Economies in Structural Steel Design using Different Steel Grade

by

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

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(Dr. Narayanan Sambu Potty)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(MOHAMMAD NAJIB BIN MOHD SALIM)

ABSTRACT

The purpose of this study is to investigate the economies in using different steel grade in designing steel structures. Most of the steel structure exist today are using conventional grade of steel for instance S355 or S460. The used of high strength steel able to benefit from the weight saving and reduced fabrication costs of using thin plates (Sedlacek & Muller, n.d). However high grade steel is mostly known as difficult to fabrication due to the high content of carbon, which can be improved by using appropriate heat treatment. Nowadays there is a treatment in producing structural steel such as thermo-mechanical controlled process, which able to produce leaner steel and less carbon content. The result of less carbon content is affecting the fabrication properties; the lesser the carbon will increase the fabrication properties. The higher fabrication properties enable to lesser cost in fabrication due to non-require or lesser temperature in preheating process. Therefore the used of high steel grade able to provide saving in term of material cost and fabrication cost.

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TABLE OF CONTENT

LIST OF FIGURE

LIST OF TABLE

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Steel is one of most important material in construction, which used in bridges, high-rise building and etc. Therefore it is important that the improvement of the efficiency of steel products in design, fabrication and service life of a steel structure. In gaining higher productivity is by using higher strength of steel (Schroter, n.d). Based on Sedlacek and Muller, n.d, the used of high strength steel able to benefit from the weight saving and reduced fabrication costs of using thin plates. High strength steel enables the designer to reduce the cross-section of steel and allow the designer to fully utilize the space available (Schoter, n.d).

The problem due to high strength steel is the difficulty of fabrication, which because of high carbon content. The strength of the steel can be increase significantly by addition of carbon, however the increment of carbon or alloying content worsen the fabrication properties (Samuelsson & Schroter, n.d). Based on Barrett, n.d., the higher strength steel required special attention in welding such as preheating procedure. The production of steel such as heat treatment influences the quality of the steel. Based on Samuelsson and Schroter, n.d, the effect of heat treatment influence on the microstructure and grain size. The process consist of achievement of a fine-grained structure resulting in higher strength as well as better toughness of the material compared to a coarse-grained structure.

1.2 Problem Statement

High strength steel is not prefer choice in construction due to fabrication issue, which makes S275 and S355 common choice. The problem of high strength steel is the fabrication and erection difficulty due to the alloying content in the production of steel. Alloying content influence the strength of the steel which the higher addition of alloying content result higher strength of steel. However the higher alloying content cause reduction in fabrication properties. Therefore heat treatment such as thermo-mechanical controlled process able to produce low carbon content, which improved the weldability and higher strength steel. The process using extremely fine-grained microstructure and combination of rolling steps at particular temperature and the strength is obtained by the grain refinement allow to reduce the carbon and alloy content.

Therefore this study focusing on the economical of using high strength steel in building design as the high strength steel allow designer to choose smaller cross-section of the steel and reduce the number of steel member

1.3 Objective and Scope of Project

The objective of the research is to:

1. To identify the economies in weight of the building.
2. To determine the impact on using High Strength Steel related to fabrication aspect on economy.

This study will be focusing on the economical of high grade of steel in building design. The research will used computer modeling analysis such as STAADPRO to determine the high grade of steel capable in replacing the common grade of steel economically in term of cross-section, size and strength of the member. Others will depend on the research based on the fabrication properties of the high grade of steel which allow the used of high strength steel in replacing the common grade of steel.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The steel structure is commonly used in construction, which it provides high strength, lightweight and easy fabrication. However the used of high strength steel is still unpopular due to uncertainties such as high cost of fabrication. The objective of this paper is;

1. To identify the economies in weight of the building.
2. To determine the impact on using High Strength Steel related to fabrication aspect on economy.

The literature review is divided into several categories in order to achieve the objective of this research;

- Different Grade of Steel.
- Effect of Alloying Content on Yield Strength and Properties of Steel.
- Fabrication Properties of High Strength Steel.
- Influence of Heat Treatment on Weldability.
- Affect of High Temperature on High Strength Steel.
- Summary.

The first metal used by human being was type of copper alloy such as bronze, which the most important metal developments throughout history have occurred in the manufacture, and use of iron and its famous alloy, steel. However, today iron and steel compose almost 95 percent of all the tonnage of metal produced in the world. Steel is defined as a combination of iron with a small amount of carbon, usually less than 1 percent. It also contains small percentages of some other elements. Although some steel has been made for at least 2000 or 3000 years, there was really no economical production method available until the middle of the nineteenth century.

Modern structural steel is greatly changed by the varying the quantities of carbon present and by adding other elements such silicon, nickel, manganese and cooper. The significant of the latter element is referred to as alloy steel. These elements have a great effect on the properties of steel such as weldability, corrosion resistance, resistance to brittle fracture and etc. Other than chemical composition which affected the physical and mechanical properties, the influenced to certain degree by rolling process and by their stress history and heat treatment able to change the physical and mechanical properties. The used of high strength steel with higher yield strength for example beam; deflections can be controlled. In addition considerable economy can be frequently be achieved with high strength steels for short and medium-length stocky columns. Other method of economical in construction is the used of high strength steel for higher stress and weaker steel for lower stress. High strength can provide superior corrosion resistance, saving in shipping, erection and foundation cost in weight saving and fireproofing cost.

2.2 Difference Grade of Steel

Steel grade can be categories into several categories, which has different yield strength and tensile strength. Table below shown types of steel grade and value of tensile and yield strength.

Standard and steel grade	Nominal Thickness of Element t (mm)			
	T ≤ 40 mm		40 mm < t ≤ 80 mm	
	f_y (MPa)	f_u (MPa)	f_y (MPa)	f_y (MPa)
EN 10025-2 S 235	235	360	215	360
S 275	275	430	255	410
S 355	355	510	335	470
S 450	440	550	410	550
EN 10025-3 S 275 N/NL	275	390	255	370
S 355 N/NL	355	490	335	470
S 420 N/NL	420	520	390	520
S 460 N/NL	460	540	430	540
EN 10025-4 S 275 M/ML	275	370	255	360
S 355 M/ML	355	470	335	450
S 420 M/ML	420	520	390	500
S 460 M/ML	460	540	430	530
EN 10025-5 S 235 W	235	360	215	340
S 355	355	510	335	490
EN 10025-6 S 460 Q/QL/QL1	460	570	440	550

The table obtained from EC3: Design of Steel Structures – Part 1-1: General Rules and Rules for Buildings.

Table 1: Nominal Values of Yield Strength and Ultimate Strength for Hot Rolled Structural Steel

The notation of ‘S’ shown that the structural steel and the number of ‘235, 275, 355, 420 and 460 indicate the minimum yield strength of steel based on the thickness of the steel used. The notation of N/NL denote of the steel is using normalized rolled weldable fine grain with different longitudinal Charpy V-notch impacts at a temperature not lower than -20°C and temperature not lower than -50°C. M/ML is a thermo-mechanically rolled weldable fine grain with the same Charpy V-notch as normalized method and lastly the Q/QL/QL1 for quenching and tempering process with longitudinal Charpy V-notch not lower than -20°C, -40°C and -60°C.

2.3 Effect of Alloying Content on Yield Strength and Properties of Steel

The alloying content used in the making of steel influence many aspect of physical and mechanical properties. Alloying content such as carbon (C) and manganese (Mn) able to increase the strength of the steel, however it reduces fabrication properties (Samuelsson & Schroter, n.d). The carbon element is used in making steel and has the effect of increasing the hardness and strength by heat treatment. Manganese is used to harden the steel and has counteracts effect of brittleness from sulphur. The alloying content in the steel not only carbon and manganese, there other alloying element such as silicon, phosphorus, sulphur and etc. This content is different with other steel grade which table below shown percentage of alloying elements that content in S355M/ML and S460 M/ML

Alloying Content (max)	S355		S460	
	M	ML	M	ML
Carbon, C	0.14	0.14	0.16	0.16
Silicon, Si	0.5	0.5	0.6	0.6
Magnesium, Mn	1.6	1.6	1.7	1.7
Nickel, Ni	0.5	0.5	0.8	0.8
Phosphorus, P	0.03	0.025	0.03	0.025
Sulphur, S	0.025	0.02	0.025	0.02
Chromium, Cr	0.3	0.3	0.3	0.3
Molybdenum, Mo	0.1	0.1	0.2	0.2
Vanadium, V	0.1	0.1	0.12	0.12
Nitrogen, N	0.015	0.015	0.025	0.025
Niobium, Nb	0.05	0.05	0.05	0.05
Thallium, Ti	0.05	0.05	0.05	0.05
Aluminium, Al	0.02	0.02	0.02	0.02
Cooper, Cu	0.55	0.55	0.55	0.55
Carbon Equivalent Value, CEV	0.45	0.45	0.48	0.48

Table 2: Alloying Element for S355 and S460

The table obtained from European Steel and Alloy Grade using EN10025-4: 2004

The table above show that the different between S355 and S460 in alloying content which influence the strength of the steel in yield and tensile. Based on Healy and Billingham (1997), the reduction of carbon content in production of steel and with the addition of Nb, V, Ni and Cu for steel grade S355EMZ for fixed offshore structure able to achieve the yield strength in the range of 350 – 500 MPa with excellent toughness and good weldability. The amount of phosphorus and sulphur between S355M and S355ML is different due to phosphorus and sulphur has different role which influencing the steel properties. The present of phosphorus help in improving the machinability in low alloy steels, aid strength and increase corrosion resistance. However the additional of phosphorus will increase the tendency of steel cracking during welding work. Sulphur addition improves machinability but does not cause hot shortness. Hot shortness is brittleness in metal occur during high temperature during deformation. The hot shortness is reduced by the addition of manganese, which combines with the sulphur to form manganese sulphide. The manganese sulphide has higher melting point, therefore able to reduce the weak spot at the grain boundaries during hot working.

2.4 Fabrication Properties of High Strength Steel

High strength steel can be produce by increase the carbon content in the steel, which able to increase the tensile, hardness and ductility. However the weldability of the steel is reduce due to the increase of the hardness of the steel. However the use of high strength steel need to paid more attention on the fabrication due to the inherent poor weldability (Homma, Tominaga & Miki, 2002). Therefore properties of modern high strength steel should have the fabrication properties, which able to reduce the fabrication cost. Based on Samuelsson and Schroter (n.d), by producing the high strength steel with good properties such as fabrication able to reduce the cost such as the reduction of structural structure, fabrication and erection cost. The used of high strength steel allow longer span of beam to be used which able to reduce the number of column used. Based on Hever and Schroter (n.d), the used of longer span beam seem to be the economical choice in constructing the railway bridges using high strength steel rather than other grades. The used of S460 in the construction of bridges able to reduce the total weight of the structure to 25% and material cost saving up to 21% compare to using S355. It also allow the used of smaller cross section of member due to high grade of steel. The importance of steel structure is the fabrication process, based on the high carbon content of steel which difficult to be fabricated. Therefore high strength steel must have adequate weldability to improve the application of high performance steel. This statement is agreed by Lwin (2002), that the improvement of weldability of high steel grade will enhance the reduction of high cost of fabrication associated high preheat temperature, heat input control, post-well treatment and other stringent control while eliminate hydrogen induced cracking in the weldment.

Other fabrication cost is preheating which used before the welding to minimize the risk of brittle failure. The process consist of reduction of the temperature gradient between the weld and adjoining base metal thus less likelihood of cracking during cooling and there is an opportunity for entrapped hydrogen, a possible source of embrittlement, to escape. The effect of preheating on structural steel is improving the ductility and notch toughness of base and weld metal, and lower transition temperature of weld. Other effect is the rapid cooling of weld, which causes severe embrittlement due to arc strikes that do not deposit weld metal are dangerous is that the heated metal cools very fast. Therefore preheated steel is prevented from local hardening. Based on the used of high performance steel of 800MPa for the construction of Minato Ohashi Bridge, the structural been exposed with a preheating temperature of no higher than 150°C with member thickness of 100mm to reduce the unfavorable elements that affect the hardness in heat affected zone (Miki et. al, 2002).

Aside of fabrication cost, the reduction used of steel able to contribute to the environment due to the small cross-section of member is used. However the importance of the steel structure is the safety, which due to the reduction of carbon content the steel able to withstand the heavy loaded, fatigue, deflection and etc. Samuelsson and Schroter (n.d), agreed that the reduction of carbon content is affecting the strength of the steel, therefore modern high strength steel able to provide excellent toughness, fabrication and brittle fracture. However to maintain the strength of the steel without effecting the weldability, cooper was used to take advantage of the precipitation-hardening phenomenon (Miki et. al, 2002).

2.5 Influence of Heat Treatment on Weldability

High strength steel is produce by using several heat treatment process such as normalized, hardening, annealing, quenching and tempering (QT) and thermo-mechanical controlled processing (TMCP). The heat treatment can be used in producing high strength steel, which based on Samuelsson and Schroter (n.d), heat treatment uses the effect of microstructure and fine-grained structure to achieve higher strength and better toughness compare to coarse-grained material. Some of the heat treatment used polycrystalline material in production of steel, which increases the strength and hardness with decreasing in grain size (Villaverde & Gonzalez, 2012).

Annealing process is a softening process which the steel is heated to a temperature above transformation temperature and the steel is held to this temperature for sufficient time before is been cooled slowly. This process will allow recrystallization and softening of the cold-worked ferrite grains, but usually will not affect the relatively small amounts of cold-worked pearlite. This treatment is usually applied to 0.6% or higher carbon content steels which to improve machinability and used to condition high carbon steel for cold drawing into wire.

Meanwhile normalized is a process in which steel is heated to a temperature above the transformation temperature and then cooled in still air. The purpose of the treatment is to obliterate the effects of any previous heat treatment such as coarse-grained structure which resulting from high forging temperature or cold working and to insure a homogeneous austenite on reheating for hardening or full annealing. The mechanical properties of the structure will be affected by the rate of cooling, considerable variations may occur in normalized steel due to differences in section thickness of the shapes being normalized. The selection heat treatment is depend on the carbon content on the steel such as the normalized method used the high carbon content of steel which influencing the weldability of the steel (Schroter, n.d).

Quenching and tempering is another method of heat treatment of steel. It consist of heating the steel above the transformation temperature and holding long enough to ensure the attainment of uniform temperature and solution of carbon in the austenite, and the rapidly cooling. The quenching and tempering method suitable for highly alloyed steel, which highly alloyed steel reduces the ductility and weldability of steel (Healy & Billingham, 1997). This also been state by Schroter (n.d), which the high alloying content influencing the weldability of the steel. Schroter continues that the quenching and tempering process used tempering of martensitic microstructure in order to obtained required tensile strength and toughness, which it produce steel that is too brittle for the use of structural application.

The other type of treatment is thermo-mechanical controlled process is a method in improving the strength, toughness, ductility and weldability of steels. The rough steel is heated to temperature of 1200°C and carried the initial hot working before the final hot work the temperature is reduce. Plastic deformation at lower temperature promotes fine grain sizes and retards precipitation. The final hot work continue to transform from austenite to ferrite which the optimum precipitate size and dispersion is obtained when the finish rolling temperature around 775°C. The cooling will result austenite to ferrite transformation and finer ferrite grains and fine dispersed precipitates. Lastly the process consist of water cooling, give a finer grain size and result in bainite formation or ferrite formation. The lean composition of thermo-mechanical controlled process steels can be beneficial with respect to weldability, which Healy and Billingham (1997), agreed that the thermo-mechanical controlled process producing the fines grain sizes to improved the strength and toughness while use low level of carbon to ensure good weldability and toughness.

Based on Villaverde and Gonzalez (2012), by varying the grain size of steel will impact the properties of steel such as tensile strength, yield strength, toughness and hardenability can be altered. The use of thermo-mechanical controlled process, the carbon content can be significantly reduced which lower the carbon equivalent and allow welding process without the possibility of cold cracking. The reduction of the carbon content in the chemical composition of steel allow for cost efficient, which the process of preheating is less needed even with greater material thickness (Hever & Schroter, n.d). Schroter agreed that the used of thermo-mechanical controlled process can avoid the used of preheating and time-money consuming step in the fabrication process and production efficiency of the fabrication yard.

2.6 Effect of High Temperature on High Strength Steel

The high temperature occur on the steel structure is due to the expose of fire. The design of the high strength steel should provide higher fire resistance than conventional steel. The behavior of steel in elevated temperature is depend on the composition of the steel such as the alloying content show the mechanical properties of the steel while composition such as molybdenum, chromium and niobium can increase the fire resistance properties of steel, where as the chrome and nickel can enhance the corrosion resistance of steel (Wang, Liu & Kodur, 2013). However the strength of steel will definitely change due to the increase of temperature, as the temperature increase the strength of the steel and ductility is generally decrease. Qiang, Bijlaard and Kolstein (2011), agreed that the strength and stiffness of steel loses with increase of temperature. As tragedy 9/11, the steel structure of the World Trade Center collapse due to steel exposure to fire which lead to steel failure as the strength deteriorate. The increases of exposure of high strength steel to fire allow more time of evacuation.

Based on Villaverde and Gonzalez (2012) the increment of the temperature allow the grain size to slightly increase, which could result decrease in performance of the steel. However the insignificant of change due to the increment to 920°C doesn’t effect the steel hardness at the high temperature. The grain size has effect on the mechanical properties of the steel. Based on above explanation the heat treatment used the grain size in determine the strength of the steel. As the temperature is increasing the grain size increase, it affects the mechanical properties of the steel. This statement agreed by Wang et.al (2013), which as the temperature increase, other properties such as strength and ductility of Q460 are generally decreased except at

800°C when the ductility increase. This phenomenon occurs due to the increase of grain size on steel.

The grain size effect is influence by the heat treatment process, which affects the performance the steel due to fire. Experiment done by Qiang, Bijlaard and Kolstein (2011), on two different type of steel which result the performance of S460M using heat treatment of thermo-mechanical controlled process is better in elevated temperature than S460N than using heat treatment of normalized. The performance is based on the yield strength, elastic modulus and the ductility of the steel. The tensile strength of the steel is difference due to the increment of the temperature. As the temperature increase to 500°C to 600°C, the mechanical behavior of the higher steel is greater than lower steel. However the steel doesn't behave as plastic deformation and necking not occurring at the 800°C unless at temperature of 500 – 650°C which the steel behave plastic deformation and formation of necking occur (Villaverde & Gonzalez, 2012).

Based on Wang et. al (2013), the increment of temperature doesn't reduce the tensile strength of steel, for example the S460 steel have higher tensile strength at temperature of 200 - 450°C compare to tensile at room temperature. The increase of tensile strength is due to the deformation aging of carbon and nitrogen interstitial atoms in the temperature range of 200 - 450°C. However the steel able to regain its strength during cooled down after expose to the high temperature. Steel grade S460 and S690 been expose to elevated temperature below 600°C, during its cooled down the steel able to regain its elastic modulus. Exposure beyond 600°C, the S460 and S690 unable recover due to the degradation of its elastic modulus but the S690 steel grade loses its elastic modulus more quickly compare to S460 (Qiang et.al, 2011). This statement is agreed by Wang et. al (2013), which the S460 steel have higher yield strength at 200°C to 450°C than the room temperature although there no increase in ultimate strength . Wang et. al, continues that at elevated temperature of 600°C the S460 able to retain 70% of its room temperature strength, which higher than conventional mild steel. However yield strength and ultimate strength decrease at a faster rate beyond 600°C. Qiang et. al (2011), added that the post fire has no effect the yield strength until it achieve temperature above 600°C and able to regain more percentage of yield strength than S690, however both of the steel grade have sufficient ductility after being exposed to fire. Based on Qiang, Bijlaard and Kolstein (2013), the post fire for high strength steel of 960MPa able to retain its elastic modulus and ultimate strength to 75% after cooling from temperature up to 800°C and at least 60% for 1000°C. The failure mode of high strength steel S960 behave a ductile failure with necking and no brittle failure at elevated temperature.

2.7 Summary

As the objective above, the use of high strength steel able to reduce the construction cost in fabrication, material and etc. High strength steel production should have high fabrication properties without compromise the strength of the structure. The relation between the strength and fabrication is due to the composition of the steel which alloying content is used in increasing the strength but decrease the weldability and composition such as molybdenum, chromium and niobium able to increase the fire resistance and corrosion resistance.

In designing steel structure, value of yield strength is used to determine the size of structure used. As the higher yield strength used, the small cross-section can be applied. The yield strength increases due to increase of steel grade and it shown that the higher grade of steel can cause smaller section to be implement, hence high strength steel can be economical.

Other than composition, which influence the strength of the steel, heat treatment able to change the mechanical properties of the steel. There are several heat treatments such as annealing, normalized, thermo-mechanical controlled process and etc. however the used of thermo-mechanical controlled process able to produce steel with high strength, adequate weldability and high exposure to fire compare to normalized based on the experiment done by Qiang et. al (2011). The thermo-mechanical controlled process used fine grain sizes, which able to improved the strength and toughness although the steel content low carbon to ensure good weldability and toughness.

Lastly the fire resistance of high strength steel is depending on the composition of the steel. As stated by Wang et. Al (2013), the chemical composition of steel has and effect on high temperature properties. This been proven by Qiang et. al (2011), which the S460 and S690 have different rate of elastic and yield strength changing due to increment of temperature. The changing rate between the steel grades is due to the different chemical composition. Therefore the use of high strength steel able to reduce the cost; in fabrication due to welding which most of high grade of steel have high content of carbon, in weight and strength ratio which high strength steel only produce in light weight and less member used in the structure and lastly able to provide adequate fire resistance.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The objective for this research is;

1. To identify the economies in weight of the building.
2. To determine the issue of High Strength Steel related to fabrication aspect.

The methodology is used to determine the economical aspect in using high strength steel in building design. The methodology can be divided into two aspects, which are structural analysis using computer software and conduct an interview with steel fabricator. Figure 1 shows the flow chart of methodology of this analysis. The details of the methodology will be explained further later in this chapter.

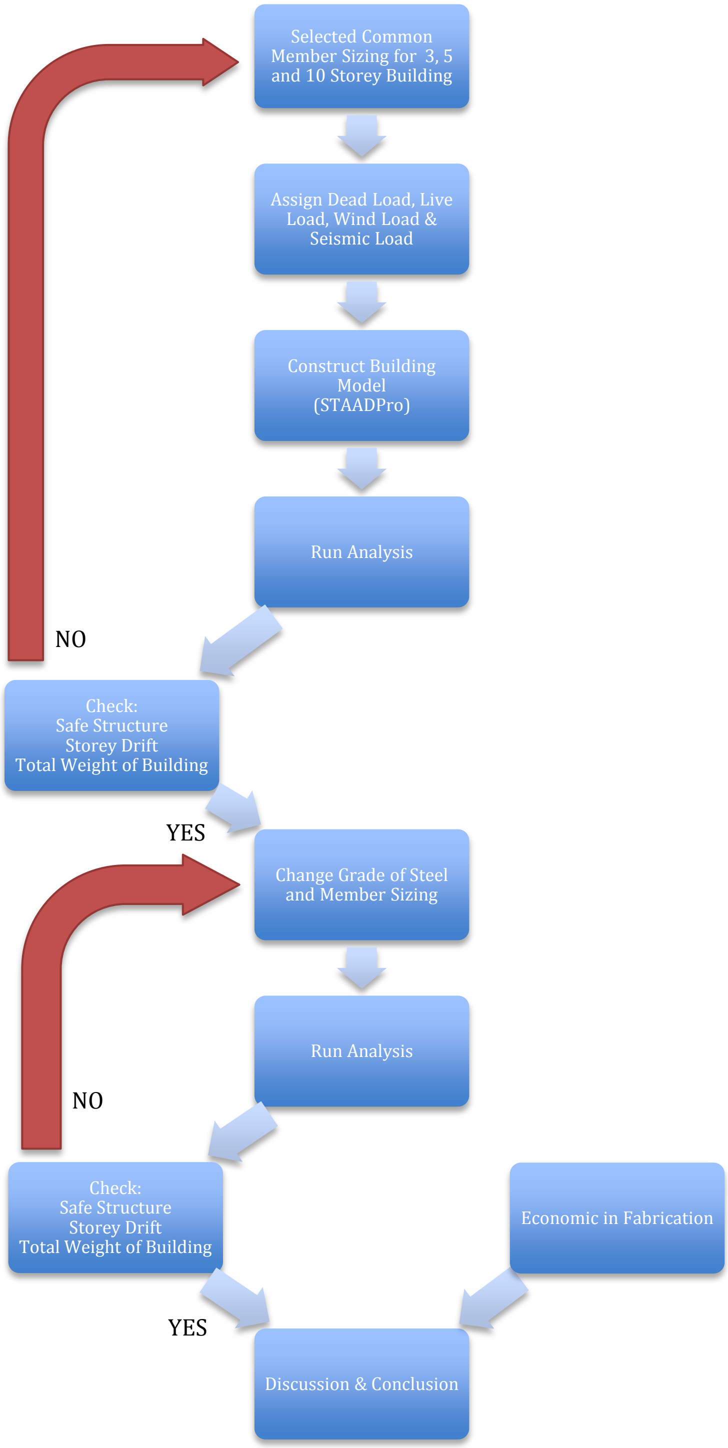

Figure 1: Methodology Flow Chart

3.2 Construct Building Material and Analysis Using STAADPRO

3.2.1 General

There are 5 type of building height, which consists of 3, 5, 10, 15 and 20 storey of building. They are modeled in STAADPro 2007 and checked against Eurocode and British Code after all the loads and member properties are assigned. The building is constructed in a way that it has column-to-column distance of 6 meter, on x-axis and z-axis. The reinforced slab thickness is taken as 150mm and the height of each storey will be 3 meter as common practice and minimum required storey height of building in Malaysia. The building will be categorize as residential building and made up of steel frame material.

3.2.2 Loadings

The loadings apply to the building such as dead load, live load and wind load is taken from the BS6399. The load combination will follow as stated in British Code.

3.2.3 Dead Load

Dead load is the load that apply to the structure due to it self weight of the structure, load of other structures such as masonry, slab and etc. The brick wall will be assumed to be installing on to entire beam on every storey. The grade of the concrete used for 3 categorize building is grade 24kN/m^3, which it apply for the 150mm thick slab and the finishes.

The detail of Dead Load applied on the structure:

RC Slab	= 24 kN/ m^3 x 0.15m		= 3.6 kN/m^2
Finishes	= 24 kN/ m^3 x 0.05m		= 1.2 kN/m^2
		Total	= 4.8 kN/m^2
Brick wall	= 5.2 kN/m^2 x 3.0 m		= 15.6 kN/m

3.2.4 Live Load

The live load is the loads assume to be produced by the intended occupancy or user, including the weight of movable partitions, distributed, concentrated, impact and inertia except wind loads. The value of $5kN/m^2$ will be used as live load according to BS6399 and applied from first floor until top floor. Reduction in total distributed imposed floor loads shall be in accordance with table 2 and 3 of BS6399-1. This reduction is necessary because the resulted loads on the ground floor column will not design optimized if not consider the reduction.

Number of floors including the roof	Reduction (%)
1	0
2	10
3	20
4	30
5 to 10	40
Over 10	50

Table 3: Reduction In Total Distributed Imposed Floor Loads With Number Of Storeys

Area supported (m2)	Reduction (%)
0	0
50	5
100	10
150	15
200	20
Above 250	25

Table 4: Reduction In Total Distributed Imposed Floor Loads On A Supporting Beam or Girder With Floor Area

3.2.5 Wind Load

The wind load design as per EC1-4-1991

The basic wind velocity: V_b = 35.1m/s

The design wind speed: $V_{m(z)} = C_{r(z)}\, C_{o(z)}\, V_b$

$C_{r(z)}$ = Roughness factor

$C_{o(z)}$ = Orography factor, 1.0

Since the area of study is located in Kuala Lumpur, the selection will be terrain category 4; Area in which at least 15% of the surface is covered with buildings and their average height exceed 15m. This category covers only the centers of large towns and cities where the buildings are not only high, but are also not too widely spaced. The Value of topography factor will be taken as 1 for its assumption on level topography under normal circumstance. Design for basic wind speed for Kuala Lumpur area is 35.1 m/s, peak 3-second gust at 10m above grade for a 50-year return period (Shafii & Othman, 2004).

The peak velocity pressure can be determined by using;

$$q_p(z) = \left[1 + 7 \cdot l_v(z)\right] \cdot \frac{1}{2} \cdot \rho \cdot v_m^2(z)$$

Where:

$l_{v(z)}$ = turbulence intensity at height *z.*

ρ = air density, 1.25kg/m^3

The turbulence intensity, $l_{v(z)}$ can be determine by using formula below;

$$l_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_l}{c_o(z) \cdot \ln(z/z_0)} \quad \text{for} \quad z_{min} \le z \le z_{max}$$

$$l_v(z) = l_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

Where:

k_1 = turbulence factor, 1.0

c_o = orography factor.

z_o = roughness length.

Internal and external pressures are considered to act at the same time. The wind loadings per unit length w (in kN/m2) are calculated:

$$W_e = c_{pe} \times q_{p(z)}$$

Where c_{pe} is the pressure coefficient for the external pressure depending on the affected area, which more than $10m^2$. The determination of coefficient is also based on the h/d, which the height over the width of the model. Based n the Eurocode 1-4, the coefficient of external pressure can be including in all perimeter of the building. There are windward and leeward, which the windward coefficient will be positive symbol due to wind act toward the structure and leeward is negative symbol due to wind acting outside the structure. However the total wind load will be the sum of external coefficients (windward and leeward).

The calculation of wind load can be use either the two method; force coefficient and wind pressure. The table below is the detail of pressure act on the model based on the two methods.

No. of Storey	Building Height (m)	Peak Velocity Pressure (kN/m^2)	Wind Pressure on Surface (kN/m^2)		Wind Force (kN/m^2)
			WW	LW	WW
3	9	0.902	0.64	-0.270	1.140
5	15	1.11	0.81	-0.40	1.390
10	30	1.488	1.19	-0.744	2.330
15	45	30m = 1.488 45m = 1.739	1.19 1.39	-0.744 -0.932	2.330 2.510
20	60	30m = 1.488 60m = 1.910	1.19 1.53	-0.744 -1.05	2.330 2.695

Table 5: Wind Load Based On Number of Storey

3.2.6 Material Property

The determination of material property of the multistory was done with optimization based on the strength of the member in withstand the wind load, seismic load, dead and live load. The member assigned is checked based on Eurocode such as check of storey drift, which effects the occupant's comfort and combination of loads. The member assigned will be change based steel grade such as S235, S275, S350 and S450. Table below show the detail of material property.

No of Storey	Building Height (m)	Beam Size	Column Size	Remarks
S235				
3	9	UB 457 x 191 x 82	UC 254 x 254 x 107	All Floors
5	15	UB 533 x 210 x 82	UC 356 x 368 x 177	1st - 3rd Floor
			UC 254 x 254 x 89	4th - 5th Floor
10	30	UB 762 x 267 x 147	UC 356 x 406 x 340	1st - 4th Floor
			UC 356 x 368 x 177	5th - 7th Floor
			UC 305 x 305 x 97	8th - 10th Floor
15	45	UB 762 x 267 x 173	UC 356 x 406 x 467	1st – 4th Floor
			UC 356 x 406 x 340	5th – 8th Floor
			UC 356 x 368 x 202	9th – 12th Floor
			UC 305 x 305 x 97	13th – 15th Floor
S275				
3	9	UB 457 x 191 x 74	UC 254 x 254 x 89	All Floors
5	15	UB 533 x 210 x 82	UC 305 x 305 x 158	1st - 3rd Floor
			UC 305 x 305 x 97	4th - 5th Floor
10	30	UB 762 x 267 x 147	UC 305 x 305 x 283	1st - 4th Floor
			UC 305 x 305 x 158	5th - 7th Floor
			UC 305 x 305 x 97	8th - 10th Floor
15	45	UB 686 x 254 x 170	UC 356 x 406 x 393	1st – 4th Floor
			UC 356 x 406 x 287	5th – 8th Floor
			UC 356 x 368 x 177	9th – 12th Floor
			UC 203 x 203 x 86	13th – 15th Floor
20	60	UB 838 x 292 x 176	UC 356 x 406 x 551	1st – 4th Floor
			UC 356 x 406 x 393	5th – 8th Floor
			UC 356 x 406 x 287	9th – 12th Floor
			UC 305 x 305 x 198	13th – 16th Floor
			UC 254 x 254 x 107	17th – 20th Floor

No of Storey	Building Height (m)	Beam Size	Column Size	Remarks
S355				
3	9	UB 457 x 191 x 67	UC 254 x 254 x 73	All Floors
5	15	UB 533 x 210 x 82	UC 356 x 368 x 153	1st - 3rd Floor
			UC 254 x 254 x 89	4th - 5th Floor
10	30	UB 610 x 229 x 140	UC 305 x 305 x 240	1st - 4th Floor
			UC 305 x 305 x 137	5th - 7th Floor
			UC 203 x 203 x 86	8th - 10th Floor
15	45	UB 610 x 305 x 149	UC 356 x 406 x 340	1st – 4th Floor
			UC 356 x 368 x 202	5th – 8th Floor
			UC 356 x 368 x 153	9th – 12th Floor
			UC 203 x 203 x 71	13th – 15th Floor
20	60	UB 686 x 254 x 170	UC 356 x 406 x 393	1st – 4th Floor
			UC 356 x 406 x 287	5th – 8th Floor
			UC 356 x 406 x 235	9th – 12th Floor
			UC 305 x 305 x 158	13th – 16th Floor
			UC 254 x 254 x 89	17th – 20th Floor
S450				
3	9	UB 457 x 191 x 67	UC 254 x 254 x 89	All Floors
5	15	UB 533 x 210 x 82	UC 356 x 368 x 153	1st - 3rd Floor
			UC 254 x 254 x 73	4th - 5th Floor
10	30	UB 762 x 267 x 134	UC 305 x 305 x 198	1st - 4th Floor
			UC 305 x 305 118	5th - 7th Floor
			UC 254 x 254 x 73	8th - 10th Floor
15	45	UB 762 x 267 x 147	UC 356 x 406 x 287	1st – 4th Floor
			UC 356 x 368 x 177	5th – 8th Floor
			UC 254 x 254 x 132	9th – 12th Floor
			UC 203 x 203 x 60	13th – 15th Floor
20	60	UB 686 x 254 x 170	UC 356 x 406 x 340	1st – 4th Floor
			UC 356 x 406 x 235	5th – 8th Floor
			UC 305 x 305 x 198	9th – 12th Floor
			UC 305 x 305 x 137	13th – 16th Floor
			UC 254 x 254 x 89	17th – 20th Floor

Table 6: Building Material Property

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

At this part, all the result will be presented and interpreted in such ways that it could be easily understood. The result is based on the identical column no. 20 that selected for the result will be categorized into 3; Effect of storey drift, total weight and load.

4.2 Questionnaire's Responses

The responses received from the industries people and steel fabricator are some negative effects of High Strength Steel and there are some, which good effects in using High Strength Steel. The material cost of High Strength Steel is expensive compare to other types of steel and well known for its difficulty in fabrication. The difficulty in fabrication is cause by the high carbon content, which lead the brittle performance of steel. The introduction of low carbon content steel allows for easily or aid in the fabrication properties compare to high carbon content steel.

Some of the industries or oil and gas company is prefer in using the low grade steel such as S275 due to its performance in withstand load and ability in weldability. Other than concern in structure or steel grade, the engineers need to minimize the fabrication aspect such as the weld length, volume and number of structure needed for fabrication. Therefore the availability of low carbon steel able to avoid the problem occur in minimize the fabrication aspect due to the used of low carbon content high strength steel able to reduce number of structure, high possibility of weldability and able to reduce the fabrication cost. On the other hand, the used of High Strength Steel allow for faster construction due to lesser member, lesser connection concern and therefore less time consuming.

Lastly the information gained for the industries is the method of purchasing the steel in different point of view. The commercial project have different price range compare to the industries project, for example the price for industries project such as the installation of pipe rack will be expensive in steel purchasing compare to commercial project such as residential or office construction. Therefore it can be used that this research can be estimate that the cost of the steel can be determined by price per tonnage and cheaper price compare to industrial project.

4.3 Effect of Storey Drift

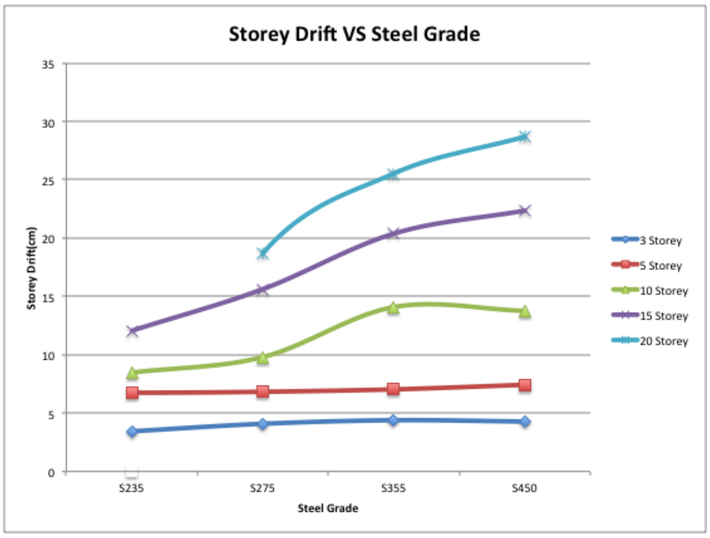

Figure 2: Relationship of Storey Drift and Steel Grade

The wind loads that act to the surface of the building effect the storey drift. However due to the changing of steel grade, the storey drift able to increase due to less resistance. Other factor that increases the storey drift is seismic load. The resistance to seismic load is based on the total weight of the building, as the sizes of the member decrease the resistance to seismic became lower and contribute to higher storey drift. However the storey drift should be limit to H/200 as per Eurocode 8 – Design of Structures for Earthquake resistance.

4.4 Effect of Total Weight

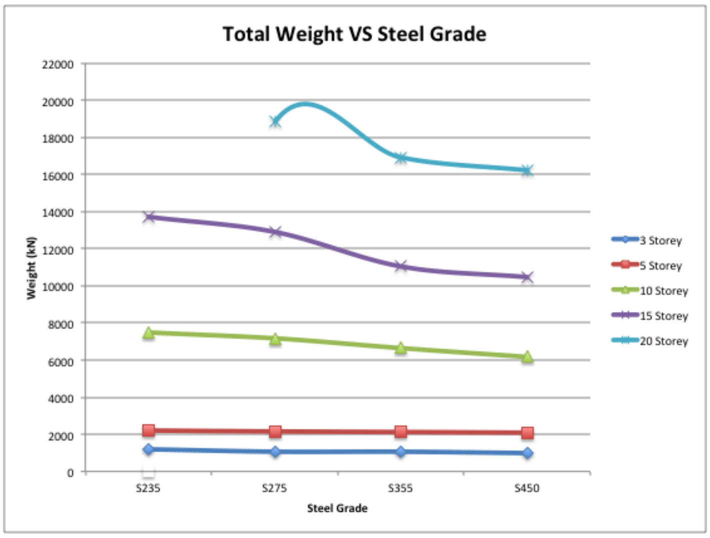

Figure 3: Relationship of Total Weight and Steel Grade

The figure above shows the relation between the total weight of the model and selection steel grade. As the selection of steel grade increase, this cause reduction of steel member size decrease due to higher yield and ultimate strength. Therefore the total weight of the model will be reducing as much as 10%.

4.5 Effect on Loads Due to Changing of Steel Grade

The used of higher steel grade, enable higher load to be resist by the member. As the sizing of the member decrease, the load on the particular member will be increase especially in lateral load. The figures below show the effect due to changing of steel grade to the loads on the member in 3, 5, 10, 15 and 20 storeys.

4.5.1 3 Storey Modeling

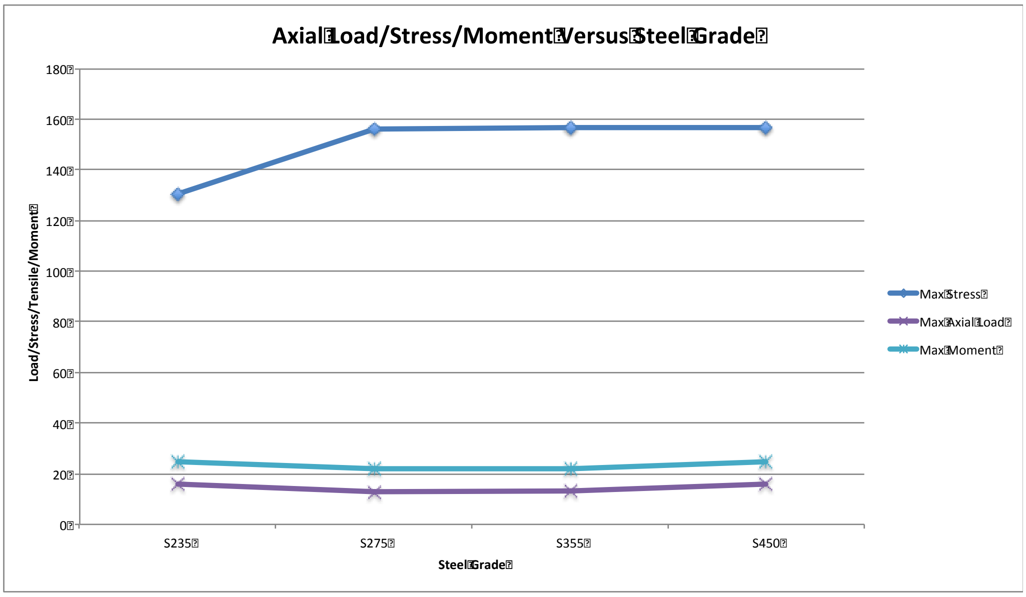

Figure 4: Relationship between Axial Load/Stress/Moment and Steel Grade for 3 Storey Model

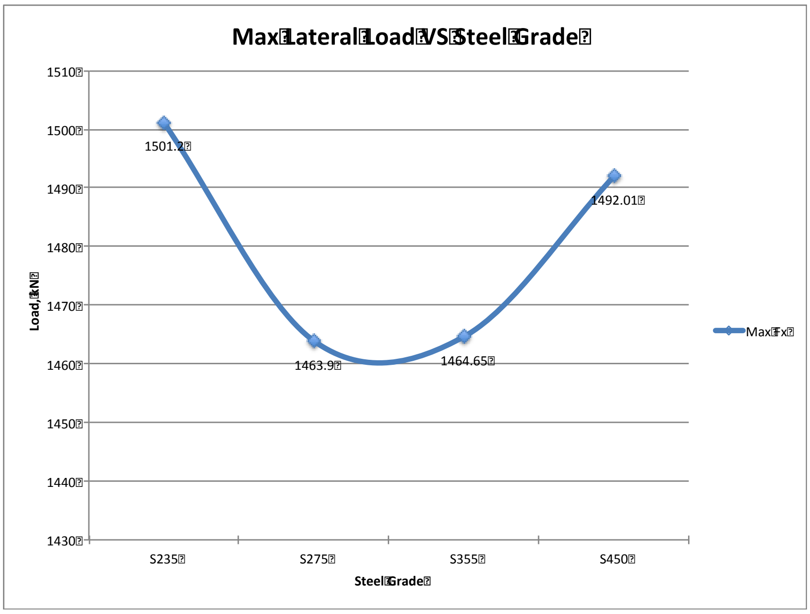

Figure 5: Relationship between Lateral Load and Steel Grade for 3 Storey Model

Based on the total weight of the model, the graph show insignificant change in weight due to limiting the storey drift. Therefore the stress occur on column 20 increase significantly from S235 to S275, however from S275 to S450 the graph remain the same pattern. This pattern occurred due to limiting the storey drift. As the steel grade increase, the lower the total weight of the model and increase the amount of drift. The storey drift occurred due to the lateral load from seismic and wind load. Other graphs such as lateral, moment and axial load show constant pattern as the steel grade increase.

4.5.2 5 Storey Modeling

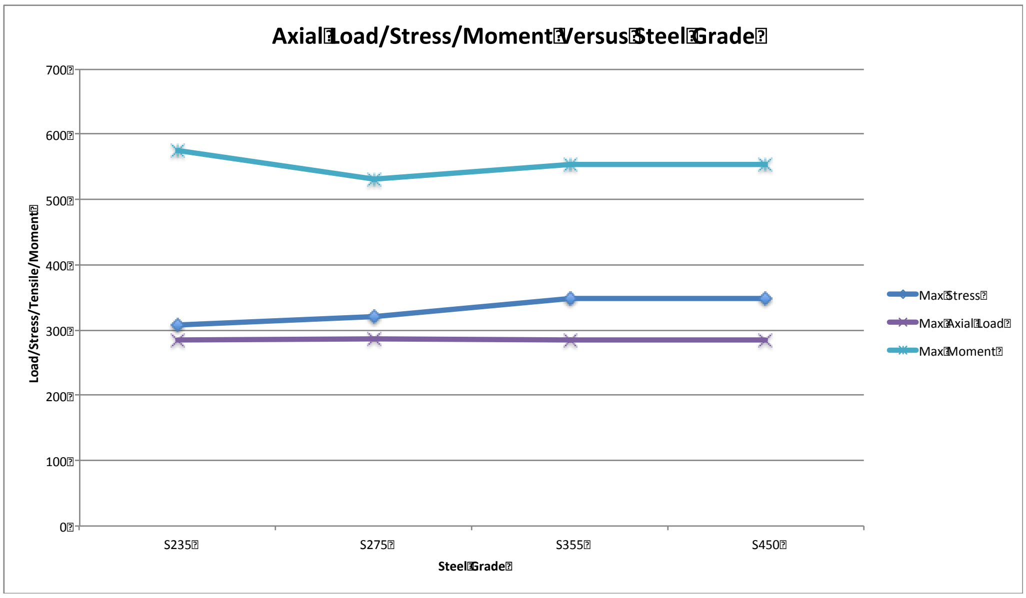

Figure 6: Relationship between Axial Load/Stress/Moment and Steel Grade for 5 Storey Model

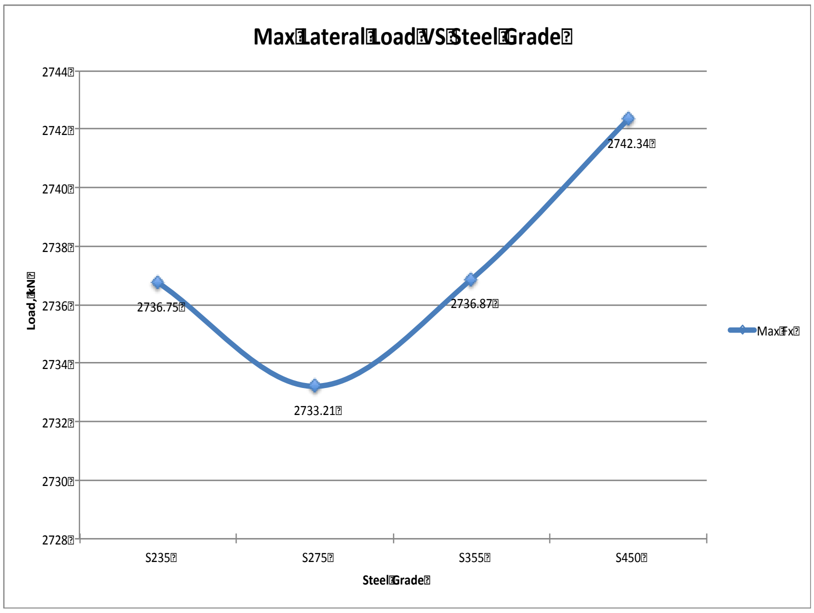

Figure 7: Relationship between Lateral Load and Steel Grade for 5 Storey Model

Based on the total weight of the model, the graph show insignificant change in weight due to limiting the storey drift. Therefore the stress occurs on column 20 increase significantly from S235 to S450. This pattern occurred due to the small cross section of column used due to higher steel grade been used. The storey drift for 5 storey are higher than the 3 storey as the load acting on the model have significant effect as the model getting higher. The concept same as moment as prove can be shown in the moment graph. The moment in column 20 is higher than the 3 storey moment graph, this show the column have to withstand the higher lateral load due to higher level of model.

4.5.3 10 Storey Modeling

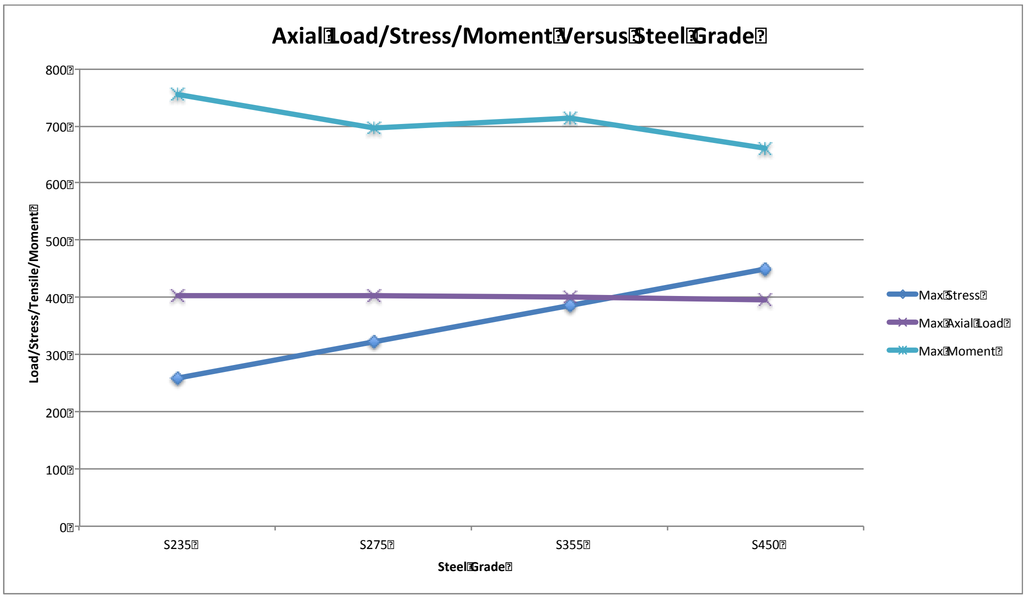

Figure 8: Relationship between Axial Load/Stress/Moment and Steel Grade for 10 Storey Model

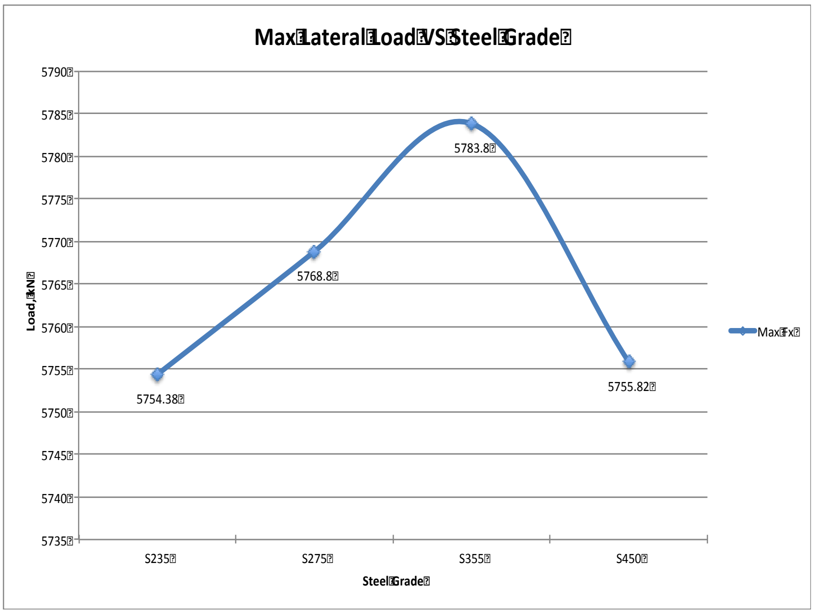

Figure 9: Relationship between Lateral Load and Steel Grade for 10 Storey Model

The graph of stress shows significant increase as the steel grade increase and small cross section used. The weight of the model reduces significantly as the level of storey increase and the value of drift increase as the storey increase. This shows that as the storey level increase, the amount of steel used can be save rather than the 5 storey and below.

4.5.4 15 Storey Modeling

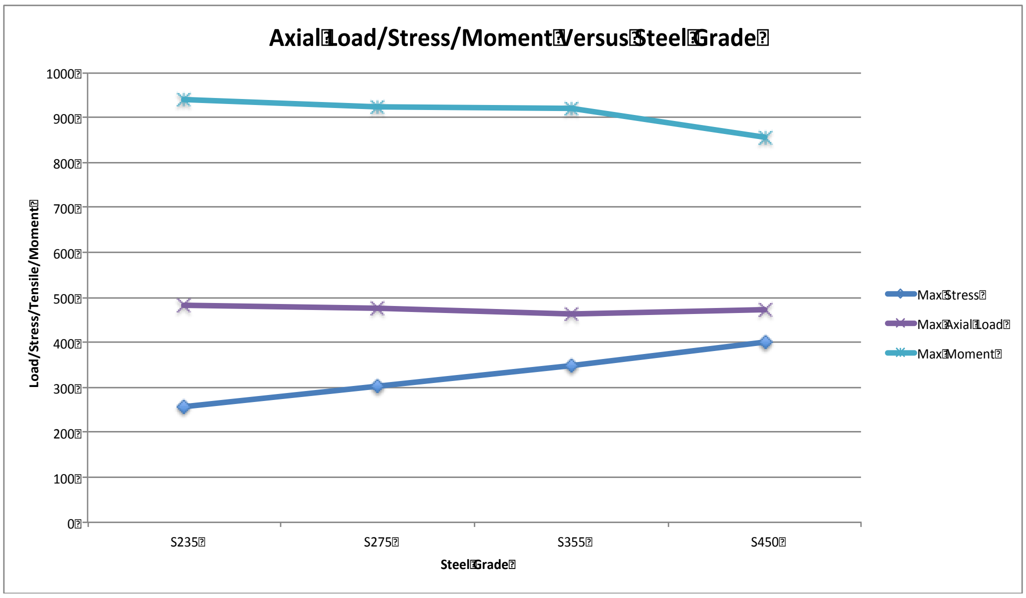

Figure 10: Relationship between Load/Stress/Moment and Steel Grade for 15 Storey Model

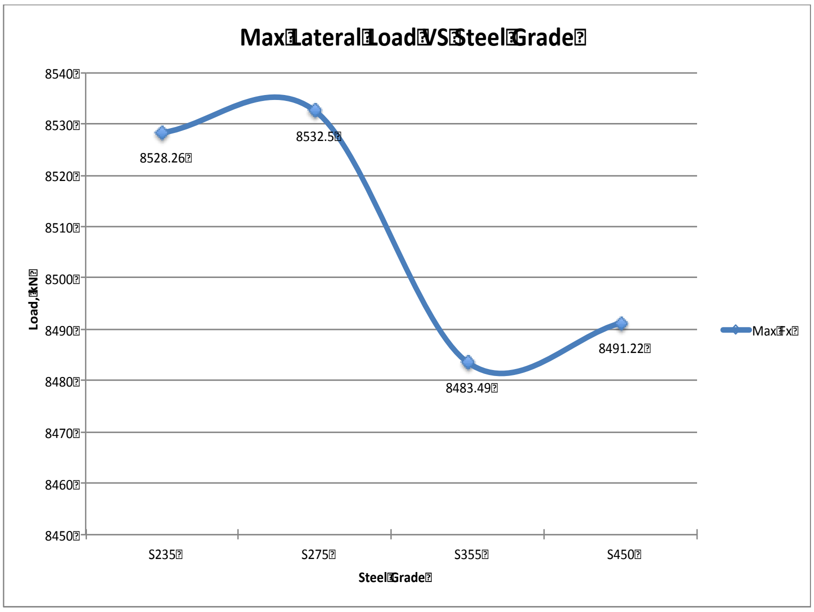

Figure 11: Relationship between Lateral Load and Steel Grade for 15 Storey Model

The stress graph shows similar pattern to the 10 storey model, increase gradually due to the increase of steel grade. This due to the used of smaller cross section of column and similar load that act to the structure.

4.5.5 20 Storey Modeling

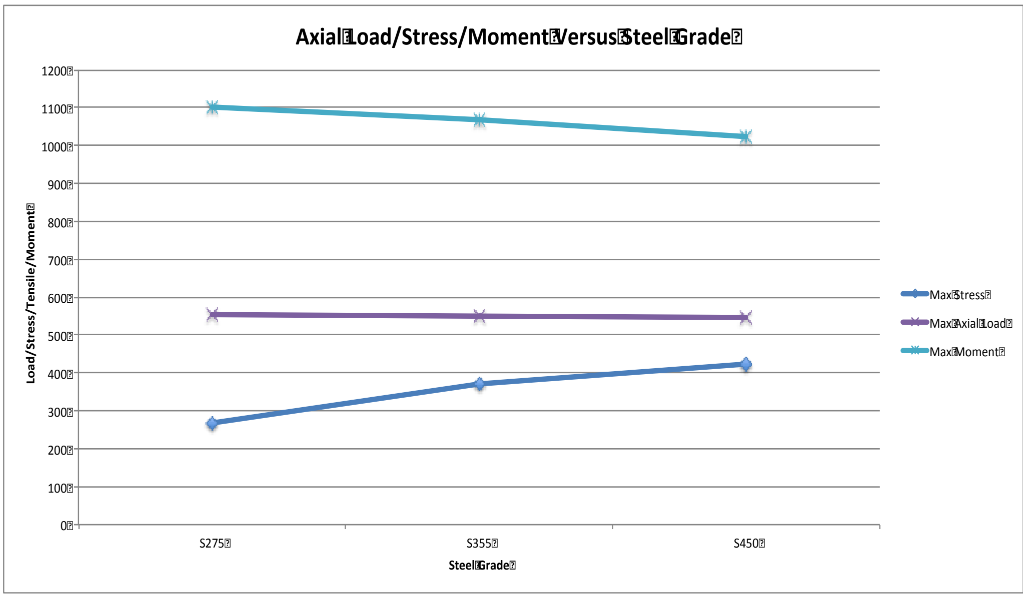

Figure 12: Relationship between Load/Stress/Moment and Steel Grade for 20 Storey Model

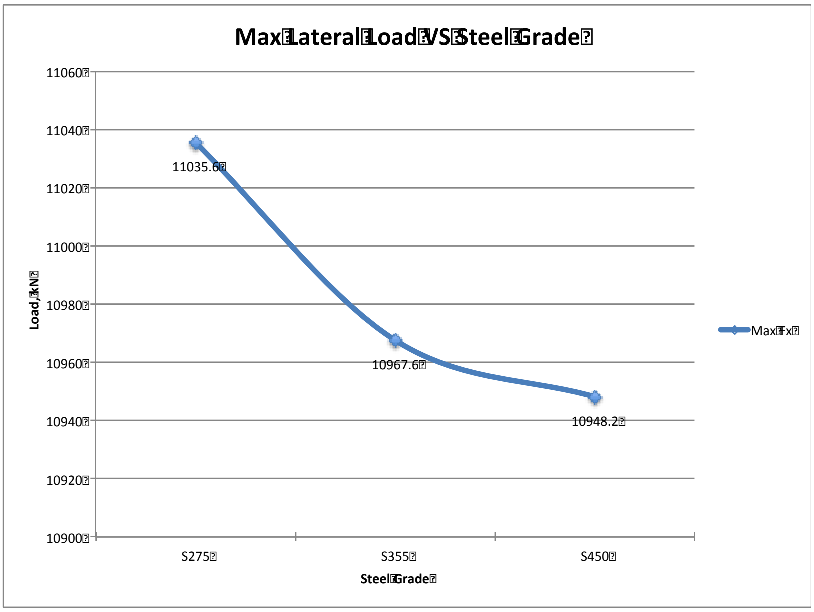

Figure 13: Relationship between Lateral Load and Steel Grade for 20 Storey Model

The graph shows that the 20 storey model only can be used steel grade in the range of S275 to S450. This due to the higher stress that been applied to the structure as the storey getting higher, even though maximum size of member been used. Other method in using lower grade of steel is by changing the framing system to other type. The stress pattern remains the same pattern as the 10 and 15 storey model, gradually increase due to small cross section used.

4.6 Fabrication Issues

The issue arise due to the used of steel structure is the fabrication cost. Most of the steel is purchase based on the weight of the steel needed and higher the amount of steel used will increase the cost of fabrication cost. It also depends on the grade of steel used, which commonly higher grade of steel requires special treatment such as preheating or post heating to prevent cracking. However there are newly construct steel, which have leaner composition of carbon (lower carbon equivalent value, CEV) that reduce the amount of fabrication cost such as the exceptional of preheating or lower preheating temperature of steel before welding depending on the thickness of the section. This type of steel capable to provide cost saving in material and fabrication cost due to the higher grade of steel used, the lesser member to be used and which lesser the amount of fabrication used.

4.6.1 Fabrication Aspect in Beam

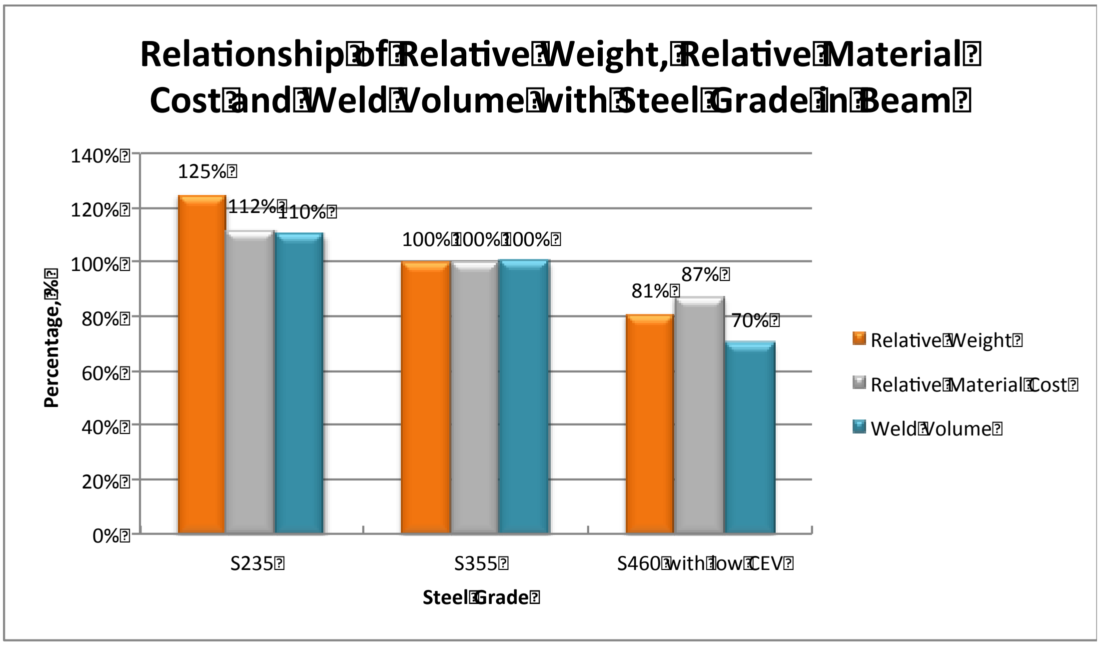

Figure 14: Relationship of Relative Weight and Material Cost with Steel Grade in Beam

The graph shows a relative comparison between material cost and weights due to the change of steel grade based on beam that have span of 7m. The value show that the used of low carbon equivalent value (CEV) able to reduce the weight and reduce the fabrication cost by reduce the volume of weld used. This due to the lesser member used in the construction enable the volume of weld used can reduce compare to the used of S355 steel grade. As for steel grade S235, the weight of the structure become higher due to bigger size and excessive member are used to the building, therefore increase the material cost. Hence the fabrication cost also is increase, as excessive member need to be connected and increase the volume of weld used. This shows that the used of high steel grade with low carbon content able to give economies in material and fabrication cost even though the material cost for high grade steel is higher compare to other grade, however it able be reduce other costs.

4.6.2 Fabrication Aspect in Column

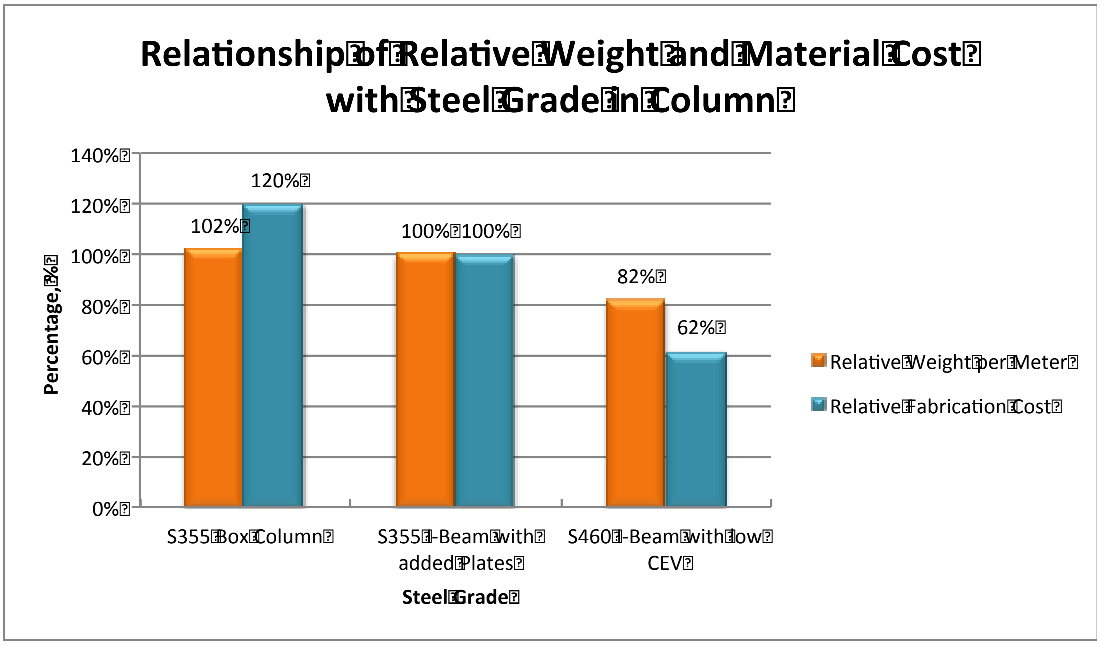

Figure 15: Relation of Relative Weight and Material Cost with Steel Grade in Column

The graph shows the relative weight and fabrication cost of column with buckling length of 4.5m. The graph indicates that the used of box column using steel grade of S355 result of increase of fabrication cost and minimal increase of weight per length. The increase of fabrication cost is due to the need of fabricating the box column compare to the use of I-shape column, which increase the needs of excessive welding. That shows in the used of S460 column, which reduce the total weight and fabrication cost. The used of high grade steel enable to select small size of column, which reduce the weight of the structure while able to withstand higher load compare to the S355 column. The used of original shape of I-shape able to reduce the fabrication cost compare to two types of column in S355.

4.6.3 Fabrication Aspect in Trusses

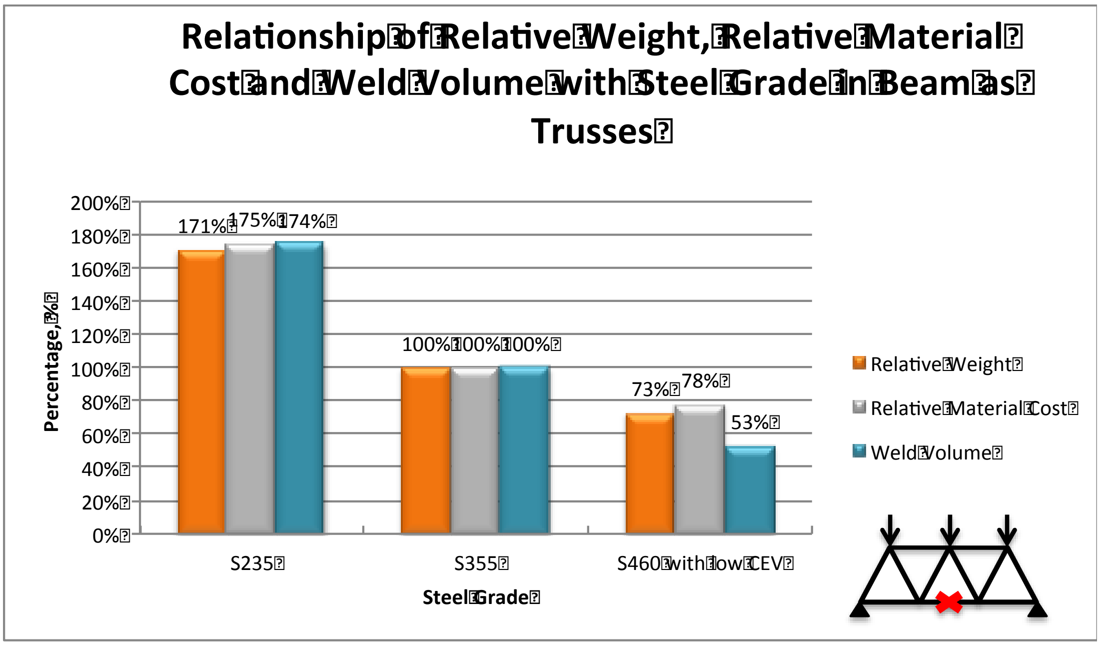

Figure 16: Relation of Relative Weight and Material Cost with Steel Grade in Beam as Trusses

The graph shows a relative weight and material cost for beam that used as trusses. It shows that pattern are similar to the beam as the used of high-grade steel able to produce economies in term of fabrication and weight. However the material cost increase due to high steel grade can be expensive but steel is normally purchase based on per tonne, which able to be reduce the total cost of material due to reduction in weight used for the structure. Compare to S235 steel, it cause 70% of increment compare to S355 in term of weight, material cost and weld volume. The used of low-grade steel, bigger size of trusses need to be used to sustain bending.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Based on the analysis using STAAD Pro, the result show that the model has weight saving properties due to the changing of steel grade. The weight saving properties need to meet the evaluation of storey drift limit, which some of the modeling have less than 10% change in weight due to limit the effect of excessive storey drift. The drift also effect by the existing of seismic force. To limit the effect of seismic, the total weight of the model play important role. The higher the weight of the model, better resistance will give to the model. Based on the result, it proved that the used of high steel grade able to give weight saving. The reduction of weight enables to save in fabrication cost as there are less member those been used, which result of less weld volume.

This project shows that the used of high grade of steel in structural steel design able to provide economies in weights and fabrication. The used of high grade steel results of less member to be used, smaller size of member and able to resist higher load with in range of allowable storey drift. This reduction of weight and lesser member will allow less fabrication to be done, therefore less weld volume used. Even though the material cost is higher compare to other grades, due to fewer members used, the high steel grade can still be economical. As overall, the economical aspect in high steel grade is depended on the total weight. The higher total weight will result higher fabrication cost.

Recommendation

The economic in using steel structure is depends on material cost, fabrication and transportation cost. The type of steel grade influence the material cost due to higher grade cost more than conventional grades. To understand more about the economies in high grade of steel, more research need to be done. Therefore below are some of suggestion to improve the current method of determine economic in steel.

- Compare the change of total weights, storey drift, loads and stresses using different software.
- More research on fabrication aspect on high-grade steel such as welding and bolting by interview or site visit to steel fabricator factory.

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