$$\boldsymbol{R_A = \frac{1}{2}wL} \qquad \textbf{3.2}$$

$$\boldsymbol{M_D = \frac{1}{2}wLx + \frac{1}{2}wx^2} \qquad \textbf{3.3}$$

By using the Sain-Venant's principle which co related the load and deflection on structure the following equation can be obtain after integrating twice.

$$\boldsymbol{EI\frac{dy}{dx} = \frac{1}{6}wx^3 + \frac{1}{4}wLx^2 + C_1} \qquad \textbf{3.4}$$

$$\boldsymbol{EI\,y = -\frac{1}{24}wx^4 + \frac{1}{12}wLx^2 + C_1x + C_2} \qquad \textbf{3.5}$$

Thus, the value of C_1 and C_2 can be obtained by using the boundary condition of $y = 0$ when $x = 0$ and $y = 0$ when $x = L$ the equation of elastic curve can be derives as follow from equation 3.5.

$$\boldsymbol{EI\,y = -\frac{1}{24}wx^4 + \frac{1}{12}wLx^2 - \frac{1}{24}wL^3x} \qquad \textbf{3.6}$$

To obtain the maximum deflection, $y_{Girder\ weight}$ the boundary relation of maximum deflection at the middle span (y_{max} = ½ L) can be used. This will give us the relation as indicated below.

$$\boldsymbol{y_{Girder\,weight} = -\frac{5wL^4}{384EI}} \qquad \textbf{3.7}$$

Same application of derivation can be used to obtain the maxim deflection due to the load at mid span, $y_{Load\ at\ mid\ span}$. The different is *w* will replace with *P* which only action at the girder mid span. The equation can be derived following the same principle as derivation of deflection on girder weight acting on its structure.

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To understand the relation, the illustration below will indicate how will be the load acting on the mid span.

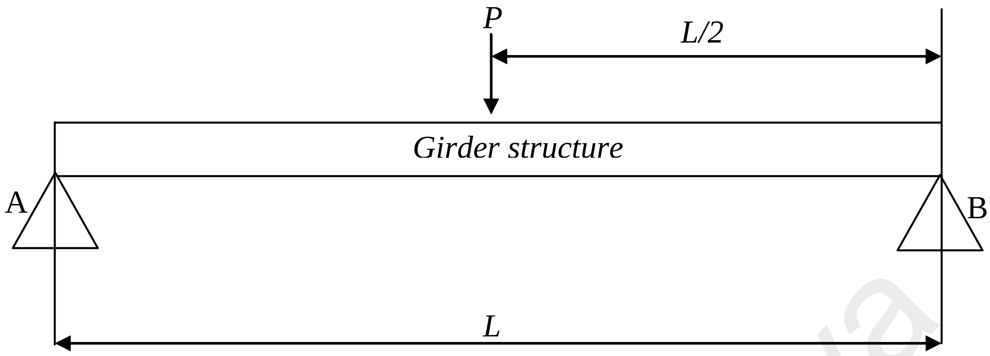

Figure 3.4: Illustration of Load Acting Girder Mid Span

Figure 3.4 illustrate the condition of load acting on the crane girder mid span. From this illustration, the deflection causes by load can be derives as follow.

$$y_{Load\ acting\ at\ mid\ span} = -\frac{PL^3}{48EI} \quad \textbf{3.8}$$

3.2.2 Boundary condition for girder deflection calculation

The equations for calculating the maximum deflection are being shown in the previous subtopic. Now to get the accurate result, the equation needs to be provided with accurate condition. From the equation, the following boundaries can be directly extracted from the manufacturer. The crane model was manufactured by MHE-Demag Malaysia Sdn Bhd for Nghi Son Project in Vietnam. Crane model is a double girder crane with capacity of 30 tones and 12.05 m span. Table below show the properties that can be directly extracted from the manufacturer.

Table 3.1: Crane Properties

Parameters	Value(Unit)
Span (*L*)	11.56 m
Young Modulus for S275JR material (*E*) (according to EN10025-2: 2004)	$2.10X10^{11}$ N/m^2

Table 3.1 shows the properties taken from the manufacturer. The span used in this calculation will be 11.56 m since this is the actual length of the girder web plate. The young modules easily can be found from EN10025 standard. Besides that, to get the deflection by the girder weight, the value of distributed load, w need to be determined. The weight of single piece of girder is 2386 kg. With the span of 11.56 m the distributed load shall be 2022.73 N/m. For the value of acting load P at the girder mid span, the weight of 100% load and crane trolley needs to be considered. Since, the calculation is on one single girder the total weight of both needs to be divided by two. It is fairly to assume that the load is equally distributed to both pieces of girder on a double girder crane. 100% load is equal to 30,000 kg and the weight of the trolley is 2,600 kg. Thus value of P is 15, 9740 N.

Furthermore, to complete the calculation, the moment of inertia acting on the crane girder structure, I_{Girder} need to be calculated. Moment of inertia can be determined by analyzing the cross section of the crane girder.

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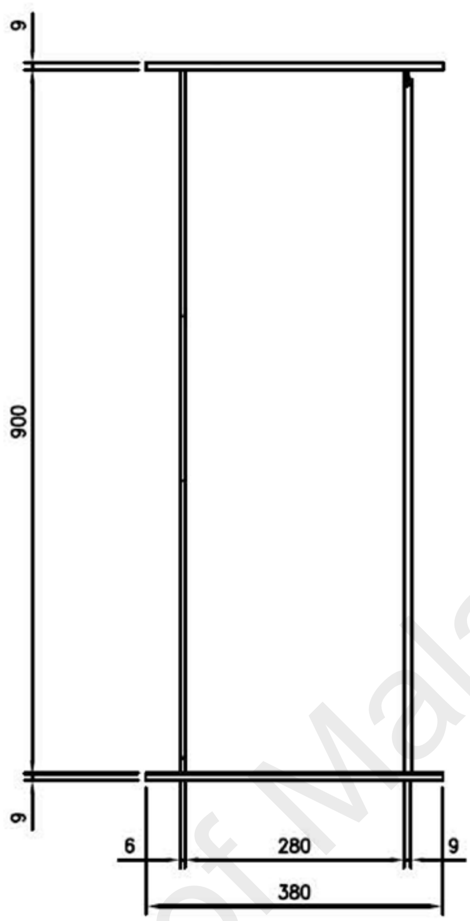

Figure 3.5: Cross Sectional of Crane Girder Structure

Figure 3.5 shows the cross sectional of crane girder used in this research. To calculate the moment of inertia, each girder element top plate, bottom plate and web plate to be identify separately with references to an axis usually at the lowest part. This axis is known as reference axis, R_o. The area of the crane parts, *a* will be determined and product of the distance from reference axis, *y* will be calculated in order to indentify the centroidal axis, $\bar{y}$. The centroidal axis, $\bar{y}$ can be determined by using the following formula.

$$\bar{y} = \frac{\sum ay}{\sum a} \qquad \textbf{3.9}$$

Once the centroidal axis known, the transfer distance, *d* can be simply determine and the produce of parts area and square of transfer distance will be known. Furthermore, the moment of inertia of each crane parts, I_o needs to be identified. Thus, the moment of inertia of the crane sectional structure, I_{Girder} will be calculated using the formula below.

$$\boldsymbol{I_{Girder} = \sum I_o + \sum ad^2} \qquad \textbf{3.10}$$

Table below was shown to simply the step in calculating the moment of inertia of the crane sectional structure, I_{Girder} as describe previously.

Table 3.2: Parameter Required In Calculating $\boldsymbol{I_{girder}}$

Part	*B(mm)*	*H(mm)*	*a(mm)*^{2}	*y(mm)*	*a x y*(mm^3)
1	380	9	3420	913.5	3124170
2	9	900	8100	459	3717900
3	380	9	3420	4.5	15390
4	6	900	5400	459	2478600
Total			20340		9336060

Part	*d(mm)*	$d^2(mm^2)$	*a x* $d^2(mm^4)$	$I_o(mm^4)$
1	454.5	206570.3	706470255	23085
2	0	0	0	546750000
3	454.5	206570.3	706470255	23085
4	0	0	0	364500000
Total			1412940510	911296170

Table 3.2 shows the parameter required to determine the moment of inertia for the crane sectional structure, I_{girder}.By using the formula 3.9, the centroidal axis, $\bar{y} = 459$. To determine the transfer distance, d distance from the references axis y need to be subtracted with the centroidal axis, $\bar{y}$. Therefore, the moment of inertia can be determine by using formula 3.10 and moment of inertia for the crane sectional structure, I_{girder} = 2324236680 mm^4 or in m^4 will be 0.00232424 m^4 . Therefore, the whole boundary condition for calculating the girder deflection can be summarized in the table below.

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Table 3.3: Boundary Condition For Calculating Girder Deflection

Parameters	Value (Unit)
Span *(L)*	11.56 m
Young Modulus for S275JR material *(E)* (according to EN10025-2: 2004)	$2.10X10^{11}$ N/m^2
Distributed load (*w*)	2022.73 N/m
Acting load (*P*)	159740 N
Moment of inertia for the crane sectional structure (I_{Girder})	0.00232424 m^4

3.2.3 Girder Deflection from Finite Element Analysis

This subtopic will discussed the calculation of girder deflection using the application of finite element analysis. To do so the girder model need to be develop. In this research the crane girder will be model using Solid Work software. The crane design will be taken from the manufacturer, MHE-Demag Malaysia Sdn. Bhd used in Nghi Son Porject in Vietnam. The crane capacity is of 30 tones and the girder design is a complete design from the main structure with the horizontal and vertical stiffener.

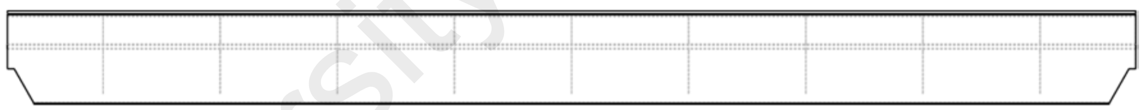

Figure 3.6: Front View of Modeled Crane Girder

Figure 3.6 show the front view of the girder, the outline of the girder clearly indicate as well as the stiffener inside the girder structure. To understand better, Figure 3.7 shows the cross sectional views of the girder, from the right, the crane trolley rails can be seen. The stiffener of the crane girder also illustrated better. The stiffeners only cover until the third quarter of the crane girder height.

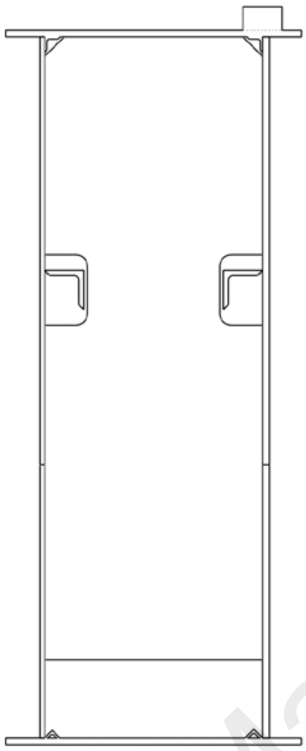

Figure 3.7: Side View of Modeled Crane Girder

The 3D model of the crane girder is now completely represented by Figure 3.8. From the figure, the rails, stiffener can be seen. This to ensure the modeled crane is exactly the same with the actual crane girder manufactured by the crane company. To make the crane more realistic, color was applied to it.

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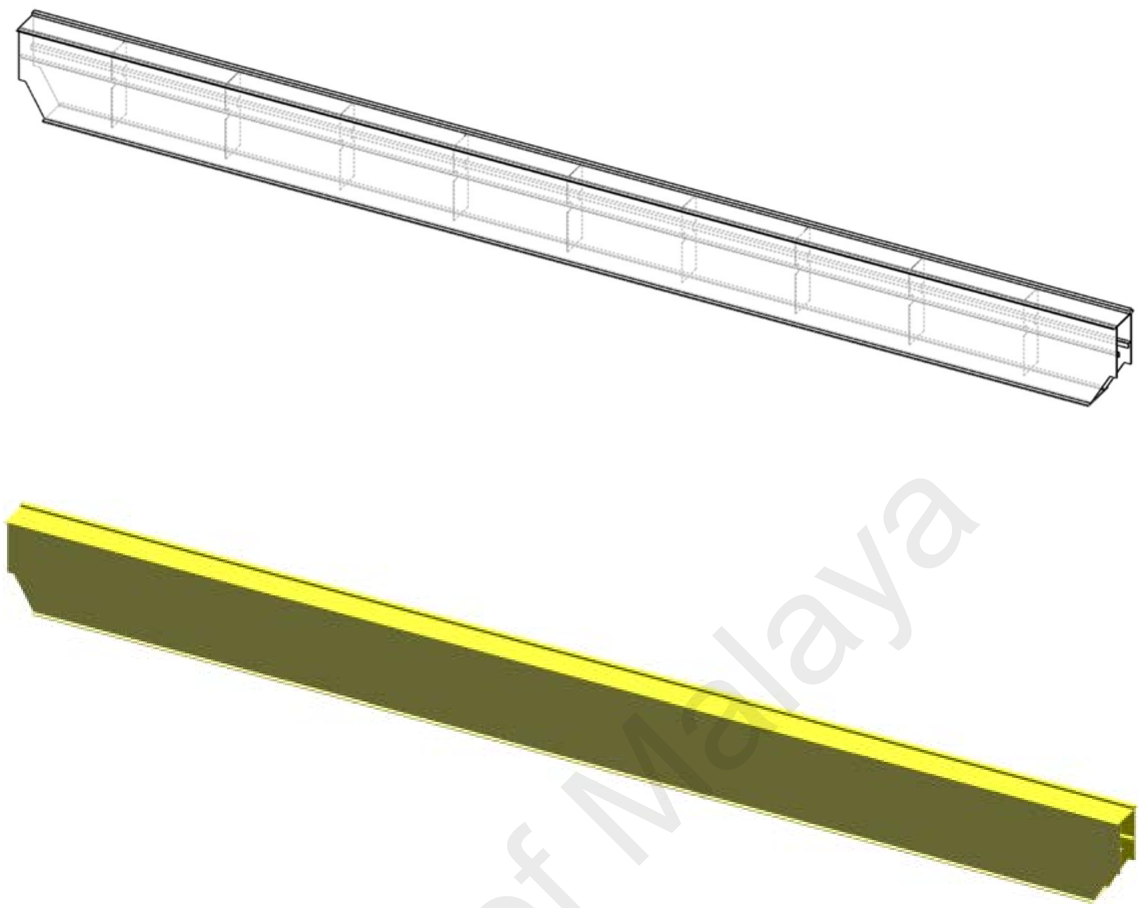

Figure 3.8: 3D View of Modeled Crane Girder

To conduct the deflection calculation, the mass properties provided by the Solid Work will be used. The crane material will be ASTM A36 an equivalent to S275R material. To observe the deflection acting load, *P* = 159,740 N will be applied to the mid span on the crane girder. The result from the simulation will be recorded and discussed. Table 3.4 summarizes the boundary condition applied in the deflection calculation simulation of the modeled girder.

Table 3.4: Boundary Condition for Calculating Girder Deflection Simulation

Parameters	Value (Unit)
Acting load at mid span *(P)*	159,740 N
Girder mass *(m)*	2171.92 Kg
Principle moment of Inertia (I_x, I_y, I_z)	(281.84, 23469.2623679.81) Kg m^2

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3.2.4 Comparison Calculation of Calculated Deflection with the Actual Deflection

The previous subtopic has clearly shown how the girder deflection calculated from both calculation through simply supported structure and deflection simulation by finite element analysis. In this chapter a brief discussion on how will the calculated deflections compared with the actual deflection. The actual deflection of the crane girder can be referred to the factory acceptance report of the crane by the manufacturer. The test was conducted by lifting 30 tones load at static condition above the ground level. The load will be places at the mid span of the crane and the crane hoist will lift the load once the load is secured on the bottom block. The load will be lifted about 200 mm to 300 mm from the ground level and will be let hanging for about 10 minutes. The inspector will use a *Theodolite* to observe the deflection by seeing the deflection on the crane girder. The inspector will need to set a reference point before the load was lifted. Once the reference point is set, the changes can be cross check with the reference point to indentify the deflection on the crane girder. For the girder model used in this research, the deflection recorded was *y = 12 mm or 0.012 m*

The comparison of the calculated deflection with the actual deflection can be done by calculating the error by using the formula below.

$$\boldsymbol{e} = \left|\frac{y_{calculated} - y_{actual}}{y_{actual}}\right| \times \mathbf{100}\% \qquad \mathbf{3.11}$$

The formula shows that error, e can be calculated from the ratio in percentage of differences of the calculated deflection, $y_{calculated}$ and actual deflection, y_{actual} to the actual deflection, y_{actual} . From the error, the differences can be recorded and evaluated for to understand the factors that affecting the crane girder deflection. These factors will be related to the previous research however, the theory behind the calculation for the calculated deflection will be mostly referred to in order to describe the differences.

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Thus, this research will provide option and suggestion to reduce the deflection of girder during load is lifted.

3.3 Conclusion

As for conclusion, this chapter have successfully describe the calculation of girder defection through two deferent method known as deflection calculation based on simply supported structure and deflection calculation by simulation of finite element analysis. The equation to calculate the deflection based on simply supported structure can be acquired by measuring the deflection of girder from the crane girder weight distribution and load acting at the crane girder mid span. The sum for both will be the crane girder deflection. To complete the calculation, boundary condition of the crane girder have been discussed and listed accordingly. Calculation of girder deflection based on simulation of finite element analysis conducted through Ansys software. The crane model was constructed based in the MHE-Demag Malaysia Sdn. Bhd design used for Nghi Son project in Vietnam. The modeled crane will be simulated of deflection analysis inside the Solid Work software. The boundary condition was also successfully defined for the simulation to take place. This chapter also brief how the actual deflection measured to be compared with the calculated deflection measured from this research. In the next chapter result from the calculation will be shows and discussed to understand the deflection factors and ways of minimize it on the girder during load was lifted.

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CHAPTER 4: RESULT

This chapter will highlighted the results of the girder deflection calculation from both deflection calculation from simply supported structure and simulation of girder deflection through finite element analysis. The results will be presented in table and respective observation will be given. Besides that, the comparison between the actual deflections with the calculated deflections will be also presented. Reading differences will be highlighted together with the error percentage. Thus, further observation will be given based on the deflection differences. Comparison between the calculated deflection and simulated deflection will be varies to two condition. Since the calculated deflection is based on purely girder cross section elements, thus the first condition for the simulated deflection will follow the calculated deflection principle. The second condition will be simulated based on the crane girder actual design as per its manufacturer. This chapter will also help us to understand the reliability of the calculation method and simulation accuracy.

4.1 Result of Girder Deflection Calculation

This subtopic will highlight and discussed the girder deflection from the used of equation 3.7 and equation 3.8. To determine the maximum deflection experience by the girder equation 3.1 will be used. Table 4.1 below shows the result from the respective equation.

Table 4.1: Girder Deflection Calculation Result

Description	Deflection (mm)
Girder deflection due girder weight (A)	0.96
Girder deflection due load at mid span (B)	10.53
Maximum girder deflection (A + B)	11.49

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Table 4.1 shows the result from calculation of girder deflation through principle of simply supported structure. The maximum deflection is 11.49 mm and contributed largely from the deflection due to the load acting at the mid span of the crane girder. Before the load was applied to the crane structure, the crane girder already deflected by 0.96 mm due to the weight which is uniformly distributed on the girder span. The important figure from this calculation will be the maximum deflection. This value will be used to compare with other deflection calculation and also with the actual girder deflection.

4.2 Result of Girder Deflection Simulation

The deflection simulation on the girder structure conducted on two different conditions. The first condition is based on a girder structure without horizontal and vertical stiffener. This condition was conducted to ensure the reliability of the design and to check calculated deflection accuracy. It is important to acknowledge that the calculated deflection of the girder is based on cross sectional elements of the girder structure only. Thus this simulation will help to evaluated to errors and help to better understand the element contributed in reducing the girder deflection. The simulation will involved two load distributions as stated in equation 3.1 where to estimate the maximum deflection, the girder deflection from the structure weight and load acting at the mid span need to be calculated accordingly. Figure 4.1 shows the deflection simulation of the girder from its weight which is uniformly distributed along the girder span.

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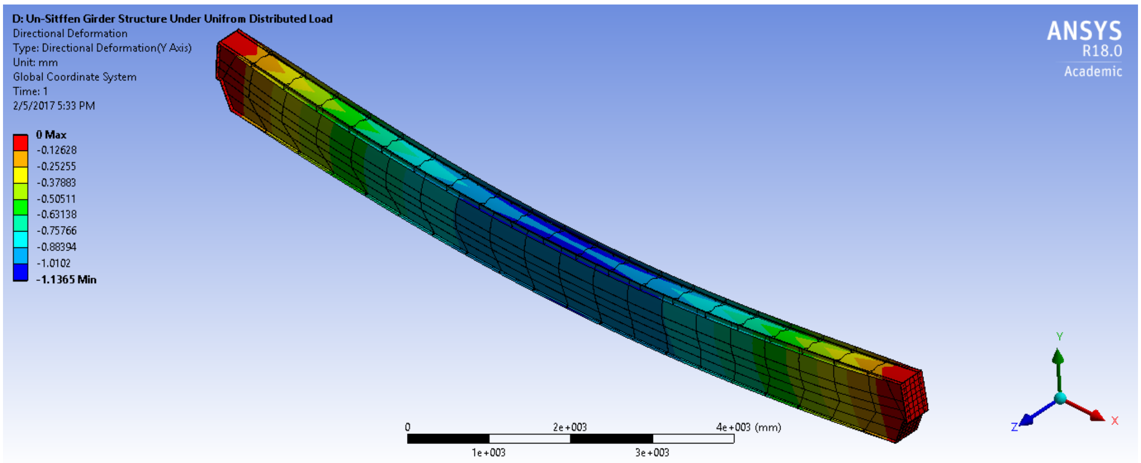

Figure 4.1: Deflection Simulation for Un-Stiffen Girder under Uniform Distributed Load

Figure 4.1 shows the simulation of the girder deflection under uniform distributed load. The deflection recorded at the centre of the girder will be the maximum deflection and the reading is 1.14 mm. The deflection will be decrease from the centre of the girder structure to the girder support on each end. The reading is less than 0.13 mm. This research only interested at the maximum deflection occurs at the centre of the crane structure. However this will not be the maximum total deflection of the crane girder. Thus, observation on the girder deflection under load acting at mid span needs to be conducted. The total girder deflection can be only determine with both information are available. Therefore, Figure 4.2 will indicate the girder deflection under load acting at mid span.

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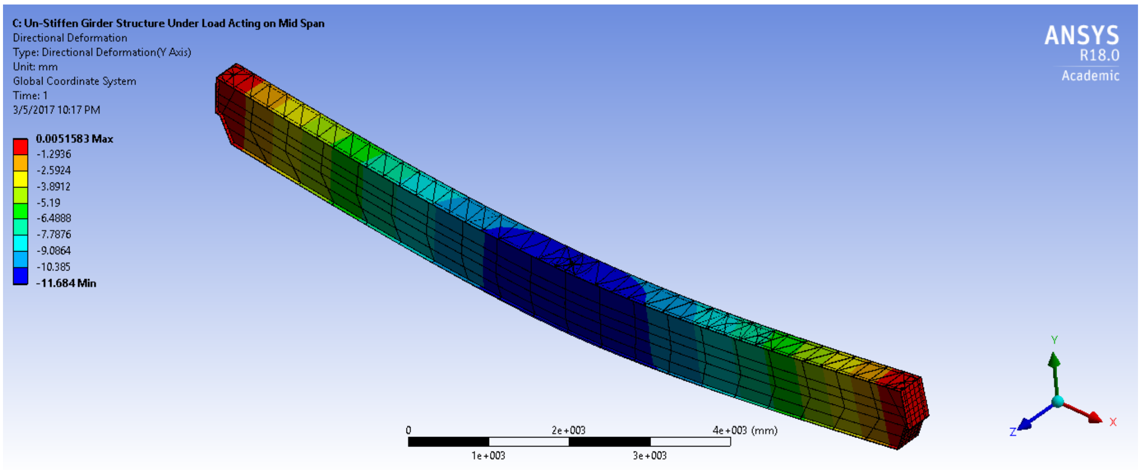

Figure 4.2: Deflection Simulation for Un-Stiffen Girder under Load Acting At Mid Span

Figure 4.2 indicate that the maximum girder deflection under load acting at mid span will be 11.68 mm which occur at the girder mid span. The deflection on the structure will become lesser from the crane mid span towards the carne edge. The recorded deflection on the crane edge is less than 1.29 mm. Thus, the total maximum deflection of un-stiffen girder structure will be 12.82 mm. This simulation will not complete without a complete girder simulation as per the manufacturer design. This simulation will improve the understanding of how will the deflection on the girder structure can be reduced accordingly. The same application is needed to understand the deflection of the complete crane structural design. Both deflection under uniform distributed load and load acting at the mid span need to be determined. Thus, figure 4.3 shows the girder deflection under uniformly distributed load for complete crane design.

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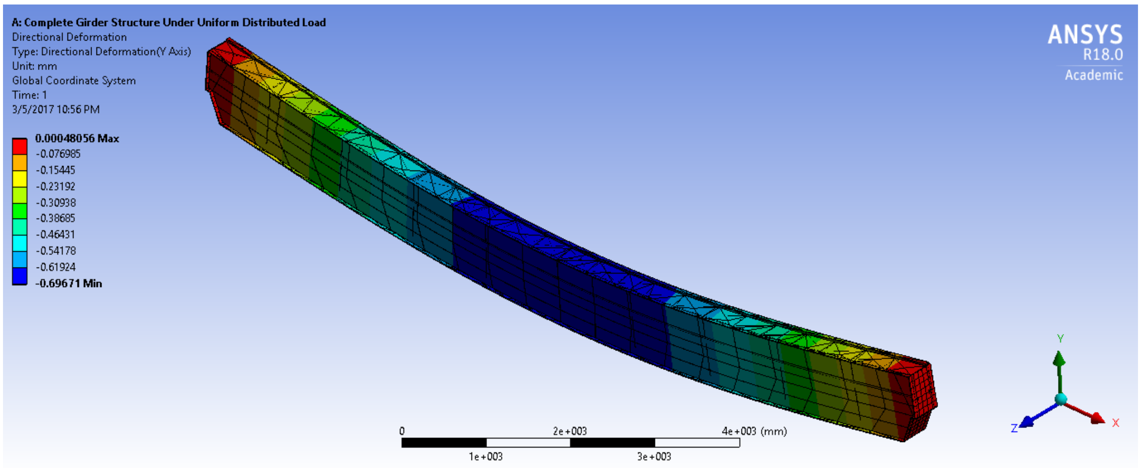

Figure 4.3: Deflection Simulation for Complete Girder under Uniform Distributed Load

Figure 4.3 reflected that the maximum deflection of a complete girder structural design is only 0.67 mm at the crane mid span. The girder deflection is lesser as the location change from the crane mid span towards the crane edge. It is recorded that the deflection on both crane edges are less than 0.077 mm. For simulation of the complete crane girder structural design under load acting on the mid span is represent by Figure 4.4.

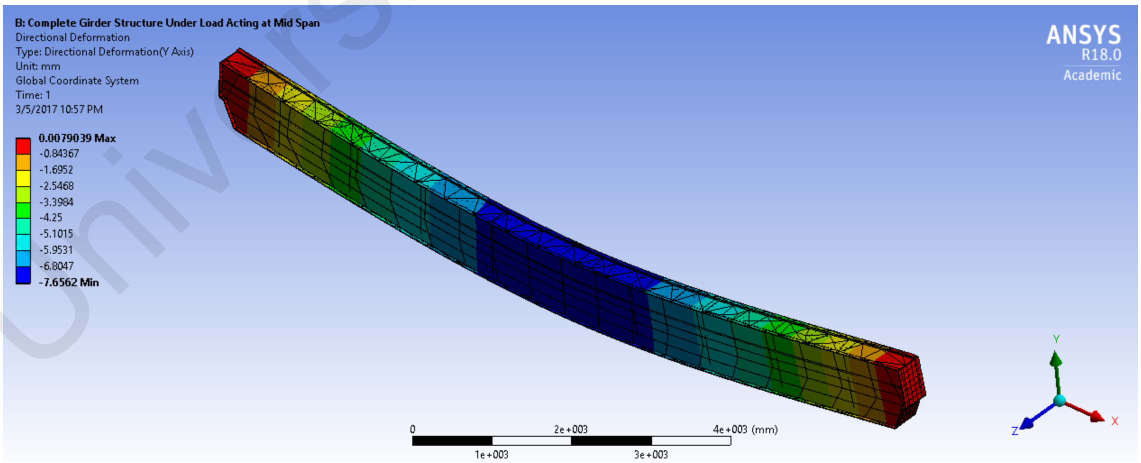

Figure 4.4: Deflection Simulation for Complete Girder under Load Acting At Mid Span

Figure 4.4 shows the maximum deflection of complete crane girder structural design occurs at the crane mid span is 7.66 mm. Besides that, the simulation also

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showing that deflection on the girder structure will reduce towards the crane edge. For this simulation condition the deflection on the crane structural edge is less than 0.84 mm. Therefore, the total maximum girder deflection for a complete crane design will be 8.33 mm. To easily understand and observe the deflection simulation on both condition. Table 4.2 show the simulation summary.

Table 4.2: Girder Deflection Calculation Result

Description	Deflection (mm)
Un-stiffen crane girder maximum deflection	12.82
Complete crane girder design maximum deflection	8.33

4.3 Comparison of Calculated Deflection and Actual Deflection

For better understanding of the girder deflection, comparison between results is also important. Therefore, the deflection result between calculated and simulation deflection will be compared and observed accordingly. Percentage of error will be used as measurement for the deflection comparison. Therefore, table 4.3 indicates the deflection measurement comparison.

Table 4.3: Girder Deflection Comparison Result

Comparison Description	Error (%)
Calculated deflection with un-stiffen crane girder simulation	10.37
Calculated deflection with complete crane girder simulation	27.50
Un-stiffen crane girder with complete crane girder simulation	35.02

Table 4.3 indicated the comparison between calculated girder deflection and simulated girder deflection in term of error percentage. The difference between the calculated girder deflection with the un-stiffen crane girder deflection is only 10.37%. This shows that the calculation is reliable in determine the girder deflection and simulation show more accuracy since its involved all the elements and structure

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geometry on the girder design. The comparison between the calculated deflection and un-stiffen girder deflection simulation towards the complete crane girder deflection simulation are 27.50% and 35.02% accordingly. This gives the meaning that the deflection has been reduced significantly. The deflection measurement for the un-stiffen girder is higher compared to the calculated deflection where 12.82 mm against 11.49 mm. This is the reason why the percentage of error for un-stiffen simulation towards complete girder simulation is higher compared to the calculated girder deflection. Besides this comparison, the results will be compared with the actual girder deflection measured during load test by the crane manufacturer. The actual deflection is 12 mm and the comparison will be measured by equation 3.11. Thus, table 4.4 will show the results comparison with the actual deflection.

Table 4.4: Girder Deflection Comparison with Actual Crane Deflection

Comparison Description	Error (%)
Calculated deflection with actual crane deflection	4.25
Un-stiffen crane girder simulation with actual crane deflection	6.83
Complete crane girder simulation with actual crane deflection	30.58

Table 4.4 shows that the highest error between the deflection measurements is the comparison between the complete crane girder simulation with the actual crane deflection which is 30.58% whereas, the lowest is the comparison between the calculated deflection with the actual crane deflection which is only 4.25%. The error show only 6.83% for un-stiffen crane girder with the actual deflection. The difference of error between the calculated and un-stiffen crane girder is 2.58%. The difference is minimal since the difference of measured deflection of both methods is only 10.37%. The minimal differences indicate that the measured deflections of both methods are consistent can comparable to each other. However, error is higher for complete crane girder simulation, even the differences is consistent to be higher if compared with the

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errors with calculated deflection and un-stiffen girder simulation, it does not reflect the deflection reduction since the actual crane is comprised of complete crane girder design and whole crane geometry and structural design.

Therefore, the deflection measurements have been compared accordingly to each other together with the actual crane deflection comparison. The differences for each reading will be further discussed in the next chapter for better understanding and describing the methodology of reducing the girder deflection.

4.4 Conclusion

This chapter successfully highlighted the results for girder deflection measurement for calculated method as well as simulation method. The calculated method is directly measured from the derived equation while the simulation method dived in two condition namely un-stiffen crane girder simulation and complete crane girder simulation. Results among girder deflection measurements have been compared accordingly. In this comparison, the differences between the calculated deflection and un-stiffen crane girder simulation is marginal which show the accuracy of the calculation method and the reliable of the design. Whereas, the complete crane simulation show highly percentage of reduced deflection on the crane girder. The second comparison is between the crane deflection measurements with the actual crane deflection from the manufacturer. This comparison shows that the errors for the calculated deflection and un-stiffen crane girder simulation is marginal showing consistency. However, the complete crane girder simulation show huge gap with the actual crane deflection. The results will be further discussed in the next chapter to further understand the result also knowing the cause of such result and comparison.

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CHAPTER 5: DISCUSSION

In this chapter the results will interpreted and discussed to better understand the deflection phenomena on crane girder. The discussion will be focus on the comparison of girder deflection results. The first comparison will be between the calculated girder deflection and the simulation of girder deflection. The result will be compared and contract with each other and referred to the prevision works for better understanding. The next comparison is between the calculated and simulated girder deflection with the actual crane deflection from the record of the crane manufacturer. In this comparison the accuracy of each method will be highlighted. This comparison will also further educate and explain the actual crane deflection situation with contrast to the methodology used for measuring the deflection in this research. This chapter will also highlight the errors found through the calculation and simulation for the crane girder deflection measurements.

5.1 Discussion on the Girder Deflection Measurement Results

The result shows that the differences between the calculated girder deflection and simulation of un-stiffen crane girder simulation is only 10.37% error which indicate the deflection measurement is acceptable and consistence with each other. The calculated girder deflection is based on a cross sectional geometry of the crane girder. The cross sectional is consisting of top and bottom flange and web plate on both sides. The un-stiffen girder haven been design to suit this characteristic. Therefore, this has validated the calculation method used in this research as well as the boundary set for the simulation on the girder deflection. The method is basically consist of deflection causes by the girder weight and load acting on the centre of the girder span as discuss in the lecturer review. The 10.37% error comes from the elements used for each methodology. The calculation has taking consideration of four elements that represent by a

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rectangular. These elements are used to estimates the moments of inertia to represent the crane girder. However, the simulation is using a mesh function which developed from the Ansys software. This function capable of making iteration of elements that covered the actual geometry of the crane girder. The actual geometry of the crane girder is not a perfect rectangle, there are angle cut from each end of the crane web. Nevertheless, both calculation shows consistency and accuracy in calculating the crane girder deflection.

With comparison to the complete crane girder deflection, the errors from calculated deflection and un-stiffen crane girder are more than 10%. Each is showing 27.50% and 35.02% respectively. This has validated the previous research that stiffener or reinforcement along the girder structure will eventually reduced the girder deflection. Although the research suggested horizontal stiffener will become much better reinforcement, this research crane complete design show a decrease of more than 27%. The stiffeners are design both horizontal and vertical, where angle bar has been used as reinforcement on the girder horizontal direction whereas special cut plate used as a vertical reinforcement inside the girder. An important note is that, the research suggested that the reinforcement or stiffener work best if it has been lay throughout the girder structure. The exact principle used as both horizontal and vertical stiffener for the designed crane girder. The manufacture used the vertical stiffener at 1500 mm interval along the girder and the horizontal used along the crane girder on two different locations. This practice is proven capable of reducing the girder deflection especially at the mid span on the crane. The simulation of un-stiffen crane girder and complete crane girder design prove that the crane maximum deflection is on the mid span of the crane. This is easily can be understood by observing the simulation of deflection caused by the uniformly distributed load where the maximum deflection will always occurs at the crane mid span. Basically, reducing the deflection on the crane mid span will be the

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great achievement and this is proven with the design used and proposed by the crane manufacturer.

Therefore, this subtopic has successfully described the validity of the method used in this research of measuring the crane girder deflection suing calculation method and simulation. The girder deflection was also understood as well as an effective method of reducing the girder deflection. Thus, the next subtopic will help to understand the calculated deflection in comparison with the actual crane deflection.

5.2 Discussion on the Girder Deflection Measurement Results With Actual Crane Deflection

When compared to the actual girder deflection, the calculated girder deflection showing error of 4.25% while the un-stiffen girder is 6.83%. Both errors are less than 10%, however when compared the complete girder design the errors increase significantly to 30.58%. The increase does not imply that the girder deflection was reduced, rather indicating that the girder deflection alone it is not enough to reflect the deflection of the whole crane. Even though, the crane girder is the main structure experience the deflection, the whole crane system need to be understood to know the elements required to estimate the crane deflection. A crane as system consist of several main parts aside from the girders, there are including end truck and trolley. Others parts such us girder walkway will also contribute to the whole crane deflection. For this design, the crane girders are side bolted with the end truck boxes. These end truck used for supporting the girders and mounting location for the crane wheel. Accordingly, the will is the actual member which supported the whole crane on crane runway. Contrarily, our girder simulation and calculation take only consideration of the crane girder which supported from the crane edge. Thus, it is important to do full modeling of crane to really understand the deflection f the crane or develop an equation which only taking

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consideration of the crane girder deflection from the girder area instead of the whole crane system.

Nevertheless, this research can still discuss the stress experienced by the girder during deflection. As explained by previous research, deflection occurs since the deformation on the structure started. This deformation are due to the stress from force acting on the structure and for the crane application, the forces are including the load at crane mid span and the girder weight itself. Figure 5.1 and figure 5.2 indicate the stress experience by the crane.

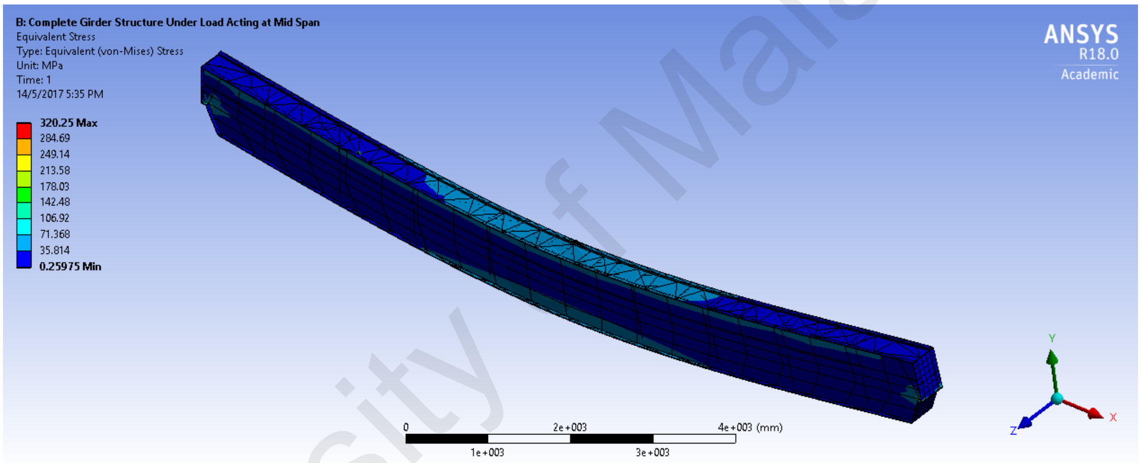

Figure 5.1: Stress Distribution for Complete Girder under Load Acting At Mid Span

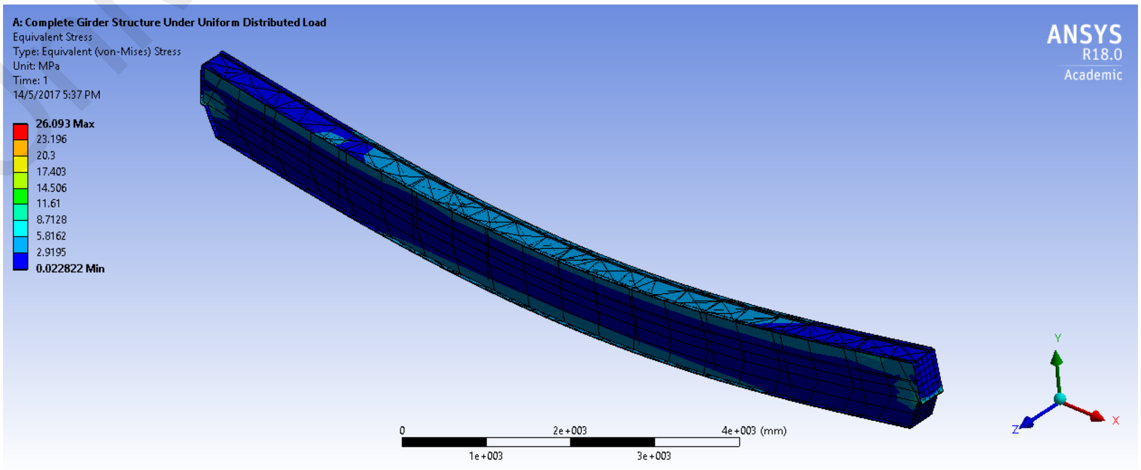

Figure 5.2: Stress Distribution for Complete Girder under Uniformly Distributed Load

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Both figure 5.1 and 5.2 shows the area on the crane girder which experience high stress distribution. The areas are bottom flange, top flange and both girder edges. The maximum recorded stress for load acting on mid span and uniformly distributed load are 320 MPa and 26 MPa respectively. Although the stress result is different due to the difference is acting force or load, the affected areas are the same. These areas are most likely contributed to the girder and crane deflection. Therefore, in the view of reducing the girder deflection, bottom and top flange should be more reinforce. The reinforcement does not need to be on the whole girder length but on the area where only highly affected. Whereas, the crane girder edge indicates the support which is to reduce the girder deflection, better mechanism of support or design need to be proposed. At current design, the girder is attached to the end truck by bolting. Thus this give better perspective on why the actual crane deflection is higher compared to the crane girder deflection. The joining method can be further discus to better understand on a way of minimizing the deflection. In relation to the actual crane system, these areas will be the major cause for deformation on the crane. However, other part especial on the end truck will most likely affected since this part is the main part that will support the crane girder. Accordingly, a better design of end truck will help to even further reduce the deflection on the crane girder as well as whole crane system.

Therefore, this subtopic has clearly indicated the comparison between the deflection measurements and actual crane deflection. There is still a gap between the measured girder deflections with the actual deflection. However from the stress distribution of the girder, the method of minimizing the girder deflection as well as complete crane system was successfully discussed.

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5.3 Conclusion

This chapter clearly discussed the comparison among the crane deflection measurements as well as compared the results with the actual crane deflection. Based on the comparison of results, the crane girder deflection was able to be reduce by the used of stiffeners or reinforcements inside the crane girder. By comparing the measurements with the actual crane deflection, a gap in the deflection measurements is highlighted however, the reducing method of girder deflection still able to be understood by observing the stress distribution on the crane girder. The relation between highly affected areas along the crane girder with the actual crane system was drawn and better methods are proposed of reducing the girder deflection. The next chapter will conclude the research objective as well as proposed recommendation for future research of achieving better results.

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CHAPTER 6: CONCLUSION

This research was conducted to understand the girder deflection when load is lifted and propose ways of minimizing it. The deflection has been studied by measuring the crane girder deflection with two different methods which are through calculation and simulation by using finite elements software. The results of girder deflection measurements were then compare to each others as well as with the crane actual deflection. The results help to better understand the deflection phenomena and finding ways of reducing the crane girder deflection. All result has been clearly discussed in previous chapters. From the results, the maximum deflection occurrence can be observed and the stress distribution on the girder structure can be clearly seen. Therefore, this chapter will summarize all the important result from this research. This chapter will also include recommendation for future research to obtain better result.

6.1 Conclusion

These research purposes are to study the crane girder deflection as well as to finding the ways of minimizing it. The crane girder deflection was measured by two different methods which are calculation and simulation through finite element analysis. Thus, based on the research objectives, the following are the conclusion from this research

i. The crane maximum deflection is based on two different elements which are deflection based on the weight of the crane girder and the load acting at the crane mid span. This can be observed from the equation derived to measure the crane deflection. The crane maximum deflection will always occur at the crane girder structure mid span and the measured deflection from the calculation is 11.49 mm whereas simulation of un-stiffen girder design conducted through the finite element analysis software, Ansys shows result of 12.82 mm. The error is only 10.37% which given the

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meaning that both methods is consistence in representing the girder deflection. The equations principle and boundary for the simulation also shows accuracy in determining the crane girder deflection.

ii. The crane girder deflection can be minimize by adding or design with stiffener or reinforcement inside the girder structure. This is justified by the reduction of 35.02% deflection when a complete crane design was simulated with finite element analysis software, Ansys. Furthermore, the deflection can be reduce more by reinforcement or better design at particular crane girder structure, especially on the crane mid span bottom flange, top flange and the crane edges. The crane girder deflection also helps to understand the way of reducing the actual crane deflection by enhancing the joining design or method between the crane girder and its end truck. This conclusion is based on the stress distribution from the simulation on the crane girder complete design.

6.2 Future Recommendation

Further improvements on this area of research are needed to achieve better and much accurate result. Throughout t the research, gap is still existed between the crane girder deflection and the actual crane deflection. The gap existed between the crane deflection derivation and the crane girder design itself. Bellows are potential recommendation for the continuity of this research:

a. The equation derivation was based on the rectangular geometry represent from the girder cross sectional area. Future research should consider the actual geometry of the crane so that precise elements can be represented to calculate the moment of inertia for the crane girder.

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b. The simulation was based on the crane girder structure only. Future research need to take care the whole crane design including the joining of each part to each other. Joining between parts is essential to determine and analyze the actual crane deflection phenomena.

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