STUDY ON HEAVY VEHICLE (TRUCK AND TRAILER) CONFIGURATION IN MALAYSIA AND ITS IMPLICATION TO ACCIDENTAL IMPACT ON BRIDGE PIER DESIGN

by

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Dissertation submitted in partial fulfillment of
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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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BACHELOR OF ENGINEERING (Hons)
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MAY 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 references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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TUAN JAZLAN BIN TUAN MOOD

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ABSTRACT

The purpose of the study is to investigate the implication of accidental impact to bridge design, especially the bridge piers. In the event of accident between heavy vehicles and bridge pier, huge accidental impact will be developed due to their massive mass. The increase of these accidents cases has caused structural engineer to consider the accidental impact of lateral load in the bridge design. Besides providing safe and economical bridge design, the other objectives are to reduce fatality and also economic loss. It is essential to assess the bridge pier that had been constructed before to test their ability to withstand the accidental impact of lateral load. The scopes of study under this research project involve the identification of various types and configuration of heavy vehicles, specifically trucks and trailers, the codes used to analyze the accidental impact of lateral loads on bridge piers and also the analysis of the bridge piers section based on the codes. The methodology of this study was divided into four main parts, which includes defining the problem statement, objectives, and chosen area of this study, literature review, data collection, and finally, the analysis and interpretation of data. At the end of the study, based on the analysis of the accidental impact to the bridge piers, it is anticipated that structural engineers that design bridges can provide adequate protection for the bridges to avoid collapse or failure of the bridge.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	Title Page	**0**
	Certification of Approval	**2**
	Certification of Originality	**3**
	Acknowledgement	**4**
	Abstract	**5**
	Table of Contents	**6**
	List of Figures	**8**
	List of Tables	**9**
1	**INTRODUCTION**	
	1.1 Background of the study	10
	1.2 Problem statement	11
	1.3 Objective	11
	1.4 Scope of study	11
2	**LITERATURE REVIEW**	
	2.1 Introduction	12
	2.2 Heavy vehicle configuration	13
	2.3 Implication of accidental impact to bridge structures	13
	2.4 Codes to assess the vehicle impacts during collision	14
3	**METHODOLOGY**	
	3.1 Research methodology	19
	3.2 Area of study	20
	3.3 Data collection	21
	3.4 Data analysis	21
	3.5 Key milestones	23
	3.5 Gantt chart	24

4 **RESULT AND ANALYSIS**

4.1 Mean impact force calculation 25

4.2 Shear and bending moment analysis 26

4.3 Reinforcement analysis 30

5 **RECOMMENDATION AND CONCLUSION**

5.1 Recommendation 38

5.2 Conclusion 39

REFERENCES **40**

APPENDICES **42**

LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 1:	Vehicle Impact during Collision	15
Figure 2:	Collision Force on Support for Bridges and Buildings.	18
Figure 3:	Research Methodology	19
Figure 4:	Elevation of Pier and Structural Idealization	26
Figure 5:	Cross Section of Bridge Piers	27
Figure 6:	Load Cases and Combination	27
Figure 7:	Shear and bending moment for case I, II, III and IV	29
Figure 8:	Pier Cross Section, stress and Strain Distribution	31
Figure 9:	Moment and Applied Force Interaction Values	32
Figure 10:	Tension and Compression Failure	36
Figure 11:	Graph of *M*-*N* Interaction	37

LIST OF TABLES

TABLE	TITLE	PAGE
Table 1: Indicative Equivalent Static Forces due to Vehicular Impact		17
Table 2: Maximum Gross Vehicle Weight for Various Axle Configurations.		20
Table 3: Collision Loads on Supports of Bridges over Highways.		22
Table 4: Gantt Chart		24
Table 5: Static Impact Force using Equations		25
Table 6: Summary of *M-N* Interaction Values		37

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Heavy vehicle is vehicle utilized to transport goods or passengers. In European Countries, heavy vehicle is defined as any road vehicle or combination of road vehicles with a gross vehicle weight rating of 4,500 kg or more (UN ECE, 2013). In Malaysia, under the Weight Restriction Orders 2003 (Amendment), heavy vehicle is classified as vehicle with the unladen weight of 7,500 kg and the largest gross vehicle weight allowable is for seven axles tipper or dumper type lorry up to 51,000 kg (RTD, 2012). Throughout this study, the type of heavy vehicle that is selected, are trucks and trailers. Several heavy vehicle characteristics which will be studied are axle loads, axle configuration in term of spacing and locations, and gross vehicle weight. Axle load is the portion of the overall weight for vehicle transported by a certain axle, while the maximum permissible load carried by a particular axle is known as axle load limit (Osama et al., 2012). On the other hand, axle configuration can be categorized into two types which are rigid and articulated.

Bridge structures comprised of several main parts, which includes beams, decks and also column or piers to support them. This study focuses on the bridge pier analysis. In the event of accident involving collision between heavy vehicles and bridge pier, they will produce huge accidental impact due to greater mass compared to other type of vehicles. A large shear force profile will be developed within a short period of time. Bridge mechanism may fail or collapse due to the loss of support from bridge piers depending upon the severity of accidental impact from collision.

1.2 Problem Statement

The main concern in designing bridges is to accommodate the axial load from vehicles that passes over them, rather the impact of lateral load onto the bridge structure. However, with the increase of cases involving collision between heavy vehicles and bridge pier, there is a growing need for structural engineer to consider the accidental impact of lateral load. Besides providing safe bridge design, the other objectives are to reduce fatality and also economic loss. Bridge piers may experience substantial damage and require fixing or reconstruction.

It is essential to assess the bridge pier that had been constructed before to ensure for their ability to withstand the accidental impact of lateral load. Piers for existing bridges may not be required to be assessed since they are constructed with adequate barriers and according to the current bridge design codes, which have been updated to include the accidental impact of lateral load.

1.3 Objective

The objectives of this study are:

- To identify and compare the various configurations of heavy vehicles, specifically trucks and trailers in Malaysia.
- To carry out analysis on bridge piers section based on lateral load from heavy vehicle.

1.4 Scope of Study

The scopes of study under this research project involved:

- Identify the various type configurations of heavy vehicles, specifically trucks and trailers in Malaysia.
- Identify the codes to analyze the accidental impact of lateral loads.
- Analyze the bridge piers section based on the codes.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Road transportation in Malaysia is growing rapidly in tandem with the vast economic development. The rapid increase in road transportation network leads not only to the development of road infrastructures but also to the technical development of the heavy vehicle such as larger bearing capacity and heavier truck and trailers (Osama et al., 2012). According to the bulletin published by Malaysian Automotive Association for October 2012 edition, a total of 54531 unit commercial vehicles had been registered until September 2012. Out of 54351 unit commercial vehicles, 12579 units of them are trucks and 714 units are prime movers. (MAA, 2012)

The rapid increase in the number of infrastructure projects and heavy vehicle manufacturing has increased the probability of collision between those two. The rise in structural collision cases has been reported in the USA as well as in other parts of the world. A total of 114 bridge failures in the United States over a 38-year period (1951 - 1988), had been analyzed. Out of the 114 failures, 17 cases (15%) of bridge failures were due to truck collision (Hartik et al., 1990). According to Wardhana and Hadiprono, 2003, similar study on analysis of 503 bridge failures over an 11-year period (1989 – 2000), has resulted in 14 cases (3%) of bridge failures were caused by collisions of trucks or other vehicles.

The collision can be accidental in the case of a vehicle going astray or intentional, as in terrorist attack. This has made vehicle collisions one of the leading causes of the structural failure. Bridge columns, lower story columns of buildings, traffic signal structures and electric poles are the most vulnerable structural members to vehicle impact. (Sharma et al., 2008)

2.2 Heavy Vehicle Configuration

Heavy vehicle configuration differs from one place to another. Heavy vehicle in European Countries is described as any road vehicle or combination of road vehicles with a gross vehicle weight of 4,500 kg or more (UN ECE, 2013).

In French, heavy vehicle is any road vehicle or combination of road vehicles with a gross vehicle weight rating (GVWR) of 4,500 kg or more. The GVWR indicates the vehicle weight, including its maximum load capacity, according to the manufacturer's specifications. (Societe de I'assurance Automobile)

$$GVWR = net\ mass + maximum\ load\ capacity$$

Meanwhile in Malaysia, heavy vehicle is defined as vehicle with the unladen weight of 7,500 kg up to the laden weight of 51,000 kg (RTD, 2012).

2.3 Implication of Accidental Impact to Bridge Structures

Bridge columns, buildings columns and electric poles are often made from reinforced concrete. Therefore the design and protection of RC columns subject to vehicle impact are important considerations. The RC column sustains damage during impact due to the transfer of large shear force over a short interval of time. Due to the short interval, the resisting mechanism is based on shear, inertia, and local deformation rather than overall displacement. Also, the damage state varies depending upon the type and severity of the impact. For minimizing the damage to the RC column and ensuring an economic design, a performance-based analysis and design is required. The damage state has to be identified with the performance level of the structure whose RC column might be subject to vehicle impact. These performance levels have to be associated with the different impact levels of vehicle for achieving the desired design criteria.

Current analysis methods and experimental procedures to estimate the shear force capacity and demand or RC columns do not capture the complex mechanism of impact events. Current procedures of estimating the shear capacity of RC columns are based on static calculations and are verified and calibrated by quasi-static experiments (Gardoni et al., 2002). These procedures are based on a cantilever RC column with the first mode of approximation. However, experiment and simulations have shown that the shear force capacity during an impact event can be higher than the values estimated by the static procedures. (Louw et al., 1992).

The increase in the shear force capacity during an impact can be attributed to various factors, such as increase in strength due to the strain rate effect, crack propagation, inertia effect, viscous damping, relative stiffness between the impacting bodies, and composite action. The behaviour of the RC cloumns also changes from the first mode approximation of the cantilever column. The current codes, Eurocode 2, previous British Standard Codes, and AASHTO-LFRD (AASHTO, 2007) and others provision assumes a constant value for the shear force demand on a bridge column. The shear force demand imposed on the RC column are often underestimated in a real collision event. (El-Tawil, 2005). A number of experiments have been conducted to understand the failure mechanism and dynamic effects during the vehicle impact. The salient features can be summarized as follows:

i. Cracks propagate throught the aggregate thickness, thus increasing the strength and toughness of the concrete member.
ii. In concrete, the brittle behaviour increases with the increase in loading rate. (Mendis et al., 2000)
iii. The strength of the reinforcing steel bar increasing with loading rate. (Malvar, 1998)
iv. Shear failure mode becomes predominant with the increasing loading.
v. A plastic hinge is formed at the point of contact.

2.4 Codes to Assess the Accidental Impacts during Collision

In assessing the accidental impacts of lateral loads during collision with the bridge structures, several codes were chosen, which includes:

i. <u>British Standard 6779 (BS 6779:Part 1:1998)</u>

The mean lateral deceleration of the centre of gravity of the vehicle resulting from an angle impact may be approximated by:

$$a = \frac{(v\sin\Theta)^2}{2\,[c\sin\Theta + \mathrm{b}(\cos\Theta - 1) + z]}$$

Where

a	is the mean lateral deceleration (m/s^2)
b	is the distance of the centre of gravity of the vehicle from the side of the vehicle (m)
c	is the distance of the centre of gravity of the vehicle from the front of the vehicle (m)
v	is the approach velocity (m/s)
z	is the sum of barrier deflection and depth of the vehicle crumpling measured perpendicularly to the face of the barrier (m)
Θ	is the angle between the path of vehicle and barrier at impact (degrees)

It follows that the mean impact force F (in kN) is obtained from equation:

$$F = ma = \frac{m(v\sin\Theta)^2}{2000\,[c\sin\Theta + b(\cos\Theta - 1) + z]}$$

where m is the vehicle mass (in kg).

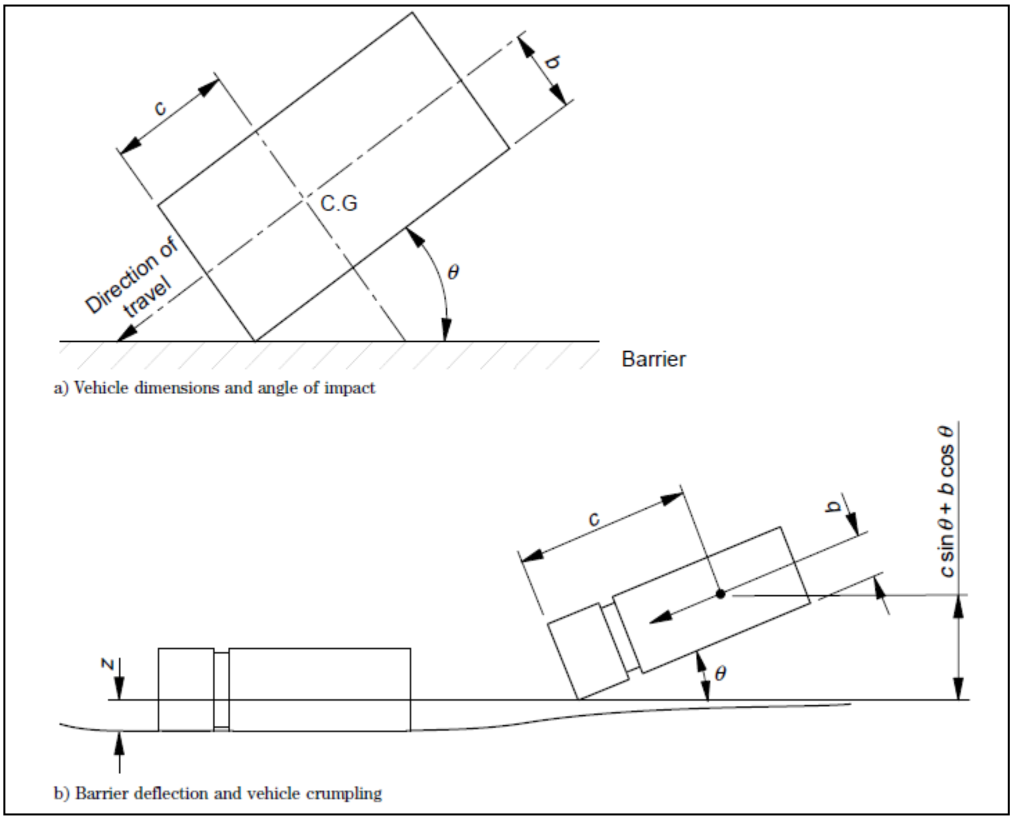


Figure 1: Vehicle impact during collision according to BS 6779.

ii. Eurocode I (EN 1991-1-7:2006)

Eurocode I EN 1991-1-7:2006 has provided provision for several fields of applications which includes:

- Impact from road vehicles. (excluding collision on lightweight structures)
- Impact from forklift trucks.
- Impact from trains. (excluding collision on lightweight structures)
- Impact from ships.
- The hard landings of helicopters on roofs.

Our interest in the application for this code is to study the impact from road vehicles towards the bridge structures. The code also stated that for bridges, the actions due to the impact and the mitigating measures provided should take into account, amongst other things, the type of traffic on and under the bridge and the consequences of the impact.

For representations of actions, several notations should be made, which are:

- Actions due to impact should be determined by a dynamic analysis or represented by an equivalent static force.
- It may be assumed that the impacting body absorbs all the energy.
- For determining the material properties of the impacting object and of the structure, upper and lower characteristic values should be used, where relevant. Strain rate effects should be also taken into account, where appropriate.
- For structural design the actions due to the impact may be represented by an equivalent static force giving the equivalent effects in the structure. This simplified model may be used for the verification of static equilibrium, for strength verifications and for the determination of deformations of the impacted structure.
- For structures which are designed to absorb impact energy by elastic-plastic deformations of members (i.e soft impact), the equivalent static loads may be determined by taking into account both plastic and the deformation capacity of such members.
- For structures for which the energy is mainly dissipated by the impacting

body (i.e hard impact), the dynamic or equivalent static forces may be determined from clauses 4.3 to 4.7 in Eurocode I EN 1991-1-7:2006.

According to clause 4.3 in Eurocode I EN 1991-1-7:2006, it described the impact on supporting substructures based on the accidental actions caused by road vehicles.

Table 1: Indicative equivalent static forces due to vehicular impact on members supporting structures over or adjacent to roadways.

Category of traffic	Force F_{dx}[a] (kN)	Force F_{dx}[a] (kN)
Motorways and country national and main roads	1000	500
Country roads in rural areas	750	375
Roads in urban area	500	250
Courtyards and parking garages with access to:		
- Cars	50	25
- Lorries[b]	150	75

[a] x = direction of normal travel, y = perpendicular to the direction of normal travel

[b] The term “lorry” refer to vehicles with minimum gross weight greater than 3.5 tons.

Based on the **Table 1**, the application of the forces F_{dx} and F_{dy} should be defined. It is recommended that F_{dx} does not act simultaneously with F_{dy}. As for the impact on the supporting structures, the applicable area of resulting collision force F should be specified. For impact from lorries (vehicles with minimum gross weight greater than 3.5 tons), the collision force F may be applied at any height h between 0.5 m to 1.5 m above the level of the carriageway or higher where certain types of protective barriers are provided. The recommended application area is a = 0.5 m (height) by 1.50 m (width) or the member width, whichever is the smaller.

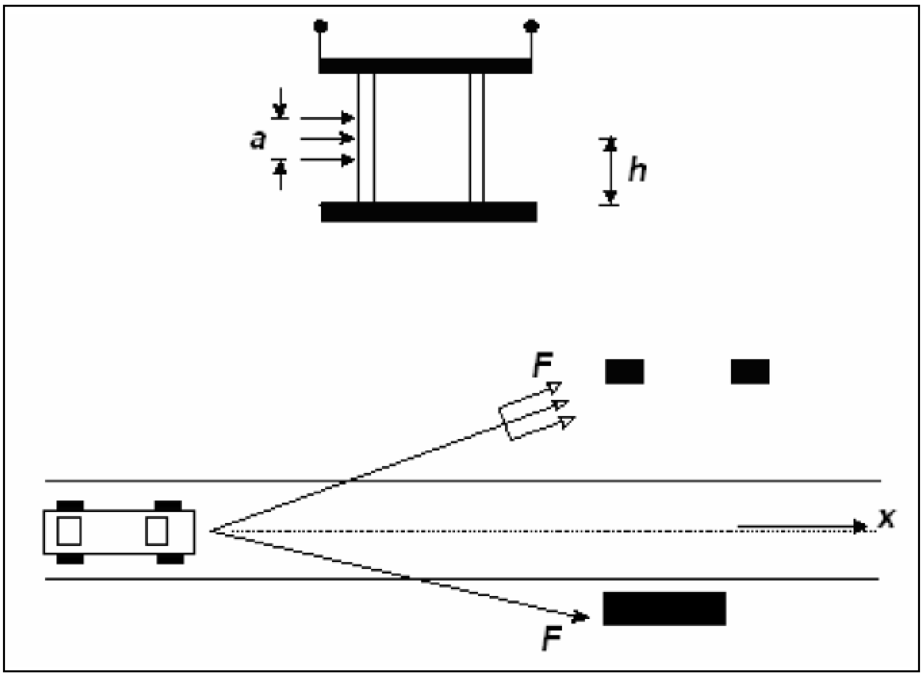


Figure 2: Collision force on supporting substructures near traffic Lanes for bridges and supporting structures for buildings.

Where

a	is the height of the recommended force application area. Ranges from 0.25 m (cars) to 0.5 m (lorries).
h	is the location of the resulting collision force F, i.e the height above the level of the carriageway. Ranges from 0.5 m (cars) to 1.50 m (lorries).
x	is the centre of the lane.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The methodology of this study was divided into four main parts, which includes:

Problem Statement and Objective of the study

- Define clearly the problem statement
- Set the area of study and the objectives

↓

Literature Review

- Gathering information from various sources such as journals, research papers and websites.

↓

Data Collection

- Identify the various type configurations of heavy vehicles, specifically trucks and trailers.
- Identify the codes to analyze the accidental impact of lateral loads.

↓

Data Analysis and Interpretation

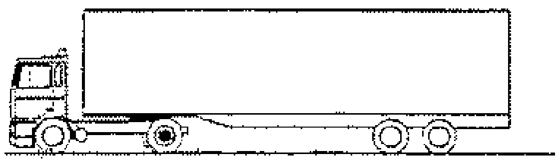
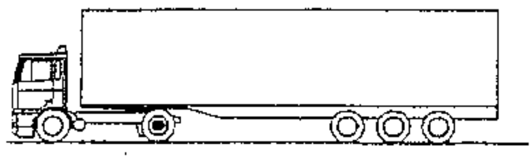
- Example of bridge pier cross section.
- Analyze the bridge piers section based on the codes.

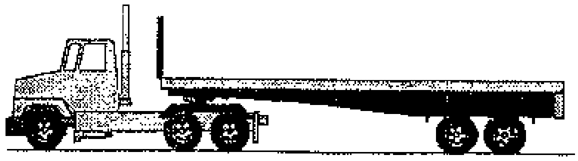
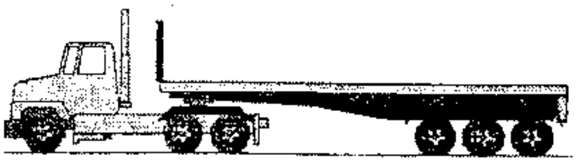
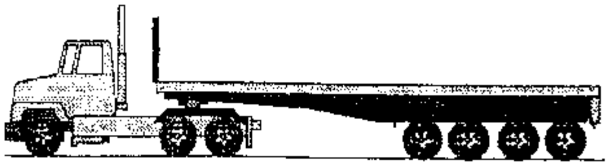
Figure 3: Research methodology

3.2 Area of Study

In the study, truck and trailers are chosen to represent the heavy vehicle due to their massive mass. Truck and trailers are categorized based on axle configuration and the loads they carried. **Table 2** shows the maximum gross vehicle weight that is allowable for various axle configurations of trucks and trailers in Malaysia.

Table 2: The maximum gross vehicle weight that is allowable for various axle configurations of trucks and trailers. (RTD, 2012)

Axle Configuration	**Maximum Gross Vehicle Weight (GVW)**	
	Peninsular	**Sabah / Sarawak**
Rigid vehicle with 2 axles (1+1) 	18,000 kg	16,000 kg
Rigid Vehicle with 3 axles (1+2) 	25,000 kg	21,000 kg
Articulate vehicle with 4 axles (1+1+2) 	37,000 kg	32,000 kg
Articulate vehicle with 5 axles (1+1+3) 	39,000 kg	34,000 kg

Articulate vehicle with 5 axles (1+2+2) 	40,000 kg	34,000 kg
Articulate vehicle with 6 axles (1+2+3) 	44,000 kg	38,000 kg
Articulate vehicle with 7 axles (1+2+4) 	51,000 kg	44,000 kg

Besides that, the bridge piers are chosen to be analysed for producing a safe design.

3.3 Data Collection

Data collections which are involved in this research project are:

- Specification drawing of every rigid and articulated vehicle configuration, distribution of weight at axles for every rigid and articulated vehicle configuration.
- Codes for bridge design and codes for analyzing the accidental impact of lateral load.

3.4 Data Analysis

There are two methods which can be adopted to analyze the accidental impact of lateral loading, which are:

i. A quasi-static method in which the impact force is replaced by an equivalent static load.
ii. A rigorous dynamic analysis

In the study, the quasi-static approach is utilized since it is simpler to apply compared to the dynamic analysis but it may yield a more conservative result.

In order to calculate the lateral loads for each configuration of truck and trailers, British Standard 6779 Part 1:1998 is used, while the analysis of bridge piers uses Eurocode I (EN 1991-1-7:2006).

Table 3: Collision loads on supports of bridges over highways.

	Load Normal to the carriageway below (kN)	**Load Normal to the carriageway below (kN)**	**Point of application on bridge support**
Main Load component	500	1000	At the most severe point between 0.75m and 1.50m above ground level adjacent to support.
Residual load component	250 (100)	500 (100)	At the most severe point between 1.00m and 3.00m above ground level adjacent to support.

For assessment of bridge supports according to EN 1991-1-7:2006, the nominal loads given in **Table 3** can be multiplied by a reduction factor of:

$$\left(\frac{30}{30+m}\right)$$

where *m* is the mass of the support member in tonnes. This reduction is based on momentum conservation and assumes that the support member (piers or column) participates in the dynamic response. Hence the deck loading or weight of foundation cannot be included when calculating m. For the assessment of bridge supports this reduced value of impact loading shall be applied statically. It has been shown by previous laboratory test, that a considerable amount of the impact energy is lost through local damage vibration and the vehicle itself. Therefore, for the assessment of foundations, deck slabs and other members directly connected to the support member, the loads in **Table 3** can be reduced by 50% and treated as acting statically. For more remote members, for example piling systems, the loads shown in **Table 3** can be reduced by 75% and treated as acting statically.

3.5 Key Milestones

Several key milestones for this research project must be achieved in order to meet the objective of this study:

Table 4: Key Milestones

No.	Activities	Date
1	Title selection, and identification of problem statement and objectives of study	Week 1
2	Completion literature review, and research methodology	Week 6
3	Submission of Proposal Defense Report	Week 7
4	Proposal Defense (Oral presentation)	Week 9
5	Submission of Interim Report	Week 14
6	Submission of Progress Report	Week 21
7	Complete the analysis of bridge pier section	Week 25
8	Submission of draft of dissertation	Week 26
9	Submission of dissertation	Week 27-28

3.6 Gantt Chart

Table 5: Gantt Chart

NO	ACTIVITIES	WEEK																											
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Preliminary Research work																												
2	Extended proposal Defense																												
3	Proposal Defense																												
4	Project Work Continues																												
5	Submit Interim Draft Report																												
6	Interim Report																												
7	Project Work Continues																												
8	Submit Progress Report																												
9	Project Work Continues																												
10	Pre-SEDEX																												
11	Submission of Draft Report																												
12	Submission of Dissertation																												
13	Submission Technical Paper																												
14	Oral Presentation																												
15	Submission of Hardbound																												

CHAPTER 4

RESULT AND ANALYSIS

4.1 Mean Impact Force Calculation

The calculation of mean impact force based on the code of BS 6779 Part 1:1998, is tabulated and shown in **Table 6**. The corresponding mass of heavy vehicles used in this analysis taken from the actual specification drawing of trucks and trailers in **Appendix I**. The value of *c*, which is distance between the centre of gravity of the vehicle to the front of vehicle, varies due to different length of heavy vehicle. For analysis, it is assumed that the angle of collision occurs completely at 90°, and hence the effect of load normal to the carriageway is omitted. The approach velocity, *v* is taken as 80 km/h or 22.22 m/s following the standard of speed limit for Malaysian roads.

Table 6: Static impact force using equations as per BS 6779.

Mass (kg)	**Allowable mass (kg)**	***b* (m)**	***c* (m)**	***v* (m/s)**	***z* (m)**	***Ɵ* (°)**	***a* (m/s^2)**	***F* (kN)**
10600	11000	1.25	2.593	22.22	1.42	90	89.363	947.244
19320	21000	1.25	6.096	22.22	1.42	90	39.397	761.158
22805	25000	1.25	4.340	22.22	1.42	90	54.737	1248.279
35040	36800	1.25	6.790	22.22	1.42	90	35.469	1242.834
36256	37000	1.25	6.250	22.22	1.42	90	39.452	1394.129
35270	39000	1.25	6.600	22.22	1.42	90	36.464	1286.100
50868	51000	1.25	6.096	22.22	1.42	90	39.397	2004.068

From the **Table 6**, the trailer which has a lateral mean impact force of 2004.1 kN is considered for analysis since it imposed the highest impact. The value is higher than the recommended value in BS 6779 Part 1:1998 code, which is 1000 kN for load parallel to the carriageway. Therefore the higher mean impact force will be taken as the basis impact force for calculation in the bridge pier analysis.

4.2 Shear and Bending Moment Analysis for Bridge Pier Section

A bridge column of dimension 1000 × 1000 × 7000 mm is considered for quasi static analysis to find the shear and bending moment caused by lateral load. The foundation is located at 2050 mm below the ground level.

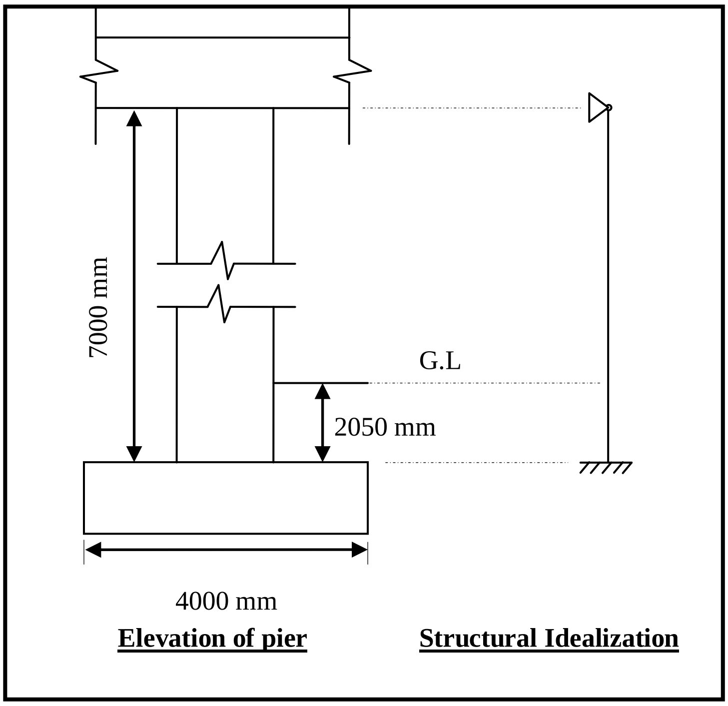


Figure 4: Elevation of pier and structural idealization

Mass of the support member, m in tonnes = (1.0×1.0×7.0) × 2.5 = 17.5 tonnes

$$\text{Reduction factor} = \left(\frac{30}{30+m}\right) = \left(\frac{30}{30+17.5}\right) = 0.632$$

The reduction factor of 0.632 is based on the momentum conservation and assumes that the support member alone participates in dynamic response, excluding the deck loading or weight of foundation when calculating m.

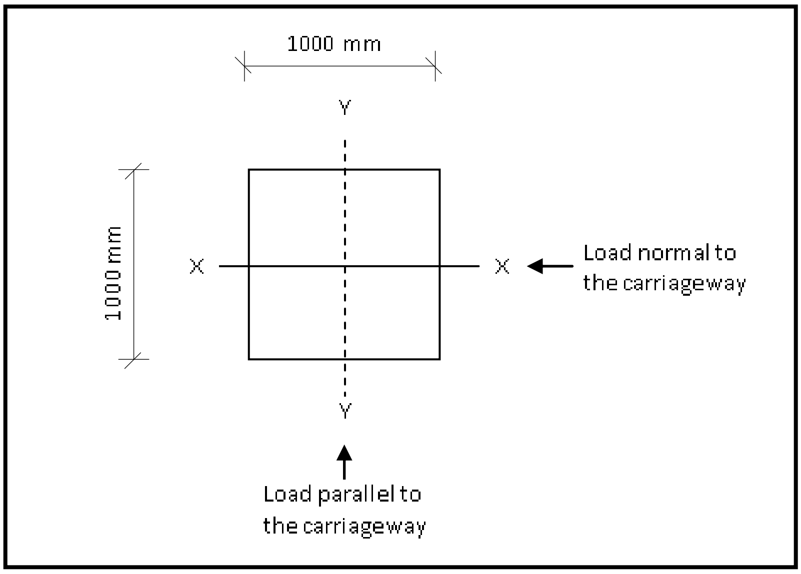


Figure 5: Cross section of bridge pier

Figure 5 shows the cross section of bridge pier, where the load parallel to the carriageway is acting. The load from normal to carriageway is zero since the assumption of angle of collision is 90°**.** The load parallel to the carriageway is shown below:

Main load	= 2004.1×0.632	= 1266.6 kN
Residual Load	= 2004.1×0.5×0.632	= 633.3 kN

To determine the bending moment and shear force, 4 load cases will be considered in this direction of load, which is shown in **Figure 6** below:

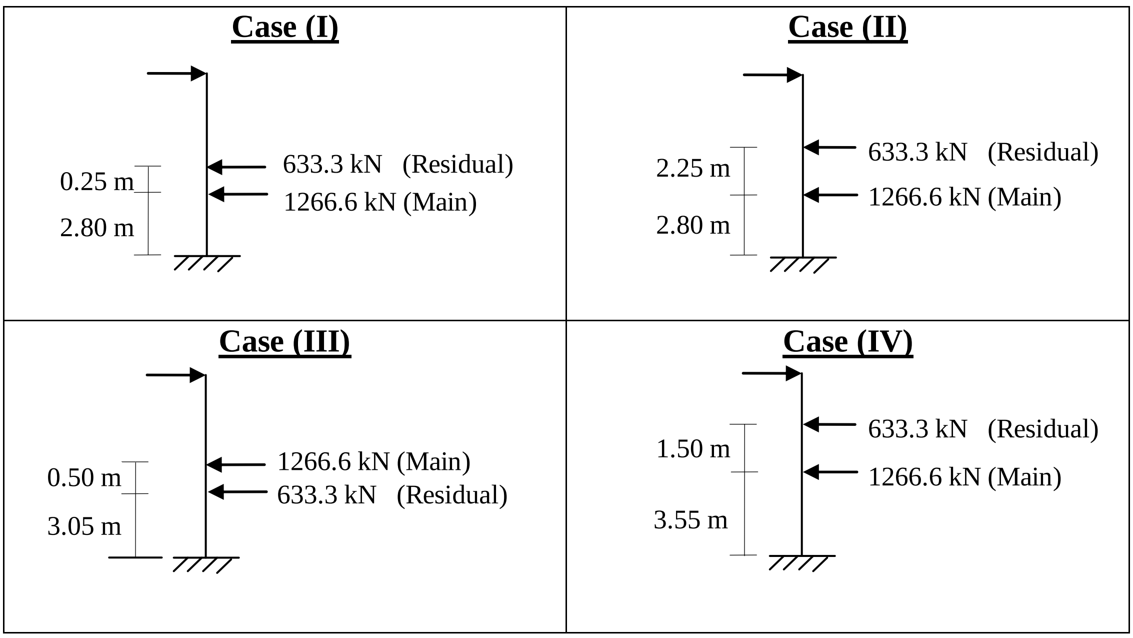


Figure 6: Load cases and combination

The material properties of concrete are shown below:

Modulus of elasticity, $E_c = (20+0.27f_{cu})$ where $f_{cu} = 40$ N/mm^2

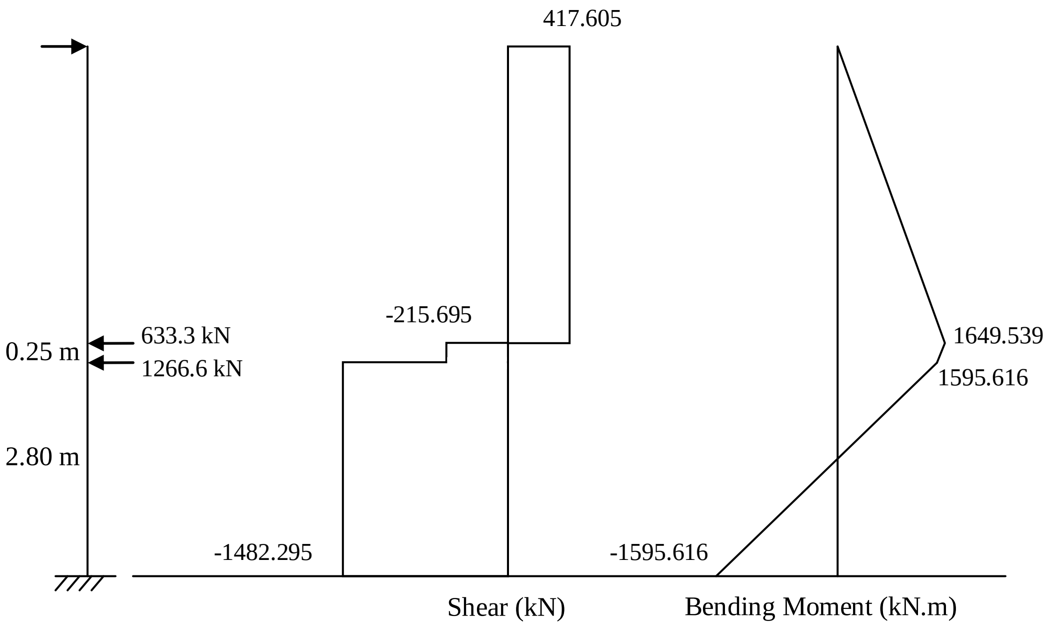
Therefore $E_c = (20+0.27\times40) = 30.8$ kN/mm^2

Poisson ratio of concrete, $v = 0.2$

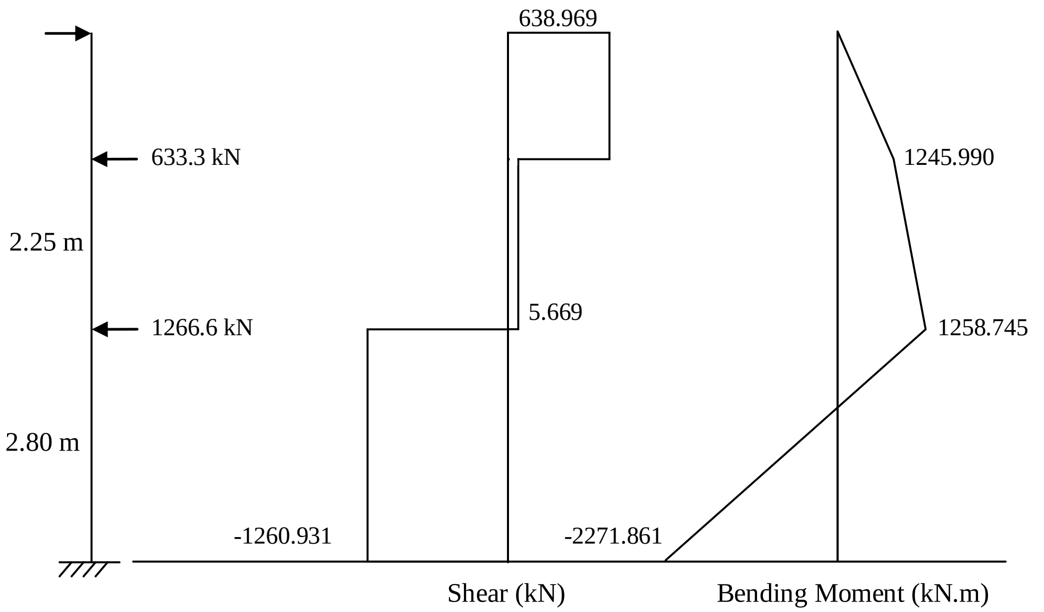
Shear modulus of concrete, $G = \dfrac{E}{2(1+v)} = \dfrac{30.8}{2(1+0.2)} = 12.83$ kN/mm^2

The result of shear and bending moment for case I, II, III, and IV are shown below:

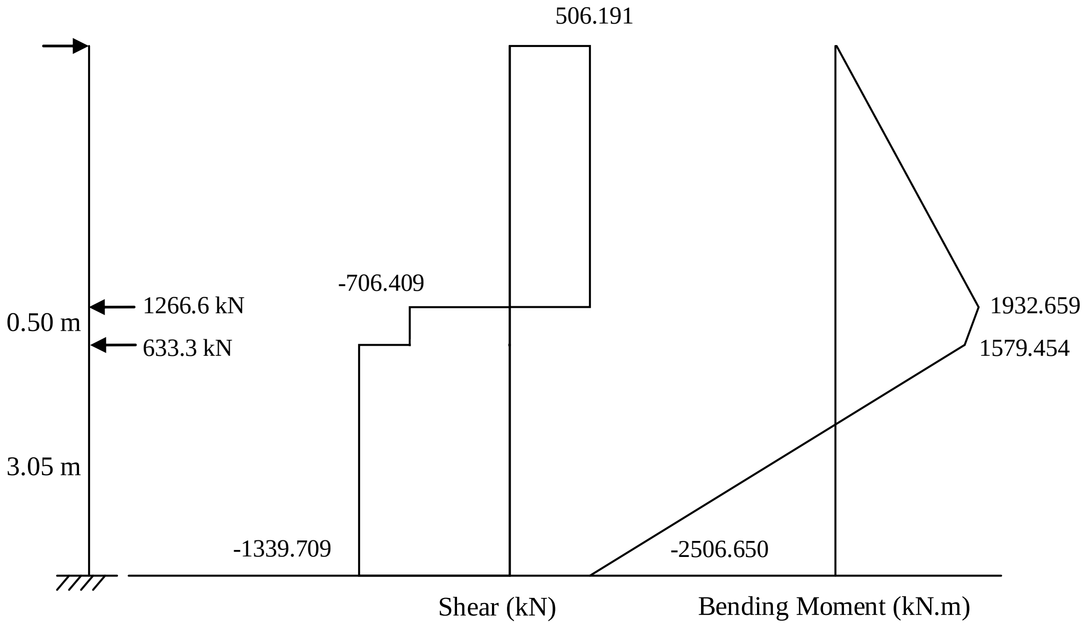
Case (I)



Case (II)



Case (III)



Case (IV)

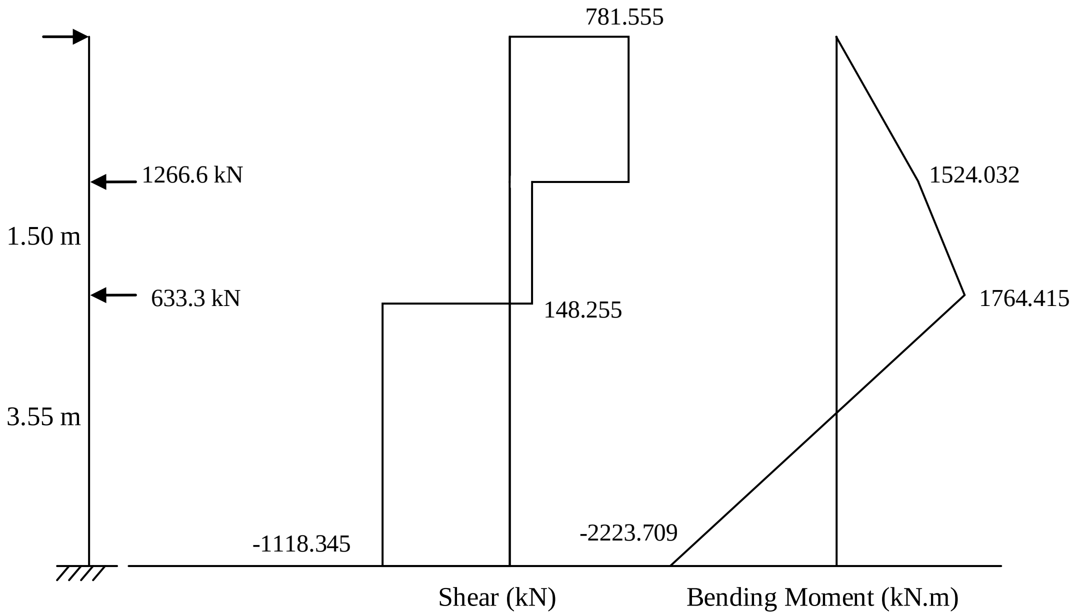


Figure 7: Shear and bending moment for case I, II, III and IV.

Based on load cases and combination in **Figure 7**, a large shear and bending moment developed in Case III. Therefore the design of bridge pier will need to be based on the largest shear and bending moment as experienced in Case III.

4.3 Reinforcement Analysis

The design of reinforcement for bridge pier has to follow certain rule. The rules that governing the minimum and maximum amounts of reinforcement in a load bearing column/piers are as follows:

i. Longitudinal steel

- A minimum of four bars is required in a rectangular column (one bar in each corner) and six bars in a circular column. Bar diameter should not be less than 12 mm.
- The minimum area of steel is given by:

$$A_s = \frac{0.10N_{ed}}{0.87f_{yk}} \geq 0.002A_c$$

- The maximum area of steel, at laps is given by ($A_{s,max}$ / A_c) <0.08, where As is the total area of longitudinal steel and Ac is the cross sectional area of the column. Otherwise, in regions away from laps, the maximum area of steel is taken as ($A_{s,max}$ / A_c) <0.04.

ii. Links

- Minimum size of links is ¼ of compression bar but not less than 6 mm.
- Maximum spacing should not exceed the less than of 20 × size for the smallest compression bar or at least lateral dimension of the column or 400 mm. This spacing should be reduced by a factor of 0.60 for a distance equal to the larger lateral dimension of the column above and below a beam or slab, and also at lapped of longitudinal bars > 14 mm diameter.
- Where the direction of the longitudinal reinforcement changes, the spacing of the links should be calculated, while taking account of the lateral forces involved. If the change in direction is less or equal to 1 in 20 number calculation is necessary.
- Every longitudinal bar placed in a corner should be held by transverse reinforcement.
- No compression bar should be further than 150 mm from a restrained bar.

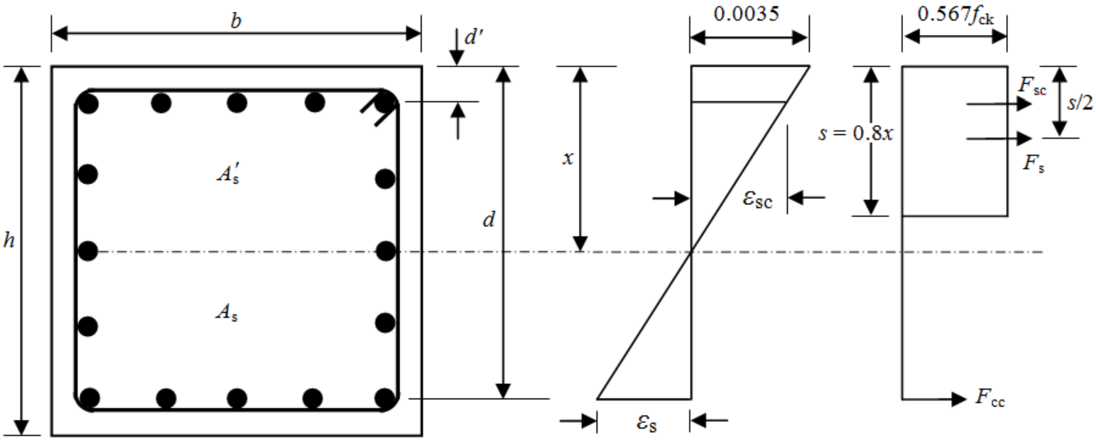


Figure 8: Illustration of column/pier cross section, stress and strain distribution. (Not to scale)

The illustration of bridge pier cross section, stress and strain distribution is shown in **Figure 8**. To calculate the reinforcement, the number of bars needed is 16T25 steel bar, with the link taken as 8 mm with 200 mm spacing. The details of the cross section are shown below:

Length of column, h = 1000 mm

Width of column, b = 1000 mm

Area of steel 16T25, A_s = 7853.0 mm^2

1. Minimum area of longitudinal reinforcement

$$A_{s,min} = \frac{0.10\ N_{ed}}{f_{yd}}, \text{ where } f_{yd} = 0.87\ f_{yk} \text{ and } N_{ed} = 0.87\ f_{yk}A_s \text{ (Assume full yield)}$$

$$= \frac{0.10\times0.87\times500\times7853.0}{0.87\times500}$$

$$= 758.3 \text{ mm}^2$$

$$d = 1000 - 50 - 8 - (32/2)$$
$$= 926 \text{ mm}$$

$$d' = 50 + 8 + (32/2)$$
$$= 74 \text{ mm}$$

For internal equilibrium $f_{yk}As = 0.85\ f_{ck}bs + f_{yk}A'_s$

For compatibility of strain

$$\varepsilon_{sc} = 0.0035\left(\frac{x - d'}{x}\right)$$

$$\varepsilon_s = 0.0035\left(\frac{d - x}{x}\right)$$

$$\varepsilon_{si} = 0.0035\left(\frac{h/2 - x}{x}\right)$$

Stress-strain relationship for the steel

$\varepsilon \geq \varepsilon_y = 0.00217 \qquad f = 0.87\, f_{yk}$

$\varepsilon < \varepsilon_y = 0.00217 \qquad f = E.\varepsilon_{sc}$

Equilibrium

$N = F_{cc} + F_{sc} + F_s + F_{si}$

$N = 0.85\, f_{ck}bs + f_{yk}A'_s + f_{yk}A_s + f_{yk}A_{si}$

Taking moment about the mid-depth section

$M = F_{cc}\,(h/2 - 0.8x/2) + F_{sc}\,(h/2 - d') + F_s\,(d - h/2) + F_{si}\,(0)$

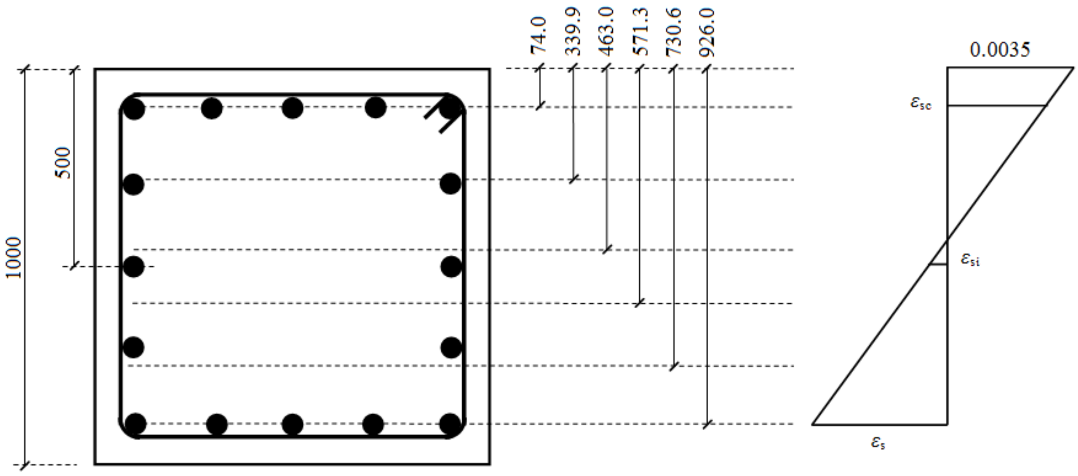


Figure 9: Moment, *M* and applied force, *N* interaction values. (Not to scale)

When *x* = 74 mm;

$$\varepsilon_{sc} = 0.0035\left(\frac{x-d'}{x}\right) = 0.0035\left(\frac{74-74}{74}\right) = 0$$

$$\varepsilon_{s} = 0.0035\left(\frac{d-x}{x}\right) = 0.0035\left(\frac{926-74}{74}\right) = 0.04030 > 0.00217$$

$$\varepsilon_{si} = 0.0035\left(\frac{h/2-x}{x}\right) = 0.0035\left(\frac{500-74}{74}\right) = 0.02014 > 0.00217$$

$$\begin{aligned} N &= 0.85\, f_{ck}bs - f_{yk}A_s - f_{yk}A_{si} \\ &= (0.85\times40\times1000\times0.8\times74) - (500\times2944.9) - (500\times1963.3) \\ &= 2012.80\times10^3 - 1472.45\times10^3 - 981.63\times10^3 \\ &= -\,441.3 \text{ kN} \end{aligned}$$

$$\begin{aligned} M &= 2012.80\times10^3\,(500 - 0.4\times74) + 1472.45\times10^3\,(926 - 500) + 0 \\ &= 946.82\times10^6 + 627.26\times10^6 + 0 \\ &= 1574.08\times10^6 \\ &= 1574.08 \text{ kN.m} \end{aligned}$$

When x = 339.9 mm;

$$\varepsilon_{sc} = 0.0035\left(\frac{x - d'}{x}\right) = 0.0035\left(\frac{339.9 - 74}{339.9}\right) = 0.00273 > 0.00217$$

$$\varepsilon_{s} = 0.0035\left(\frac{d - x}{x}\right) = 0.0035\left(\frac{926 - 339.9}{339.9}\right) = 0.00604 > 0.00217$$

$$\varepsilon_{si} = 0.0035\left(\frac{h/2 - x}{x}\right) = 0.0035\left(\frac{500 - 339.9}{339.9}\right) = 0.00165 < 0.00217$$

$$\begin{aligned} N &= 0.85 f_{ck}bs + f_{yk}A'_s - f_{yk}A_s - E.\varepsilon_{si}A_{si} \\ &= (0.85\times40\times1000\times0.8\times339.9) + (500\times2944.9) - (500\times2944.9) - (205\times10^3\times0.00165\times1963.3) \\ &= 9245.28\times10^3 + 1472.45\times10^3 - 1472.45\times10^3 - 664.09\times10^3 \\ &= 8581.2 \text{ kN} \end{aligned}$$

$$\begin{aligned} M &= 9245.28\times10^3 (500 - 0.4\times339.9) + 1472.45\times10^3 (500 - 74) + 1472.45\times10^3 (926 - 500) + 0 \\ &= 3365.65\times10^6 + 627.26\times10^6 + 627.26\times10^6 + 0 \\ &= 4620.17\times10^6 \\ &= 4620.17 \text{ kN.m} \end{aligned}$$

When x = 463.0 mm;

$$\varepsilon_{sc} = 0.0035\left(\frac{x - d'}{x}\right) = 0.0035\left(\frac{463.0 - 74}{463.0}\right) = 0.00294 > 0.00217$$

$$\varepsilon_{s} = 0.0035\left(\frac{d - x}{x}\right) = 0.0035\left(\frac{926 - 463.0}{463.0}\right) = 0.00350 > 0.00217$$

$$\varepsilon_{si} = 0.0035\left(\frac{h/2 - x}{x}\right) = 0.0035\left(\frac{500 - 463.0}{463.0}\right) = 0.00028 < 0.00217$$

$$\begin{aligned} N &= 0.85 f_{ck}bs + f_{yk}A'_s - f_{yk}A_s - E.\varepsilon_{si}A_{si} \\ &= (0.85\times40\times1000\times0.8\times463.0) + (500\times2944.9) - (500\times2944.9) - (205\times10^3\times0.00028\times1963.3) \\ &= 12593.60\times10^3 + 1472.45\times10^3 - 1472.45\times10^3 - 112.69\times10^3 \\ &= 12480.9 \text{ kN} \end{aligned}$$

$$\begin{aligned} M &= 12593.60\times10^3 (500 - 0.4\times463.0) + 1472.45\times10^3 (500 - 74) + 1472.45\times10^3 (926 - 500) + 0 \\ &= 3964.47\times10^6 + 627.26\times10^6 + 627.26\times10^6 + 0 \\ &= 5218.99\times10^6 \\ &= 5218.99 \text{ kN.m} \end{aligned}$$

When x = 500.0 mm

$$\varepsilon_{sc} = 0.0035\left(\frac{x - d'}{x}\right) = 0.0035\left(\frac{500.0 - 74}{500.0}\right) = 0.00298 > 0.00217$$

$$\varepsilon_{s} = 0.0035\left(\frac{d - x}{x}\right) = 0.0035\left(\frac{926 - 500.0}{500.0}\right) = 0.00298 > 0.00217$$

$$\varepsilon_{si} = 0.0035\left(\frac{h/2 - x}{x}\right) = 0.0035\left(\frac{500.0 - 500}{500.0}\right) = 0$$

$$\begin{aligned} N &= 0.85\, f_{ck}bs + f_{yk}A'_s - f_{yk}A_s \\ &= (0.85\times40\times1000\times0.8\times500.0) + (500\times2944.9) - (500\times2944.9) \\ &= 13600.00\times10^3 \\ &= 13600.0 \text{ kN} \end{aligned}$$

$$\begin{aligned} M &= 13600.00\times10^3\,(500 - 0.4\times500.0) + 1472.45\times10^3\,(500 - 74) + \\ &\quad 1472.45\times10^3\,(926 - 500) + 0 \\ &= 4080.00\times10^6 + 627.26\times10^6 + 627.26\times10^6 + 0 \\ &= 5334.52\times10^6 \\ &= 5334.52 \text{ kN.m} \end{aligned}$$

When x = 571.3 mm

$$\varepsilon_{sc} = 0.0035\left(\frac{x - d'}{x}\right) = 0.0035\left(\frac{571.3 - 74}{571.3}\right) = 0.00305 > 0.00217$$

$$\varepsilon_{s} = 0.0035\left(\frac{d - x}{x}\right) = 0.0035\left(\frac{926 - 571.3}{571.3}\right) = 0.002173 \approx 0.00217$$

$$\varepsilon_{si} = 0.0035\left(\frac{h/2 - x}{x}\right) = 0.0035\left(\frac{571.3 - 500}{571.3}\right) = 0.00044 < 0.00217$$

$$\begin{aligned} N &= 0.85\, f_{ck}bs + f_{yk}A'_s + E.\varepsilon_{si}A_{si} - f_{yk}A_s \\ &= (0.85\times40\times1000\times0.8\times571.3) + (500\times2944.9) + \\ &\quad (205\times10^3\times0.00044\times1963.3) - (500\times2944.9) \\ &= 15539.36\times10^3 + 1472.45\times10^3 + 177.09\times10^3 - 1472.45\times10^3 \\ &= 15716.45 \text{ kN} \end{aligned}$$

$$\begin{aligned} M &= 15539.36\times10^3\,(500 - 0.4\times571.3) + 1472.45\times10^3\,(500 - 74) + \\ &\quad 1472.45\times10^3\,(926 - 500) + 0 \\ &= 4218.63\times10^6 + 627.26\times10^6 + 627.26\times10^6 + 0 \\ &= 5473.15\times10^6 \\ &= 5473.15 \text{ kN.m} \end{aligned}$$

When x = 730.6 mm

$$\varepsilon_{sc} = 0.0035\left(\frac{x-d'}{x}\right) = 0.0035\left(\frac{730.6-74}{730.6}\right) = 0.00315 > 0.00217$$

$$\varepsilon_{s} = 0.0035\left(\frac{d-x}{x}\right) = 0.0035\left(\frac{926-730.6}{730.6}\right) = 0.00094 < 0.00217$$

$$\varepsilon_{si} = 0.0035\left(\frac{h/2-x}{x}\right) = 0.0035\left(\frac{730.6-500}{730.6}\right) = 0.00110 < 0.00217$$

$$\begin{aligned}
N &= 0.85\, f_{\text{ck}}bs + f_{\text{yk}}A'_{\text{s}} + E.\varepsilon_{si}A_{\text{si}} - E.\varepsilon_{s}A_{\text{s}} \\
&= (0.85\times40\times1000\times0.8\times730.6) + (500\times2944.9) + \\
&\quad (205\times10^3\times0.00110\times1963.3) - (205\times10^3\times0.00094\times2944.9) \\
&= 19872.32\times10^3 + 1472.45\times10^3 + 442.72\times10^3 - 567.48\times10^3 \\
&= 21220.01 \text{ kN}
\end{aligned}$$

$$\begin{aligned}
M &= 19872.32\times10^3\,(500 - 0.4\times730.6) + 1472.45\times10^3\,(500 - 74) + \\
&\quad 567.48\times10^3\,(926 - 500) + 0 \\
&= 4128.67\times10^6 + 627.26\times10^6 + 241.75\times10^6 + 0 \\
&= 4997.68\times10^6 \\
&= 4997.68 \text{ kN.m}
\end{aligned}$$

When x = 926.0 mm

$$\varepsilon_{sc} = 0.0035\left(\frac{x-d'}{x}\right) = 0.0035\left(\frac{926.0-74}{926.0}\right) = 0.00322 > 0.00217$$

$$\varepsilon_{s} = 0.0035\left(\frac{d-x}{x}\right) = 0.0035\left(\frac{926-926.0}{926.0}\right) = 0$$

$$\varepsilon_{si} = 0.0035\left(\frac{h/2-x}{x}\right) = 0.0035\left(\frac{926.0-500}{926.0}\right) = 0.00161 < 0.00217$$

$$\begin{aligned}
N &= 0.85\, f_{\text{ck}}bs + f_{\text{yk}}A'_{\text{s}} + E.\varepsilon_{si}A_{\text{si}} \\
&= (0.85\times40\times1000\times0.8\times926.0) + (500\times2944.9) + \\
&\quad (205\times10^3\times0.00161\times1963.3) \\
&= 25187.20\times10^3 + 1472.45\times10^3 + 647.99\times10^3 \\
&= 27307.64 \text{ kN}
\end{aligned}$$

$$\begin{aligned}
M &= 25187.20\times10^3\,(500 - 0.4\times926.0) + 1472.45\times10^3\,(500 - 74) + 0 \\
&= 3264.23\times10^6 + 627.26\times10^6 + 0 \\
&= 3891.49\times10^6 \\
&= 3891.49 \text{ kN.m}
\end{aligned}$$

When x = 1000.0 mm

$$\varepsilon_{sc} = 0.0035\left(\frac{x-d'}{x}\right) = 0.0035\left(\frac{1000.0-74}{1000.0}\right) = 0.00324 > 0.00217$$

$$\varepsilon_{s} = 0.0035\left(\frac{d-x}{x}\right) = 0.0035\left(\frac{1000.0-1000.0}{1000.0}\right) = 0.00026<0.00217$$

$$\varepsilon_{si} = 0.0035\left(\frac{h/2-x}{x}\right) = 0.0035\left(\frac{1000.0-500}{1000.0}\right) = 0.00175 < 0.00217$$

$$\begin{aligned} N &= 0.85\, f_{ck}bs + f_{yk}A'_s + E.\varepsilon_{si}A_{si} - E.\varepsilon_s A_s \\ &= (0.85\times40\times1000\times0.8\times1000.0) + (500\times2944.9) + \\ &\quad (205\times10^3\times0.00175\times1963.3) - (205\times10^3\times0.00026\times2944.9) \\ &= 27200.00\times10^3 + 1472.45\times10^3 + 704.33\times10^3 - 156.96\times10^3 \\ &= 29219.82 \text{ kN} \end{aligned}$$

$$\begin{aligned} M &= 27200.00\times10^3\,(500 - 0.4\times1000.0) + 1472.45\times10^3\,(500 - 74) + \\ &\quad 156.96\times10^3\,(926 - 500) + 0 \\ &= 2720.00\times10^6 + 627.26\times10^6 + 66.86\times10^6 + 0 \\ &= 3414.10\times10^6 \\ &= 3414.10 \text{ kN.} \end{aligned}$$

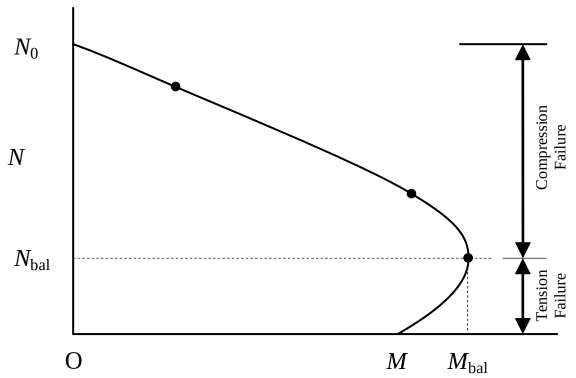


Figure 10: Tension and compression failure

The M-N interaction values can be interpreted from the **Figure 10**. The region where moment is increasing while the application load is decreasing is where the compression fails. In the region when moment inflected and start to decrease while the application load is also decreasing is where the tension also fails.

The moment, *M* and applied force, *N* interaction values for different values of *x* are summarized in **Table 6**. It is noted that the value for Moment, *M* increase steadily until it reaches maximum point before decreasing again. The increasing moment value is when the tension start to fail until it reaches inflection point where the compression steel will also failed as shown in **Figure 10**.

Table 6: Summary of *M-N* interaction values

x (mm)	ε_{sc}	ε_s	f_{sc} (N/mm^2)	f_s (N/mm^2)	N (kN)	M (kN.m)
74.0	0	> 0.00217	0	- 0.87 f_{yk}	- 441.3	1574.1
339.9	> 0.00217	> 0.00217	0.87 f_{yk}	- 0.87 f_{yk}	8581.2	4620.2
463.0	> 0.00217	> 0.00217	0.87 f_{yk}	- 0.87 f_{yk}	12480.9	5219.0
500.0	> 0.00217	> 0.00217	0.87 f_{yk}	- 0.87 f_{yk}	13600.0	5334.5
571.3	> 0.00217	0.00217	0.87 f_{yk}	- 0.87 f_{yk}	15716.5	5473.2
730.6	> 0.00217	0.00094	0.87 f_{yk}	- 0.87 f_{yk}	21220.0	4997.7
926.0	> 0.00217	0	0.87 f_{yk}	0	27307.6	3891.5
1000.0	> 0.00217	0.00026	0.87 f_{yk}	0.87 f_{yk}	29219.8	3414.1
∞	0.00217	0.00217	0.87 f_{yk}	0.87 f_{yk}	43200.0	0

From **Table 6**, a graph of the *M-N* interaction values is plotted as in **Figure 11**. The graph intersects y-axis when the moment is zero and the applied load is 43200 kN. Therefore, the tension start to fail when load applied is 5473.2 kN and the moment is 15716.5 kN.m. The value of shear and bending moment from **Figure 7** is well below the M-N value when the tension fails. Therefore the bridge pier design is acceptable.

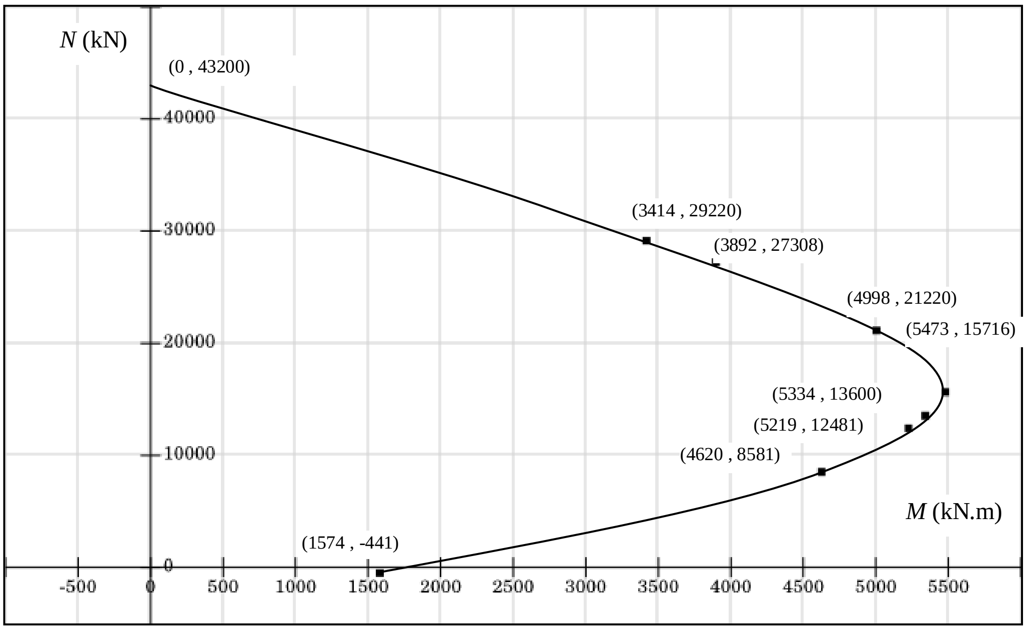


Figure 11: Graph of *M-N* interaction

CHAPTER 5

RECOMMENDATION AND CONCLUSION

5.1 Recommendation

In this study, the assumptions that are listed may be improved to get a better analysis of result. Among the assumption made are:

i. Quasi-static analysis

Quasi-static analysis produces an acceptable but conservative result. However to analyze for the different performance level of bridge structures, it is recommended to use dynamic analysis since it gives a more accurate result. For the assessment of existing bridge supports, a quasi-static analysis should be carried out in the first instance while dynamic analysis may be used if the structure fails under quasi-static analysis.

ii. The angle of collision.

The angle of collision is taken as 90°, in which only the load parallel to the carriageway is considered. However in actual accident cases, the angle of collision might not be perfectly 90°, resulting in a portion of loads coming from the direction normal to the carriageway. It is recommended to analyse the mean impact force using different possible angle to a get a more thorough result.

iii. The bridge pier type and dimension

The bridge pier type used in this study has a square dimension. Actual bridge pier type may vary from circular or rectangular shape. Besides that the dimension used, which is 1000×1000 mm, is very modest, and it may capable to withstand the lateral load but not be economical to construct. It is proposed that the analysis is being done using other types of bridge support either circular or rectangular and also the different dimensions compare the result.

iv. Different velocity of vehicles

Malaysian speed limit is capped at different level according to type of roads. For state roads the speed limit is taken as 80 km/h, while federal road and highways are capped at 90 km/h and 110 km/h respectively.

5.2 Conclusion

The objectives of the study is find the various configurations of heavy vehicles, specifically trucks and trailers and carry out analysis on bridge design based on accidental impact of lateral load due to heavy vehicle. Among all the bridge structures design, the author focus on the analysis of accidental impact towards the bridge piers. The configurations of truck and trailers can be divided into six categories according to axle configuration and maximum gross vehicle weight which includes:

- 2 axles (1+1)
- 3 axles (1+2)
- 4 axles (1+1+2)
- 5 axles (1+1+3) , (1+2+2)
- 6 axles (1+2+3)
- 7 axles (1+2+4)

Based on the author's quasi-static analysis on the section of bridge piers, the design of bridge pier with the dimension of 1000×1000×7000mm is acceptable following with the assumption that the angle of collision is taken at 90° in which the load is parallel to the carriageway.

As a conclusion, it is essential to assess the bridge pier that had been constructed before to ensure for their ability to withstand the accidental impact of lateral load. During the impact of lateral load, the bridge piers may experience substantial damage and loses its strength to support the bridge structures, and the bridge may collapse. Besides that the bridge may require fixing or reconstruction even if it not severely affected. Current bridges in construction do not pose much problem since most of them are adequately equipped with barriers and designed to withstand the lateral load.

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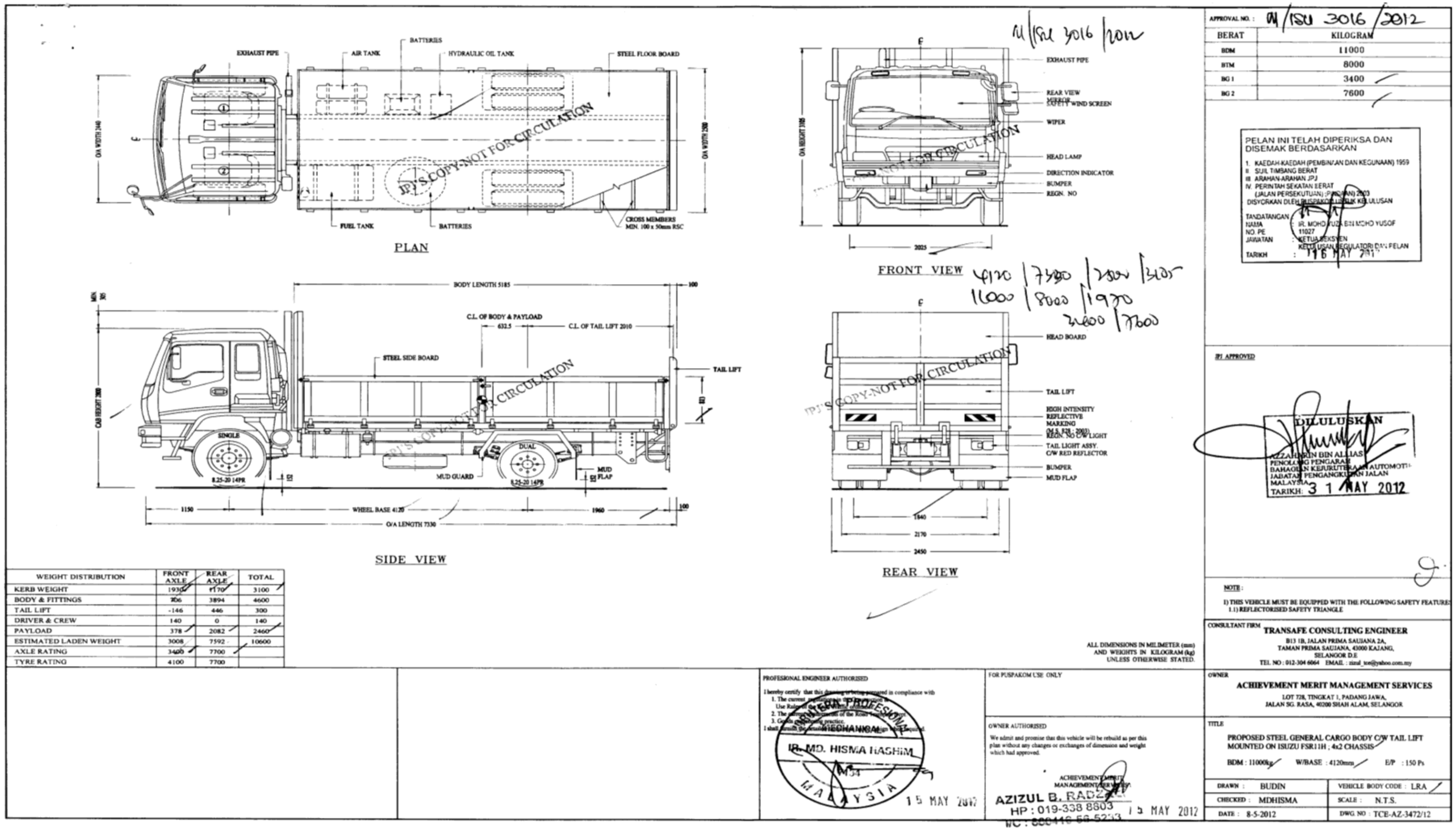
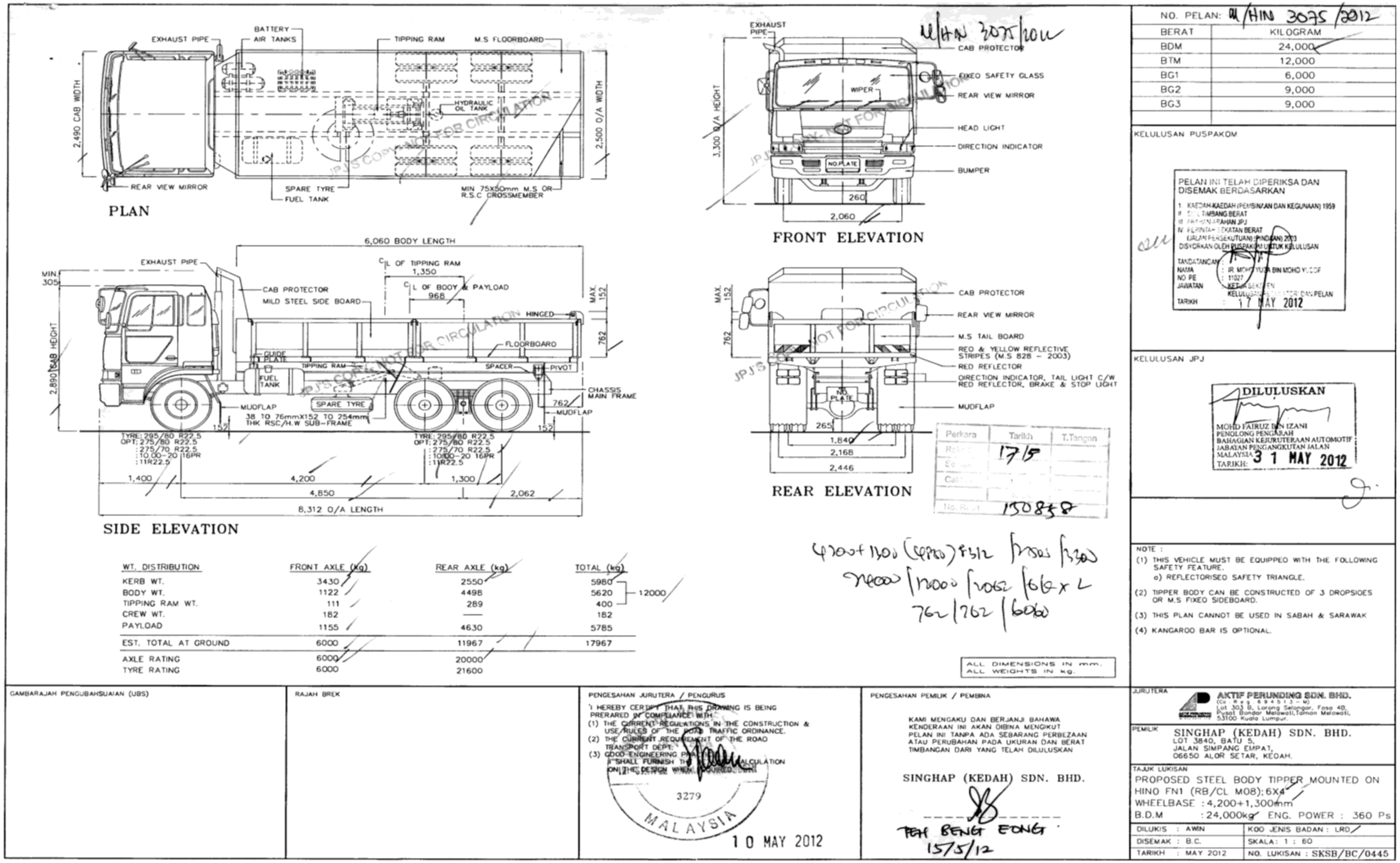
APPENDICES

Appendix I – Specification drawing of truck and trailers (Rigid 1-1)

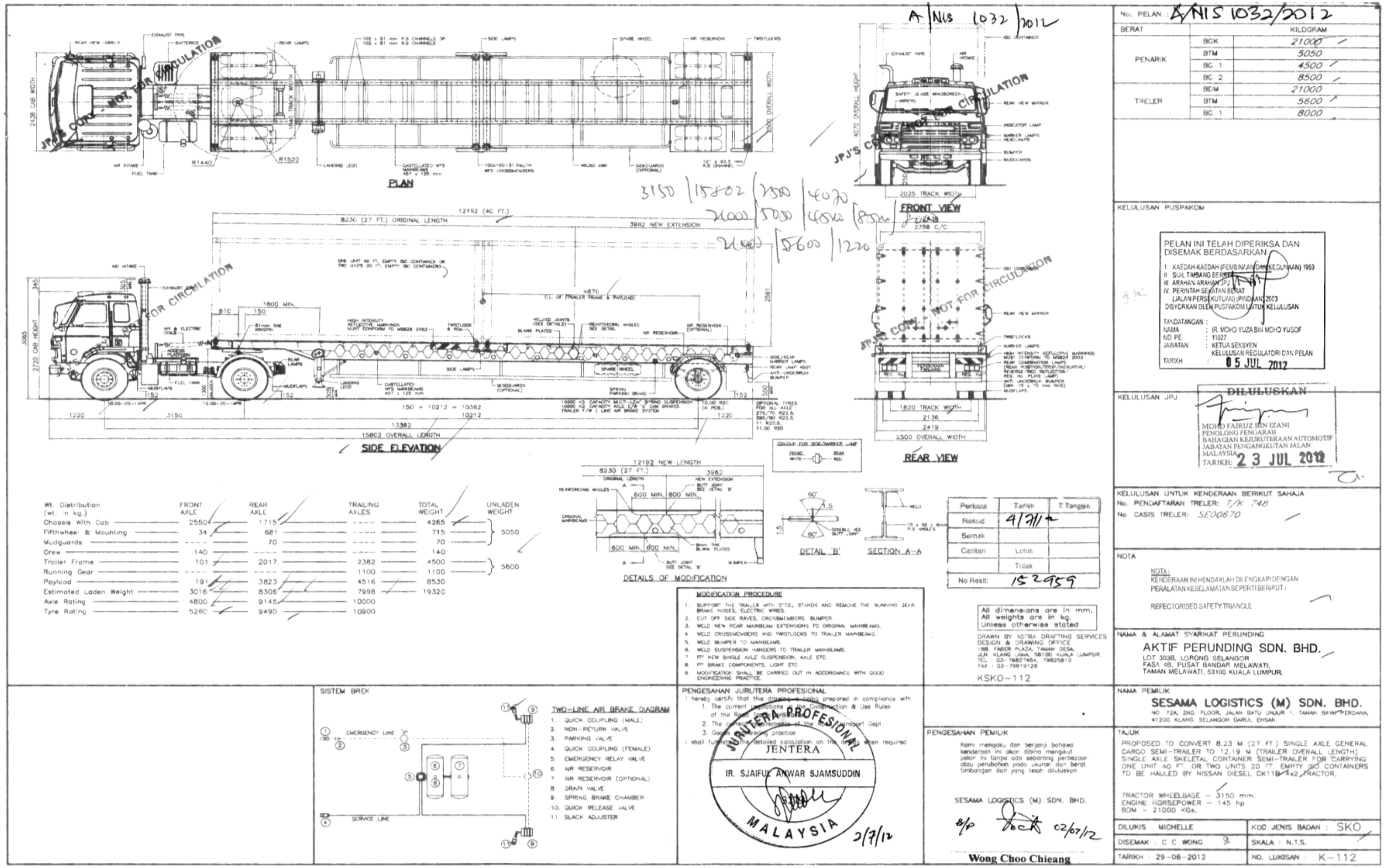


WEIGHT DISTRIBUTION	FRONT AXLE	REAR AXLE	TOTAL
KERB WEIGHT	1930	1170	3100
BODY & FITTINGS	706	3894	4600
TAIL LIFT	-146	446	300
DRIVER & CREW	140	0	140
PAYLOAD	378	2082	2460
ESTIMATED LADEN WEIGHT	3008	7592	10600
AXLE RATING	3400	7700	
TYRE RATING	4100	7700	

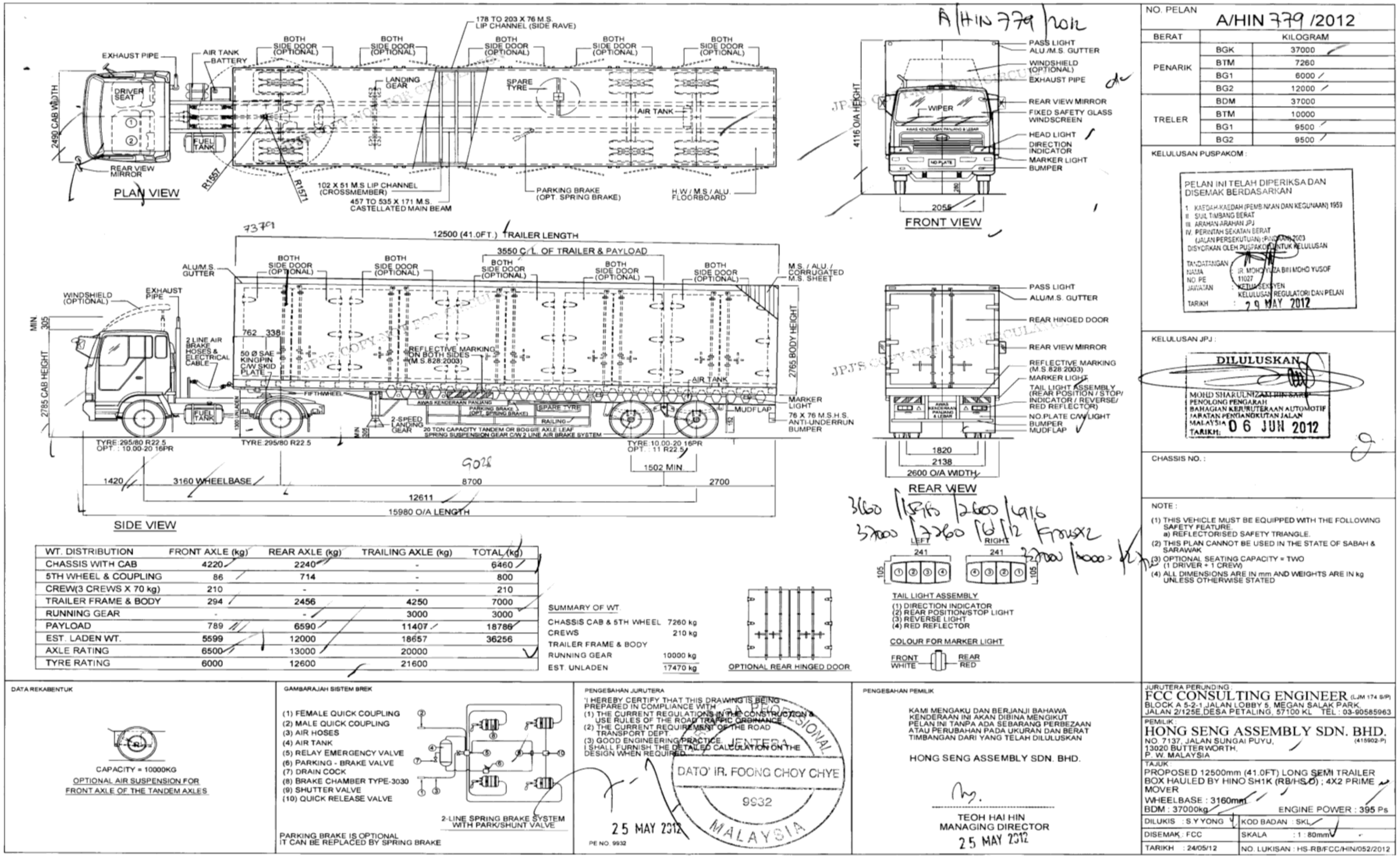
Appendix I – Specification drawing of truck and trailers (Rigid 1-2)



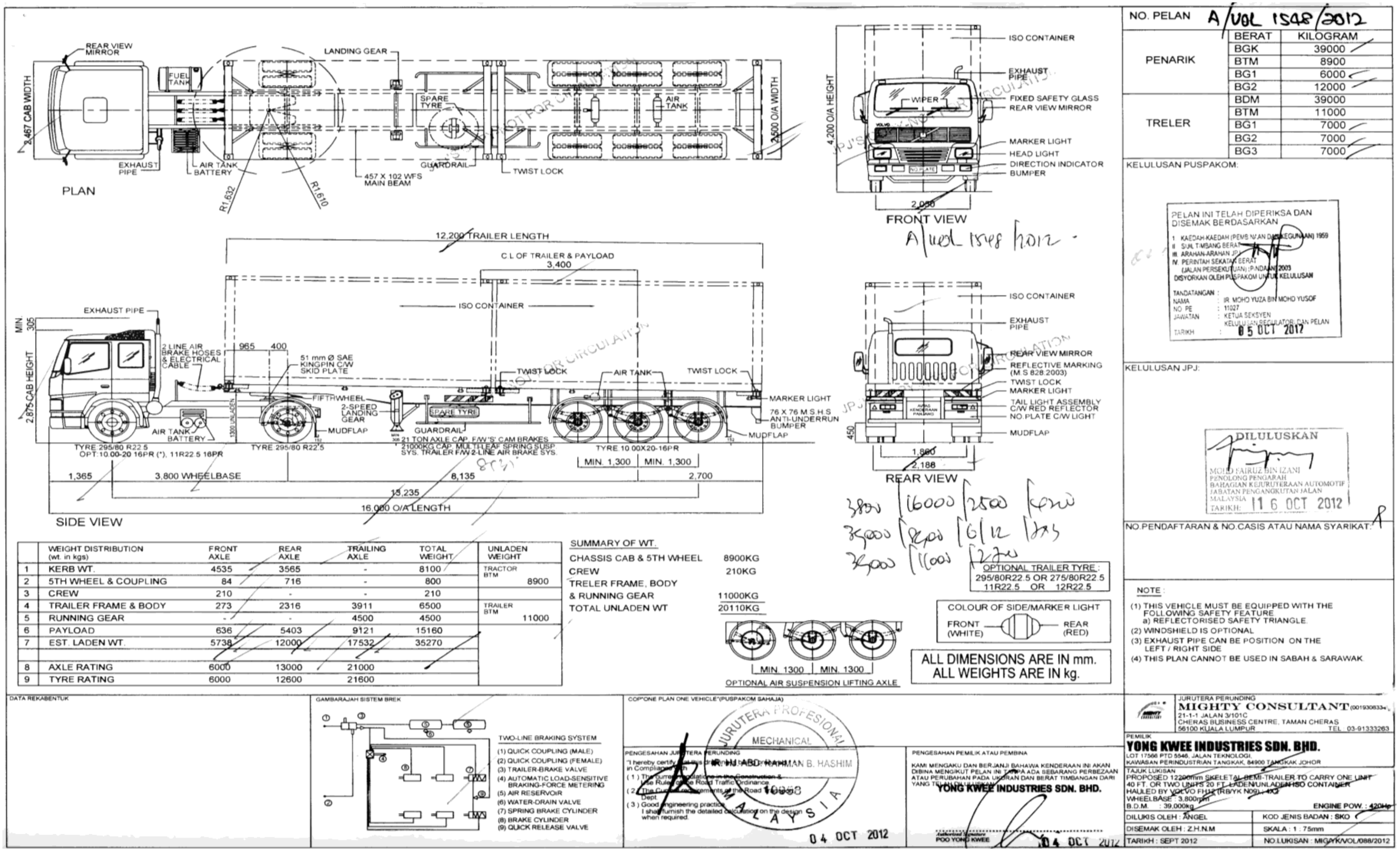
Appendix I – Specification drawing of truck and trailers (Articulated 1-1-1)



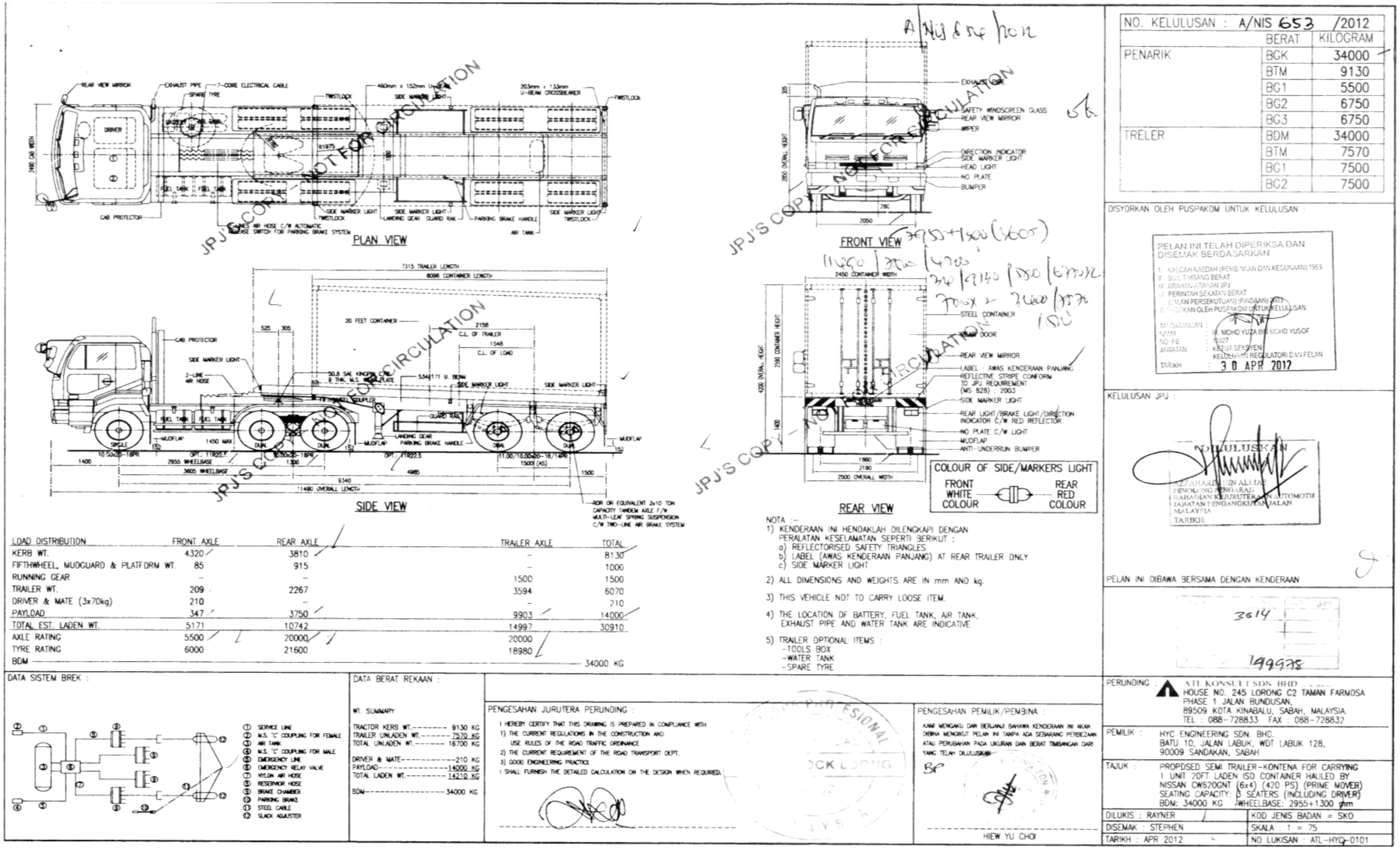
Appendix I – Specification drawing of truck and trailers (Articulated 1-1-2)



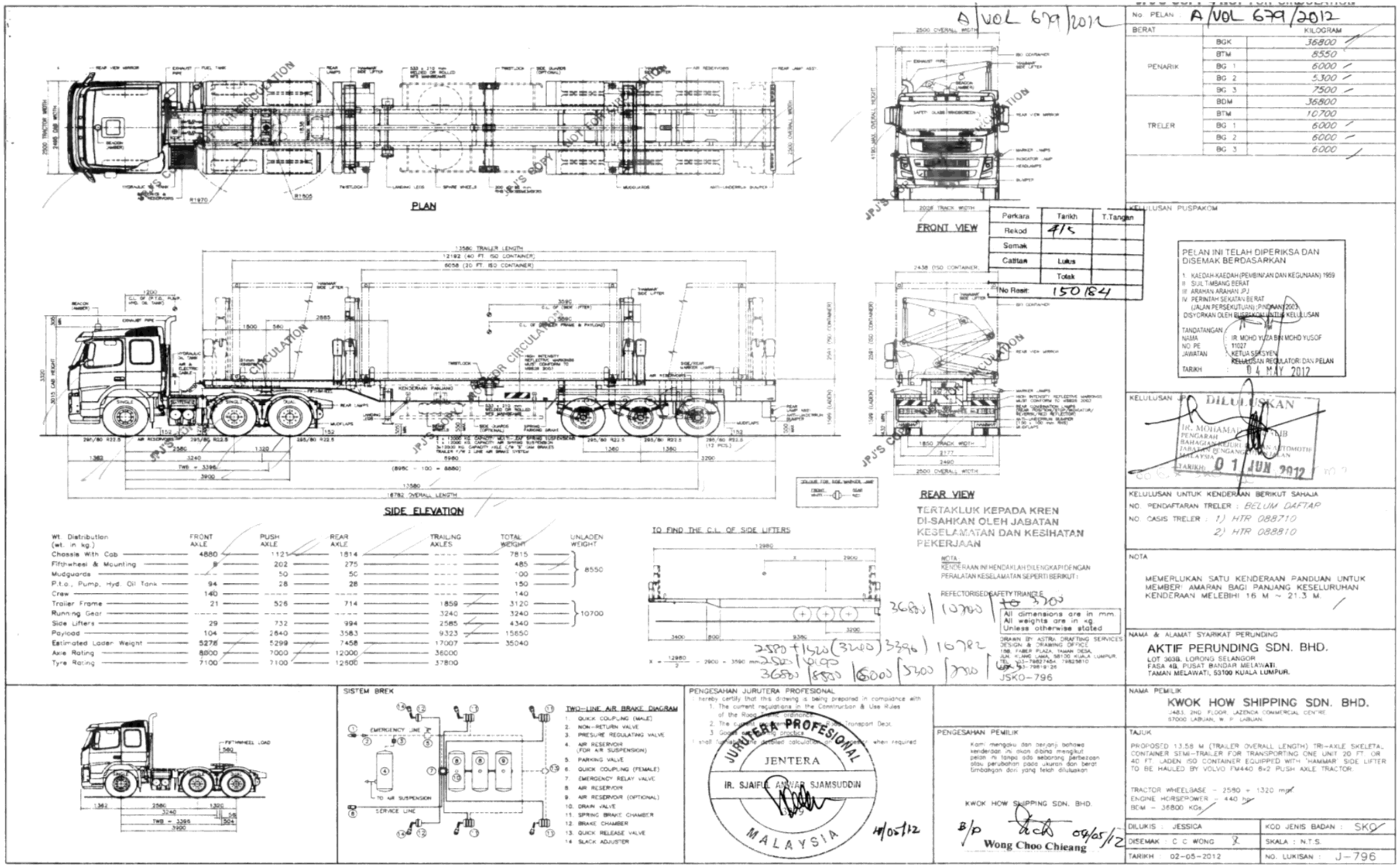
Appendix I – Specification drawing of truck and trailers (Articulated 1-1-3)



Appendix I – Specification drawing of truck and trailers (Articulated 1-2-2)



Appendix I – Specification drawing of truck and trailers (Articulated 1-2-3)



Appendix I – Specification drawing of truck and trailers (Articulated 1-2-4)