Journal of Energy and Safety Technology
JEST
RESEARCH ARTICLE Open Access

False Work Accident: Forensic Engineering Investigation Approach

Mohd Shamsuri Khalid *[1,2], Balya Mulkan Wijaya [3], Mohd Nazri Mat Jarid [3], Nur Athirah Diyana Mohammad Yusof[1], Mohammad Lui Juhari [4].

[1] Department Creative Artificial Intelligence, Faculty of Artificial Intelligence, UTMKL, Jalan Sultan Yahya Petra, 54100, Kuala Lumpur, Malaysia
[2] Construction Quality and Maintenance Research Group (CQM), UTMKL, Jalan Sultan Yahya Petra, 54100, Kuala Lumpur, Malaysia
[3] Forensic Engineering Division, Department Occupational Safety and Health Malaysia Setia Perkasa 4. Setia Complex, Federal Government Administrative Centre, 62530 Putrajaya, Malaysia
[4] Centre for Research in Development, Sosial and Environment (SEEDS), faculty of Social Science and Humanities, National University of Malaysia, 43600, Bangi UKM, Malaysia

Corresponding author: m.shamsuri@utm.my

Article History

Received:	Received in revised form:	Accepted:	Published Online:
November 27, 2024	May 14, 2025	June 15, 2025	June 18, 2025

ABSTRACT

On June 19, 2021, at 7:15 PM, the collapse of a falsework structure at a construction site in Selangor caused one fatality, injured another worker, and severely damaged the falsework. Prior to the collapse, five workers were engaged in pouring concrete into a formwork box at channel P116R. Method of forensic engineering investigation as such by triangulation of approach visual inspections and measurements were conducted on the components used for the falsework structure. A review of technical documents was performed, focusing on the design specifications, engineering drawings, and procedures for the installation of the falsework. A structural analysis was carried out based on the technical data obtained. This study investigates the collapse of a falsework structure at a construction site in Selangor, resulting in one fatality and one injury. Forensic analysis revealed that the structure failed under a concrete load of 32.08 cubic meters (50.74 kN/m²), exceeding its capacity. The investigation included onsite inspections, structural analysis, and review of technical documents, concluding that inadequate bracing and joint integrity were primary causes of failure.

Keywords: Falsework Structure; Forensic Engineering Investigation; Concrete; Forensic Analysis; Formwork.

1.0 INTRODUCTION

Forensic engineering is a specialized field that involves the investigation of failures, accidents, and defects in engineering systems, structures, and products. In Malaysia, forensic engineering has gained significant importance due to the increasing complexity of engineering projects, urbanization, and the need for accountability in engineering practices. This field plays a critical role in ensuring safety, reliability, and compliance with standards in various industries, including construction, manufacturing, transportation, and energy. Forensic engineering is the application of engineering principles and methodologies to investigate failures, accidents, or defects in structures, systems, materials, or products. The primary goal of forensic engineering is to determine the root cause of a failure or accident, provide expert analysis, and recommend measures to prevent future occurrences. This field often involves collaboration with legal professionals, as forensic engineers may be called upon to provide expert testimony in court cases or legal disputes.[8].

© 2025 Penerbit UTM Press. All rights reserved

However, data from Forensic Engineering Division (FED), Department Occupational Safety and Health (DOSH) Malaysia stated from year 2000 - 2022:

Table 1. Data Investigated by FED, (DOSM Malaysia)

	YEAR	CASE
1	2018	15
2	2019	16
3	2020	17
4	2021	18
5	2022	12*

Legend 12* -Data up until July 2022

Data from the Forensic Engineering Department (FED) and the Department of Occupational Safety and Health (DOSH) Malaysia indicate a significant number of forensic engineering cases have been investigated by the department. These cases span various industries, with a notable focus on the construction sector, which has seen several high-profile incidents requiring detailed forensic analysis. Forensic engineering has played a crucial role in investigating these cases, providing insights into the causes of failures and recommending measures to prevent recurrence. Several notable construction-related cases in Malaysia have been investigated through forensic engineering, including:

1. Highland Towers Collapse (1993): Forensic investigations determined that the collapse was caused by a combination of poor drainage systems, slope instability, and inadequate maintenance practices. This tragic incident led to significant changes in building regulations and slope management protocols in Malaysia.
2. MRT Construction Accidents: During the construction of the Mass Rapid Transit (MRT) system, several accidents, including crane collapses and scaffolding failures, were investigated by forensic engineers. These investigations identified key issues such as design flaws, insufficient safety measures, and human errors, prompting improvements in construction practices and safety standards.
3. Penang Second Bridge Cracks: Forensic engineers analyzed cracks and defects in the Penang Second Bridge, attributing them to material defects and construction errors. The findings led to recommendations for enhanced quality control and maintenance procedures to ensure the structural integrity of the bridge.

This study focuses on a specific case investigated in 2021, highlightingth about the collapse of the falsework structure at a construction site in Selangor at 7:15 PM on June 19, 2021, resulted in the death of one worker and the injury of another, as well as severe damage to the falsework. Prior to the collapse, five workers were engaged in pouring concrete into a formwork box at channel P116R. Visual inspections and measurements were conducted on the components used for the falsework structure. A review of technical documents was performed, focusing on the design specifications, engineering drawings, and procedures for the installation of the falsework. A structural analysis was carried out based on the technical data obtained.

1.1 Chronology of Incidence

On the day of the incident, five workers were carrying out the task of pouring wet concrete into the segmental Stitching Formwork at channel P116R at around 4:30 PM, using a mobile crane as described below (Figure 1):

Figure 1. Condition before accident

The total volume of the formwork was 109.04 m^3. During the pouring of the first layer of concrete with the total volume of the formwork was 109.04 m^3.(Figure 2)

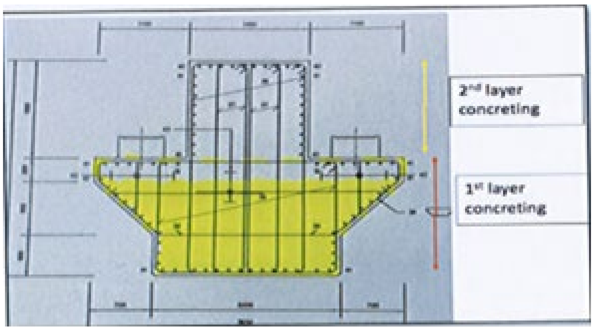

Figure 2. Formwork concrete of layer

Figure 3. Falsework structure

In addition, the chronological sketch of the incident has been reconstructed based on the triangulation of information such as witness statement, documents, photos and onsite evidence is as follows:

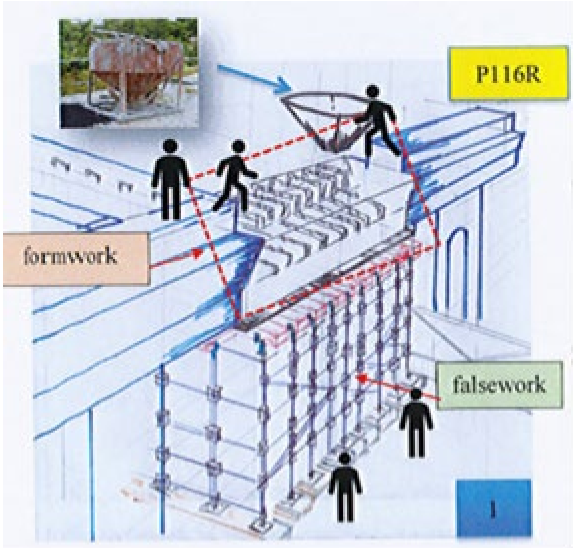

Figure 4. Sketch of incident (BEFORE -1)

The above process of pouring the wet concrete into the formwork at pillar (P116R). (Figure 4). Time 4.30 pm by using mobile crane.

Figure 5. Sketch of incident (BEFORE-2)

The activities commenced at 6:50 PM, with the concrete pouring reaching its fourth batch. (Figure 5). The crane operator was actively monitoring the operation. During this time, the operator heard a loud cracking sound. Subsequently, the scaffolding began to gradually collapse, descending towards the ground.

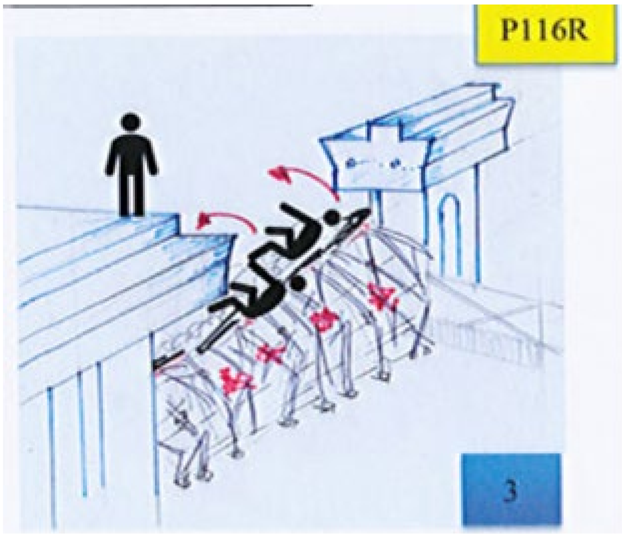

Figure 6. Sketch of incident (AFTER)

Following this, the crane operator heard a series of loud cracking sounds, resembling a domino effect. The formwork and falsework then completely collapsed to the ground. (Figure 6)

2.0 METHODOLOGY

Forensic engineering investigations conducted by the Forensic Engineering Department (FED) of DOSH Malaysia must adhere to a stringent approach and follow established procedures as outlined in the PK 04 Manual. The process involved in trangulation of all approachs, documents and finding to justify the root causes of the accident. In summary, these investigations are typically carried out in three key steps, which include. (Figure 7):

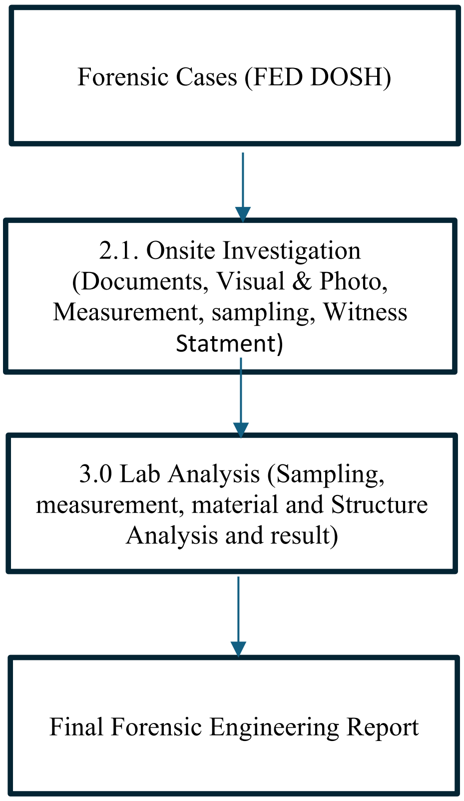

Figure 7. PK 04 Manual - Forensic Engineering Department (FED) of DOSH Malaysia

2.1 Onsite Inspection

A thorough onsite inspection of the incident location is generally conducted, encompassing both visual and physical examinations of the falsework system and its components. Documentation related to the material specifications of the falsework, such as sleeve couplers, extended tubes, sheet piles, and other directly related items, including concrete vibrators and scaffold components such as U-heads and bracing, is carefully reviewed. Measurements of sampled items are also taken to ensure accuracy. Furthermore, the technical drawings of the scaffold system are meticulously reviewed and cross-checked with the actual setup at the site to identify any discrepancies or deviations.

2.1.1 Falsework

Falsework, also known as temporary support, structures, refers to a temporary framework used to support a structure during its construction until it becomes self-supporting. Despite being a non-permanent structure that is dismantled after use, falsework performs a critical function like that of a permanent structure. If not properly designed, installed, and managed, falsework poses significant risks, including structural failures and safety hazards. It is important to distinguish between scaffolding and falsework. Scaffolding is primarily used to provide working platforms for construction activities, whereas falsework is specifically designed to support structural elements during construction. However, there is some overlap in their applications. Components of scaffolding systems, such as modular scaffolds, can be utilized as part of falsework systems, and vice versa. For example, as illustrated in Figure 8, falsework may consist of modular scaffold components combined with steel I-beams to support formwork made of timber.

Figure 8. Modular scaffolds used as falsework

The primary function of falsework is to provide temporary support for various loads that may occur during the construction of a structure. These loads include Dead Load (permanent weight of the structure), Live Load (temporary loads such as workers and equipment), Wind Load (lateral forces caused by wind), and Dynamic Load (forces resulting from movement or vibration). In addition to vertical support, falsework also requires lateral support to maintain stability. This can be achieved through Diagonal Bracing or Tie Backs, which prevents lateral movement and ensures the overall stability of the structure. Another critical aspect of falsework design is the joints (connections) between components. The condition and type of joints significantly influence the Effective Length (LE) of the columns, which affects their load-bearing capacity and stability. For falsework systems that utilize scaffold components, the vertical columns are typically connected using joint pins, which can be implemented through methods such as sleeve joints or spigot connections. These connections between vertical scaffold columns form lifts (levels) within the falsework structure, enabling it to support the construction process effectively.

Key Design Elements of Falsework:

1. Load Support: Falsework must be designed to withstand dead loads, live loads, wind loads, and dynamic loads during construction.
2. Lateral Stability: Diagonal bracing or tie backs are essential to prevent lateral displacement and ensure structural stability.
3. Joint Design: The type and condition of joints directly impact the effective length and load-bearing capacity of columns.
4. Scaffold Integration: When scaffold components are used in falsework, joint pins (e.g., sleeve joints or spigot connections) are commonly employed to connect vertical columns and create stable lifts.

However, the specification of material has been checked to eliminate the possibilities of direct and indirect causes of the accident.

2.1.2 Material Spesification

During the onsite inspection, all relevant data pertaining to the premises, plant, and materials involved in the incident were gathered. The primary material identified as a contributing factor in the incident was the falsework. The falsework, along with the associated components utilized by the contractor for its assembly at the site, is currently under detailed analysis. The specifications of the falsework are outlined below:

Table 1. Component of falsework

No.	Item	Detail
1	Commodity	Scaffold tube
2	Specification	48.3 mm x 4.o m x 6000 mm
3	Issued date	3/2/2018
4	Scaffold's Comp.	BS1139- Scaffold Tube (6m) (1000 pcs)
5	Material	C 0.016%, Si 0.17%, Mn 0.33%, P 0.025%, S 0.019%
6	Physical Property	T.S 380 (N/mm^2). Y.S 273 (N/mm^2) dan E.L 26%

2.1.3 Sleeve Couple

The inspection revealed that the joint between standards using sleeve couplers on the falsework was employed to achieve the required height (Figure 9). It was also found that some sleeve couplers were torn and bent, as illustrated in Figure 10.

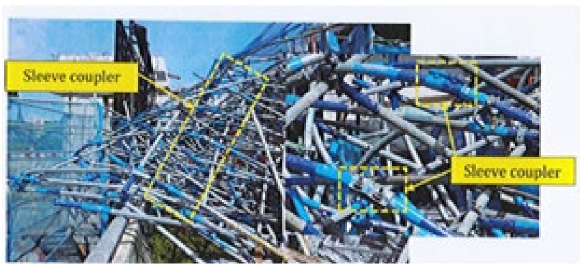

Figure 9. Position of sleeve coupler

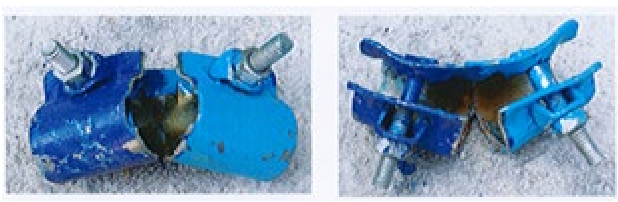

Figure 10. Damage of sleeve coupler

2.1.4 Extended Tube

Further inspection revealed that an extender tube was used at the joint between standards, with two sleeve couplers showing signs of tearing, as illustrated in Figure 11. Several sleeve couplers along with the extender tube were found in the collapse area, as shown in Figure 12.

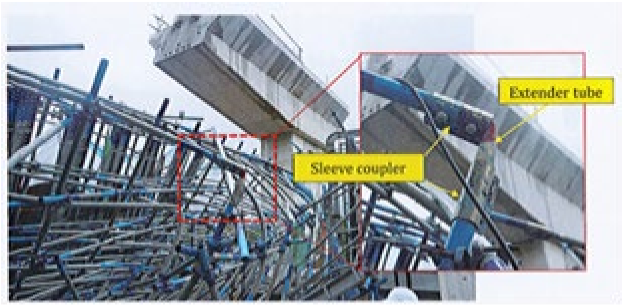

Figure 11. Position of sleeve coupler

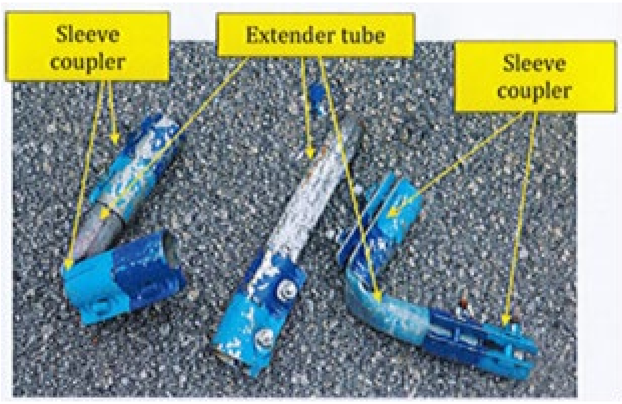

Figure 12. Damage of sleeve coupler and extender bar

2.1.5 Sheet Pile

At the scene, it was observed that 6 sheet pile units, which served as sole boards for the base jacks of the falsework structure, were completely bent and had collapsed. (Figure 13).

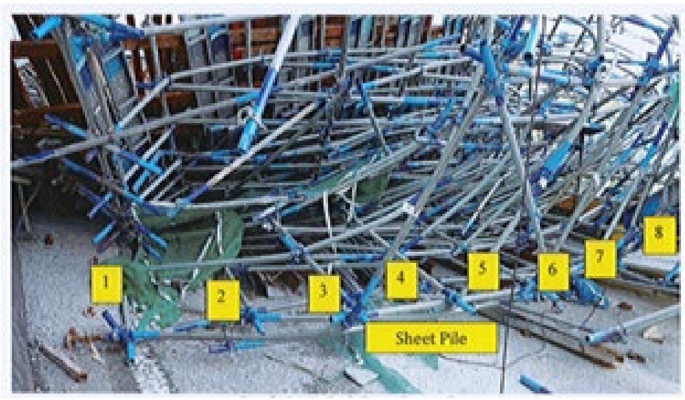

Figure 13. Actual of bending based jack

2.1.6 Vibrator Concrete

An inspection of the formwork collapse area revealed that two units of concrete vibrators were used to compact and level the freshly poured concrete within the formwork, as shown in Figfure 14.

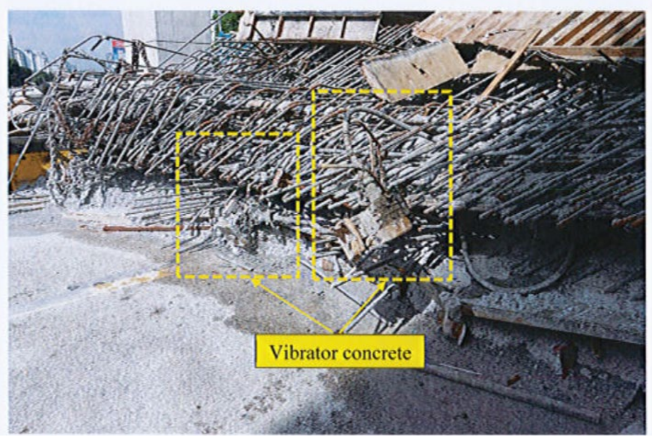

Figure 14. Location of 2 Vibrators

2.1.7 U head

The onsite inspection found the use of five types of corroded U-heads varying in diameter, length, and extension, as shown in Figure 15

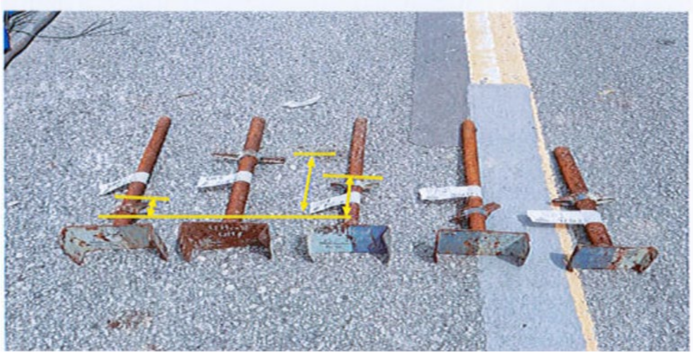
Figure 15. U Head

At locations P118R and P119R near the incident site, there is an in-progress falsework structure installed by the contractor, identical to the collapsed falsework shown in the Figure 16.

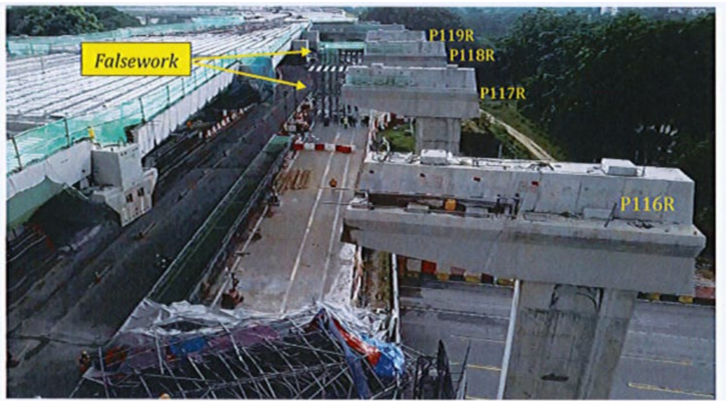

Figure 16. Falsework Structure

Hence, further inspection of the U-head installation on the falsework revealed that it was improperly installed, as shown in the Figure 17 a, b and c.

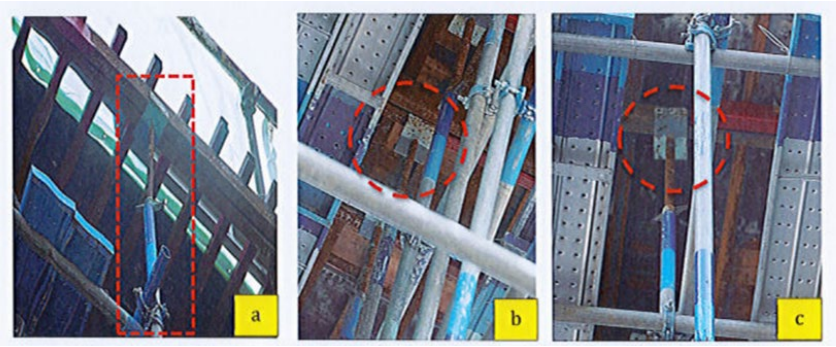

Figure 17. a: Benfing U Hear bar., 14 **b:** and 14 **c:** U Head and steel bar improper setting

2.1.8 Bacing Placement

Further inspection at the incident site revealed that the bracing installation on the collapsed falsework was not secured to standard, as appropriate couplers were not used, as shown in the Figure 18.

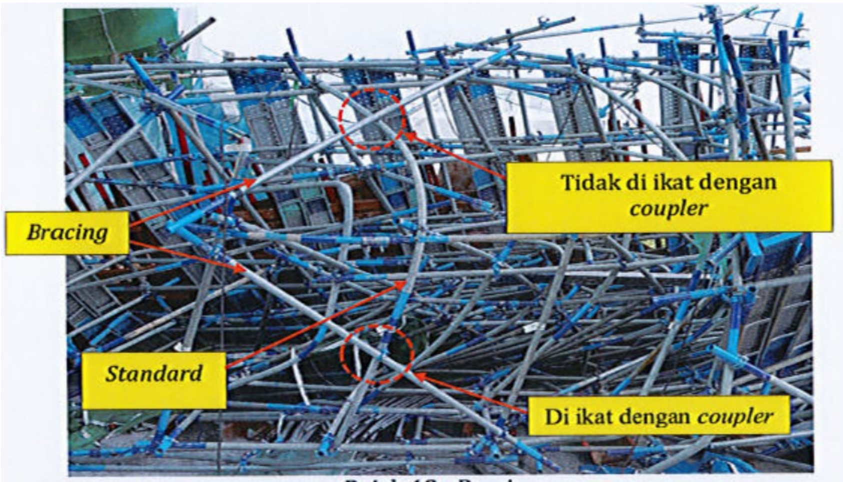

Figure 18. Bracing

2.1.9 Reviewing on Engineering and Technical Drawing (TD)

A thoroughly review and inspection of the engineering and technical drawings found no specific engineering design related to the falsework installation at P116R. However, the contractor proceeded with construction by referring to general engineering drawings provided by consulting firm X, as shown in the Figure 19. These referenced drawings are typical engineering plans used for all falsework structures on the construction site.

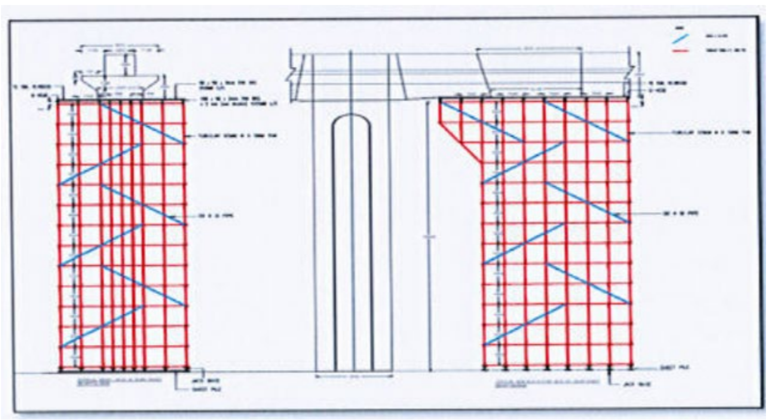

Figure 19. Engineering and Technical Drawing (TD)

2.1.10 Mesurement of the Tube Pipe

Measurements were conducted on a stockpile of tube pipes intended for use in falsework at a nearby collapse site. The results from these measurements indicate a range of tube pipe lengths, including 3 meters, 1.5 meters, 1 meter, 300 cm, and 150 cm. Figure 20.

Figure 20. Measurement by Forensic Investigator

3.0 FORENSIC ANALYSIS

Forensic Analysis that been carried out by the FED DOSH Malaysia generally involved in 2 processes:
1. Analltics Analysis (Falsework Structure, Falsework component measurement that compare to the Code)
2. Structure Analysis, (data Input to seek the Failure of the Falsework

Hence, all sample that gathered from the onsite inspections suc as technical drawings (consfiscate from the Contractor) and analysis and calculation by using the code and actual component been done. Comparing o fhte sample gatherd from the onsite and do measure and compare the actual items with the code. Meanwhile form the data retrieve been input in the software analysis to find out the anomly and structure analysis of the system

3.1 Falsework Structure

Falsework (temporary support structures) serves as a provisional framework designed to support the construction of structures such as formwork, ensuring stability until the permanent structure is sufficiently self-supporting. Several key considerations are essential in constructing falsework. Although it is a temporary structure meant to be dismantled after use, its role is like that of permanent structures, carrying significant risk if not managed properly. Falsework structures can be assembled using scaffolding components, with tube pipes acting as standards (uprights) or bracings, secured by various joint components such as right-angle couplers, swivel couplers, and sleeve couplers. Additionally, U-heads and base jacks function as support components, as depicted in the accompanying Figure 21.

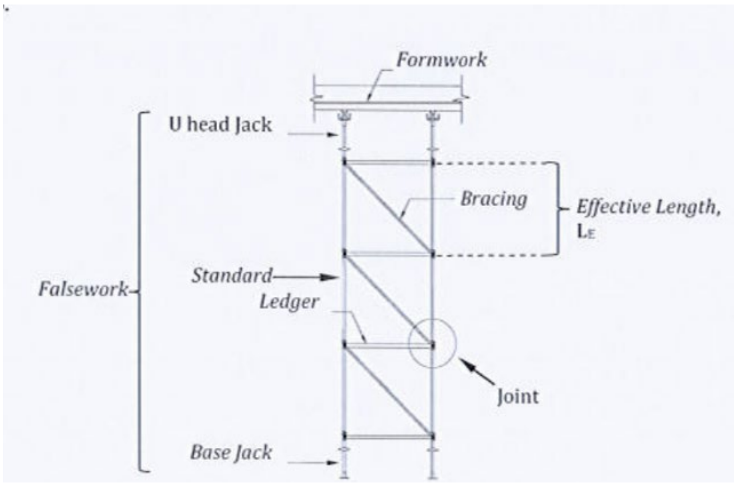

Figure 21. Falsework Structure

The primary function of falsework is to support dead loads, live loads, wind loads, and dynamic loads that may occur during the construction of a structure. In addition to providing vertical support, falsework must also incorporate lateral support, which can be achieved through bracing or tiebacks to maintain stability. Joint integrity is a crucial aspect of falsework construction, as the condition of joints can directly impact the effective length, L_E, of the structural elements.

3.2 Joint

The joints between scaffold uprights are critical in determining the strength of a falsework structure, as these components are connected across multiple units to achieve the desired height. A commonly used method for connecting scaffold tubes is the sleeve coupler. The 2D layout and description of scaffolding components are illustrated in Figure 22, where the falsework jointing begins at the top and ends at the base using U-heads and base jacks. Both the U-head and base jack extensions are adjustable, allowing for height modifications based on the formwork box level. Further connections between uprights are achieved using the sleeve coupling method. Eccentricity at these joints is a key consideration, as load distribution across components may not always align perfectly, affecting the overall stability of the structure.

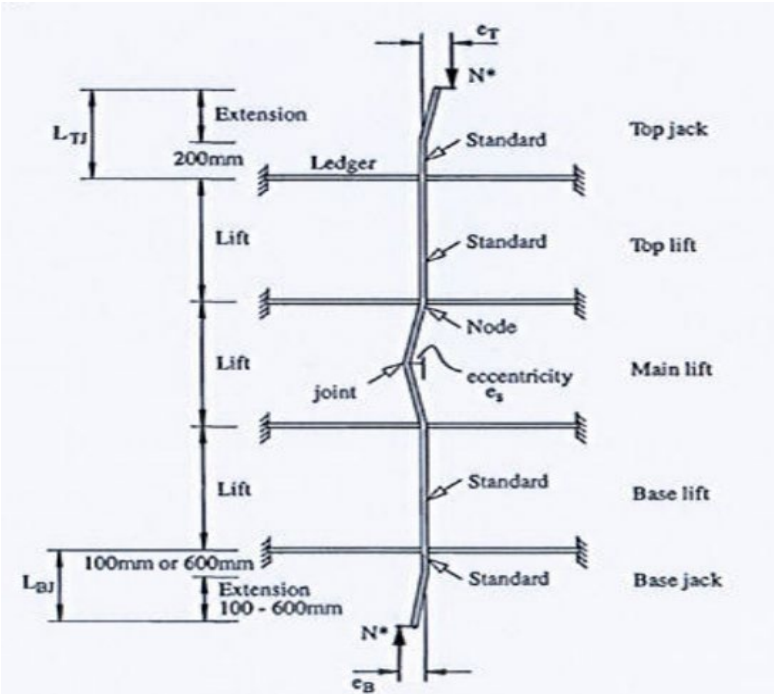

Figure 22. 2D Sketch

The diameter difference between scaffolding and sleeve couplers allows for lateral movement, resulting in the eccentricity of the connecting tool. This setup enables vertical loads to be transmitted directly from one scaffold pole to another rather than through the sleeve coupler. In theory, under normal conditions, the sleeve coupler does not bear any load. This can be achieved by ensuring that the sleeve coupler and scaffolding components are fitted closely, allowing for the direct transfer of load from the upper pole to the lower pole. A free-body diagram illustrating the joint and eccentricity is presented in Figure 23.

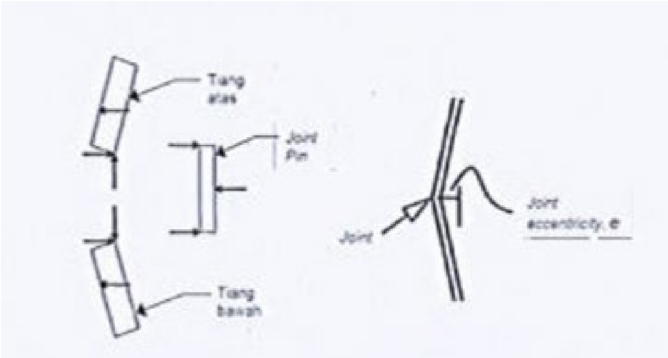

Figure 23. Free body diagram fot joint and eccentricity

3.3 Mesurement of Extender Tube

Measurements have been taken in terms of outer diameter (OD), inner diameter (ID), and thickness for the extender tube sample obtained from the collapsed falsework structure, as depicted in Figure 24. The measurement results are presented in Table 2.

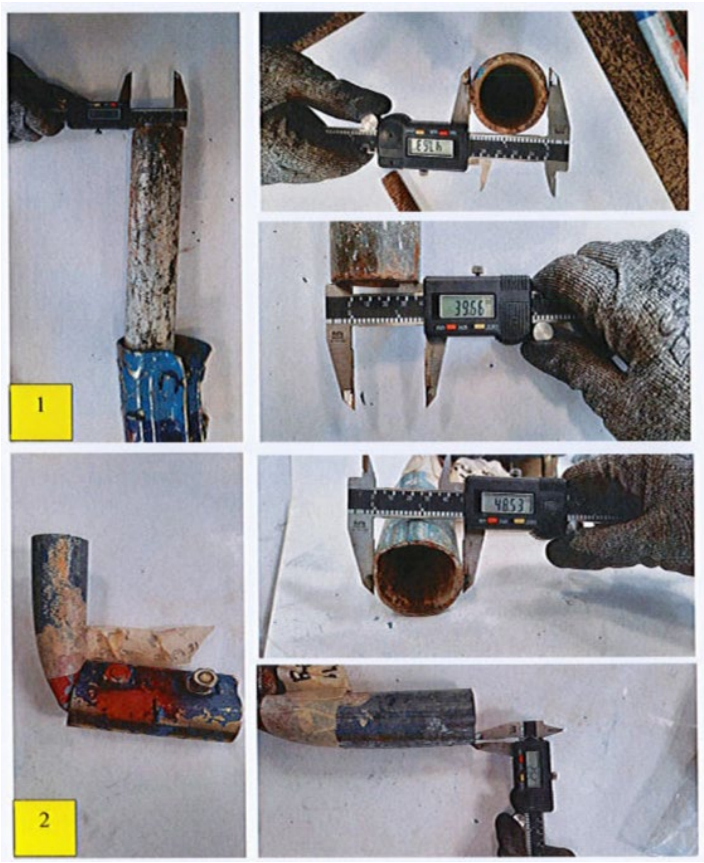

Figure 24. Measurement of Extender Tube

Table 2. Measurement reading

Extender Tube	Measurement	Units
1	OD	47.6mm
	ID	39.6 mm
	Thickness	3,00mm
2	OD	48.5mm
	ID	45.9mm
	Thickness	2,96mm

The results of the measurements for the extender tube and standard indicate a significant difference in thickness, as shown in Figure 25 and Table 3.

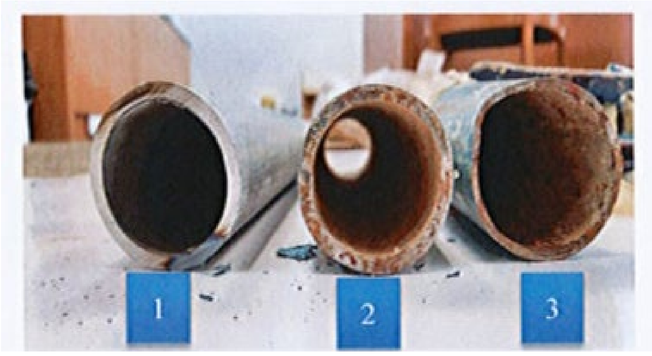

Figure 25. Thickness Variation

Table 3. The measurement results indicate a significant difference in thickness

Bil	Thickness	Units
1	Standard	8.82 mm
2	Extender Tube 1	3.00 mm
3	Extender Tube 2	2.96 mm

3.4 U Head

Several U-head samples collected from the collapse site, labeled as UH1, UH4, and UH5, were measured for physical appearance to enable a comparative analysis among the three U-heads. Measurements were conducted across corresponding segments of each U-head, as shown in Figures 26a, 26b, and 26c, with the measurement readings presented in Table 4.

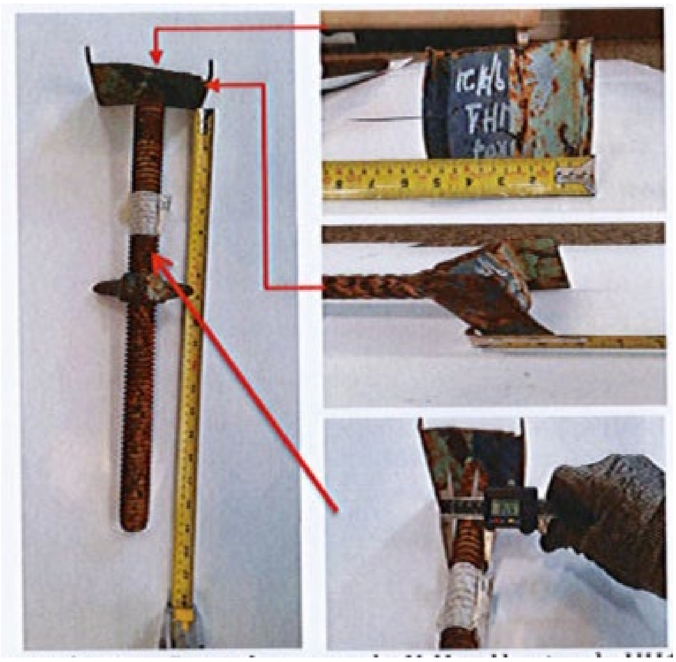

Figure 26 a. Measurement of U Head (UH1)

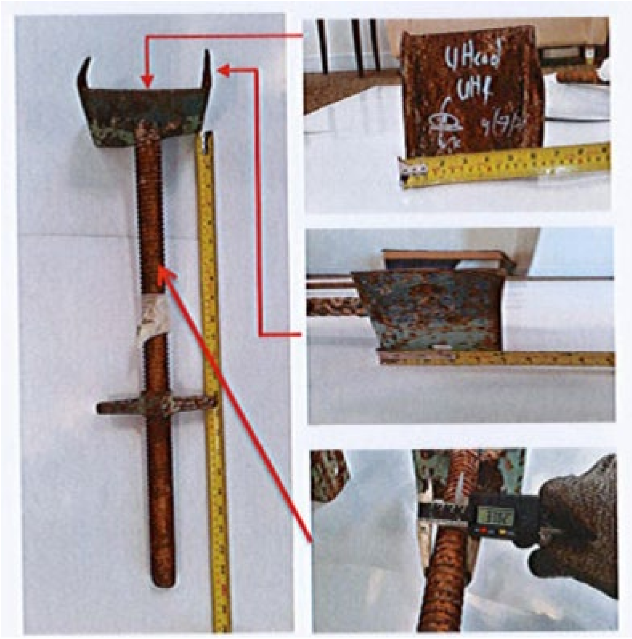

Figure 26 b. Measurement of U Head (UH4)

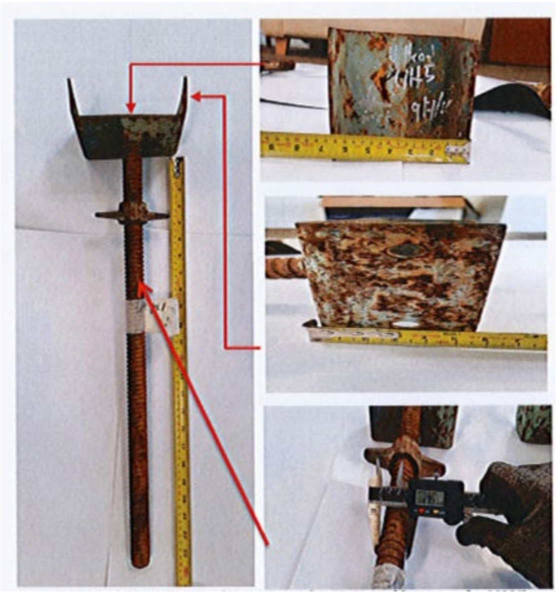

Figure 26 c. Measurement of U Head (UH5)

Table 4. Measurement of U Head

U Head	Items	Units
UH1	U Head	13.0mm
	Side of U Head	2.5mm
	Standard	48.0mm
	Diameter of Standard	3.4mm
UH4	U Head	16.0mm
	Sideof U Head	5.0mm
	Standard	56.0mm
	Diameter of Standard	3.4mm
UH5	U Head	16.5mm
	Side of U Head	5.5mm
	Standard	60.0mm
	Diameter of Standard	2.9mm

3.5 Sleece Copler

Measurements have also been conducted on the outer diameter (OD), inner diameter (ID), and thickness of the sleeve coupler samples collected from the work site, as shown in Figure 27. The measurement results are presented in Table 5.

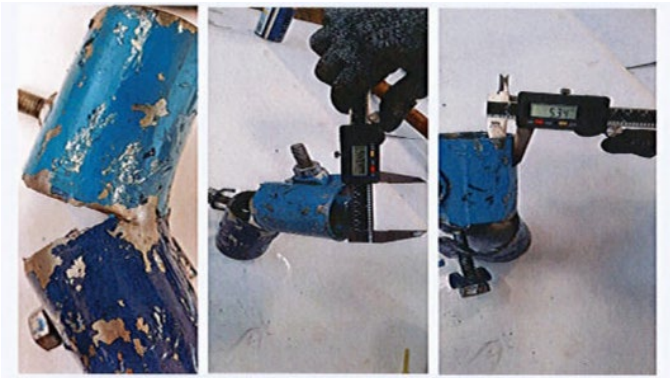

Figure 27. Measement on Sleeve Coupler

Table 5. The measurement reading

Bil.	Coupler	Units
1.	Outer Diameter (OD)	54.7 mm
2.	Internal Diameter (ID)	49.5 mm

3.6 Structural Analysis (Load Calculations)

The concrete work process involves two layers. The first layer consists of concrete poured into the formwork to a depth of 1.75 meters. Once this concrete has set, wet concrete for the second layer is poured to reach the full depth of 3.25 meters. However, the wet concrete could only be poured to a depth of 1.4 meters before the falsework collapsed. The load calculations borne by the falsework at this depth are as follows:

Volume of Concrete = 8.766 m ((2.2 x 1.4) + 2 (0.725 x 0.8/2)) = **32.08 m^3**.
Weight of Concrete = 24.3 kN/m3 x 32.08 m^3 = **779.54 kN**
Weight of Reinforcement Bar = 110 kN (based on the statement from the Main Contractor)
Total Load = 779.54 kN + 110 kN = **889.54 kN**

3.7 Computational Structural Analysis

This analysis was conducted using computational software to assess the falsework structure's deformation under load when wet concrete is poured into the formwork.
The parameters for the analysis are as follows:

Falsework System = Tubular
Scaffold Tube Size = 48.3 mm (D) x 4.0 mm thick
Yield Strength = 235 N/mm2
Tensile Strength = 380 N/mm2

The analysis model was developed based on observations at the site and information provided by the contractor. The modeling was created according to the installation method employed at the site and referenced the sketches made by the forensic investigator during the examination. Several factors were taken into consideration, including the spacing between standards, the position of joints, and bracing. The dimensions of the falsework at location P116R are 7.5 meters in height, 7 meters in length (at the bottom), 8 meters in length (at the top), and 6 meters in width, as illustrated in the isometric view shown in Figure 28. The supported surface area of the formwork is 8.766 meters in length, as indicated in Figure 29.

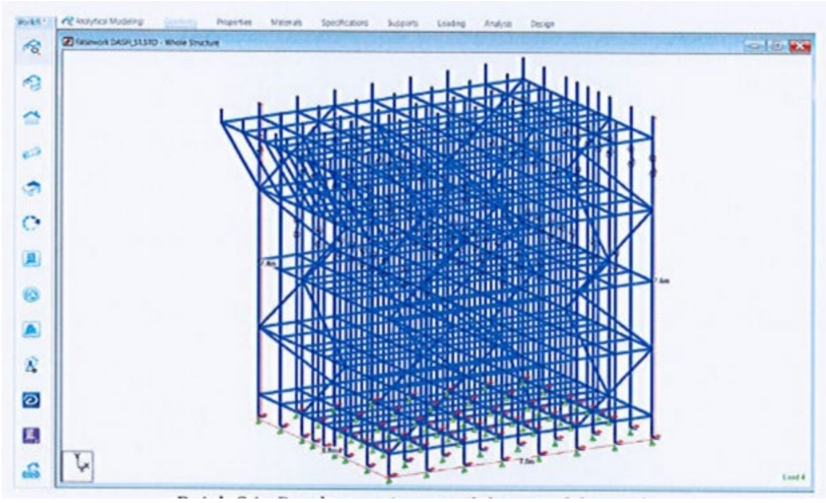

Figure 28. Isometric of Faselwork

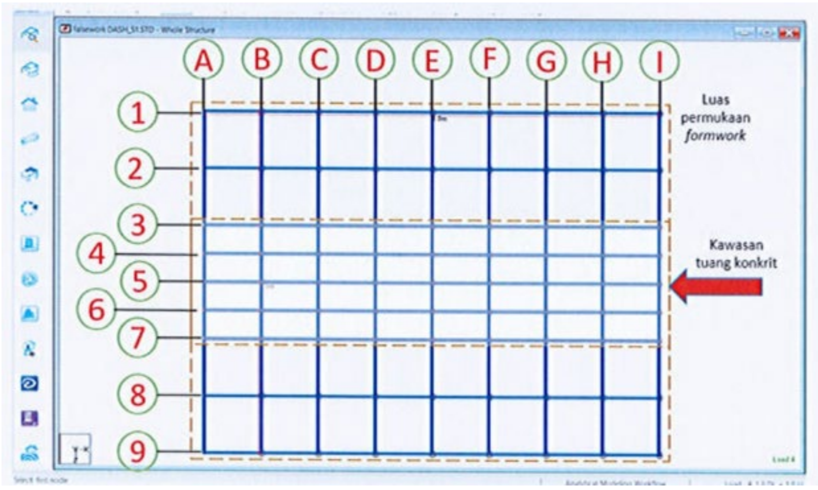

Figure 29. Top View

The positions of the joints and bracing for each frame are illustrated in Figures 30 to 35.

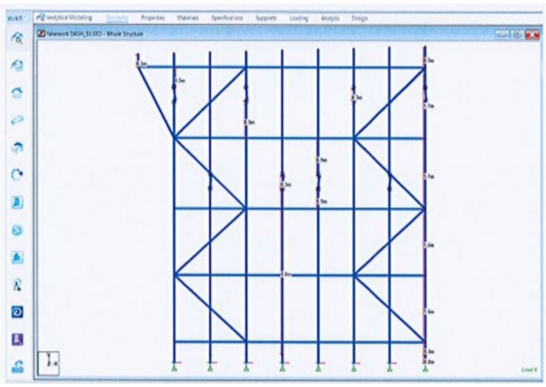

Figure 30. Side View of Grid 1 & 9

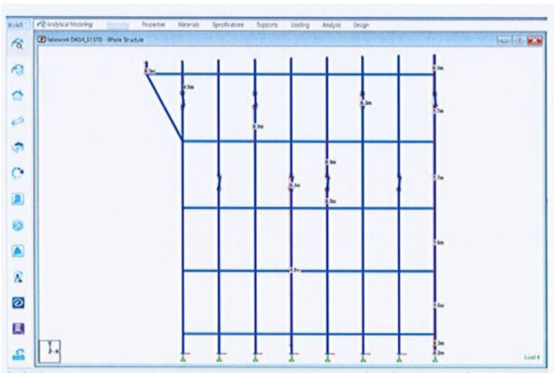

Figure 31. Side View of Grid 2, 4, 5, 6, & 8

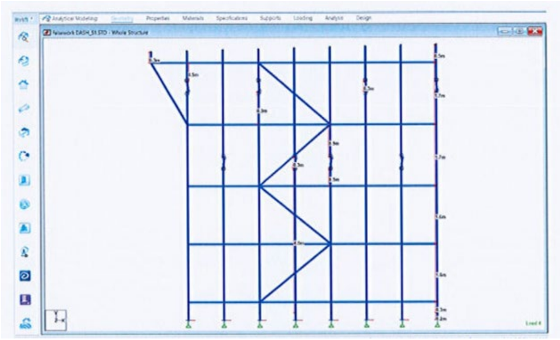

Figure 32. Side View of Grid 3 & 7

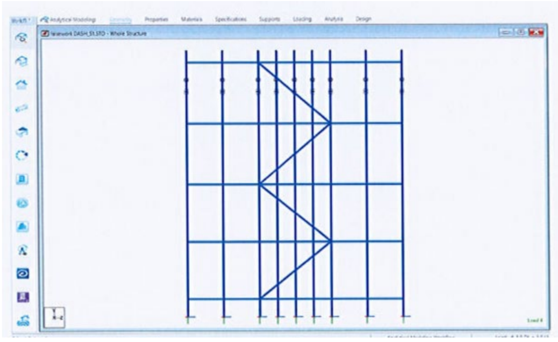

Figure 33. Side View of Grid B & D

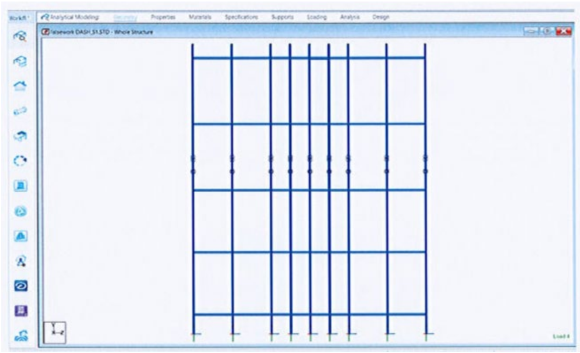

Figure 34. Side View of Grid C, E, F, & H

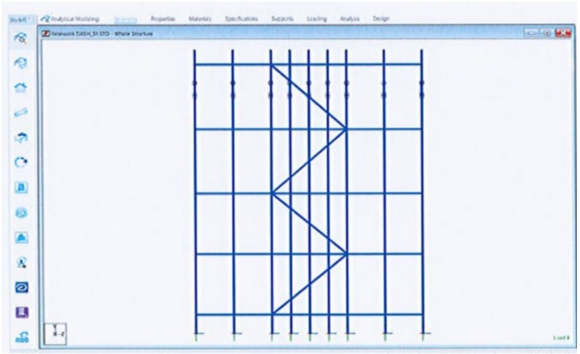

Figure 35. Side View of Grid G & I

The load acting on the falsework is a uniform distributed load (UDL) of 50.74 kN/m³, resulting from the concrete poured to a depth of 1.4 meters. Figure 36.

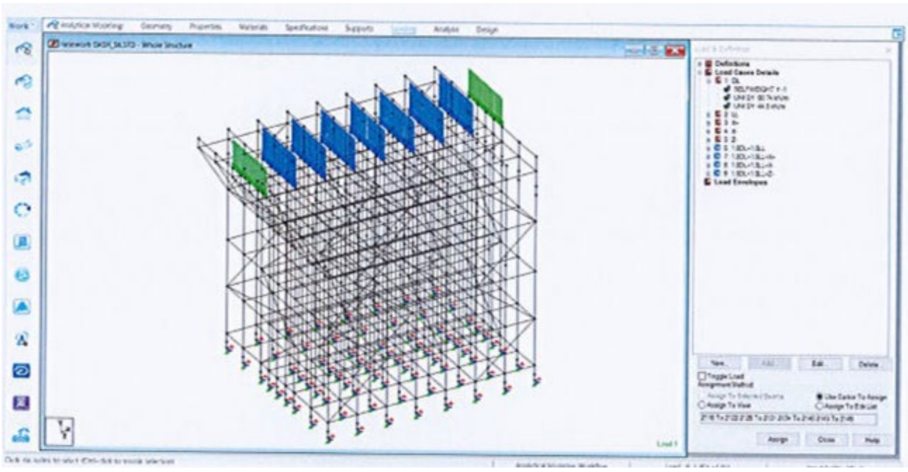

Figure 36. Dead loads of 50.74 kN/m and 44.8 kN/m

The live load is 2.5 kN/m², which accounts for the presence of workers, equipment, and components situated on the formwork during the wet concrete pouring process. Figure 37.

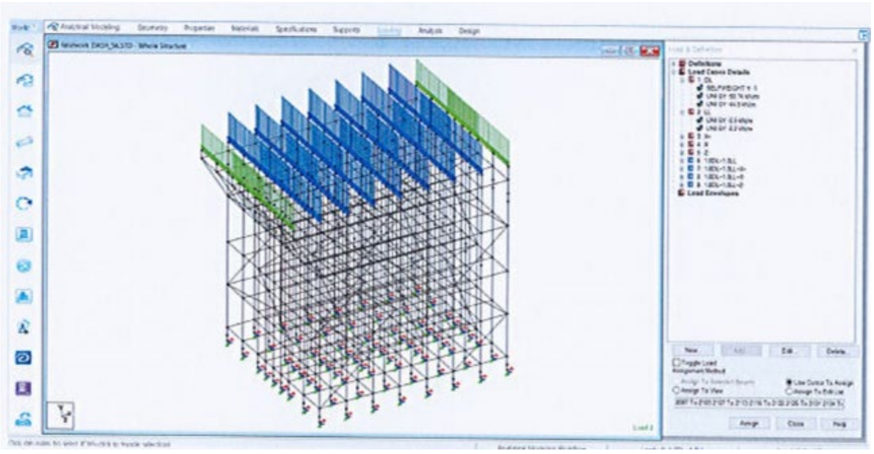

Figure 37. Dead loads of 2.5 kN/m and 2.2 kN/m

British Standards 5957 (Clause 19.2.9.2) stipulates that bracing is required to maintain the position of the nodal points (connections) in falsework. The bracing in any direction at the nodal points should be capable of resisting lateral forces equivalent to 2.5% of the axial load acting on that node. The calculated horizontal load amounts to 22.24 kN (2.5% x 889.54) in one direction. Figure 38a, b and c.

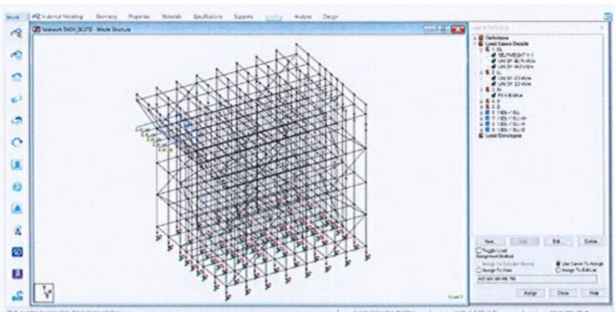

Figure 38a: Horizontal load X+4.45 kN

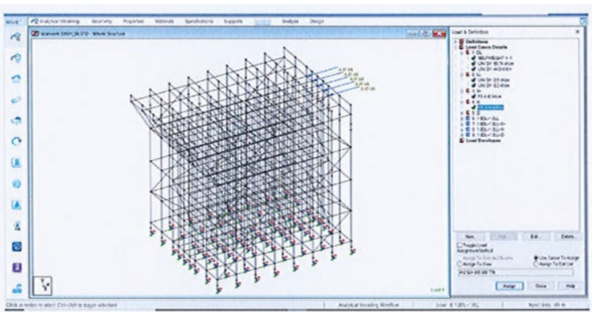

Figure 38b. Horizontal load X-4.45 kN

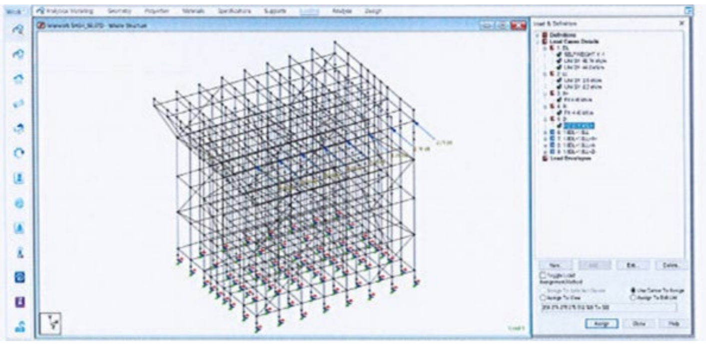

Figure 38c. Horizontal load Z – 2.78 kN

4.0 LIMITATION

This study has a few limitations and assumptions being made in narrowing down the multiple possibilities of accidents occurring:

1. Assumption on the concrete load is adistribute load as the evidence on the site indicates that all the concrete has been done and the 4th pouring inti the formwork.
2. Concretew vibration has been excluded from the analysis due to its small significant in the analysis because the ascaffold arrangement it different from the actual.

5.0 RESULTS AND DISCUSSION

5.1 Components Mesearument

Measurements were taken from the samples obtained at the accident site were compared with the standards outlined in BS 1139, MS 1462-1, and the manufacturer's specifications, as presented in Table 6. This comparison revealed that several component measurements, such as those for the extender bar, U head, and sleeve coupler, exceeded the established limits. Additionally, the measurements of these components confirmed the presence of a gap between the outer diameter (OD) of the tube and the inner diameter (ID) of the coupler, which allows for relative movement between the two components. This movement is proportional to the load applied to the standards (tubes) that have joints. The impact of the relative movement between the components on the overall stability of the structure will be addressed in an analysis that includes considerations of eccentricity.

Table 6. Comparison of material dimensions

Components	Average Outer Diameter (OD) (mm)	Average Thickness (mm)	Tolerance (mm)				
			OD (mm)	Difference (mm)	Thickness (mm)	Difference (mm)	Results
Extender Tube	48.05	2.89	48.3*	- 0.25	4	-1.02	FAIL
Standard Tube	48.72	4.42	48.3*	0.42	4	0.42	OK
U Head	85 X 130	-	150 X 130**	-65 X 130	-	-	FAIL
Sleeve Coupler	54.7	2.6	57.2***	2.5	3.5	-0.9	FAIL

*BS1139
**MS1462-1
*** Mitrascaff Spesifications.

5.2 Comparison of Engineering Drawings and Falsework Construction on Site

As stated in Figure 16, the contractor constructed the falsework solely by referencing a single approved engineering drawing provided by the engineer. A geometric comparison between the structure depicted in the engineering drawing and the materials on site (illustrated in Figure 16) was conducted to assess the applicability of the engineering drawing as a construction reference. The results of this review are presented in Table 7. The comparison revealed significant discrepancies between the geometries of the structure as illustrated in the drawing and the actual construction on site. Due to these notable differences, the engineering drawing cannot accurately represent the on-site construction, as technically, the typical drawing serves as a reference for similar structures.

Table 7. Comparison of engineering drawings and construction

ITEMS	Engineering Drawing (ED) (mm)	As Built (mm)	Percentage Difference (mm)
Height	20	7.6	163%
length	9	8	12.5%
Width	6	6	-
spacing between standards (tubes)	1	1	-
spacing between ledgers	1.5	1.7	13%
Length of the cantilever area	2	1	50%

5.3 Deflection of Falsework

The displacement of members and nodes was examined to assess the overall behavior of the structure when subjected to the load of wet concrete. The deflection limit specified in BS 975 is 0.15% of the total height. For this falsework structure, the allowable deflection is 11.4 m (0.15% x 7600 mm). The form of the deflection is illustrated in Figure 39.

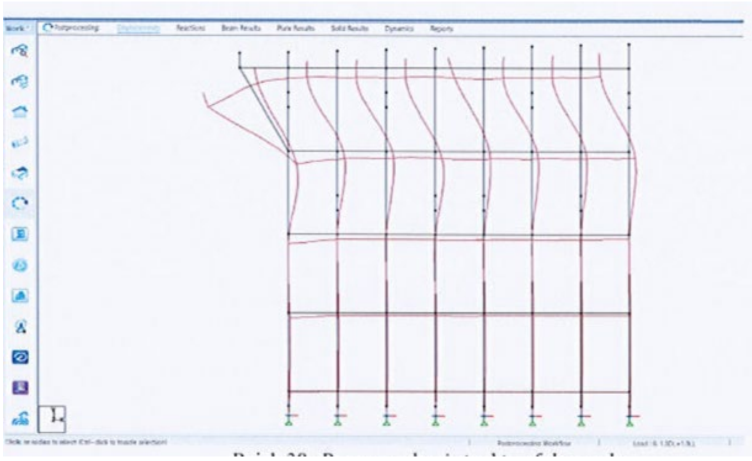

Figure 39. Deflection of the Falsework Structure

The analysis results (Table 8) indicate that the maximum deflection recorded is 16.969 mm, which exceeds the permissible limit. Beam Displaccement Detail Summary from standard BS5976.

Table 8. Resultant Deflection

Displacements shown in italic indicate the presence of an offset

	Beam	L/C	d (m)	X (mm)	Y (mm)	Z (mm)	Resultant (mm)
Max X	1400	3:X+	0.4	**6.824**	0.040	0	6.824
Min X	1400	8:1.0DL+1.0LL-	0.4	**-14.249**	-2.075	0	14.399
Max Y	1301	3:X+	0	6.465	**1.311**	-0.016	6.596
Min Y	1310	8:1.0DL+1.0LL-	0.3	-14.173	**-9.331**	0.000	16.969
Max Z	1431	8:1.0DL+1.0LL-	0	-3.287	-0.933	**1.858**	3.889
Min Z	1165	9:1.0DL+1.0LL-	1.5	-3.791	-0.462	**-6.717**	7.727
Max Rst	1310	8:1.0DL+1.0LL-	0.3	-14.173	-9.331	0.000	**16.969**

5.4 Axial Load

The structural response to the applied loads generates axial forces acting on the individual members. Depending on the distribution across the structure, these axial forces will determine whether the structural members experience tensile or compressive forces. The analysis results (Table 9) indicate that the maximum axial force acting on a member is 46.9 kN (compression). Positive readings indicate compressive forces, while negative readings signify tensile forces. The capacity of the tubular falsework to withstand axial loads is detailed in Table B.2 of BS 5975. For falsework installed with a lift height of 1.6 m, the capacity of the tube is 39.2 kN (new) and 34.5 kN (old) (Table 10). A comparison of the analytical values with those in BS 5975 reveals that the axial force acting on the members of the tubular falsework has exceeded its capacity. Beam End Force Summary- BS5976.

Table 9. Analysis Results

or an beam.

	Beam	Node	L/C	Axial	Shear		Torsion	Bending	
				Fx (kN)	Fy (kN)	Fz (kN)	Mx (kN m)	My (kN m)	Mz (kN m)
Max Fx	1339	581	7:1.0DL+1.0LL+	46.90	0.21	-0.03	-0.000	0.023892	0.154
Min Fx	1185	438	8:1.0DL+1.0LL+	-39.84	-0.00	0.01	0.002	0.037	-0.026
Max Fy	2120	490	8:1.0DL+1.0LL+	1.69	18.09	-0.49	0.066	0.002	2.194
Min Fy	2147	818	8:1.0DL+1.0LL+	1.70	-18.04	0.50	-0.065	0.004	2.176
Max Fz	1086	421	8:1.0DL+1.0LL+	17.13	-0.61	6.49	0.051614	-0.781	-0.089
Min Fz	1534	749	8:1.0DL+1.0LL+	17.16	-0.61	-6.47	-0.052	0.780	-0.088
Max Mx	2118	488	8:1.0DL+1.0LL+	2.89	8.95	-0.69	0.094	0.068	-0.716
Min Mx	900	258	8:1.0DL+1.0LL+	0.60	-0.12	0.06	-0.092	-0.003	-0.071

Table 10. Schedule B.2 BS 5975

Table B.2 — *Safe axial loads in compression for Type 4 steel scaffold tubes manufactured in accordance with BS EN 39:2001*

Effective length, L_e	"As new" tubes: Slenderness ratio, λ	"As new" tubes: Safe axial load, P_c	"Used" tubes: Slenderness ratio, λ	"Used" tubes: Safe axial load, P_c
mm		kN		kN
200	12.7	79.3	12.8	70.6
400	25.4	76.5	25.7	68.0
600	38.1	70.9	38.5	63.0
800	50.8	65.0	51.3	57.7
1 000	63.5	58.6	64.2	51.9
1 200	76.2	51.9	77.0	45.9
1 400	88.9	45.3	89.9	39.9
1 600	101.7	39.2	102.7	34.5
1 800	114.4	33.7	115.5	29.6
2 000	127.1	29.1	128.4	25.6
2 200	139.8	25.3	141.2	22.1
2 400	152.5	22.0	154.0	19.3
2 600	165.2	19.3	166.9	16.9
2 800	177.9	17.1	179.7	14.9

5.5 Eccentricity

Eccentricity loading occurs during the installation of falsework due to the positioning of steel sections not being aligned with the centroid of the U head. The eccentricity limit specified in BS 975 is 25 mm. The analysis, which accounted for eccentricity, indicated effects on the connections between the tubes, as shown in Figure 40, where high moments (Mz) were observed at the connection nodes. Theoretically, these forces act on the connections because there is a gap between the tube and the coupler, allowing for movement of the tube and subsequently redistributing the concentrated forces to the sleeve coupler.

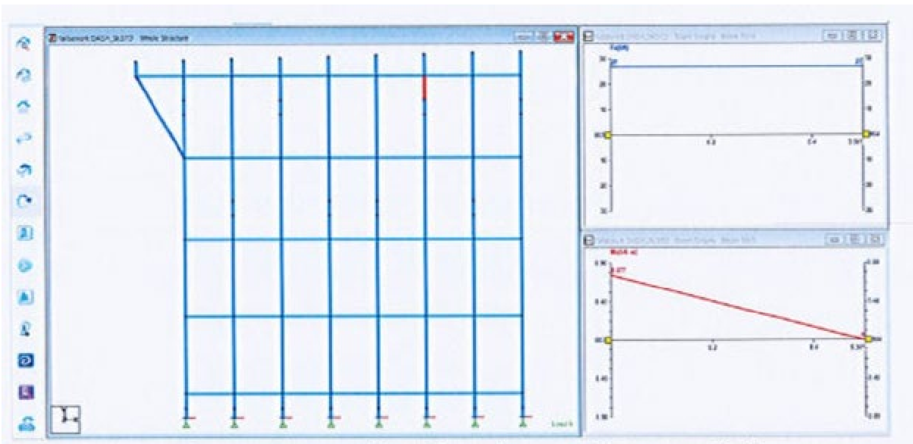

Figure 40. Moment at the connection node (sleeve coupler)

An assessment of the capacity of the sleeve coupler was conducted to determine its performance when subjected to the moments generated by the load of concrete acting on the falsework structure. The free body diagram for the sleeve coupler is illustrated in Figure 41.

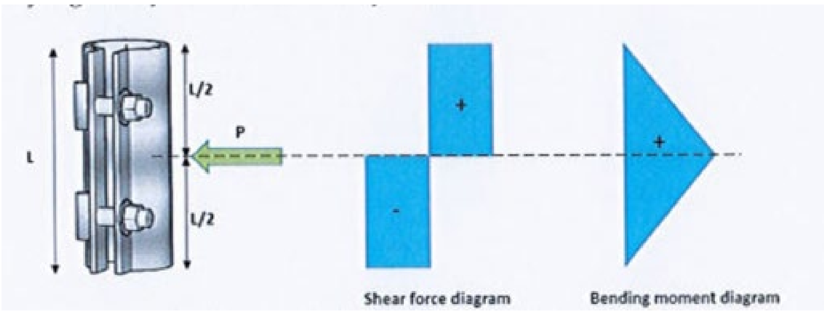

Figure 41. Free body diagram of sleeve coupler

The safe working load for the coupler, as specified in BS 5976, is shown in Table 11, with the bending limit for the sleeve coupler set at 0.59 kNm. The bending moment Mz on the sleeve coupler, according to the model, is 0.677 kNm, as illustrated in Figure 42. A comparison between the allowable limit and the actual value reveals that the sleeve coupler has experienced bending beyond its capacity.

Table 11. Safe Working Load of Couplers

Table B.4 — *Safe working loads for individual couplers and fittings*

Coupler type	Resistance	Safe load, moment or stiffness
Right angle coupler (Class A)	Slipping force (in kN)	6.1
	Cruciform stiffness (in kNm/rad)	10.0[A]
	Cruciform bending (in kNm)	0.24[A]
Swivel coupler (Class A)	Slipping force (in kN)	6.1
Friction type sleeve coupler (Class B)	Slipping force (in kN)	3.0
	Bending (in kNm)	0.59
Internal joint pin (expanding spigot coupler)	Slipping force (in kN)	0.0
	Bending (in kNm)	21.0
Parallel coupler	Slipping force (in kN)	4.7
Putlog coupler	Slipping force (in kN)	0.63[B]
	Cruciform stiffness (in kNm/rad)	2.0[A]
	Cruciform stiffness (in kNm)	0.06[A]
Adjustable base plate	Axial compression (in kN)	30.0

NOTE These figures are based on Annex C of BS EN 12811-1:2003 and are for use with Type 4 steel tubes.

[A] The designer should be satisfied that the right angle couplers being used conform to BS EN 74-1:2005 Class A. Data on cruciform strength and stiffness has to be obtained from the supplier/manufacturer to check.

[B] From BS 1139-2.2:1991.

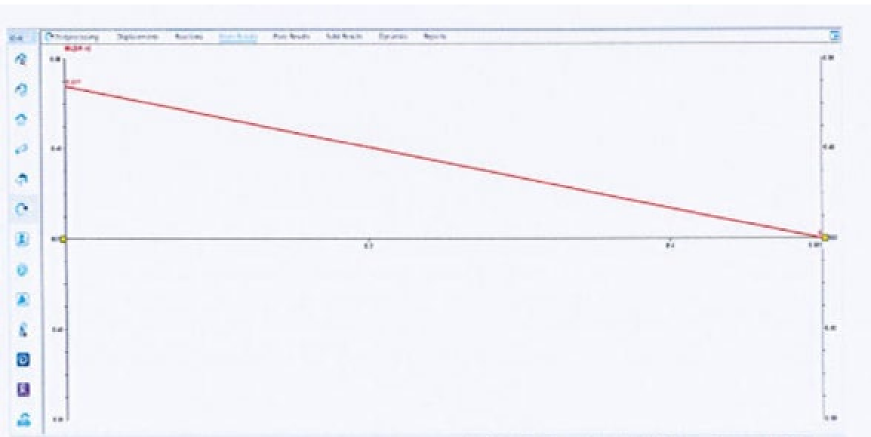

Figure 42. Bending Moment of 0.677 kNm at the Node (Sleeve Coupler)

A summary comparison between the results of the analysis and the limits established in BS 5975 is presented in Table 12. According to design principles, if a particular analysis value exceeds the permissible limit specified in the standard code, the structural design is deemed to have failed. In theory, the term "limit state" refers to a condition of potential failure, where the structure is no longer able to perform its intended function satisfactorily in terms of both safety and serviceability (i.e., it either collapses or becomes unserviceable).

Table 12. Analysis summary

Parameter	Analysis Result	Limit Value BS 5975	Results
Deflection (Structure)	16.97 mm	11.40 mm	Fail
Axial Force (Tube)	46.90 mm	34.50 kn	Fail
Deflection (Sleeve Coupler)	0.68 mm	0.59 knm	Fail

6.0 CONCLUSION

The forensic engineering findings were derived through a combination of quantitative and qualitative approaches, based on circumstantial evidence gathered from the accident site. Results from the computational forensic structural analysis, including stability analysis, finite element analysis, and capacity calculations, indicate that the immediate cause of the falsework collapse was the structure's inability to support the load of the wet concrete applied to it. The findings are as follows:

a. Failure occurs when the falsework structure receives a load of 32.08 meters of concrete, equivalent to 50.74 kN/m², while the concrete is poured to a depth of 1.4 meters.
b. This load causes the construction materials of the structure to deform, exceeding the safe limits.
c. Some sections of the falsework tubing experience axial forces that exceed their compressive strength capacity.
d. Some sleeve coupler joints experience bending that exceeds safe limits.

ACKNOWLEDGEMENT

The author acknowledges the Forensic Engineering Lab (FEL) and its staff at Forensic Engineering Division (FED), Department Occupational Safety & Health Malaysia as part of this investigation and study with Faculty Artificial Intelligence (FAI), UTMKL.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this paper.

REFERENCES

[1] Balya Mulkan Wijaya Mohammad Yusuf. (2017). *Faktor Rembatan(Bracing) dan Penyambung (joint) Terhadap kekuatan Binaan Komponen Perancanh (Scaffold) yang Digunakan Sebagai Penyangga Sementara (Falsework)*. Laporan Penyiasatan Kejuruteraan Forensik. Bahagian Kejuruteraan Forensik. Jabatan keselamatan Kesihatan Pekerjaan Malaysia.
[2] Construction Research Institute of Malaysia (CREAM). (2014). *Test on steel frame scaffolding report*.
[3] Osman, M. H., *et al*. (1998). Design and performance of tubular steel scaffold. *Journal of Civil Engineering, 11*(1).
[4] J. E., R. H., & Hancock, G. J. (2000). Structure stability of braced scaffold and formwork with spigot joints.
[5] CASE. (2006). *Tests of formwork subassemblies and component investigation report No. S1499*. Centre for Advance Structural Engineering, School of Civil Engineering, University of Sydney.
[6] J. R., Rasmussen, K. J., & Zhang, H. (2013). Optimising of scaffold system.
[7] British Standards Institution. (2011). *BS 5975:2008: Code of practice for temporary works procedures and the permissible stress design of falsework*.
[8] Lewis, G. L. (2003). *Forensic materials engineering: Case studies*. CRC Press.
[9] Forensic Engineering Investigation Data, FED, DOSH Malaysia.