DESIGN AND ANALYSIS OF FRAME SCAFFOLDING CAPACITY USING THICKNESS AND MATERIAL AS VARIABLES

JEGATHIS A/L MURUGESU

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
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DESIGN AND ANALYSIS OF FRAME SCAFFOLDING CAPACITY USING THICKNESS AND MATERIAL AS VARIABLES

ABSTRACT

This thesis presents a comprehensive investigation of the design and analysis, based by variable thickness and material of steel frame scaffolding systems. Support scaffolding systems are used to provide temporary support to timber formwork systems, reinforcement, concrete, workmen and equipment, during the construction of permanent structures such as buildings and bridges. Conventional steel frame or called as a frame scaffold steel are the focus of the thesis. This thesis includes the collection and statistical analysis on thickness and material especially on material of JIS 3444 STK 500 and JIS 3444 STK 400 of load effects occurring as a result of after load test on steel frame scaffolding. A comprehensive series data based have been collected before test and purely test hand on tests, three major consideration have been taken which is tensile strength, yield strength and elongation based on chosen material.. This load capacity test exercise also provides statistical data for modelling error. The higher tensile strength analysis to determine the suitable material with right thickness for steel frame scaffolding. The research showed that strength of scaffolding is not just depends on steel frame but also depends on thickness which in this case we use 2.3mm and 2.5mm of the scaffolding system.

DESIGN AND ANALYSIS CAPACITY OF FRAME SCAFFOLDING USING VARIABE THICKNESS AND MATERIAL

ABSTRAK

Tesis ini membentangkan penyiasatan komprehensif mengenai reka bentuk dan analysis, berdasarkan ketebalan dan material perancah rangka besi. Sistem sokongan perancah digunakan untuk memberi sokongan sementara kepada sistem kerja kayu, tetulang, konkrit, pekerja dan peralatan kayu, semasa pembinaan struktur tetap seperti bangunan dan jambatan. Bingkai keluli konvensional atau dipanggil sebagai bingkai perancah rangka adalah tumpuan tesis.Tesis ini merangkumi pengumpulan dan analisis statistik mengenai ketebalan dan material dari JIS 3444 STK 500 dan JIS 3444 STK 400 kesan beban yang berlaku akibat daripada ujian beban pada rangka rangka besi. Data berasaskan siri komprehensif telah digabungkan sebelum ujian danbeberapa ujian ke atas perancah, tiga pertimbangan utama telah diambil iaitu kekuatan tegangan, tegangan kasar dan eleogasi berdasarkan bahan yang dipilih. Latihan kapasiti beban ini juga menyediakan data statistik untuk kesalahan pemodelan . Analisis kekuatan tegangan yang lebih tinggi untuk menentukan bahan yang boleh digunakan dengan ketebalan yang tepat untuk perancah bingkai baja. Kajian ini menunjukkan bahawa kekuatan perancah tidak hanya bergantung kepada bingkai keluli tetapi juga bergantung kepada ketebalan yang dalam kes ini kita menggunakan 2.3mm dan 2.5mm sistem perancah.

ACKNOWLEDGEMENTS

As I hereby want to say thanks to University of Malaya for giving an opportunity to do a research which can improvise my technical career in future.

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PRINCIPAL NOTATIONS

A	cross-sectional area
d	distance between objects
d_e	external diameter of the tube
d_i	internal diameter of the tube
d_o	outside diameter
E	Young's modulus
E_o	initial Young's modulus
f_y	yield strength
h	height of the scaffold unit
h_e	effective height of the scaffold
H	height of the scaffold system
L	one-storey height of the scaffold unit; member length
L_h	lift height
N	number of storeys
p_c	compressive strength of the column
p_c	elastic buckling strength of the column
p_y	yield strength of the steel tube
P	vertical load
P_{cr}	critical load
Q	total load effect
t	wall thickness
α_a	compression member factor
γ_i	load factors
δ	deflection

CHAPTER 1: INTRODUCTION

1.0 Introduction on Scaffold and Problem Statement

Scaffolds are temporary structures generally used in construction to support various types of loads. The vertical loads on scaffold can be from laborers, construction equipment, formworks, and construction materials. Commonly, scaffolds must also be designed to withstand lateral loads, including wind loads, impact loads, and earthquake loads. Depending on the use of the scaffolds, they may be categorized as the access scaffolds or the support scaffolds. The access scaffolds are used to support light to moderate loads from laborers, small construction material and equipment for safe working space. They are usually attached to buildings with ties and only one bay wide. Support scaffolds, or sometimes called falsework, are subjected to heavy loads, for example, concrete weight in the formwork. Both types of scaffolds can be seen in everyday construction as shown in Figure 1.1. Current scaffolding frame with thickness of 1.9mm occurring major safety issue such as framework collapse, buckling and easily damage during erecting, dismantling and transferring. Major failure been identify due to material and thickness of current scaffolding frame. Due to this failure, many major companies facing property damage, injuries and financial losses.

(a) (b)

Figure 1.1: Typical scaffold systems: (a) access scaffold; and (b) support scaffold

This report presents a review of scaffold research in the analysis and modelling, including the design of scaffold systems. In addition, it covers a brief description of scaffold systems, types of connections, and construction recommendations. In terms of modelling, it focuses on how complex joints and boundary conditions have been modelled and how geometric imperfections have been taken into account. For the design of scaffold systems, it summarizes the current procedure based on the standards of practice.

With such a tremendous investment in the form of lives and property resting on the scaffolding system, it is imperative for all involved to know with a high degree of certainty the load carrying capacity. However, construction practice today relies primarily on experience and tradition in setting the amount of load that a particular scaffolding arrangement can safely carry. Although many manufacturers have recently begun to accumulate load test data on components of their systems, such information alone does not provide a direct means of predicting the ultimate carrying capacity of a complete system on the job site.

1.1 Formwork and Falsework

Formwork means the surface of the form and framing used to contain and shape wet concrete until it is self-supporting. Formwork includes the forms on or within which the concrete is poured and the frames and bracing which provide stability. Although commonly referred to as part of the formwork assembly, the joists, bearers, bracing, foundations and footings are technically referred to as falsework. Falsework means the temporary structure used to support a permanent structure, material, plant, equipment and people until the construction of the permanent structure has advanced to the stage where it is self-supporting. Falsework includes the foundations, footings and all structural members supporting the permanent structural elements. Falsework can be used to support formwork of concrete, prefabricated concrete elements, steel sections or stone arches, for example during bridge construction.

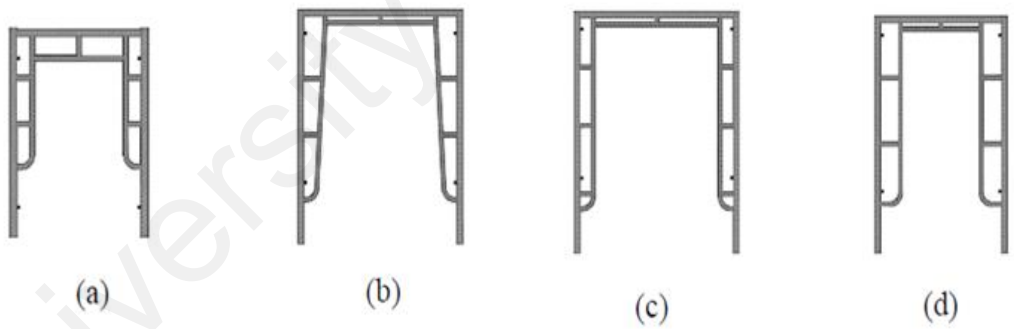


Figure 1.2: Conventional Frames with various dimensional

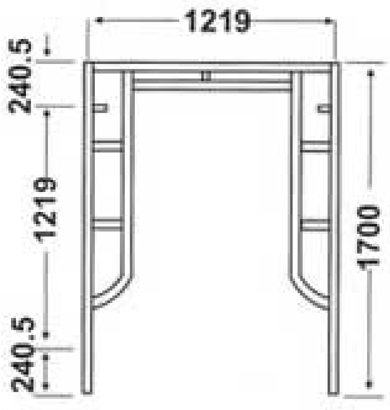


Figure 1.3: Conventional Frame Scaffold Dimension

1.2 Frame Scaffolding Material

The basic lightweight tube scaffolding that became the standard and revolutionised scaffolding becoming the baseline for decades. With one basic 13kg unit a scaffold of various sizes and heights could be assembled easily by a couple of labourers without the nuts or bolts previously needed. Tubes are usually made either of steel or aluminium, although there is composite scaffolding, which uses filament wound tubes of glass fibre in a nylon or polyester matrix, because of the high cost of composite tube, it is usually only used when there is a risk from overhead electric cables that cannot be isolated. If steel, they are either coloured or galvanised. The main difference between the two types of metal tubes is the lower weight of aluminium tubes. However they are more flexible and have a lower resistance to stress. Tubes are generally bought in 6.3 m lengths and can then be cut down to certain typical sizes.

1.3 Objective

1 Study the ultimate load capacity and buckling action on frame scaffolding of 2.5mm and 2.3mm thickness using two materials JIS 3444 STK 500 and JIS 3444 STK 400.

2 Analytical capacity and compare load test with current existing frame scaffolding.

CHAPTER 2: LITARATURE REVIEW

2.0 Introduction

Over the past several years, different scaffolding systems have been designed to support permanent and temporary works during different stages of construction all over the world. With such a tremendous investment in the form of lives and property resting on the scaffolding system, it is imperative for all involved to know with a high degree of certainty the load carrying capacity. However, construction practice today relies primarily on experience and tradition in setting the amount of load that a particular scaffolding arrangement can safely carry. The consequences of overloading scaffoldings are evident in the recent accidents. In this chapter, it will be continue more on detail information of suitable Conventional frame scaffolding materials and dimension. The material justification will be proven based on load test done on particular material chosen for this conventional scaffolding system.

The industry has experienced a gigantic growth in this century, the market appeared to be leading to the development of improvement at a very large scale process. The great need for scaffolding has also increased the importance at utilizes scaffolding systems in order to support men, materials and structural elements. There is no doubt that material and properties has made significant contribution on scaffolding material selection and design in the industrialized countries.

On the other hand it has become clear that selection of material for scaffolding is based on usage and application of industries. Although many manufacturers have recently begun to accumulate load test data on components of their systems, such information alone does not provide a direct means of predicting the ultimate carrying capacity of a complete system on the job site. The recent scaffolding collapses at Persiaran Barat in

Petaling Jaya cause three foreign workers injured, while three others trapped when temporary structure of an under construction collapse demonstrate the potentially fatal consequences of overloading scaffolding systems and failure due to material and design (Jui-LinPeng, 2017).

Figure 2.1: Scaffolding collapse at Jalan barat, Petaling jaya.

The question is which suitable material and design of scaffolding is suitable for Conventional Scaffolding. The basic lightweight tube scaffolding that became the standard, tubes are usually made either of steel or aluminum, although there is composite scaffolding, which uses filament wound tubes of glass fiber in a nylon or polyester matrix, because of the high cost of composite tube, it is usually only used when there is a risk from overhead electric cables that cannot be isolated. If steel, they are either colored or galvanized. The tubes come in a variety of lengths and a standard diameter of 42.7 mm.

2.1 Frame Scaffold Systems

Scaffolding systems are used as temporary support for structures under construction or needing repair. Their primary function is to support various types of loads such as vertical loads imposed by workmen, construction equipment, and construction materials. Scaffolds must also be designed to withstand lateral loads such as wind loads, impact loads, and earthquake loads (Brand, R.E MacGrew Hill).

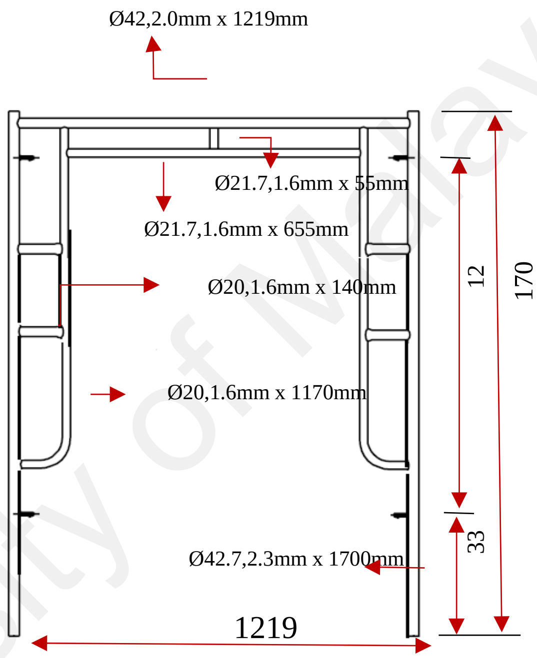


Figure 2.2: Steel Frame Scaffolding with Dimensions

2.1.1 Steel Scaffolding Classification

Scaffolding is classified as either access or support, depending on its application. Access scaffolds are typically used around the perimeter of buildings and provide vertical access on a construction site. Access scaffolds are designed to support small loads such as workers and their equipment. They are usually configured as a single bay that is tied to a building for lateral stability, as seen in Figure 6. Support scaffolds are typically referred to as 'false work' and are used as platforms to support timber formwork for reinforced concrete slab construction. They are typically heavily loaded under the weight of formwork, newly poured concrete, stacked materials, as well as construction workers and their equipment. Support scaffolding systems are used to support timber bearers which pass through the top "U-head" connection. These bearers are orientated along their strong axis and typically span between three or four U-head connections. Wet concrete is then poured onto this timber deck to form a slab. This entire timber system is known as the 'formwork system' refer to Figure 6, and is subsequently supported by the scaffolding system or 'false work system' (Robert G.Beale, 2014)

Figure 2.3: Falsework and Formwork Component

2.2 Scaffold Configurations

Support scaffolding systems are common forms of temporary support within the Malaysia construction industry and their configuration and component usage have remained the same for many years due to the high cost of replacing inventory. Support scaffold systems are typically constructed from a Steel Frame system of circular hollow steel tubes and feature joints which allow the system to be easily assembled for quick erection, dismantling, and transportation. Frame scaffolding systems vary in height from ground level to the top of the building and consist of a number of lifts that are constructed using vertical Steel Frames connected with bracing and ladder frames, as seen in Figure 2.3. The common configurations of steel support scaffolds includes standard door type, knee braced door type, construct staircase and stick type. Each of these configurations can be seen in Figure 2.4.

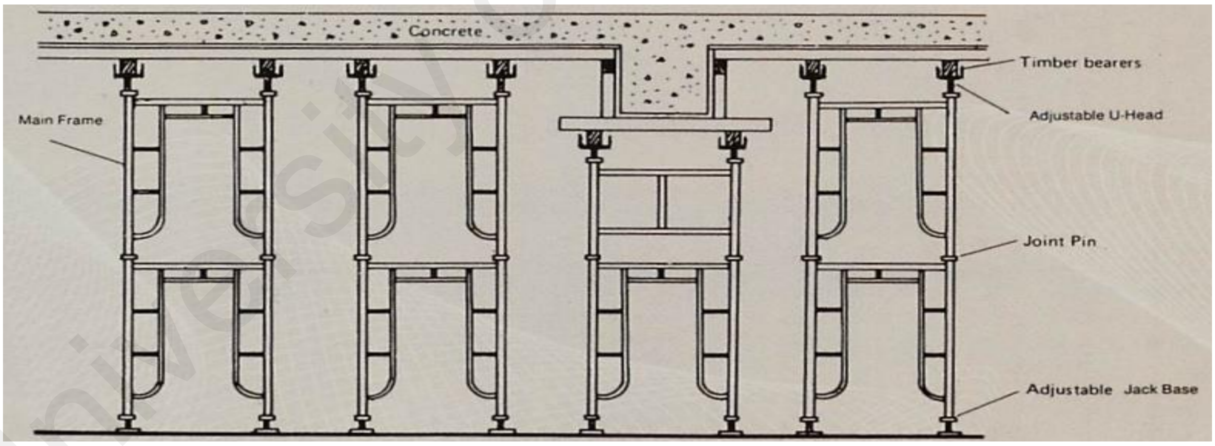


Figure 2.4: Typical components and configuration of a single scaffolding system layout

Scaffold systems can be adapted to a particular job so their height can increase from one storey to top of the building as well as having many horizontal rows, depending on the type of construction. Being a temporary structure, scaffold members are reused from one job to another, and geometric imperfections, particularly in highly loaded standards are typical (Chung-WeiWu, 2013).

2.3 Main Causes of Scaffolding Failures

There are very significant findings from the forensic investigations of each scaffolding failure from which clear evidence exists that amongst other causes the main reasons for scaffolding collapses are:

1. Overloading of scaffolding systems

2. Material Failure

3. Insufficient strength

Furthermore, it was determined that 74 percent of scaffolding collapses occurred during the pouring of concrete, and the main cause was material and its strength. Errors related to reinforcement cover and concrete workmanship contributes to overall system risk. Although this data is arguably out of date, more recent incidents have confirmed these results. The possible causes of collapses were identified as material failure of the scaffold systems, instability of shoring components, partial loading of wet concrete whilst in the formwork, the placement pattern of concrete, and a concentration of load due to placement (Wei TongChena, 2009).

Since steel scaffolding is a temporary structure the serviceability limit states do not generally govern design, so the yield stress should be greater than 235 N/mm^2 state design is critically important. Due to the slender form of scaffolding, ultimate failure generally occurs because of buckling. The two most common types of buckling are out of plane and in plane buckling (as seen in Figure 7), with standards buckling in a single or double curvature depending on the boundary support conditions and the system. Metal scaffolding equivalent uniformly distributed load is between 0.75 kN/m^2 for class 1 and 6.0 kN/m^2 for class 6. In MS 1462 the maximum design wind pressure is 770 N/m^2 and the working wind is 200 N/m^2.

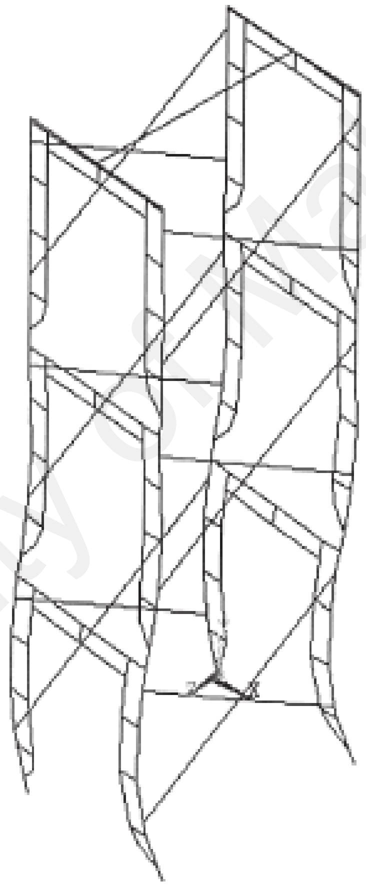


Figure 2.5: Predicted Buckled Shape for Steel Frame

A factor of safety 2.0 is used to give the allowable axial load on frames. For 42.7mm outer diameter and 2.3 mm thickness tubular steel, the safe load effective length is equal to 40 kn. three dimensional analysis determined that if the cross braces offered more lateral support the scaffold units would deform in plane (EwaBłazik-Borowa, 2013)

2.4 Materials

2.4.1 Steel Tubes

Steel tubes shall comply with AS 1576.3 or BS 1139 and meet the following requirements:

Minimum yield strength 200 MPa

Outside diameter 48.3 mm

Minimum wall thickness 4.0 mm

Steel tubes must complying BS 6323 from parts 1 to 4, and with a minimum outside diameter and wall thickness 48.3 mm and 3.2 mm respectively are used for scaffolding, such tubes shall be galvanized in accordance with Annex A of BS 1139 section.

2.4.2 Aluminum Tubes

Aluminum tubes must comply with AS 1576.3 or BS 1139 from part 1 to 2 and meet the following requirements:

Minimum yield strength 241 MPa

Outside diameter 48.4 mm

Minimum wall thickness 4.47 mm

All scaffolding accessories shall be manufactured from material in accordance equivalent material with performance test requirements. Where the design call for the use of material strictly in accordance with manufacturer's recommendation and shall me performance test requirements.

2.4.3 Grades and Symbol

Table 2.1: Grades and Symbol

i. **Symbol Of Class**	ii. **Former Symbol**
iii. STK 290	iv. STK 30
v. STK 400	vi. STK 41
vii. STK 500	viii. STK 51
ix. STK 490	x. STK 50
xi. STK 540	xii. STK 55

Table 2.2: World Standard Comparative Table

KS		ASTM		JIS		DIN		BS	
Number	Grades	Number	Grades	Number	Grades	Number	Grades	Number	Grades
D 3566	SPS 290 (new)	A500	Gr A	G -3444	STK290	….	….	6323	HFW2
	SPS 30 (old)				(STK30)				
	SPS 400 (new)	A252	Gr 2		STK400	….	….	6323	HFW4
	SPS 41 (old)	A500	Gr A		(STK41)				RAW4
		A501							HFS4
	SPS 500 (new)	A500	Gr C		STK500	….	….	….	….
	SPS 51 (old)				(STK51)				

2.4.4 Japan Industry standard (JIS)

2.4.4.1 JIS G3444 STK500

JIS G3444 is the standard of carbon steel tubes for general structural purposes. JIS G3444 STK500 steel tube minimum tensile strength of 500 MPa, yield strength of 355 MPa. The minimum elongation of JIS G3444 STK500 seamless steel pipelines 25%.STK500 steel tubing has excellent welding performance and toughness.

I. Steel Grade: STK500
II. Standard: JIS G3444
III. Brand Name: Upworld Industrial
IV. Out diameter 6-1000mm
V. Wall thickness 1-70mm

Table 2.3: JIS G3444 STK500 steel pipeline chemical composition

Symbol of class	C	Si	Mn	P	S
STK 500	0.24 max	0.35 max	0.30 to 1.30	0.040 max	0.040 max

Table 2.4: Mechanical properties for STK 500

Mechanical properties	Tensile strength N/mm^2	Yield point of proof stress N/mm^2	Elongation %	
			No.11 & No. 12 Test pieces	No. 5 Test pieces
			Longitudinal direction	Transverse direction
Method of manufacture	Seamless, butt-welding, electric resistance welding and arc welding process			
Outside diameter	Full range	Full range	Over 40 min	
STK 500	500 min	355 min	15 min`	10 min

2.4.4.2 JIS G3444 STK400

JIS G3444 is the standard of carbon steel tubes for general structural purposes. JIS G3444 STK400 steel tube minimum tensile strength of 400MPa, yield strength of 235 MPa. The minimum elongation of JIS G3444 STK400 seamless steel pipelines 23%.STK 400 steel tubing has excellent welding performance and toughness.

I. Steel Grade: STK400
II. Steel Grade: STK400
III. Standard: JIS G3444
IV. Brand Name: Upworld Industrial
V. Out diameter 6-1000mm
VI. Wall thickness 1-70mm

Table 2.5: JIS G3444 STK400 steel pipeline chemical composition

Symbol of class	C	Si	Mn	P	S
STK 500	0.24 max	-	-	0.040 max	0.040 max

Table 2.6: Mechanical properties for STK 400

Mechanical properties	Tensile strength N/mm^2	Yield point of proof stress N/mm^2	Elongation %	
			No.11 & No. 12 Test pieces	No. 5 Test pieces
			Longitudinal direction	Transverse direction
Method of manufacture	Seamless, butt-welding, electric resistance welding and arc welding process			
Outside diameter	Full range	Full range	Over 40 min	
STK 500	400 min	235 min	23 min`	18 min

2.5 Deterministic Methods of Design

The development of current reliability based load and resistance factor design (LRFD) has its origins rooted in allowable stress design which requires that the stresses resulting from loads are less than a working stress level, based on successful similar past experiences. The design standard committee typically specified the value of allowable stress as some fraction of the mechanical properties of the material (for example, the ultimate tensile strength). A permissible safety level was assumed to exist if the elastically determined stresses did not exceed the allowable working stresses, which were a fraction of the yield strength (H.Zhang, 2010).

That is:

$$\sigma 1 = \frac{\sigma \mathrm{ui}}{\text{safety factor}}$$

Where σui accounts for the permissible stresses derived from the strength of the material and are $\sigma 1$ the expected applied stresses. The safety factor existed to reduce the material strength or the resistance properties and was traditionally selected on past experience, experimental observations, accepted practices, and even using a 'professionals feelings about the relative variability of various materials' (Ellingwood, 1980). However, the allowable stress design did not guarantee a constant level of safety for all structures, nor did it account for the effect that different types of loads had on each other, for example, when one load counteracts the effects of another. Load factor theory was deterministic and used factors to increase the expected loads on a structure in order to ensure that the resistance was satisfactory. A structure will collapse if the factored sum of loads (γQ) are greater than the resistance (R_{ul}) of the structure or member. That is, $R_{ul} \leq \gamma Q$ .In contrast to the allowable stress design which analyses a structure at a member level, the load factor method is applied to the structure in its entirety and took into account the consequences of failure and the possibility of unknown loadings.

2.6 Effective Lengths

Identification of the effective length of a column is critical to the design processes. Researchers have suggested values for the effective length of a column based on buckling analysis models because the amount of end restraints in the vertical standards of scaffold systems is difficult to determine. The effective length coefficients of steel scaffold systems were conservatively assumed to be for idealized boundary conditions. The effective lengths for steel scaffolds were back calculated from finite element models with the various boundary conditions and were found to be in the range of 1.06 to 1.40. An effective length of 1.2 times the height of each storey (L.B.Weesner, 2001)

2.7 Bracing Systems

Diagonal cross bracing is a critical factor in the stability of a system, because it can also increase the load carrying capacity and reduce the effective lengths of scaffold. In a study of Cross bracing (as seen in Figure 2.16) in single storey scaffold systems, Peng (2004) identified that cross bracing was twice as stiff as other bracing. Furthermore, the diagonal bracing is an efficient restraint to the system because small lateral displacements were calculated as opposed to scaffold systems without bracing (TayakornChandrangsu, 2011)

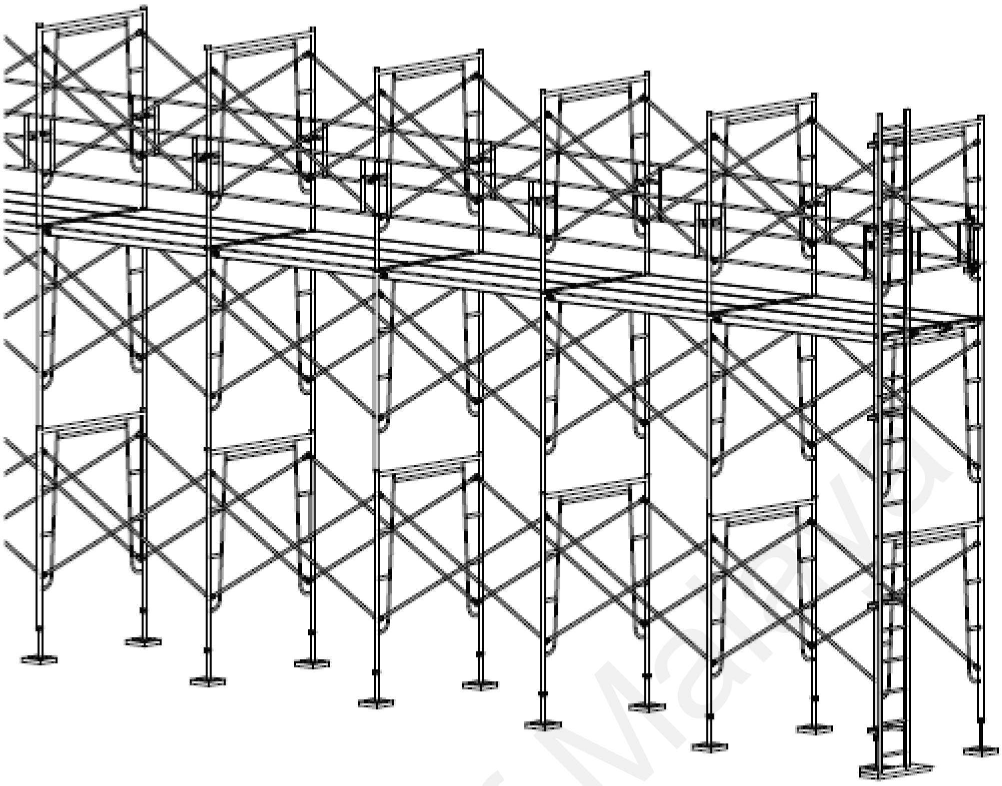


Figure 2.6: Steel Frame installation with bracings

2.8 Ultimate load of scaffolding system

The load carrying capacity was affected by the length of horizontal stringers, vertical shores, and the stiffness of stringers and the position of strong shores. The load carrying capacity of a system could be increased by adding strong shores. The length of the horizontal stringer increased or the stiffness of the horizontal stringer decreased, the ultimate load carrying capacity of the system was reduced. However, in a symmetrical arrangement of strong shores, the ultimate loads were not affected by an increase in the stiffness of stringers. Varying the lengths of the vertical bracing had different effects on the system depending on the arrangement.

2.9 Safety maximum load

Safety is a function of the maximum load imposed on a structure throughout its design life. On the other side of the design equation, safety is also a function of the strength or resistance capacity of the structure. Safety is therefore a function of how much greater the Resistance is to the amount of Load applied to a structure. That is, the lifetime maximum load and actual resistance of a structure is difficult to predict because any prediction is subject to uncertainty so having no risk of failure is not economically justifiable. Furthermore, safety may only be assured in terms of the probability that the available resistance will withstand a maximum load or load combination. Limit State Design involves the consideration of different scenarios under which a structure will cease to fulfil its intended function. The two limit states most commonly designed for are:

Serviceability Limit State: failure from normal operations which causes deterioration of routine functionality. This includes unacceptable deformations, excess vibrations, and structural defects.

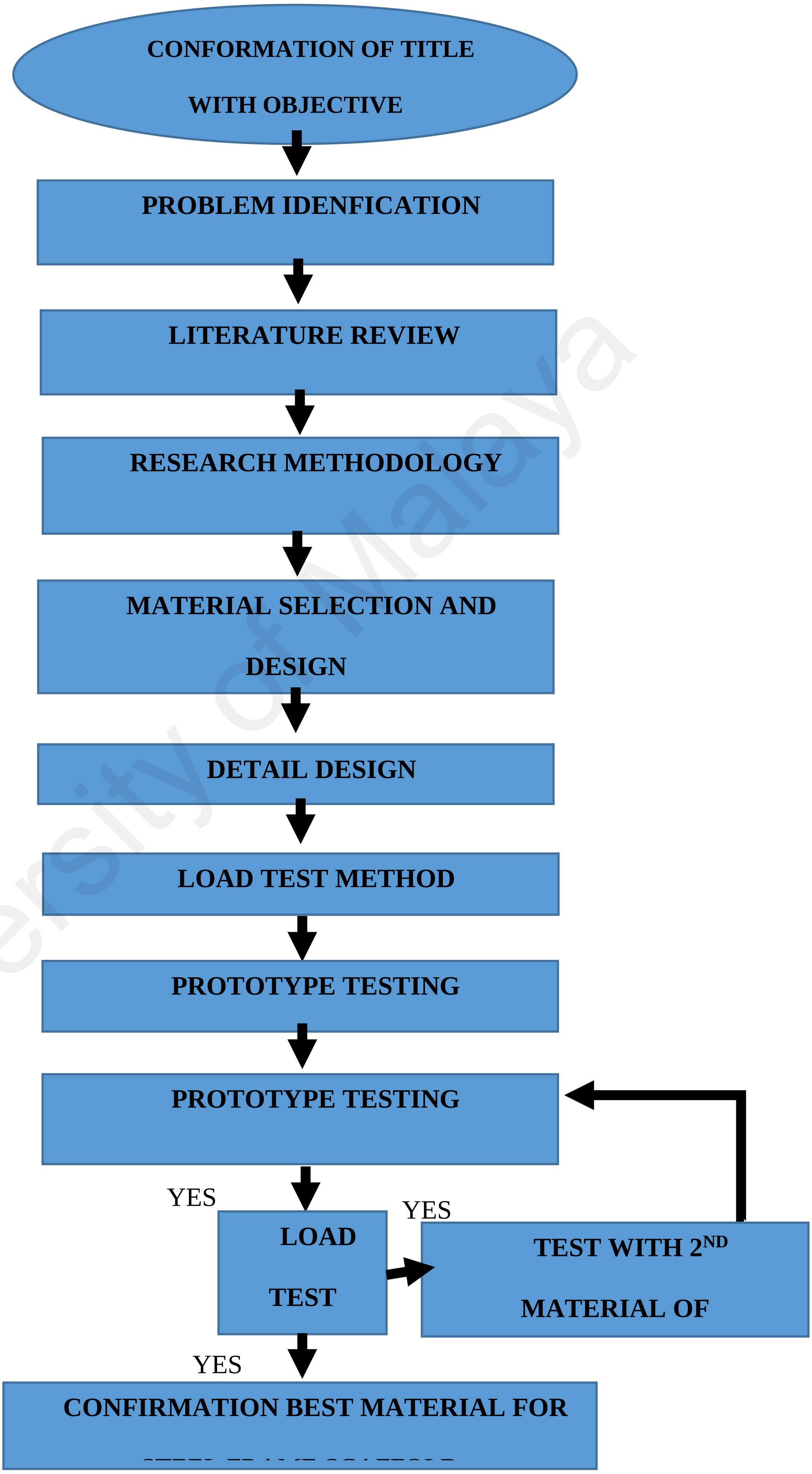
Ultimate Limit State: failure and collapse of structure as a result of catastrophic losses of structural strength and stiffness. This includes loss of structural equilibrium, achievement of maximum resistance, and collapse due to buckling.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter describes the methodology and design used to reach the objective. A configuration has been chosen which is similar to steel frame used in other field. Atmospheric influences are especially important for containment applications. For initial stage, the idea and concept of the title is studied and chosen. Information, data or other sources that related to the load test of steel frame system is found out. The information is collected by research method and experimental works while the work is done by method of research and experimental works. The load test of steel frame itself provides some resistance to the

3.2 Thesis flow chart



3.2 Research objective and contents

This study explores the structural behaviors of single row steel frame scaffolds by conducting loading tests based on various material of steel frame scaffold we commonly used in construction sites. In addition to providing the dimensions and elastic modulus of the steel scaffolds, test results of this study provide a valuable reference for determining related parameters in follow up numerical analyses, including the bending moment stiffness's of scaffold joints, U-shaped screw jacks and base screw jacks. Hopefully, results of this study can facilitate efforts to improve the material selection and l design of steel frame steel scaffolds. In particular, this this study focuses on the following objectives:

- determine the load carrying capacities and failure steel frame scaffolds with various material setups to function as the basis for strength comparison;
- Compare existing Frame scaffolding with load test and analytical capacity

3.4 Modelling of Steel Frame Scaffolding with 2.3mm thickness

The design of Conventional Frame Scaffolding is been sketch and drawn referring to the original scale set by Malaysia Standard (MS 1462) Metal scaffolding – Prefabricated scaffolds guides. The given data and dimension are based by clauses and standards from CIDB. Four different varieties of frame scaffolding were tested in the work reported herein. Frames A through C were manufactured by various Scaffolding company. All test assemblies were formed from components selected base by material from manufacture on hand. The dimensions and properties of each are given from two common material used for manufacture Frame scaffold which is JIS 3444 STK 500 AND JIS 3444 STK 400. In each of the load tests, six frames were used to erect a three high stack with tubular cross bracing at each of the three levels, as shown in Figs 7. The overall height of the tested assembly was approximately 5.1 m. Each frame assembly was erected by company crews using procedures for squaring and alignment of the system followed on commercial installations.

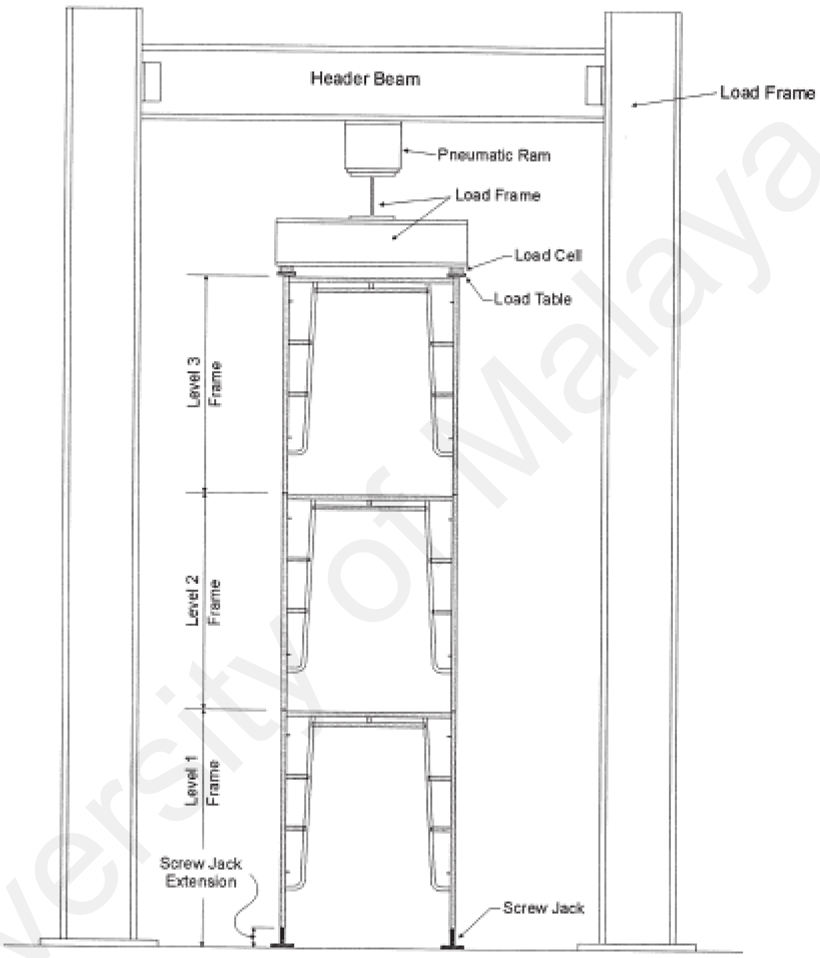


Figure 3.1: End view of scaffold testing assembly.

3.5 Material and tool selection

In order to fabricate this steel frame scaffolding, the material needed as below.

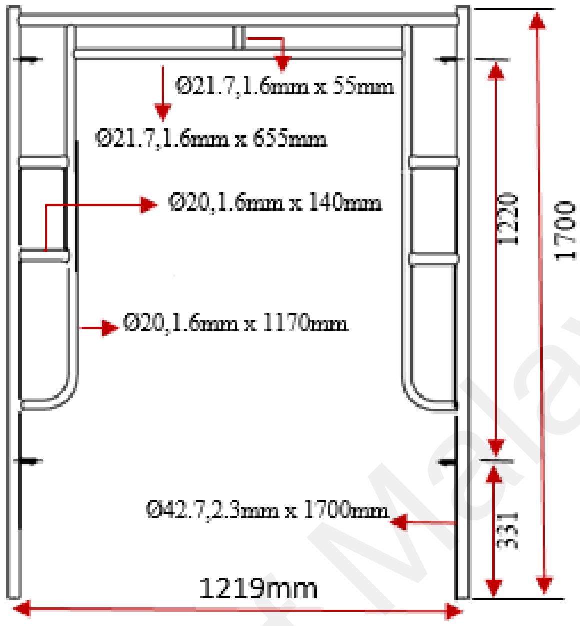


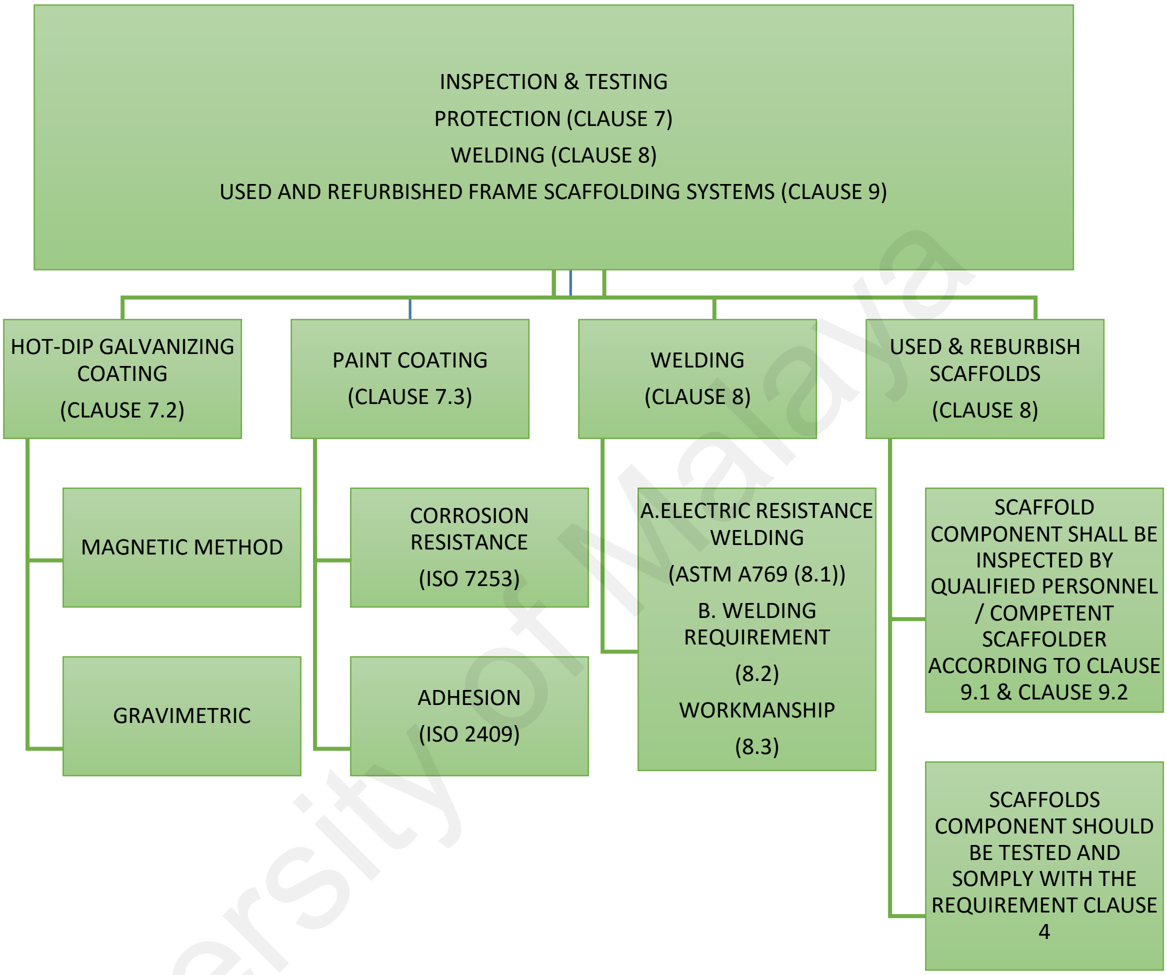
Figure 3.2: Steel frame scaffold dimension with other member parts

1. Part A - Ø42.7,2.3mm x 1700mm
2. Part B - Ø42,2.0mm x 1219mm
3. Part C - Ø20,1.6mm x 1170mm
4. Part D - Ø20,1.6mm x 140mm
5. Part E - Ø21.7,1.6mm x 655mm
6. Part F - Ø21.7,1.6mm x 55mm

All parts is welded together according to Clause 7 & Clause 8 of CIDB inspection and testing, protection (Clause 7) and welding (Clause 8).

3.6 Prefabricated scaffolds – Specification for steel frame scaffolding

Chart 3.1: Inspection and Testing with clauses



3.7 Specification of Scaffolding Components

The national standard specification of steel frame scaffolding is drafted by Standard Industries and Research Institute of Malaysia (SIRIM). Dimension and performance requirement of frame scaffold components is given in the standards shown in table 1. The term used is illustrated in figure 1 which is not regarded as part of the specification. The frame scaffolding and its components shall meet the performance requirement of the table when tested with the standard.

Table 3.2: Dimensional and performance requirement

Component	**Dimensions**	**Constitutional part**	**Load test Requirement**
Vertical Frames	42.7 x 2.5 27.2 x 2.0 14.0	Standard and horizontal member Reinforment member Cross brace pin	Deflection under 9.81kN = 10mm max Compressive strength = 73kN min for 1.8m and 68kN higher than 1.8m height
Cross Brace	21.7 x 2.0 7.5	Brace member Hinge pin	Compressive strength = 7.3kN min Strength of hinge pin = 5.88kN min
Horizontal frame	42.7 x 2.5 34.0 x 2.3 8.0	Tube member Transverse member hook	Deflection = 10mm max Bending strength 4.9kN
Adjustable jacks	35 140 x 140	Shank baseplate	Compressive strength = 59.8kN min

3.7.1 Tolerances of tube

MS 1462-2-1 for steel tube and MS 1462-2-2 for aluminum tube covers tube size and thickness as follows.

Table 3.3. Diameter, thickness and dimensional tolerance of tubes

		Steel	Aluminium
Diameter	Size	48.30mm	48.30mm
	Tolerance	±0.5mm	±0.5mm
Thickness	Size	3.2mm, 4.0mm	4.47mm
	Tolerance	10%	±0.56mm
NOTE 10: The values in this table are for illustration purpose only in this CIS, which are extracted from clause 7.5 of MS 1462-2-1: 2010 (for Steel) and Table 1 MS 1462-2-2:2010 (for Aluminium).			

3.8 Manufacturing Process of Steel Pipe

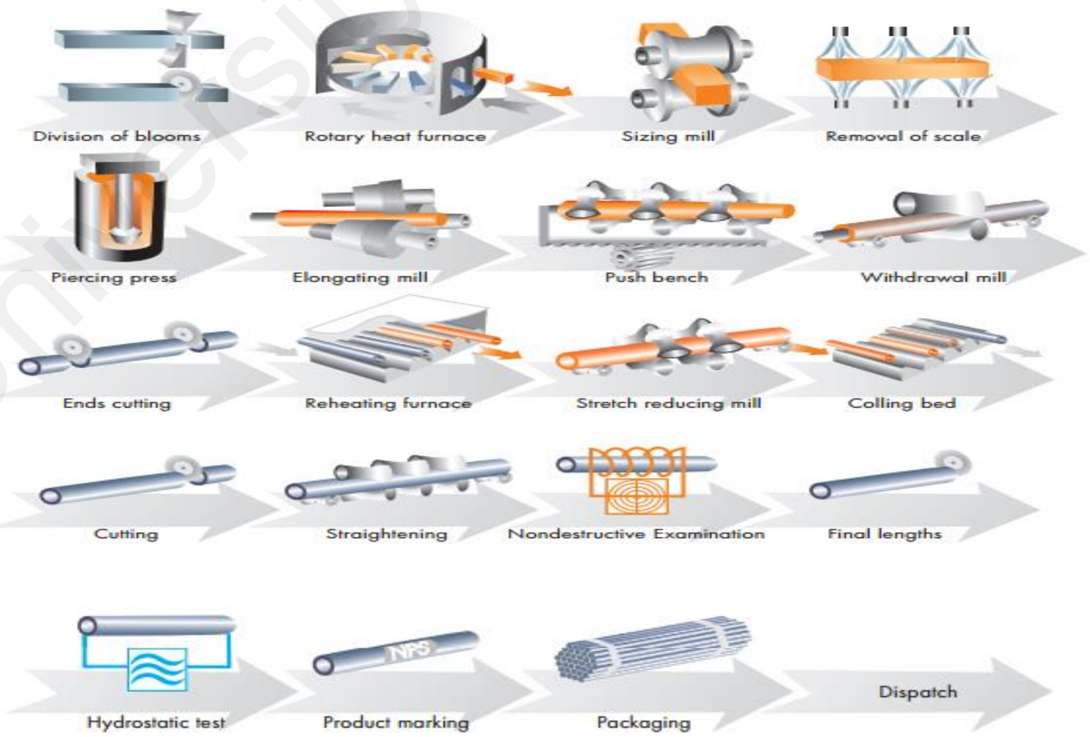


Figure 3.3: Hot finished tubes production

3.9 Comparison between STK 500 and STK 400

Chart 3.2: Radar chart comparison between STK500 AND STK 400

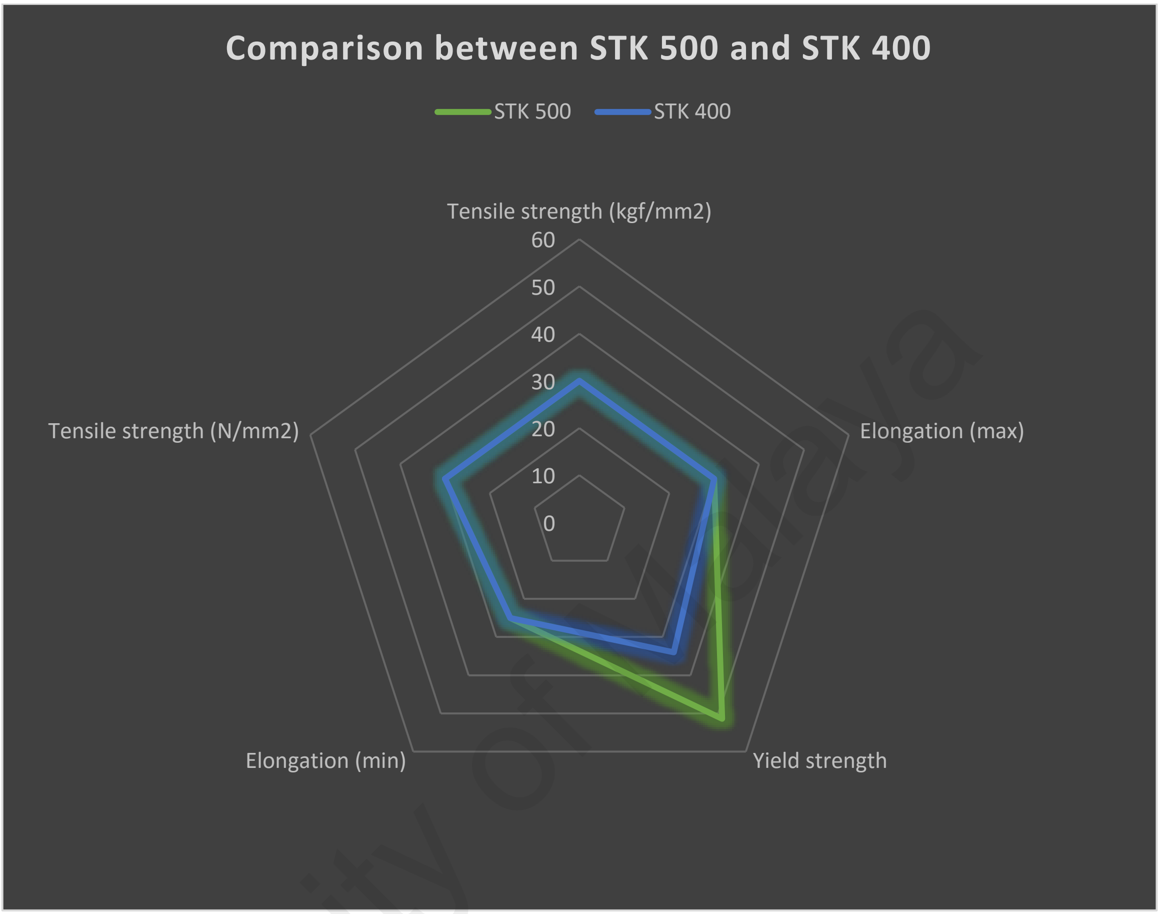
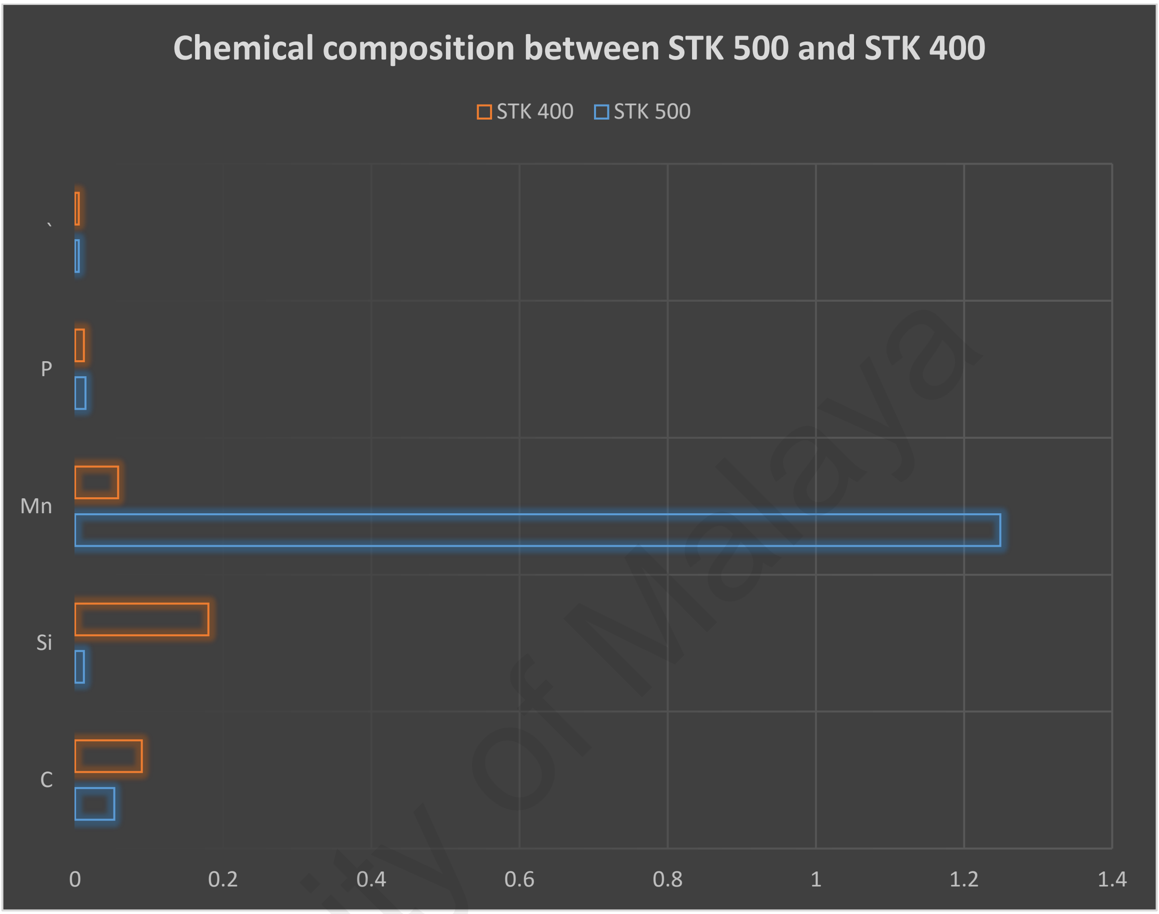


Chart 3.1: Radar chart comparison between STK500 AND STK 400

The tensile strength, yield strength and elongation are determined from standard test pieces, which may be the full section of the product or longitudinal or transverse strip specimen. The location of strip test pieces should be away from the weld, for circular hollow section and midway between corners on the side not effected by the weld for square and rectangular hollow sections.

3.10 Chemical composition between STK 500 and STK 400

Chart 3.3: Radar chart chemical comparison between STK500 AND STK 400



It's been notice that, there are 5 different element which is similar for both material which is Carbon, Silicon, Manganese, Phosphorus and Sulphur. The content of chemical composition changes the characteristic of the material itself. It believe STK500 contain high Manganese compare to STK 400 but STK 400 contains highest number chemical of Silicon compare to STK 500.

3.11 Test Planning

The accurate reflection the conditions on construction sites by using three setups of single row of steel frame scaffolds, one bay steel frame scaffold with various thickness and material. The first loading is applied to obtain load carrying capacity of each setups of steel frame scaffold. After unloading, each setup of steel scaffold is reset and then, the load carrying capacity of steel frame scaffold in the worst condition on the construction site is determine using the second loading.

3.11.1 One bay Steel Frame Scaffold

Test are performed on one bay steel scaffold to provide a reference for test on single row steel frame scaffold. These tests are conduct on various thickness and material of one bay steel frame scaffold with height of 3 story which is 5.1m. The steel scaffold used in this test are same in dimension and design but only various by thickness and material. The top of each steel frame is attach together with join pin in the mid-section. The top and bottom steel frame scaffold structure are attach with 650mm jack base and u-head. The scaffolding structure is reinforced with cross brace on both side of frames. Figure 44 shows the setup of entire scaffold. Unless otherwise specified, the top and bottom arrangement as well as the cross brace. Also the setup of their storey scaffolding structure is similar to that of another side of the frame. The Dimensional of each member of frame is similar to another.

3.12 Graphical Results

The tests performed at Huatraco Sdn Bhd Laboratory measured the material characteristics of the conventional frame with material of JIS 344 STK 500 and JIS 344 STK 400. 3 tests were performed with two different material and two different thickness of vertical member of selected frame scaffold. The results will produce from a software of load test equipment. The results showed a relationship between the force (axial load) and buckling action which react with stroke length which will appear when the load is applied. The force-stroke relationship and then plotted for each test and the results are shown in Figure 4.1 to Figure 4.3. More information regarding each test, including observations and photographic evidence, can be seen in the clear and distinct pattern of buckling occurred during the test.

This was confirmed through an analysis of the experimental data, which showed a point of instability (Figure 4.1 to figure 4.3). The load generated by the hydraulic ram caused a linear increase in the load recorded by the load cells and this was combined with a secondary application of load from steel blocks that became more and more eccentric as rotation continued. Other critical findings from the experiment related to the results attained from the three different frames with same storey height.

CHAPTER 4: RESULTS AND DISCUSSION

As mentioned in the second chapter, the design and material is heart of Steel Frame scaffolding system. I must make sure that the material selection suites my design of steel frame scaffolding. Based on previous design, the thickness of the vertical member is major concern because the load will be distribute through the vertical member of the frames I choose two type of nozzle suitable for my design.

4.1 Modeling for Load test

In order to fully capture the behavior of the scaffolding system, there model was chosen based by thickness and material.

1st Model

Product	: Frame (STK 500)
Product size	: 1219mm X 1700mm X 2.5mm
Model	: SM 101
Method of Test	: Specification for Steel Frame Scaffoldings

2nd Model

Product	: Frame (STK 500)
Product size	: 1219mm X 1700mm X 2.3mm
Model	: SM 101
Method of Test	: Specification For Steel Frame Scaffoldings

3rd Model

Product	: Frame (STK 400)
Product size	:1219mm X 1700mm X 2.5mm
Model	: SM 101
Method of Test	: Specification for Steel Frame Scaffoldings

4.2 Chemical properties on STK 500 and STK 400 with Various Thickness

4.2.1 Chemical properties for JIG 3444 STK 500 thickness 2.5mm

Sample Name : X-2/8/STK 500/ø42.7 X 2.5

Material : JIG 3444

Specification : STK 500

Method name : Fe-10-M

Size : Ø42.7 X 2.5

Table 4.1: Chemical properties for JIG 3444 STK 500 thickness 2.5mm

Meas.	1	2	3	<*x*>
	%	%	%	%
	Conc.	Conc.	Conc.	Conc.
C	0.161	0.163	0.163	*0.162*
Si	0.162	0.167	0.166	*0.165*
Mn	1.01	1.01	1.00	*1.01*
P	0.0262	0.0234	0.0232	0.0234
S	0.0209	0.0205	0.0208	0.0207
Cr	0.0156	0.0156	0.0156	0.0156
Mo	<0.00100	<0.00100	<0.00100	<0.00100
Ni	0.0064	0.0059	0.0068	0.0064
Al	0.00055	0.00013	0.00082	0.00090
Nb	<0.00100	<0.00100	0.0014	0.0011
U	0.0093	0.0091	0.0092	0.0092
Ti	<0.00020	0.00036	0.00032	0.00029
V	0.0292	0.0296	0.0299	0.0296
N	0.0050	0.0042	0.0035	0.0042
B	<0.00020	<0.00020	<0.00020	<0.00020

4.2.1.1 Summary of chemical composition

Kinetics of inclusion transformations are controlled by mass of chemical composition in each metal type. All chemical composition and slag changes contributes changes of characteristic and strength of the particular material. There is a strong relation between metal and nonmetal substance in which consider as main substance for metal forming. Carbon (C) and Manganese (Mn), For JIG 3444 STK 500 thickness 2.5mm the Carbon contain is 0.162% while Manganese is 1.01%, the highest value of chemical composition in this metal. This ratio is the highest substance in other two metal and at the same time STK 500 with thickness 2.5mm having the highest rate. Other substance are consider equally same with other two metal compositions. This test has be done three times to get average value of chemical composition for this particular metal. This chemical composition results is collected from lab report produced by company called Huatraco Sdn Bhd. As part of the test design, we set out with the goal to understand the chemical composition which could related to strength would important criteria to choose perfect material.

4.2.2 Chemical properties for JIG 3444 STK 400 thickness 2.5mm

Sample Name : X-2/8/STK 400/ø42.7 X 2.5

Material : JIG 3444

Specification : STK 400

Method name : Fe-10-M

Size : Ø42.7 X 2.5

Table 4.1: Chemical properties for JIG 3444 STK 400 thickness 2.5mm

Meas.	**1**	**2**	**3**	**<*x*>**
	%	**%**	**%**	**%**
	Conc.	**Conc.**	**Conc.**	**Conc.**
C	0.174	0.172	0.173	0.173
Si	0.0975	0.0969	0.0994	0.0980
Mn	0.447	0.442	0.441	0.443
P	0.0210	0.0199	0.0204	0.0204
S	0.0342	0.0320	0.0360	0.0341
Cr	0.0153	0.0153	0.0155	0.0154
Mo	<0.00100	<0.00100	<0.00100	<0.00100
Ni	0.0078	0.0078	0.0081	0.0079
Al	0.0065	0.0089	0.0065	0.0070
Nb	<0.00100	0.0012	<0.00100	0.0011
U	0.0121	0.0121	0.0122	0.0121
Ti	0.00023	0.00032	0.00020	0.00025
V	0.0023	0.0023	0.0022	0.0023
N	0.0079	<0.00100	0.0041	0.0023
B	<0.00200	<0.00200	<0.00200	<0.00200

4.2.2.1 Summary of chemical composition

For JIG 3444 STK 400 thickness 2.5mm the Carbon contain is 0.173% while Manganese is 0.443%, the highest value of chemical composition in this metal. This ratio is the highest substance in other two metal and at the same time STK 400 with thickness 2.5mm having the highest rate. The value of Carbon contain is higher than STK500 WITH THICKNESS OF 2.5MM, instead of that the composition of Manganese is very low compare to STK 500 thickness 2.5mm.Other substance are consider equally same with other two metal compositions. This test has be done three times to get average value of chemical composition for this particular metal. The carbon contain in this metal is higher compare to other two metal, while manganese contain is the lowest among the two metal.

4.2.3 Chemical properties for JIG 3444 STK 500 thickness 2.3mm

Sample Name : X-2/8/STK 500/ø42.7 X 2.3

Material : JIG 3444

Specification : STK 500

Method name : Fe-10-M

Size : Ø42.7 X 2.3

Table 4.3: Chemical properties for JIG 3444 STK 500 thickness 2.3mm

Meas.	**1**	**2**	**3**	**<*x*>**
	%	**%**	**%**	**%**
	Conc.	**Conc.**	**Conc.**	**Conc.**
C	0.159	0.159	0.157	0.158
Si	0.210	0.212	0.215	0.212
Mn	1.37	1.39	1.38	1.38
P	0.0392	0.0377	0.0401	0.0390
S	0.0226	0.0219	0.0253	0.0233
Cr	0.0226	0.0227	0.0225	0.0227
Mo	<0.00100	<0.00100	<0.00100	<0.00100
Ni	0.0070	0.0071	0.0073	0.0071
Al	0.0015	0.0034	0.0020	0.0020
Nb	<0.00100	<0.00100	0.0011	0.0010
U	0.0083	0.0083	0.0083	0.0083
Ti	0.00023	0.00062	0.00044	0.00043
V	0.0047	0.0051	0.0049	0.0049
N	0.0035	0.0029	0.0021	0.0049
B	<00020	<00020	<00020	<00020

4.2.3.1 Summary of chemical composition

For JIG 3444 STK 500 thickness 2.3mm the Carbon contain is 0.158% while Manganese is 1.38%, the highest value of chemical composition in this metal. This ratio is the highest substance in other two metal and at the same time STK 500 with thickness 2.3mm having the highest rate. The value of Carbon contain is lowest among the three material tested on lab, the composition of Manganese is Highest compare to other two material 2.5mm. High contain of manganese consider as easiest to be rusted. Other substance are consider equally same with other two metal compositions. This test has be done three times to get average value of chemical composition for this particular metal.

4.3 Compression test report

4.3.1 JIS 344 STK 500 ø42.7mm X 2.5mm

Material : ø42.7mm X 2.5mm JIS 3444 – STK 500

Temperature :22.5 °C - 22.7 °C

Test type : Tensile

	Outer Diameter	**Thickness**	**Gauge length**
Units	mm	mm	mm
x-2/8	42.6200	2.3900	50.00

Name	**Elastic**	**YS**	**TS**	**ELONGATION**	**Final Gauge length**
Parameter	**40.120 kN**	**0.2%**			
units	**N/mm²**	**N/mm²**	**N/mm²**	**%**	**mm**
X-2/8	**3841.58**	**397.268**	**462.652**	**18.1200**	**59.0600**

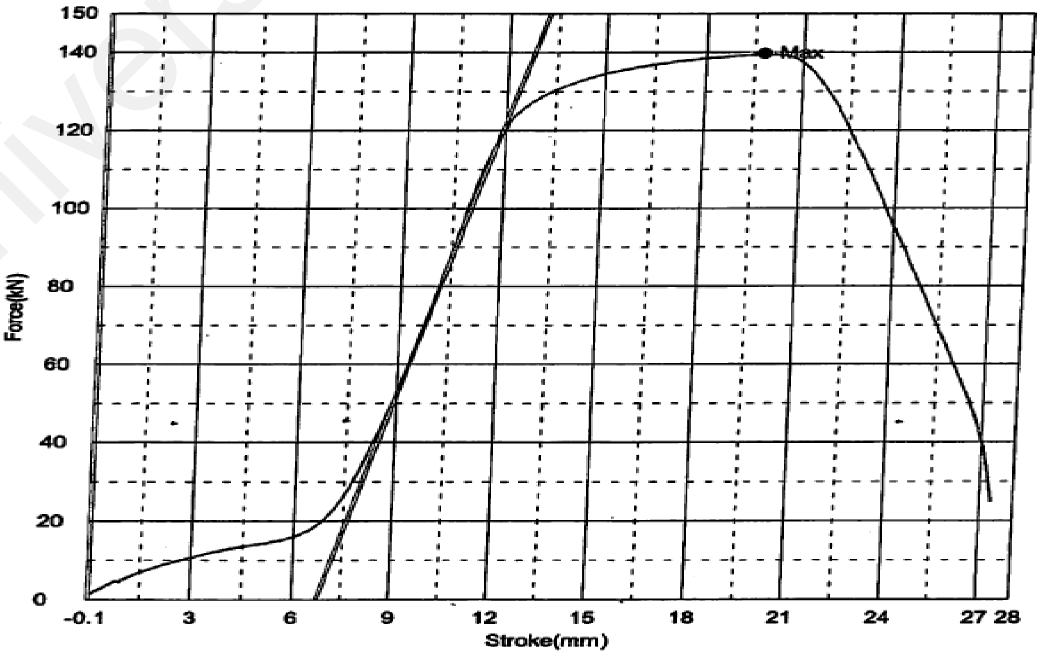


Figure 4.1: Results of load test for STK 500 with thickness of 2.5mm

4.3.1.1 Summary of Tensile Test

The test device mainly consists of a basic frame and the load cross vertical frame members. The steel frame contains the bottom join with Jack base and U-Head at the top, consisting of a force measuring device for measuring the testing Tensile strength. The height of the frame is 5.1m and this allows rod specimens with buckling occur to be examined. In order to standardize the results, a comparison of the compressive tensile strength and yield strength was performed. The percentage of Elongation and Elasticity of the collagen based scaffolds were differ when tested in compression compared with in tension whereas the produced results is Tensile strength =462.652 N/mm^2 and Yield strength =397.268 N/mm^2 with percentage of Elongation of 18.12%. In contrast, those properties of the based on the material and thickness of the steel frame scaffolding. In addition the Gauge length produce in the test is 59.06mm, this resulted show the maximum stroke length for this material is resulting at 140kN of force (Fig.4.1).

4.3.2 JIS 344 STK 400 ø42.7mm X 2.5mm

Material : ø42.7mm X 2.5mm JIS 3444 – STK 400

Temperature : 22.5 °C - 22.7 °C

Test type : Tensile

	Outer Diameter	Thickness	Gauge length
Units	mm	mm	mm
x-3/8	42.7900	2.1800	50.00

Name	Elastic	YS	TS	ELONGATION	Final Gauge length
Parameter	**35.100kN**	**0.2%**			
units	**N/mm²**	**N/mm²**	**N/mm²**	**%**	**mm**
X-3/8	**3680.94**	**402.697**	**478.147**	**17.6000**	**58.8000**

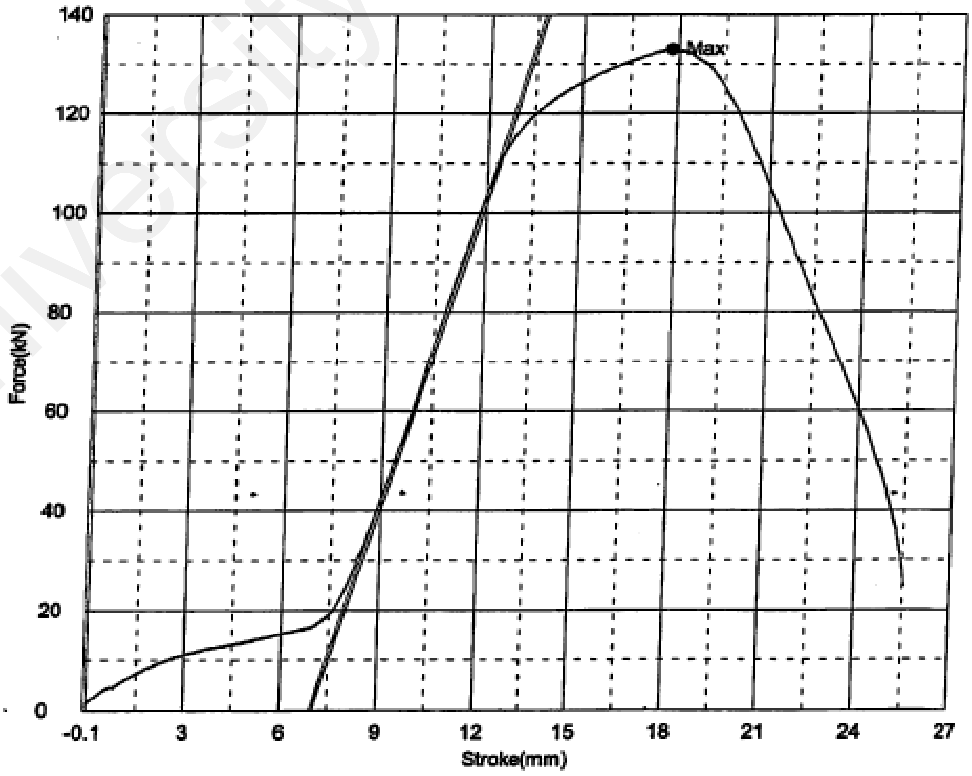


Figure 4.2: Results of load test for STK 400 with thickness of 2.5mm

4.3.2.1 Summary of Tensile Test

Second material is tested with the same height of 5.1m and examine the buckling effect after apply load on the steel Frame. A comparison of the compressive tensile strength and yield strength was resulted. The percentage of Elongation and Elasticity of the collagen based scaffolds were differ when tested in compression compared with in tension whereas the produced results is Tensile strength = 478.1472 N/mm^2 and Yield strength =402.697N/mm^2 with percentage of Elongation of 17.60%. In contrast, those properties of the based on the material and thickness of the steel frame scaffolding. In addition the Gauge length produce in the test is 58.80 mm, this resulted show the maximum stroke length for this material is resulting at 132kN of force (Fig.4.2).

4.3.3 JIS 344 STK 500 ø42.7mm X 2.3mm

Material : ø42.7mm X 2.3mm JIS 3444 – STK 500

Temperature : 22.5 °C - 22.7 °C

Test type : Tensile

	Outer Diameter	Thickness	Gauge length
Units	mm	mm	mm
x-4/8	42.7900	2.2100	50.00

Name	Elastic	YS	TS	ELONGATION	Final Gauge length
Parameter	**35.100kN**	**0.2%**			
units	**N/mm²**	**N/mm²**	**N/mm²**	**%**	**mm**
X-4/8	**12443.9**	**466.676**	**508.876**	**15.9329**	**112.646**

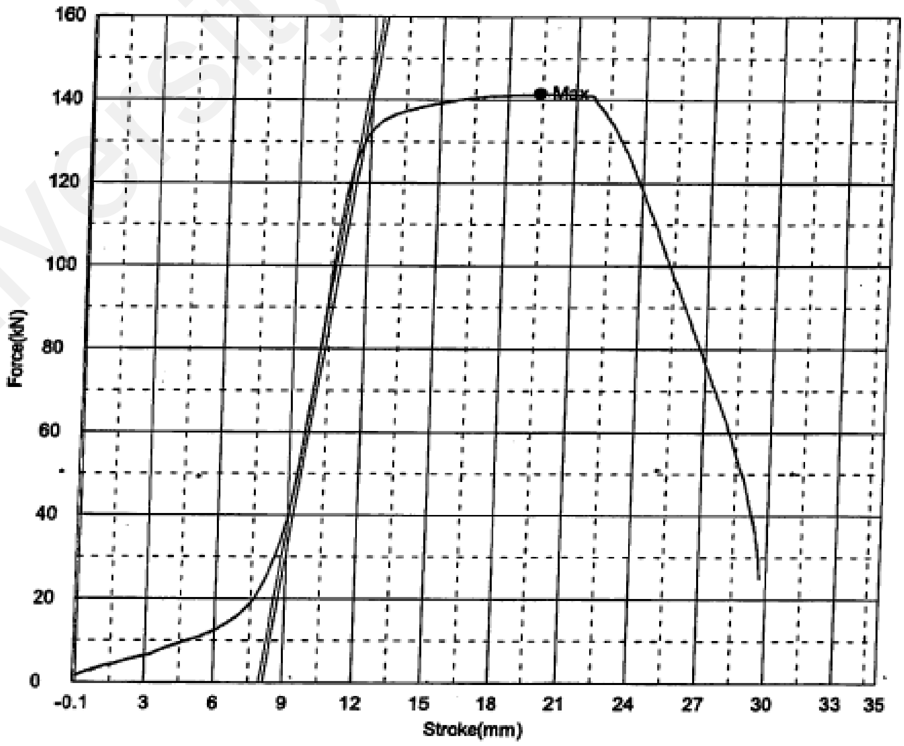


Figure 4.3: Results of load test for STK 500 with thickness 2.3mm

4.3.3.1 Summary of Tensile Test

Third and final material is tested with the same height of 5.1m and examine the buckling effect after apply load on the steel Frame. A comparison of the compressive tensile strength and yield strength was resulted. The percentage of Elongation and Elasticity of the collagen based scaffolds were differ when tested in compression compared with in tension whereas the produced results is Tensile strength =508.876N/mm^2 and Yield strength =466.676 N/mm^2 with percentage of Elongation of 15.93%. In contrast, those properties of the based on the material and thickness of the steel frame scaffolding. In addition the Gauge length produce in the test is 112.646 mm, this resulted show the maximum stroke length for this material is resulting at 140kN of force (Fig.4.3).

4.4 Compression test results

<u>1st Model</u>

Product : Frame (STK 500)

Product size : 1219mm X 1700mm X 2.5mm

Model : SM 101

Method of Test : Specification for Steel Frame Scaffoldings

Specification	Test results	Remarks
<u>Compressive Strength of vertical tube</u>		
Average value	Average : 15 100kg	Tensile – Passed
Indivudial value	1) 15100kg	Yield strength – Passes
		% elongation - Passed

<u>2nd Model</u>

Product : Frame (STK 500)

Product size : 1219mm X 1700mm X 2.3mm

Model : SM 101

Method of Test : Specification for Steel Frame Scaffoldings

Specification	Test results	Remarks
<u>Compressive Strength of vertical tube</u>		
Average value	Average : 12 200kg	Tensile – Failed
		Yield strength – Passes
Indivudial value	1) 12200kg	
		% eleongation - Passed

3rd Model

Product : Frame (STK 400)

Product size : 1219mm X 1700mm X 2.5mm

Model : SM 101

Method of Test : Specification for Steel Frame Scaffoldings

Specification	Test results	Remarks
Compressive Strength of vertical tube Average value Indivudial value	Average : 12 150kg 1) 12150kg	Tensile – Passed Yield strength – Passes % eleongation - Failed

4.5 Summary

A conclusion is been done based on the conducted test upon three selected material with various thickness and material. This test is been done to prove highest force and longest stroke, it means the force applied can go further before buckling occur. From the results its proven that 2nd material which is JIG 3444 STK 400 with thickness of 2.5mm is totally differ in results where the buckling happen sooner at the Force of 132 kN with the length of stroke of 17.45 mm. This results is shows that STK 400 is not suitable material for steel frame scaffolding. Meanwhile, there are another two material which shows good results as per targeted results. From the results we obtain two material with similar force but slightly different in stroke length. JIG 3444 STK 500 is proven as suitable material, in the conducted test STK 500 with thickness of 2.5mm have reach maximum stroke length at the force of 140kN and thickness 2.3mm reach the same amount of force but differ in the stroke length. STK 500 with thickness of 2.3mm has produce buckling at the length of 19.5 mm while STK 500 with thickness reach the highest with 20.15mm.From this results its shown that, JIG 3444 STK 500 with thickness of 2.5mm can carry more load capacity compare with other two material. As a conclusion, the chosen and recommend steel frame scaffolding is from material JIG 3444 STK 500 thickness 2.5mm. Other critical findings from the experiment related to the results attained from the three different test configurations shows there was major change in stroke length between all three tested frames. The only significant change in stroke length was associated with the buckling point amount of load on the system which shows the maximum load taken for the particular tested frames, which is possibly could occur on site. This phenomenon could be attributed to the durability and superior structural capacity of the steel frame scaffolding.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, some basic considerations for the design of steel frame scaffold have been presented. Although steel frame scaffold is wide use in construction field, the basic principles of design and material selection should be considered. From the test, STK 500 with diameter of 2.5mm have better tensile strength, yield strength and percentage of elongation compare to other two frames.

Load carrying capacity is also depends on storey heights and bay, the more higher we will get lower loading capacity. This loading capacity can be used for endorsement of calculation for used for steel frame scaffold with selected formwork.

In the study, second loading are regards as the worst condition for reused steel frame scaffold. The average ratio of dividing the load capacity of second loading by those first loading is 0.63 compare to first loading is 0.13.Additionaly, when under a maximum load, the vertical displacement all setups of multi bay should be less than 20mm.Designers can select appropriate strength reduction factor of reused steel frame scaffolding, based on design requirements. These models can be designed with a load and resistance factor design formula for checking the system's capacity, substantially reducing the need for full scale load tests. Load eccentricity is known to affect the stability and strength of steel scaffolding and for the system being investigated, it was possible that a bearer could cause a load eccentricity. A survey of technical design engineers suggested that it was better to brace the bottom lift first and then the middle lift because the top lift was generally used by workmen to access the timber formwork. Finally, an optimisation process was undertaken to determine the most efficient bracing configurations, and it utilised every component of the research.

5.2 Recommendation

5.2.1 Recommendation based on material selection and design

1. Use timber based or concrete blinding for both is preferred to ensure overall bearing

2 . More diagonal bracing can give more load capacity on site usage.

5.2.2 Recommendation to improve load capacity

1. Other vertical member of frames can be improvise with higher thickness, this can give move load capacity and reduce buckling in short period.

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APPENDIX A

Table 1. Material quality, dimensions and tolerances for components of frame scaffoldings

Member	Component		Material quality	Dimensions (mm) Outer diameter	Dimensions (mm) Thickness	Tolerances Outer diameter	Tolerances Thickness
Vertical frame	Vertical post and horizontal member		STK 500 specified in JIS G3444 or equivalent	42.7	2.5	±0.25	±0.3
	Reinforcement member		STK 400 specified in JIS G3444 or equivalent	27.2	2.0		
	Cross brace pin		SS 400 specified in JIS G3101 or equivalent	14.0		±1.0	
Cross brace	Brace member		STK 400 specified in JIS G3444 or equivalent	21.7	2.0	±0.25	±0.3
	Hinge pin		SWRM 20 specified in JIS G3505 (Low carbon steel wire rods) or equivalent	7.5		±0.7	
Horizontal frame	Tube member		STK 500 specified in JIS G3444 or equivalent	42.7	2.5	±0.25	±0.3
	Arm or traverse member		STK 400 specified in JIS G3444 or equivalent	34.0	2.3		
	Clamp or hook		SS 400 specified in JIS G3101 or equivalent		8.0	-	±0.8
Catwalk or tread board	Catwalk member	Steel plate	SPHC specified in JIS G3131 or equivalent	500*	1.2	-	±0.1
	Clamp or hook		SS 400 specified in JIS G3101 or equivalent		8.0	-	±0.8
Adjustable base plate/ U-head	Threaded bar		SS 330 specified in JIS G3101 or equivalent	32**	-	-	-
	Plate for adjustable base plate		SS 330 specified in JIS G3101 or equivalent	120 x 120***	5.4***	-	-
	Plate for U-head		SS 330 specified in JIS G3101 or equivalent	160 x 120***	5.4***	-	-
	Adjusting nut		FCMB 310 specified in JIS G5702 (Blackheart malleable iron castings) or equivalent	-	-	-	-
Bracket	Vertical, lateral & diagonal members		SGP specified in JIS G3452 or SS 330 specified in JIS G3101 or equivalent	-	-	-	-
	Metal fittings	Bolt, nut & pin	SS 330 specified in JIS G3101 or equivalent	-	-	-	-
		Parts other than bolt, nut & pin	SPHD specified in JIS G3131 or equivalent	-	-	-	-
Wall tie	Principal member		SGP specified in JIS G3452 or SS 330 specified in JIS G3101 or equivalent	-	-	-	-
	Gripper metal fittings	Bolt, nut & pin	SS 330 specified in JIS G3101 or equivalent	-	-	-	-
		Parts other than bolt, nut & pin	SPHD specified in JIS G3131 or equivalent	-	-	-	-
	Metal fittings		SS 400 specified in JIS G3101 or equivalent	-	-	-	-

APPENDIX B

Table 1 (Continuation) . Material quality, dimensions and tolerances for components of frame scaffoldings

Member	Component		Metallic quality	Dimensions (mm)		Tolerances	
				Outer diameter	Thickness	Outer diameter	Thickness
Joint pin	Tenon		SGP specified in JIS G3452 r equivalent	95†	2.2	-	-
	Collar			25†		-	-
Arm lock			SS 330 specified in JIS G3101 or equivalent	38 (plate width*)	3.1 (plate thickness)	-	±0.3
Global bracing system	Diagonal and horizontal brace		STK 500 specified in JIS G3444 or equivalent	48.6	2.5	±0.25	±0.3
	Clamp or fitting	Body and cover	SPHD specified in JIS G 3131	42.7~48.6	3***	±1.0	-
		Bolt, nut and pin	**SS330** specified in JIS G 3101	12**	-	-	-
Side protection/ Guard rail	Tube member		STK 500 specified in JIS G3444 or equivalent	48.6	2.5	±0.25	±0.3
	Clamp or fitting	Body and cover	SPHD specified in JIS G 3131	42.7~48.6	3***	±1.0	-
		Bolt, nut and pin	**SS330** specified in JIS G 3101	12**	-	-	-
Toe board	Board Member	**lipped channel**	SPHC specified in JIS G 3131 or equivalent	180*	1.2	-	±0.1

* Minimum width
**... Minimum diameter
*** Minimum dimension
† Minimum length

APPENDIX C

ASTM

Classification		ASTM A672 A45	A50	A55	B55	B60	B65	B70	C55	C60	C65	C70
Application		-										
Chemical composition(%)	C(Max.)	0.17	0.22	0.28	0.20	0.24	0.28	0.31	0.18	0.21	0.24	0.27
	Si(Max.)	-	-	-	0.15–0.40	0.15–0.40	0.15–0.40	0.15–0.40	0.15–0.40	0.15–0.40	0.15–0.40	0.15–0.40
	Mn(Max.)	0.90	0.90	0.90	0.90	0.90	0.90	1.20	0.60–0.90	0.60–0.90	0.85–1.20	0.85–1.20
	P(Max.)	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
	S(Max.)	0.04	0.04	0.04	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
	Others	-	-	-	-	-	-	-	-	-	-	-
Mechanical properties: Tensile strength (Min.)	PSI	-	-	-	-	-	-	-	-	-	-	-
	MPa	315–450	345–485	380–515	380–515	415–550	450–585	485–620	380–515	415–550	450–585	485–620
	kgf/mm^2	32.2–45.9	35.2–49.5	38.8–52.6	38.8–52.6	42.4–56.1	45.9–59.7	49.5–63.3	38.8–52.6	42.2–56.1	45.9–59.7	49.5–63.3
Yield point (Min.)	PSI	-	-	-	-	-	-	-	-	-	-	-
	MPa	165	185	205	205	220	240	260	205	220	240	260
	kgf/mm^2	16.9	18.9	21.0	21.0	22.5	24.5	26.6	21.0	22.5	24.6	26.6
Elongation (min.)		30	28	27	27	25	23	21	27	25	23	21
Flattening test		-										
Bending test		-										

Classification	Class	Test	
Hydrostatic test	Class 10	-	P = 2St/D
	Class 11	-	
	Class 12	TEST	
	Class 13	TEST	
	Class 20	-	
	Class 21	-	
	Class 22	TEST	
	Class 23	TEST	
NDT (Non-Destructive Test)	Class 10	-	-
	Class 11	TEST(RT)	
	Class 12	TEST(RT)	
	Class 13	-	
	Class 20	-	
	Class 21	TEST(RT)	
	Class 22	TEST(RT)	
	Class 23	-	
Others			-

KS (JIS)

Classification		KS D 3507 (JIS G 3452) SPP (SGP)	KS D 3537 (JIS G 3442) SPPW (SGPW)	KS D 3565 STWW 290 (300A below)	KS D 3565 STWW 370 (300A below)	KS D 3565 STWW 400 (350A below)	KS D 3583 (JIS G 3457) SPW 400 (STPY 400)	KS D 3562 (JIS G 3454) SPPS 38 (STPG 370)	KS D 3562 (JIS G 3454) SPPS 42 (STPG 410)	KS D 3569 (JIS G 3460) SPLT 39 (STPL 380)	KS D 3570 (JIS G 3456) SPHT 38 (STPT 370)	KS D 3570 (JIS G 3456) SPHT 42 (STPT 410)
Name of specification		Carbon steel pipes for ordinary piping	Galvanized steel pipes for water service	Coated steel pipes for water works			Arc welded carbon steel pipes	Carbon steel pipes for pressure services		Steel pipes for low temperature service	Carbon steel pipes for high temperature service	
Chemical composition (%)	C(Max.)	-	-	-	0.25	0.25	0.25	0.25	0.30	0.25	0.25	0.30
	Si(Max.)	-	-	-	-	-	-	0.35	0.35	0.35	0.10–0.35	0.10–0.35
	Mn(Max.)	-	-	-	-	-	-	0.30–0.90	0.30–1.00	1.35	0.30–0.90	0.30–1.00
	P(Max.)	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.035	0.035	0.035
	S(Max.)	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.035	0.035	0.035
	Others	-	-	-	-	-	-	-	-	-	-	-
Mechanical properties: Tensile strength (min.)	kgf/mm^2	30	30	30	38	41	41	38	42	39	38	42
	N/mm^2	294	294	294	373	402	400	373	412	382	373	412
Yield point (min.)	kgf/mm^2	-	-	-	22	23	23	22	25	21	22	25
	N/mm^2	-	-	-	216	226	226	216	245	206	216	245
Elongation (min.) (%)	No. 11 specimen, No. 12 Specimen	30	30	30	30	-	-	30	25	35	30	25
	No. 5 specimen	25	25	25	25	18	18	25	20	25	25	20
Flattening test	H : Distance between Flattening plates(mm) D : Outside diameter of the pipe(mm) t : Wall thickness of the pipe(mm)	H = 2/3D	H = 2/3D	H = 2/3D (Electric resistance welded pipe)			-	Welded part H = 2/3D Base metal H = 1/3D		H = (1+e)t / (e+t/D) e = 0.08	H = (1+e)t / (e+t/D) e = 0.07	
Bending test	Bending angle X Inside radius (D : Outside diameter of the pipe)	90° X 6D (pipes of 50A or below, substitute with flattening test)	90° X 6D (pipes of 50A or below)	-			-	90° X 6D (Pipes of 40A or below, substitute with flattening test)		90° X 6D (Pipes of 50mm or below, substitute with flattening test)	90° X 6D (Pipes of 50mm or below, substitute with flattening test)	
Hydro static test	Test pressure (kgf/cm^2)	25	25	Letter symbol of grade / Test pressure: STWW 290: 25 STWW 370: 35 STWW 400 A: 25 STWW 400 B: 30			25	Schedule No. / Test pressure: 10: 20 20: 35 30: 50 40: 60 60: 90 80: 120		Schedule No. / Test pressure: 10: 20 20: 35 30: 50 40: 60 60: 90 80: 120	Schedule No. / Test pressure: 10: 20 20: 35 30: 50 40: 60 60: 90 80: 120	
Non-destructive Test	Ultrasonic test or eddy current test	substitute with hydrostatic test	substitute with hydrostatic test	Substitute with hydrostatic test (Selection of one from ultrasonic test, eddy current test, radiographic test)			substitute with hydrostatic test	substitute with hydrostatic test		substitute with hydrostatic test	substitute with hydrostatic test	
Others		Galvanized pipes (uniformity test 5 times)	Weight of zinc coating (average 400g/m²) Uniformity test 6 times	Tensile strength test for welded part (Arc welded steel pipes)			Tensile strength test for welded part	-		Charpy impact test	-	

APPENDIX D

KS (JIS)

Classification \ Specification			STKM 11A	STKM 12A	STKM 12B	STKM 12C	STKM 13A	STKM 13B	STKM 13C	STKM 14A	STKM 14B	STKM 14C	STKM 15A	STKM 15C	STKM 16A	STKM 16C	STKM 17A	STKM 17C	STKM 18A	STKM 18B	STKM 18C	STKM 19A	STKM 19C	STKM 20A
			KS D 3517 (JIS G 3445)																					
Name of specification			Carbon steel Tubes for machine structural purposes																					
Chemical composition(%)	C(Max.)		0.12	0.20			0.25			0.30			0.25 ~ 0.35		0.35 ~ 0.45		0.45 ~ 0.55		0.18			0.25		0.25
Chemical composition(%)	Si(Max.)		0.35	0.35			0.35			0.35			0.35		0.40		0.40		0.55			0.55		0.55
Chemical composition(%)	Mn(Max.)		0.60	0.60			0.30 ~ 0.90			0.30 ~ 1.00			0.30 ~ 1.00		0.40 ~ 1.00		0.40 ~ 1.00		1.50			1.50		1.60
Chemical composition(%)	P(Max.)		0.040	0.040			0.040			0.040			0.040		0.40		0.40		0.040			0.040		0.040
Chemical composition(%)	S(Max.)		0.040	0.040			0.040			0.040			0.040		0.40		0.40		0.040			0.040		0.040
Chemical composition(%)	Others		-	-			-			-			-		-		-		-			-		Nb or V 0.15 below
Mechanical properties	Tensile strength (min.)	kgf/mm²	30	35	40	48	38	45	52	42	51	56	48	59	52	63	56	66	45	50	52	50	56	55
Mechanical properties	Tensile strength (min.)	N/mm²	290	340	390	470	370	440	510	410	500	550	470	580	510	620	550	650	440	490	510	490	550	540
Mechanical properties	Yield point (min.)	kgf/mm²	-	18	28	36	22	31	39	25	36	42	28	44	33	47	35	49	28	32	39	32	42	40
Mechanical properties	Yield point (min.)	N/mm²	-	175	275	356	215	305	380	245	355	410	275	430	325	460	345	480	275	315	380	315	410	390
Mechanical properties	Elongation (min.) (%)	No. 11 specimen / No. 12 Specimen	35	35	25	20	30	20	15	25	15	15	22	12	20	12	20	10	25	23	15	23	15	23
Mechanical properties	Elongation (min.) (%)	No. 5 specimen	30	30	20	15	25	15	10	20	10	10	17	7	15	7	15	5	20	18	10	18	10	18
Flattening test	H : Distance between Flattening plates(mm) D : Outside diameter of the pipe(mm) t : Wall thickness of the pipe(mm)		H = 1/2D	H = 2/3D	H = 2/3D	-	H = 2/3D	H = 3/4D	-	H = 3/4D	H = 7/8D	-	H = 3/4D	-	H = 7/8D	-	H = 7/8D	-	H = 7/8D	H = 7/8D	-	H = 7/8D	-	H = 7/8D
Bending test	Bending angle X inside radius (D : Outside diameter of the pipe) Pipes of 50mm or below (Outside Diameter)		180° X 4D	90° X 6D	90° X 6D	-	90° X 6D	90° X 6D	-	90° X 6D	90° X 8D	-	90° X 6D	-	90° X 8D	-	90° X 8D	-	90° X 6D	90° X 8D	-	90° X 6D	-	90° X 6D
Hydrostatic test	Hydrostatic test pressure (kgf/cm²)		By agreement																					
Non-destructive Test	Ultrasonic test or eddy current test		By agreement																					
Others			-																					

KS (JIS)

Classification \ Specification			STK 290 (STK 290)	STK 400 (STK 400)	STK 500 (STK 500)	STK 490 (STK490)	STK 540 (STK 540)	SPS 400 (SKK 400)	SPS 490 (SKK 490)	STKT 540 (STKT 540)	STKT 590 (STKT 590)
			KS D 3566 (JIS G 3444)					KS F 4602 (JIS A 5525)		KS D 3780 (JIS G 3474)	
Name of specification			Carbon steel tubes for general structural purposes					Steel pipe piles		High tensile strength steel for tower structural purposes	
Chemical composition (%)	C(Max.)		-	0.25	0.24	0.18	0.23	0.25	0.18	0.23	0.12
Chemical composition (%)	Si(Max.)		-	-	0.35	0.55	0.55	-	0.55	0.55	0.40
Chemical composition (%)	Mn(Max.)		-	-	0.30 ~ 1.30	1.50	1.50	-	1.50	1.50	2.00
Chemical composition (%)	P(Max.)		0.050	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.030
Chemical composition (%)	S(Max.)		0.050	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.030
Chemical composition (%)	Others		-	-	-	-	-	-	-	-	0.15 (Nb+V)
Mechanical properties	Tensile strength (min.)	kgf/mm²	30	41	51	50	55	41	50	55	60 ~ 70
Mechanical properties	Tensile strength (min.)	N/mm²	290	400	500	490	540	400	490	540	590 ~ 740
Mechanical properties	Yield point (min.)	kgf/mm²	-	24	36	32	40	24	32	40	45
Mechanical properties	Yield point (min.)	N/mm²	-	235	356	315	390	235	315	390	440
Mechanical properties	Elongation (min.) (%)	No. 11 specimen / No. 12 Specimen	30	23	15	23	20	23	23	20	20
Mechanical properties	Elongation (min.) (%)	No. 5 specimen	25	18	10	18	16	18	18	16	16
Flattening test	H : Distance between Flattening plates(mm) D : Outside diameter of the pipe(mm) t : Wall thickness of the pipe(mm)		H = 2/3D	H = 2/3D	H = 7/8D	H = 7/8D	H = 7/8D	H = 2/3D	H = 7/8D	H = 7/8D	H = 3/4D
			Electric resistance welded pipe					Electric resistance welded pipe		Electric resistance welded pipe	
Bending test	Bending angle X inside radius (D : Outside diameter of the pipe)		90° X 6D	90° X 6D	90° X 8D	90° X 6D	90° X 6D	-		-	
			Pipes of 50mm or below, substitute with flattening test								
Hydrostatic test	Hydrostatic test pressure (kgf/cm²)		By agreement					By agreement		By agreement	
Non-destructive Test	Ultrasonic test or eddy current test or radiographic test		By agreement					By agreement		By agreement	
Others			Tensile strength test for welded part (Arc welded steel pipes 350mm or above)					Tensile strength test for welded part (Arc welded steel pipes)		- Tensile strength test for welded part (Arc welded steel pipes 350mm or above) - Impact test (STKT590) - 0.40% or less for carbon unit quantity	

APPENDIX E

Technical Specification References

Classification	Specifications	Designation of Grade	Mechanical Properties: Tensile Strength N/mm² (t ≤ 3mm)	Tensile Strength N/mm² (3mm < t ≤ 40mm)	Yield Strength Min. N/mm²	Elongation Min. % CHS	Elongation Min. % RHS or SHS	Chemical Composition %: C Max	Si Max	Mn Max	P Max	S Max	Al Max	Ni Max	CEV Max	Cu	Impact Properties: Test Temperature °C	Min average impact energy for standard test piece J
Cold formed welded structural hollow sections of non-alloy and fine grain steels	BS EN 10219	S235JRH	360-510	360-510	235	24		0.17	-	1.40	0.045	0.045	-	-	0.35	-	20	27
		S275J0H	430-580	410-560	275	20		0.20	-	1.50	0.040	0.040	-	-	0.40	-	0	27
		S275J2H	430-580	410-560	275	20		0.20	-	1.50	0.035	0.035	-	-	0.40	-	-20	27
		S355J0H	510-680	470-630	355	20		0.22	0.55	1.60	0.040	0.040	-	-	0.45	-	0	27
		S355J2H	510-680	470-630	355	20		0.22	0.55	1.60	0.035	0.035	-	-	0.45	-	-20	27
Structural Steel Hollow Sections for Australian Standard	AS 1163	C 250	320		250	22	18	0.12	0.05	0.50	0.040	0.030	0.10	0.10	0.25	-	-	-
		C 250 L0	320		250	22	18	0.12	0.05	0.50	0.040	0.030	0.10	0.10	0.25	-	0	27
		C 350	430		350	20	16	0.20	0.35	1.60	0.040	0.030	0.10	0.10	0.39	-	-	-
		C 350 L0	430		350	20	16	0.20	0.35	1.60	0.040	0.030	0.10	0.10	0.39	-	0	27
		C 450	500		450	16	14	0.20	0.45	1.60	0.040	0.030	0.03	0.10	0.39	-	-	-
		C 450 L0	500		450	16	14	0.20	0.45	1.60	0.040	0.030	0.03	0.10	0.39	-	0	27
Carbon Steel Square Pipes for General Structure Purposes	JIS G 3466	STKR 400	400		245	-	23 min	0.25			0.04	0.04	-	-	-	-	-	-
		STKR 490	490		325	-	23 min	0.18	0.55	1.50	0.04	0.04	-	-	-	-	-	-
Carbon Steel Tubes For General	JIS G 3444	STK 290	290		-	30 min 25 min	-	-	-	-	0.050	0.050	-	-	-	-	-	-
		STK 400	400		235	23 min 18 min	-	0.25	-	-	0.040	0.040	-	-	-	-	-	-
		STK 500	500		355	15 min 10 min	-	0.24	0.350	0.30 to 1.30	0.040	0.040	-	-	-	-	-	-
		STK 540	540		390	20 min 16 min	-	0.23	0.550	1.500	0.040	0.040	-	-	-	-	-	-
Cold-Formed Welded Carbon Steel Structural — SHS & RHS	ASTM A 500	Grade A	310		270	As specified in ASTM A500 specification		0.26	-	1.40	0.045	0.045	-	-	-	0.18 min	-	-
		Grade B	400		315			0.26	-	1.40	0.045	0.045	-	-	-	0.18 min	-	-
		Grade C	425		345			0.23	-	1.35	0.045	0.045	-	-	-	0.18 min	-	-
		Grade D	400		250			0.26	-	1.40	0.045	0.045	-	-	-	0.18 min	-	-
Cold-Formed Welded Carbon Steel Structural — CHS		Grade A	310		230			0.26	-	1.40	0.045	0.045	-	-	-	0.18 min	-	-
		Grade B	400		290			0.26	-	1.40	0.045	0.045	-	-	-	0.18 min	-	-
		Grade C	425		315			0.23	-	1.35	0.045	0.045	-	-	-	0.18 min	-	-
		Grade D	400		250			0.26	-	1.40	0.045	0.045	-	-	-	0.18 min	-	-
Lipped Channels & Plain Channels	JIS G 3350	SSC 400	400-540		245	21 min		0.25	-	-	0.035	0.035	-	-	-		-	-
High Tensile C Purlin	Equivalent to ASTM A446 Gr. E				450	550		12	0.40	-	-	0.30	0.04	-	-		-	-

NOTES :
a) The impact properties of steel qualities J0 and J2 are verified by laboratory testing only when specified at at the time of the inquiry and order.
b) The steel qualities J0 and J2 can be produced upon request with extra cost.
c) (xx) Test piece No. 11 and 12
d) (xx) Test piece No. 5
- When the tensile test is carried out on No. 5 and 12 test piece for the tube under 8mm in wall thickness, the minimum elongation value shall be determined by reducing 1.5% per 1mm of decrease in wall thickness from the values given in the Table above and rounding off the value obtained to integer in accordance with JIS Z 8401.
e) t - thickness
CHS - Circular Hollow Sections
RHS - Rectangular Hollow Sections
SHS - Square Hollow Sections

APPENDIX F

Carbon Steel Tubes For General Structural Purposes

JIS G 3444 - 1988 - STK 290
JIS G 3444 - 1988 - STK 400
JIS G 3444 - 1988 - STK 500
JIS G 3444 - 1988 - STK 540

Outside Diameter	Wall Thickness	Calculated Weight	Cross Sectional Area	Geometrical Moment of Inertia	Modulus of Section	Radius of Gyration of Area
mm	mm	kg/m	cm^2	cm^4	cm^3	cm
21.7	2.0	0.972	1.238	0.607	0.560	0.700
27.2	2.0	1.24	1.583	1.26	0.930	0.890
	2.3	1.41	1.799	1.41	1.03	0.880
34.0	2.3	1.80	2.291	2.89	1.70	1.12
42.7	2.3	2.29	2.919	5.97	2.80	1.43
	2.5	2.48	3.157	6.40	3.00	1.42
	2.8	2.76	3.510	7.02	3.29	1.41
48.6	2.3	2.63	3.345	8.99	3.70	1.64
	2.5	2.84	3.621	9.65	3.97	1.63
	2.8	3.16	4.029	10.6	4.36	1.62
	3.2	3.58	4.564	11.8	4.86	1.61
60.5	2.3	3.30	4.205	17.8	5.90	2.06
	3.2	4.52	5.760	23.7	7.84	2.03
	4.0	5.57	7.100	28.5	9.41	2.00
76.3	2.8	5.08	6.465	43.7	11.5	2.60
	3.2	5.77	7.349	49.2	12.9	2.59
	4.0	7.13	9.085	59.5	15.6	2.56
89.1	2.8	5.96	7.591	70.7	15.9	3.05
	3.2	6.78	8.636	79.8	17.9	3.04
	4.0	8.39	10.69	97.0	21.8	3.01
101.6	3.2	7.76	9.892	120	23.6	3.48
	4.0	9.63	12.26	146	28.8	3.45
	5.0	11.9	15.17	177	34.9	3.42
114.3	3.2	8.77	11.17	172	30.2	3.93
	3.6	9.83	12.52	192	33.6	3.92
	4.5	12.2	15.52	234	41.0	3.89
	5.6	15.0	19.12	283	49.6	3.85
139.8	3.6	12.1	15.40	357	51.1	4.82
	4.0	13.4	17.07	394	56.3	4.80
	4.5	15.0	19.13	438	62.7	4.79
	6.0	19.8	25.22	566	80.9	4.74
165.2	4.5	17.8	22.72	734	88.90	5.68
	5.0	19.8	25.16	808	97.8	5.67
	6.0	23.6	30.01	952	115	5.63
	7.0	27.3	34.79	1090	132	5.60

APPENDIX G

Carbon Steel Tubes For General Structural Purposes

JIS G 3444 - 1988 - STK 290
JIS G 3444 - 1988 - STK 400
JIS G 3444 - 1988 - STK 500
JIS G 3444 - 1988 - STK 540

Outside Diameter	Wall Thickness	Calculated Weight	Cross-Sectional Area	Geometrical Moment of Inertia	Modulus of Section	Radius of Gyration of Area
mm	mm	kg/mm	cm^2	cm^4	cm^3	cm
190.7	4.5	20.7	26.32	1140	120	6.59
	5.0	22.9	29.17	1260	132	6.57
	6.0	27.3	34.82	1490	156	6.53
	7.0	31.7	40.40	1710	179	6.50
216.3	4.5	23.5	29.94	1680	155	7.48
	6.0	31.1	39.64	2190	203	7.44
	7.0	36.1	46.03	2520	233	7.40
267.4	6.0	38.7	49.27	421x10	315	9.24
	6.6	42.4	54.08	460x10	344	9.22
	7.0	45.0	57.26	486x10	363	9.21
	8.0	51.2	65.19	549x10	411	9.18
	9.0	57.3	73.06	614x10	457	9.14
	9.3	59.2	75.41	629x10	470	9.13
355.6	6.4	55.1	70.21	107×10^{2}	602	12.30
	7.9	67.7	86.29	130×10^{2}	734	12.30
	9.0	76.9	98.00	147×10^{2}	828	12.30
	9.5	81.1	103.30	155×10^{2}	871	12.20
	12.0	102.0	129.50	191×10^{2}	108x10	12.20
	12.7	107.0	136.80	201×10^{2}	113x10	12.10
406.4	7.9	77.6	98.90	196×10^{2}	967	14.10
	9.0	88.2	112.40	222×10^{2}	109x10	14.10
	9.5	93.0	118.50	233×10^{2}	115x10	14.00
	12.0	117.0	148.70	289×10^{2}	142x10	14.00
	12.7	123.0	157.10	305×10^{2}	150x10	13.90
	16.0	154.0	196.20	374×10^{2}	184x10	13.80
457.2	9.0	99.5	126.70	318×10^{2}	140x10	15.80
	9.5	105.0	133.60	335×10^{2}	147x10	15.80
	12.0	132.0	167.80	416×10^{2}	182x10	15.70
	12.7	139.0	177.30	438×10^{2}	192x10	15.70
	16.0	174.0	221.80	540×10^{2}	236x10	15.60

Tolerances:

Description	Tolerance	
Thickness (t)	t < 3mm	± 0.3mm
	3mm ≤ t < 12mm	± 10%
	12mm ≥ t	± 10%, - 1.2mm
Outside Diameter (OD)	OD < 50mm	± 0.25mm
	50mm ≥ OD	± 0.5%