ANALYSING AND PREDICTING FALSEWORK FAILURE IN HONG KONG

by

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Abstract

Falsework is a temporary structure supporting the permanent structure while it is not self-supporting. Falsework is commonly required in concrete construction which involves a number of parties such as the design engineer, contractor, subcontractor, supplier and checking engineer. In the past, many failures occurred due to procedural inadequacy such as confusion in responsibility delineation and communication. In Hong Kong, during the last six years, at least eight major falsework collapses have been reported.

Researchers studying falsework failures have devised models for analysis and prediction. However, procedural inadequacy has not been adequately considered and assessed in these models. Further, these models were mainly used to predict the likelihood of eventual failure at loading stage without evaluating the safety condition at various stages of falsework construction.

The overall aim of this thesis was to develop a procedural framework that can be used to assess the proneness to failure at different stages of constructing falsework in Hong Kong, thus, warning can be given promptly. The objectives of the research were:

- to review the practices of falsework scaffolding;
- to compare the different control systems on the design and construction of falsework;
- to analyse the causes of falsework failures; and
- to develop a procedural framework for assessing the safety of falsework at various stages.

To identify the causes, fifty failure cases were analysed. Nine site visits to Hong Kong, Macao, China, Taiwan and Singapore, where falsework failures occurred, were made. A total of thirty-three tests of falsework scaffolding materials were performed in the laboratory. A procedural framework based on Balloon Theory was developed to assess the procedural errors for analysing and predicting falsework failure.

The research yielded the following outcomes:

- the identification of causes, frequency and impacts to falsework failures;
- the classification of the key and critical activities of falsework under the five essential stages, i.e. design, erecting, loading, dismantling and anew;
- recommendations on the loadbearing capacity of the new and used falsework scaffolding material;
- the graphical presentation and assessment of the procedural errors accumulated throughout various stages;
- the flowchart, showing the role of various parties and the impact due to changes in the construction method of the permanent works and falsework, for analysing and predicting failures; and
- a procedural framework to analyse and predict falsework failures.

Fifteen construction professionals confirmed that the procedural framework would be very useful in monitoring the performance of falsework as required under the latest Code of Practice for Metal Scaffolding Safety issued by the Labour Department of Hong Kong.

Keywords: Falsework failures, analysis, prediction, Hong Kong

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I would like to thank Professor A. D. F. Price for his time, advice and patience during the period I worked towards the production of this thesis.

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This research work is specially dedicated to all those who had been injured or lost their valuable life during falsework failures.

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CHAPTER ONE

INTRODUCTION

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INTRODUCTION

1.1 Introduction

Falsework are temporary structures used to support a permanent structure while it is not self-supporting (BSI BS5975 1996). Falsework failures during construction have been reported quite frequently (Elliott 1973, Bragg 1975, Hadipriono & Wang 1986, Tsai & Hadipriono 1990, Poon 1997). During the last six years, at least eight major falsework collapses have occurred in Hong Kong. These accidents have not only resulted in delays to construction works and extra cost, but also the loss of human life (Poon & Price 1991).

This research aims to develop a procedural framework for analysing and predicting falsework failure in Hong Kong. The causes of falsework failure have been extracted from failure reports. The cumulative effect of various causes is assessed at different stages of falsework activities in order to identify the most critical stage and to assess the proneness of failures.

This introductory chapter presents a brief summary of: the background to the problem; definition and characteristics of falsework; a justification of the research; the research aim and objectives; the methodology used; a procedural framework for falsework failure analysis and prediction; organisation of the thesis and the summary of research achievements.

1.2 Background to problem

Concrete construction is very common in Hong Kong with an annual consumption of over 10 million cubic metres (Wang 1995). Massive quantities of concrete are not only required for public housing projects and private works, but also in new town development and infrastructure projects which often include the construction of a number of highway bridges and footbridges.

Concrete bridge construction always involves the erection of falsework. There have been a number of collapses of falsework during bridge construction in Hong Kong and in many other cities (Poon 1996a). Despite previous research that has been performed on the topic around the world (Bragg 1975, Hadipriono 1986b), there is little in-depth investigation into the failures in Hong Kong.

In the design and construction of concrete bridges, a number of parties are normally involved. The professionals responsible for falsework activities for a typical bridgework contract in Hong Kong are shown in Table 1.1 (BS5975 1996).

Table 1.1 Responsible parties and falsework activities of a bridgework contract

Party responsible	**Falsework Activities**
Engineer/ Resident Engineer	Overseeing falsework design and construction
Contractor/Subcontractor	Formwork and falsework design
Checking Engineer	Checking and approval of falsework design and construction
Contractor	Construction method
Contractor	Supervision of construction
Specialist Subcontractor	Post-tensioning/precast beam placement
Supplier	Supplying falsework scaffolding materials
Subcontractor	Falsework erection and dismantling
Subcontractor	Concreting

As depicted in many falsework failure reports, inadequacy or improper practice of one or more of the above activities often leads to failure and collapse of falsework during construction (Bragg 1975, Hadipriono 1985, 1986a, 1986b). The quality and extent of contribution of each member of the construction team will be different due to their experience and competence, control system etc. (Ayyub 1985), and will have an effect on the safety of the structure during construction.

There have been many falsework failures arising from the use of the conventional control system of "Design by Contractor and Check by Engineer" (Hadipriono 1986b, 1987). Subsequently, some failure reports suggested that the appointment of a Falsework Coordinator (Bragg 1975, BS5975 1996) or an Independent Checking Engineer (ICE) can minimise failures in communication between the parties (Hadipriono 1985b). However, a serious falsework failure occurred during construction in Hong Kong despite a third party checking system had been adopted for this project (Poon 1996a). There was evidence that the contractor had ignored the role of the ICE in certifying the design as well as the revised construction method.

As a result of the high rates of injuries and fatalities in the UK construction industry, the Construction (Design and Management) Regulations 1994 was developed and implemented. Amongst other recommended measures, the "designer" now requires to consider health and safety in the design and to assess the risk. The "designer" includes the Engineer who designs the permanent works as well as the Contractor who designs the temporary works.

Likewise in Hong Kong, a high rate of accidents on building sites has stimulated the Buildings Department to enforce, in stages, the Site Supervision Plan System which requires professionals to assess the construction works and site conditions, and implement appropriate degree of supervision.

1.3 Definition of falsework

Falsework, in the British Standard BS5975 (1996), is defined as "Any temporary structure used to support a permanent structure while it is not self supporting". One typical application of this definition is the steel scaffolds supporting the timber formwork on top of which concrete is being placed. When the poured concrete has developed sufficient strength, the falsework can be dismantled. However, this definition is not free of misunderstanding. Illingworth (1987) has commented that the definition is not entirely satisfactory because some other construction works such as diaphragm walling also satisfies the definition, yet they are not considered as falsework. He defined falsework as any temporary structure, in which the main load carrying members are vertical, used to support a permanent structure and any associated raking elements during its erection and until it is self supporting. This definition distinctly emphasises on the main supports being vertical and has the merits of ensuring the Falsework Coordinator's activities, as listed in BS5975 (1996) are within the scope of works of the revised definition (Illingworth 1987).

Emphasising the vertical members as the main supports can be far from the true situation on many construction sites. Many horizontal members are always spanning above a space where access is necessary, and are supported by vertical members at the ends. A number of collapses have been recorded regarding the buckling failure at the web of the I-beams (Braggs 1975, Poon 1997). Had Illingworth's modified definition of falsework been adopted, the I-beams need to be classified and included as formwork which by definition are those members in immediate contact with concrete.

In this research, the BS5975 definition is adopted and the study concentrates particularly on the scaffolds that are structural systems providing mainly the vertical supports to a permanent structure which is not yet self-supporting.

1.4 Characteristics of falsework

As interpreted from BS5975 (1996), falsework is a temporary structure used to support a permanent structure during its strength development process. A simple timber strut, an adjustable metal prop, the tubular scaffold systems and I-beams are examples of falsework elements. The form and materials used are often dictated by the loads the falsework is designed to carry. In this research, the type of scaffolding system most commonly used in Hong Kong would be studied and tested.

The falsework scaffold systems possess the following distinctive characteristics (Concrete Society 1971, Poon 1996b).

- Falsework has a very short life on site. Once the permanent works has been built, the associated falsework will be dismantled.
- Falsework comprises slender units for ease of handling in assembling and dismantling. They should be durable and properly maintained for repeated use.
- Falsework is subjected to varying loading conditions which arise from and during construction, and are often difficult to predict with a high degree of accuracy.
- Falsework is not normally held down by permanent foundations, but relies on its own weight to restore stability.
- Simple analysis and design techniques are considered as adequate for falsework scaffolding (Bragg 1975). However, there have been many common errors found in load assessment such as neglecting horizontal and inclined pressure of concrete on inclined formwork which can lead to collapse of falsework (Bragg 1975).
- Falsework structures are designed by the Contractor or subcontractor, and require approval by the Engineer. In Hong Kong, for contracts involving substantial temporary works, an Independent Checking Engineer is required for checking the design and construction of the falsework (Hong Kong Government 1992).
- The collapse of falsework for large works, causing delays and injuries, is often spectacular and usually attracts considerable public attention.

1.5 Justification

Since the seventies, several researchers have investigated the causes of falsework failures (Bragg 1975, Hadipriono 1986b, 1987). They have identified the linguistic variables that are often used to describe the factors and conditions affecting the safety of construction operations. For instance, the designer could be described as having either ‘adequate’ or ‘inadequate’ experience and the falsework erected is in ‘new’ or ‘used’ condition. Moreover, the effect of these factors on the safety of the construction operations has been expressed in linguistic terms too (Ayyub 1985). Fuzzy set theory was introduced by Zadeh (1965) and, since then, it has been used extensively to translate the linguistic variables into mathematical measures. For example, the fuzzy set concept was used to assess the safety and performance of temporary works (Ayyub 1985, Hadipriono 1985a, 1985b, 1986a). The procedural frameworks derived by Blockley (1977) and Hadipriono (1985a, 1985b, 1986a) for predicting failure, however, have not included the effect of procedural inadequacies which have been identified as one of the key causes for failures (Bragg 1975, Hadipriono 1985b, 1986b).

During the last six years, five workers were killed and over eighteen workers were injured in eight major falsework failures in Hong Kong. On average, at least one severe failure occurred every year. In 1982, the falsework scaffold supporting the crosshead of a bridge pier of the Tuen Mun Highway collapsed during concreting (Labour Dept. 1982). In 1986, the partially erected falsework collapsed during rectification at the Tsing Yi North Bridge site (Labour Dept. 1986). In 1995, a 75-ton precast concrete bridge segment crashed through the supporting scaffold while being moved to a pier of the Route 3 Highway (South China Morning Post 1995). In January 1996, two precast concrete beams temporarily supported by falsework scaffold fell to the road below, during the construction of a footbridge at Tseung Kwan O (Poon 1996b). In December 1998, seven construction workers were injured when a half-finished flyover collapsed on to a Tsing Yi construction site (South China Morning Post 1998). Two falsework construction collapsed during concreting in 1999 and as recent as in January 2001, a falsework scaffolding supporting a precast concrete beam and in situ concrete slab collapsed, killing a worker. In all these accidents, construction was delayed and fatalities recorded. It is not surprising that many minor failures involving no injuries go unreported or unnoticed by the public. Despite their occurrences, there has been no systematic study of falsework failures with prediction of their happening in Hong Kong.

Modifications in controlling falsework activities have been suggested and implemented in many different ways. For example, BS5975 recommends the appointment of a Falsework Coordinator who is employed by the Contractor and is in charge of all falsework activities. For major construction contracts in Hong Kong, the Checking Engineer who is independent of the Contractor is required to check the design and construction of falsework. In the UK, the Construction (Design and Management) Regulations 1994 require the designer to pay adequate regard to health and safety risks in their design irrespective of the work nature, whether it is permanent or not. At various stages of a project, designers have to contribute to avoiding and combating health and safety risks in construction so that foreseeable risks can be avoided. There is apparently a shift of emphasis in control from passive checking to proactive consideration for safety during the design stage. The effect on safety by adopting these proactive approaches, however, has not been studied and assessed.

The main reasons for this research are:

- the effectiveness of the control system employing the Independent Checking Engineer was doubtful in view of two recent major falsework collapses in Hong Kong;
- there was no monitoring system available in the industry for checking the safety conditions of the metal scaffolding as required by Code of Practice for Metal Scaffolding Safety (Labour Department 2001); and
- there was no procedural framework available for analysing and predicting falsework failure in Hong Kong.

1.6 Aim and objectives

The aim of this research study is to develop a procedural framework that will assess the safety conditions and the proneness to failure at different stages of designing and constructing the falsework in Hong Kong with the following objectives:

- to review the practices of falsework scaffolding;
- to determine the impact on safety of the falsework by adopting different control systems on the design and construction of falsework;
- to analyse the causes of falsework failures; and
- to devise a procedural framework to assess the safety condition for the falsework at different stages.

1.7 Methodology

In developing a procedural framework to analyse and predict falsework failure in Hong

Kong, different data sets were collected and verified. Thus, a number of different methods have been used in this research.

- An extensive literature review of the topic and unstructured interviews were undertaken to determine the essential activities of falsework and the scope of professionals' responsibility.
- In order to justify the confidence in determining the loadbearing capacity of the scaffold systems, different systems commonly used in Hong Kong were tested under compression load until failure. The test results were compared with the supplier's recommendations.
- To understand the importance of communication and procedural causes, sixteen construction accidents were investigated for the possible causes.
- To investigate the causes of falsework failures, visits to sites and case collection were undertaken.
- Primary and secondary data for the failure causes were extracted from past failure reports using content analysis. The causes were retrieved according to a defined format stating the principal procedural cause and the stage at which failure had occurred.
- The impact of procedural errors on the factor of safety of falsework were interpreted from falsework failure reports.
- A procedural framework was developed for assessing the safety condition of falsework at different stages, using anticipated procedural errors.
- Professionals were interviewed to confirm the relevance and importance of the causes abstracted from various sources, and to provide feedback on the use of the procedural framework.

1.8 Procedural framework development

The procedural framework for analysing and predicting falsework failure is based on the input and output approach. The input would be the procedural errors and the output from the procedural framework is failure or proneness to failure.

The contribution of each procedural cause towards failure was identified from falsework failure reports. The severity of causes was ascertained for initiating a collapse. For a particular falsework construction, the possible procedural errors would be assessed with reference to the failure cases and aggregated at various stages in order to indicate the proneness of the falsework to failure at a certain stage.

The development of the procedural framework consists of the following.

- Establish the common key activities for falsework construction.
- From falsework failure reports, identify the severity of procedural errors towards failure.
- Establish the aggregation of the errors in justifying a failure.
- For monitoring the safety performance of a particular falsework construction, assess the likelihood of the procedural errors and their severity with respect to failure reports or by professional judgement.
- Sum the errors to indicate the safety of the falsework or proneness to failure.

1.9 Thesis organisation

This thesis comprises eleven chapters. The following is a guide to the organisation of the thesis and presents a brief description of the contents of each chapter.

Chapter 1 introduces to the topic, identifies the aim and objectives, justifies the research, enlists the methodology, and outlines the development of the failure prediction procedural framework. Different sets of data were collected and verified in this research. The different research methods used are discussed in Chapter 2, with explanation of why they were being used. Because of the characteristics of the falsework scaffolding, a review of the activities and responsibilities for falsework is presented in Chapter 3 which also discusses the different control systems together with their influence on failures. Chapters 4 and 5 include the review of failure reports and guidelines. Different types of failure reports were analysed in order to retrieve the causes and their importance for the failures. Chapter 6 includes case studies based on private investigation on failures occurred in Hong Kong and nearby cities. Chapter 7 gives an account of the process and the results of the load tests on the scaffolding systems commonly available in Hong Kong. The correlation of strength of the scaffolds with age was performed so as to derive a recommendation for determining their loadbearing capacity. A thorough review of the analysis, prevention and prediction of falsework failure is discussed in Chapter 8. Falsework failure analysis based on procedural inadequacies was presented in Chapter 9. The procedural framework for analysing and predicting falsework failure was developed in Chapter 10 with feedback from professionals on the usefulness of the procedural framework. The last chapter concludes the research, citing the limitation of the procedural framework developed and recommendations for further study. The layout of the thesis is depicted diagrammatically in Figure 1.1.

1.10 Summary of research achievements

A procedural framework is developed to analyse falsework failures and predict the likelihood of a collapse during construction. As inadequate procedures will lead to the reduction of factor of safety by increasing the stresses or by lowering the loadbearing capacity, the falsework will eventually fail due to the accumulation of the errors. The procedures are assessed in terms of the consequence, the frequency of the occurrence and the effectiveness in control. The assessment, relating to the allowable stress and factor of safety of the falsework, can be used to analyse the causes of a collapse and indicate the proneness of a failure. Some research findings have been incorporated into the Code of Practice for Metal Scaffolding Safety issued by the Labour Department of Hong Kong in 2001. The professionals interviewed agreed that a checklist based on the developed procedural framework is useful for site staff to monitor the safety of the falsework on site.

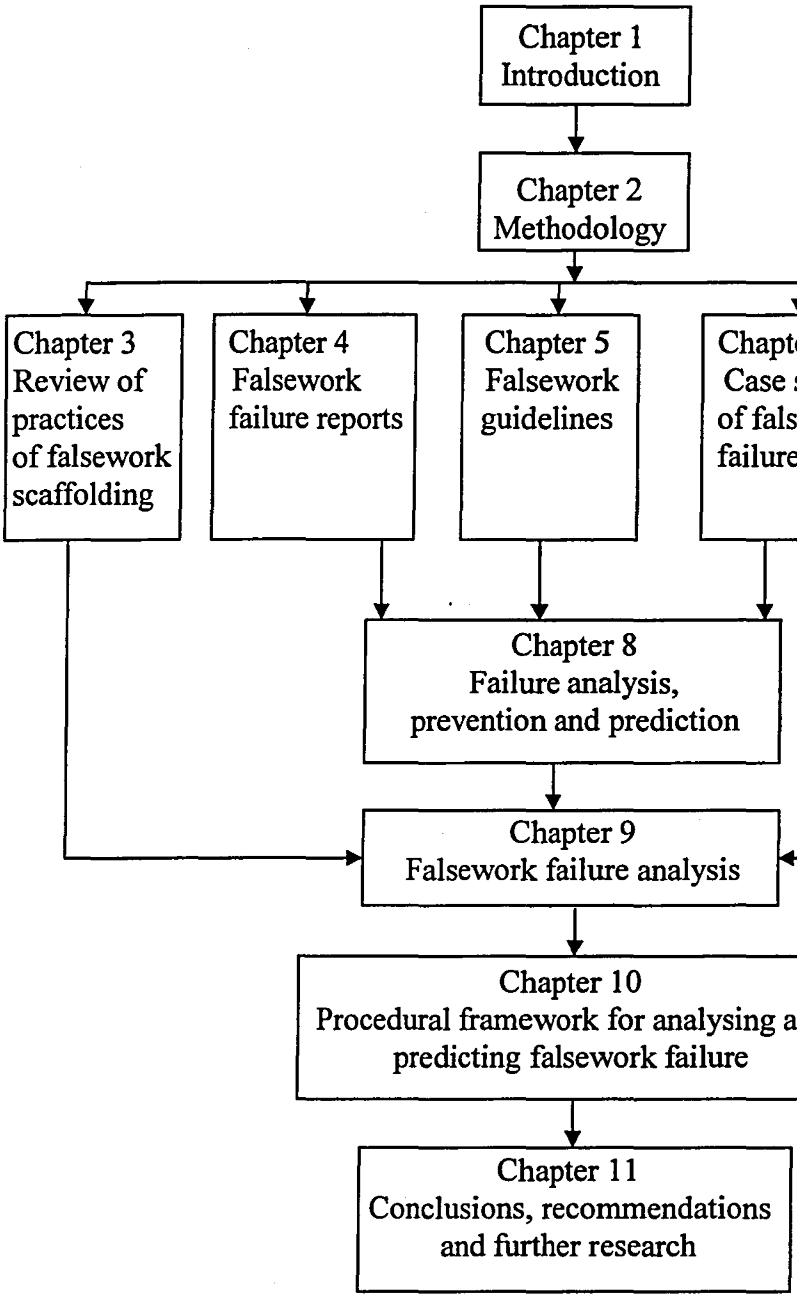

Figure 1.1 Layout of the thesis

CHAPTER TWO

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CHAPTER TWO

RESEARCH METHODOLODY

2.1 Introduction

There are many factors contributing to the collapse of falsework. In view of the variety of data to be collected, several methods have been used including literature review, interviews, load tests, content analysis and case studies. Research design is important as it shows the logical sequence that connects data to the research problem and ultimately to its conclusions of the research work (Yin 1984). The collected data can be of a quantitative or qualitative nature. This chapter outlines the methodology employed in order to realise the aim and objectives of this research.

2.2 Background

Investigations of construction failures have been undertaken by a number of researchers. Bragg's Committee (1975) studied falsework failures extensively. In 1976, Smith presented his study of the causes of bridge failures during and after construction. In 1979, two independent investigations of errors in concrete structures were undertaken in North America and Europe (Fraczek 1979, Hauser 1979). In the eighties, Hadipriono studied the various causes of falsework failures (Hadipriono 1987). Later Poon (1991) analysed the causes of fifty-seven bridges failures during construction.

As a consequence of studying the failure causes, a number of approaches have been put forward by researchers to predict the performance or failures of falsework. Blockley (1977), Ayyub (1985) and Hadipriono (1985a, 1986a) developed models to predict construction failures by an input and output mechanism. The input factors were derived from failure reports and, using the fuzzy sets logic, their importance and probability of failures were linked. Given a set of factors and with subjective assessment by the professionals, the output would be in the form of predictions of the likelihood of falsework failure. Similar applications in damage assessment and decision making in construction operations have been suggested by other researchers (Yao 1980, Ayyub 1985).

A similar approach for predicting falsework failure in Hong Kong has been adopted in this research for two reasons.

- First, there is no feedback received from the construction industry in using the prediction models as proposed by other researchers.
- Second, the failure prediction procedural framework to be developed in this research can provide a quick assessment of the conditions of falsework activities. In view of the falsework collapses in Hong Kong (Poon 1996b), such device would be useful to resident staff on site.

The procedural framework to be developed in this research will provide a better picture of falsework construction by presenting the activities of falsework in sequence and illustrating the contribution of the parties involved. It can be used to pinpoint and identify what has gone wrong should an accident occur. Further, it incorporates the effect of procedural inadequacies which had not been considered in the models devised previously (Blockley 1977, Hadipriono 1985a, 1985b, 1986a).

Inputs to prediction models can be classified as qualitative or quantitative by nature. For failure predictions, most of the input data are qualitative descriptions as suggested by Hadipriono (1985a, 1985b) and supported by other researchers (Blockley 1977, Yao 1980, Ayyub 1985). The classification of causes into enabling, triggering and procedural errors by Hadipriono would be discussed and adopted in this research.

Most of these causes are usually specified in linguistic terms and it is very difficult, if not impossible, to describe or classify them quantitatively. For example, the designer's experience cannot be simply represented by a figure are often described as very experienced, moderately experienced or inexperienced. The only input factor which may be described precisely by a figure is the loadbearing capacity of the falsework scaffolding which can be derived by load testing in the laboratory under conditions similar to those on construction sites.

Since both quantitative and qualitative data were required to develop the procedural framework, a number of different techniques were used including literature review, content analysis, case study, laboratory tests, accidents analysis and interviews. Figure 2.1 shows the research methodology adopted in this research and details of the methods used are described in the following sections.

Literature review on the practices, guidelines and code of practices of falsework and failure mechanism was performed.

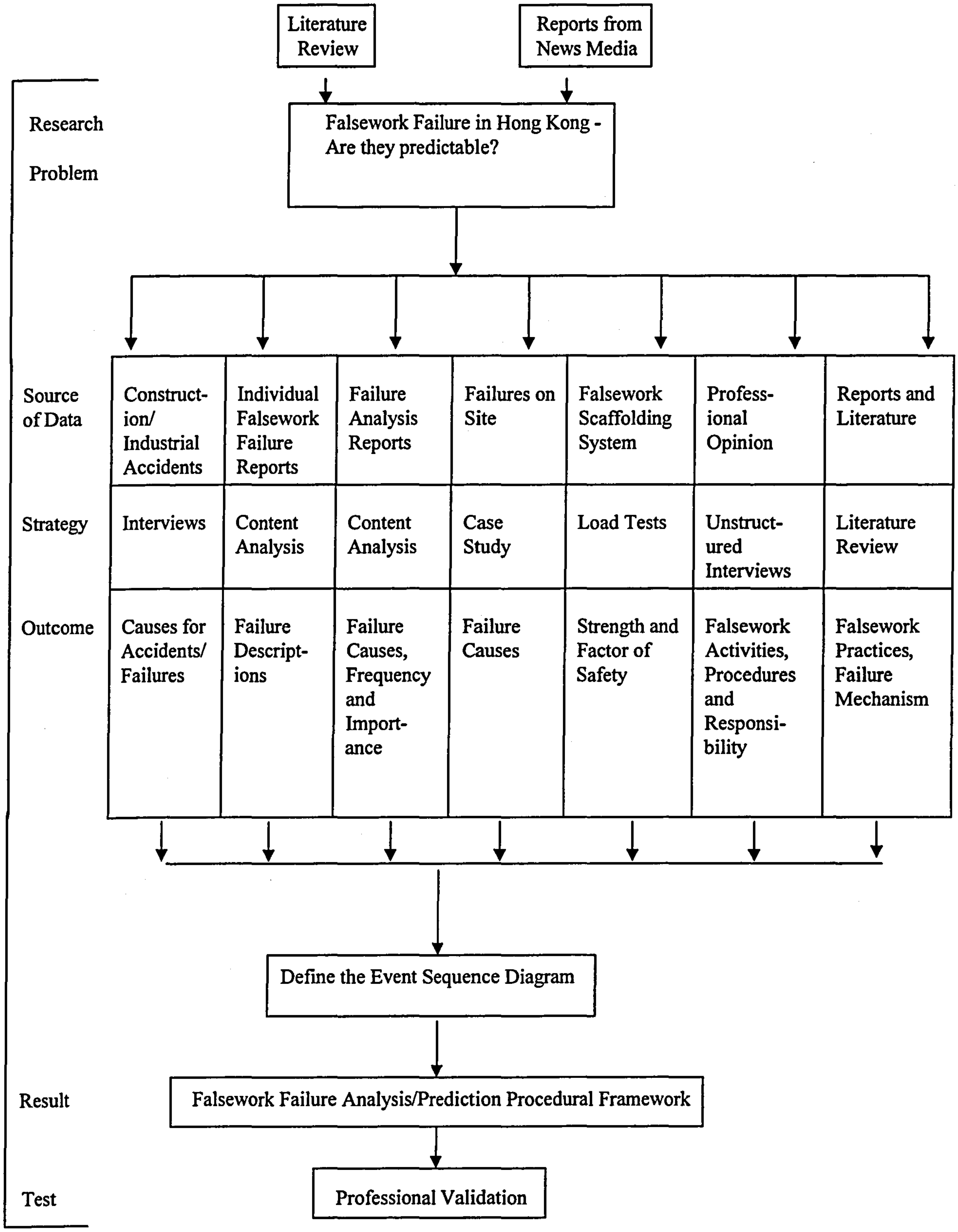
Structural interviews with injured persons were conducted in determining the causes for construction accidents and failures.

Content analysis (Berelson 1952, Holsti 1969) was used to extract the description of causes of construction failures and falsework failures, their frequency and their importance.

Case study was adopted to investigate the process and causes of falsework failures on site. These were known cases with reports by the media or professional journals. Nine site visits representing fifty per cent of the failures known during the research period have been made.

Load tests were carried out to determine the loadbearing capacity and factor of safety of falsework scaffolds commonly used in Hong Kong. Six out of about twenty major suppliers provided the ready to be used scaffold frames for testing.

Unstructured interviews were conducted to collect professional opinions on falsework activities, procedures and responsibilities, and for the validation of the developed procedural framework. A total of fifteen professionals who have undertaken the roles of Independent Checking Engineer, resident engineer, falsework scaffold supplier, structural engineer from a government department, safety officer and contractor's project engineers were interviewed. They represented the parties taking part in the design and construction of falsework.



Source of Data	Construction/ Industrial Accidents	Individual Falsework Failure Reports	Failure Analysis Reports	Failures on Site	Falsework Scaffolding System	Professional Opinion	Reports and Literature
Strategy	Interviews	Content Analysis	Content Analysis	Case Study	Load Tests	Unstructured Interviews	Literature Review
Outcome	Causes for Accidents/ Failures	Failure Descriptions	Failure Causes, Frequency and Importance	Failure Causes	Strength and Factor of Safety	Falsework Activities, Procedures and Responsibility	Falsework Practices, Failure Mechanism

Figure 2.1 Research methodology used

2.3 Falsework failure reports

As causes of a failure can only be analysed after the accident has occurred, the best means to identify the causes is by retrieving them from failure reports. However, failure reports are not easy to obtain due to the following reasons.

- Most parties involved in an accident are not willing to disclose further information because of legal restrictions imposed upon them and of the fear of jeopardising the relationship particularly with those possessing finance interest or future clients.
- Recent events are still surrounded with litigation (Pidgeon 1990).
- Old events are difficult to research accurately (Pidgeon 1990).

Nevertheless, altogether fifty falsework failure cases during construction, large and small, were collected. The publications include Bragg's Committee Report, professional journals such as Engineering News Record, New Civil Engineer and Construction Today, and formal reports prepared by the relevant government departments. Private investigations also were performed on failures in Hong Kong and nearby places. These reported failures occurred in over twenty cities during the last forty years. The details of the incidents range from a full investigation report to a brief news description.

In retrieving the information from the failure reports, the technique of content analysis has been used. Content analysis, as defined by Berelson (1952), is a research technique for the objective, systematic and quantitative description of the manifest content of communication. To identify the causes in an objective way, the failure cases would be described or summarised using the following format:

cause → event → consequence

Figure 2.2: Description of failure cases

The consequence was collapse of the falsework and, in most of the cases, the permanent works under construction. The event would be the stage that the incident started to occur. The cause was identified as being the most important enabling cause. Since different types of report will have varying degrees of accuracies, each of the causes identified will carry a degree of reliability in the procedural framework based on whether the publication is the result of a full proper investigation or just a brief description in the news media.

In a similar way, extensive review of the research reports on the analysis of falsework and other structural failures on a collective basis provided much information in the identification of the possible causes and their relative importance towards failures.

Retrieval of the data from the reports must satisfy the requirements of objectivity, system and generality (Holsti 1969). Holsti (1969, page 3) further explained that:

> "Objectivity stipulates that each step in the research process must be performed on the basis of explicitly formulated rules and procedures. Systematic means that the inclusion and exclusion of content or categories is done to consistently applied rules. Generality requires that the findings must have theoretical relevance."

As data from the failure reports were collected in accordance with the defined format, the above mentioned principles were observed and followed.

2.4 Construction accident reports

In view of scarce opportunity to actually undertake the investigation and analyse a falsework failure, a study of some general construction accidents has been undertaken in order to apply the techniques used in analysing the falsework failure. The processing of these accidents is similar to falsework failures despite of the different nature of the incidence. These accidents were simple and involved just a few persons, but full of human errors which can be identified as enabling, triggering and in particular procedural causes. In many instances, no supervision was provided as commonly found in falsework collapses. Study of procedural inadequacy in these accidents can be applied to analysis of falsework failures. Causes of accidents can be investigated as illustrated in Figure 2.3.

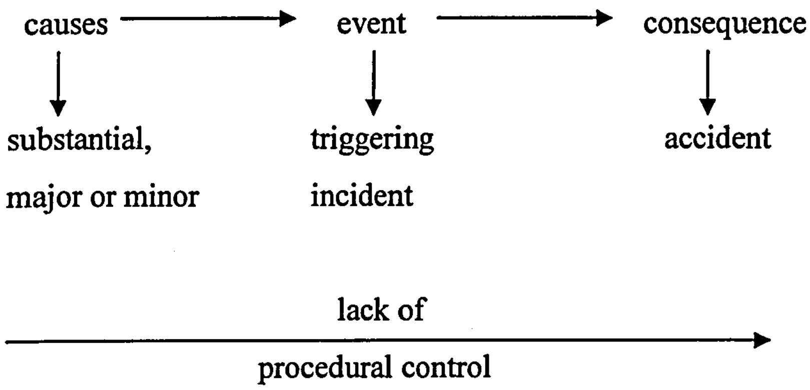


Figure 2.3: Investigation of construction accidents

Experience gained in investigating these accidents can help understand the occurrence of falsework failures. Accidents can also be presented and better interpreted by Event Sequence Diagrams (ESD).

ESD (Pidgcon et al. 1990) is similar in basic philosophy to the event tree technique. The diagram provides a powerful means of representing and accessing information about the sequences of events preceding a failure or near-miss incident. The ESD are simple tree structures showing the temporal order and relationship of events leading up to a particular outcome.

Appointed by the Legal Aid Department in Hong Kong, the author was asked to investigate construction and industrial accidents which involved injuries or casualties. Since 1997, a total of sixteen reports were analysed using the following procedures:

- study documentary evidence such as witness reports and accident reports prepared by officials of Labour Department;
- carry out structural interviews/ interrogatives with the plaintiff (with the solicitor's presence);
- use ESD to list the sequence of activities leading to the accident;
- use professional/ research knowledge to ascertain the sequence and justify the responsibilities;

- confirm findings within the report material with the plaintiff; and
- check with relevant legal or contract obligations to ascertain whether there were breaches of regulations.

The sixteen reports are summarised in Table 2.1:

Table 2.1: Sixteen reports of accidents

Name of injured /deceased person	Event
1. Siu Kit Tai	Fell from a canopy during washing and cleaning.
2. Wong Wing Yee	Hit abruptly by the breaker used in drilling the surrounding concrete when excavating a hand-dug caisson.
3. Lee Long Ching	Fell from a height when trimming and splitting a large rock mass.
4. Mok Shun Fong	Hit by the descending hoist inside the hoist-way during fixing of a water tap.
5. Tsang Pik Man	Fell from the inadequately fenced platform during overhead installation of air conditioning ducts.
6. Ngan Chung Tak	Hit by a piece of steel bar during its swinging and lowering.
7. Chan Wai Ho	Hit by a trolley due to improper procedures in the movement of trolleys.
8. Hung Man Wing	Hit by the swinging of chute (duck-tongue) of the ready-mixed concrete truck due to lack of communication.
9. Chow Yum Hung	Electrocuted under an improper and unsuitable conditions for welding works.
10. Wong Loi Fat	Back injury in lifting a cement bag.
11. Shin Yang Yen	Hit by collapse of the false ceiling during dismantling of the door and the door frame.
12. Wong Loi Tim	Hit by a slewing hydraulic breaker during demolition of concrete caisson column in top down basement construction.
13. Chui King Kwong	Crushed by the collapse of a power-operated working platform during its testing operation.
14. Chan Lung Kwan	Hit by the collapsing wall of a water tank during demolition of the tank and the roofing material.

15. Leung Yiu Wah	Back injury when handling a bale of waste paper after compressing and tying.
16. Tse Yeung Sing	Hit by the collapsing structural steelwork during the dismantling of a strut supported by a prop in basement construction

2.5 Case studies

At least seventeen major falsework collapses occurred in Hong Kong and nearby places during the period of this research. Nine sites were visited in order to verify the causes and events identified from the failure reports. A case study approach was used in order to find out the sequence of the activities leading to collapses. It also helps to explore the causes and who has been involved in the collapse. Despite the traditional prejudices against the case study strategy, Yin (1989, page 23) made the following comment.

> "A case study from a research strategy point of view may be defined as an empirical inquiry that investigates a contemporary phenomenon within its real life context, when the boundaries between the phenomenon and the context are not clearly evident, and in which multiple sources of evidence are used. It is particularly valuable in answering who, why and how questions in management research".

The nine sites visited were located in China, Taiwan, Singapore, Macao and Hong Kong. Three collapses occurred in both Hong Kong and China, and one each in Taiwan, Singapore and Macau. Not all sites visited allowed entry and private enquiry. However, the site conditions surveyed and interviews with personnel involved in the project or who had knowledge about the incident did give valuable information which served as another source of opinion to confirm the information available. Furthermore, the practices and control systems used for falsework construction in these places were compared with reference to their possible causes of failure (Poon 1991). Chapter 6 presents the study of the cases visited.

2.6 Laboratory tests

Defective material is one of the possible causes of falsework collapse. On many occasions falsework scaffolding systems are made up of used materials. Quite often they have not been properly maintained or repaired as observed from sites of failure (Poon 1989).

The loadbearing capacity of falsework scaffold is always uncertain. When the falsework supplier delivers the scaffolding material, a certificate of the test result can be available upon request. Load tests are often performed at the place of their manufacture when the scaffolding material is new. Different methods might have been used by the suppliers in determining the strength of the scaffold. Moreover, the reduction in strength due to age and deterioration of these used materials is unknown although BS5975 recommends a blanket reduction factor of 0.85 for used scaffold tubes.

To determine the loadbearing capacity and the factor of safety of the falsework scaffolding used in Hong Kong, a series of load tests were undertaken in the structures laboratory of Department of Civil Engineering, The University of Hong Kong. Six main suppliers provided the materials which were in a ready-to-be-used condition. These six suppliers are listed below.

(1) Modern (International) Plants & Machineries Ltd.
(2) Canyon Engineering Work, the agent for Acrow Products.
(3) Scaffolding Engineering Co.
(4) Joint Constructional Plants & Machineries Co. Ltd. and Joint Formwork Co. Ltd.
(5) Vector Scaffolding Ltd.
(6) Advance Equipment Service.

The most common scaffold frame systems, in both the new and used conditions, were loaded until failure. The factor of safety with respect to their recommended working loads was then tabulated. The thirty-three test results provided a useful guideline in recommending the strength to be used in design. Chapter 7 gives a full account of the load tests of the systems and the correlation of their strength with age and origin.

2.7 Review of practices

In order to establish the key activities for falsework, a literature review was undertaken on the conditions of the contracts to ascertain personnel's responsibility with respect to the activities concerned. Professionals were interviewed so as to determine the sequence of activities, procedures and responsibilities under different control systems.

There are principally three control systems regarding the use of falsework. The key difference is whether the falsework is checked and approved by the Engineer, the Contractor's Falsework Coordinator or the Independent Checking Engineer. These systems will be discussed in Chapter 3 and will be considered in the development of the procedural framework for failure analysis and prediction.

2.8 Procedural framework

The procedural framework is based on simple input and output mechanism. The inputs are causes of failures and their effects are shown in the event sequence diagram which was established by professional opinion and from failure reports. The following diagram shows the effect of the causes on a particular stage of falsework activities.

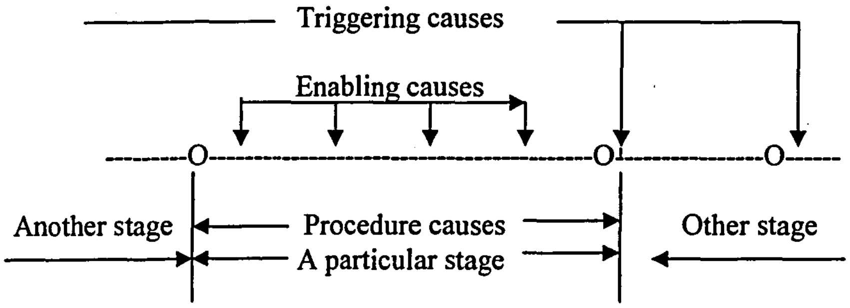


Figure 2.4: Different causes of failure for a particular stage of falsework activities

The whole project of falsework construction can be broken into a number of stages. Within a particular stage, there will be a number of essential procedures. Each procedure may incorporate enabling causes which contribute to the design and construction of the falsework. The triggering cause is usually the event which initiates the failure.

The contribution to failure by procedural causes accumulated at various stages and their consequence can be modified by the effectiveness in the control system. At certain events, triggering causes will have an effect on failure. The failure probability will be aggregated and checked at various stages. The failure of the falsework is similar to the bursting of a balloon. The development of the procedural framework based on Balloon Theory (Blockley 1992) is presented in Chapter 10. Validation of the procedural framework was performed with the help of professionals engaged in the falsework activities will also be discussed.

2.9 Summary

Different methodologies adopted in this research have been highlighted. To predict the proneness of falsework to failure, the causes of the past failures were analysed and extracted from failure reports. There has been considerable difficulty in obtaining the reports mainly due to confidentiality. The nature of the causes, as identified, required different approaches for data collection and verification. The methods employed in this research include content analysis, case studies, laboratory tests, literature review and interviews. A procedural framework based on Balloon Theory will be developed to analyse and predict the falsework failures. The usefulness of the procedural framework would be validated by professionals and practitioners involved in falsework design and construction. The practices of falsework scaffolding will be discussed in the next chapter.

CHAPTER THREE

REVIEW OF PRACTICES OF FALSEWORK SCAFFOLDING

CHAPTER THREE
REVIEW OF PRACTICES OF FALSEWORK SCAFFOLDING

3.1 Introduction

Falsework is often required for concrete construction and is used to support the freshly placed plastic concrete until the concrete has sufficient strength to support itself (Hover 1981). The falsework is then dismantled, maintained and, if necessary, repaired for the next job. Despite its temporary nature, a number of parties will take part in these activities of design, construction, dismantling and maintenance. This chapter, based on literature review and informal interviews, presents a review of the falsework activities. The responsibilities of individuals involved in the activities are examined and the principal control systems regarding falsework construction are discussed.

3.2 Falsework activities and responsibilities

Although falsework, as a kind of temporary works, is normally designed and constructed by the Contractor, other professionals such as resident engineer, Independent Checking Engineer are also involved (Hover 1981, BS5975 1996). Falsework may be hired from a specialist supplier but such subcontracting would increase the number of organisations under the control of the Contractor (Illingworth 1987). Sometimes, the falsework supplier may have taken part in the preliminary design of the temporary structure. To provide a clear picture of the falsework activities and the personnel responsibilities, the practices during the design and construction of the falsework are reviewed and generalised for the formulation of a procedural framework used for analysing and predicting failures.

In a paper entitled "Analysis of structural accidents", Blockley (1977) described that the design, construction and use are the key stages of a structural project. The design is performed by a designer whose discipline depends on the nature and details of the works to be performed such as architectural, structural, building services etc. Construction is the process of converting the design into reality and will be performed by the Contractor. The designer may have certain control in this stage, depending on the type of construction contract adopted. The loading stage refers to the functioning of the falsework as laid down in the design.

As explained in Section 1.4, falsework is a temporary structure which has a relatively limited life span on site, i.e. starting from before the construction of the permanent works until the latter is self supporting. Such work will normally take a number of weeks to complete for a typical concrete construction. Despite the fact that falsework has a short life span on site, it has five key stages of activities, i.e. design, erection, loading, taking down and anew stages.

3.2.1 The design stage

A rational design approach is required for any structure to satisfy the requirements of safety, services and economy. Falsework is of no exception (Hover 1981). It should be designed in accordance with recognised engineering principles including consideration of materials, workmanship and site conditions (Poon 1990). As falsework scaffolds comprise assembled members, the method of analysis should be based on the distribution of load between members (BS5975 1996).

It is always possible to design falsework from first principles, but many construction problems are recurring and standard solutions can be applied with frequently used methods and equipment. Section Eight of BS5975 deals with the application of standard solution. All designed solutions need to be prepared by suitably experienced persons and in accordance with appropriate code of practice such as BS5975. The responsibility of the falsework designer is no different from that of the permanent works designer's (Illingworth 1987).

3.2.1.1 The design brief

This brief is the collection of all relevant data affecting the design of the falsework. It refers to the availability of materials and equipment and should provide necessary information to devise a complete plan regarding the method of construction about permanent and temporary works. It may include extra information on site conditions (Bragg 1975). Early collection of data is important so as to allow sufficient time for subsequent activities. The preparation of the brief materials depends on the scale of the works. For example, a large amount of information will be required in a major bridge project with a special construction method. The resources of the information should include previous site operations, discussion with personnel having local knowledge and parameters in designing the permanent works. Section 6.2.1 of BS5975 lists the typical examples of information that should be collected in the design of the permanent works. In particular, Illingworth (1987) states that the following information must be known to the designer besides the structure's loading.

- The sequence of construction planned, i.e. the order of loading the falsework.
- Any plant loads that the falsework may have to accept.
- The method of placing loads on to the falsework, e.g. any likelihood of shock or surge loads.
- Any redistribution of loads as a result of post-tensioning the concrete which is poured in situ.
- Any other loads or situations that are not obvious.

3.2.1.2 The Designer

In the case of using falsework scaffolding for buildings and bridges construction, the design and supply of the temporary structure is very often sublet to a scaffolding company which specialises in this type of work (ibid). Very often the engineer employed by the supplier prepares a preliminary design and a list of required components for acceptance by the Contractor. The Contractor's staff will scrutinise and alter the design should it be found necessary.

If the Contractor possesses sufficient amount of falsework scaffold materials which are either in stock or returned from a completed job, the design may be performed by the in-house planning or engineering department. The loadbearing capacity of scaffold material is usually quoted in the supplier's catalogue. If the scaffolding material is new, the loadbearing capacity used in design may be based on the quote in supplier's catalogue. However, should reused or repaired materials be erected, the designer adopts a lower loadbearing capacity, based on his experience in examining the worn-out and deteriorated materials. The Concrete Society Technical Report No.4 on Falsework (1971), a joint report of the Concrete Society and the Institute of Structural Engineers, suggested that where scaffold tube is corroded, the basic permissible stresses used in design should be reduced by a factor of 0.95 for lightly pitted tubes and 0.85 for heavily pitted tubes. BS 5975 adopts a factor of 0.85 across the board for used tubes. Sometimes, a strength lower than the recommended factor has to be decided by engineer's experience and technical expertise, owing to the uncertainty arising from the worn-out materials.

3.2.1.3 Checking the design

Whether the falsework design is performed by the Contractor, or is a modification based on the supplier's preliminary scheme, the Contractor is still responsible for the adequacy of the design. Under the Conditions of Contract (Sixth Edition) of the Institution of Civil Engineers, the Contractor has to submit the design to the Engineer for approval. The Engineer will check the construction methods and ensure that the erection of the proposed falsework will not cause detriment to the permanent works. Even with the Engineer's approval, the Contractor is still held responsible for the falsework design.

This type of conventional control system of "Design by Contractor and Check by Engineer" has been used for decades. One major criticism of adopting this approach is that the responsibility for falsework construction was not clear (Hadipriono 1986b). Many contractors have taken the advantage of this system. In many instances, they submitted incomplete falsework designs to the Engineer for checking and comments for improvement. The Engineer, in general, is more interested in the permanent works construction than checking the temporary works thoroughly. While making comments on the Contractor's design, the Engineer always tries to avoid the implicit responsibility, e.g. in reply, they state "No objection". In other words, for whatever reasons, there could have been no detailed checking of the falsework design by the professionally competent engineer. In view of the deficiency of this system which has been confirmed by many failure reports (Elliott 1973, Hadipriono 1985), many researchers have suggested ways so as to make some improvements to this conventional control system (Elliott 1973, Melchers 1977, Hadipriono 1986, Ellingwood 1987). The modified control systems which are adopted currently for large construction projects will be discussed in Section 3.3.

3.2.2 The erection stage

Having received the Engineer's consent but with no formal approval on the falsework design, the Contractor can proceed to the erection stage of the falsework. The erection can be performed by the Contractor's workforce, or can be sublet to the labour subcontractor or the material supplier. The erection is normally a straight forward process during which the units are assembled although different proprietary systems may require special procedures for erection. The Contractor must ensure that the materials are erected in accordance with the approved drawings. The site conditions can be quite different from the expectation of the falsework designer, so deviation from the original design is always inevitable. The Contractor must assure that the designer is always aware of any changes and approval is obtained from appropriate personnel if necessary, as failures were often reported due to a lack of communication between the parties involved.

3.2.3 The loading stage

This is probably the most important part of the functioning of the temporary structure during its short life on site. For in-situ concrete construction, the falsework is subject to the loads from the dead weight of the falsework and formwork, the imposed load of the concrete and construction plant, and environment loads such as wind and rain. This is the stage that the most severe loading condition affects the falsework.

The imposed loads which are applied in different periods within this stage can cause different load distribution onto the falsework. For example, the falsework will support formwork and steel reinforcement dead loads before concreting as well as the concrete loads afterwards. Post-tensioning, if performed, will cause uneven loads on the scaffold systems. As a result, the Engineer's approval is normally required before the load is applied on to the temporary structure.

A common practice in Hong Kong is to sublet the erection of formwork, the fixing of reinforcement and the placing of concrete to subcontractors. Post-tensioning in most of the cases will be undertaken by the specialist subcontractor. Proper coordination is very important when considering the so many different parties involved in applying loads to falsework within a relatively short time period.

3.2.4 The taking down stage

Falsework is no longer required once the permanent work becomes self-supporting. However, dismantling will require prior approval of the Engineer who is to ensure the permanent structure is really strong enough to support itself. In particular, if post-tensioning has to be performed, the removal of falsework must proceed in a way that is not detrimental to the permanent works. Study of many failures has revealed that the premature removal of falsework was one of the common causes for failure at this stage when the concrete member has not gained the strength that can sufficiently support itself. The removal of falsework is usually performed by the same company but not by the same gang of workers who have erected them. Proper dismantling procedure should be strictly adhered to so as to reduce the risk of injury to the workers and damage to scaffolding materials.

3.2.5 The anew stage

Scaffold materials must be regularly maintained and repaired so as to allow future reuse. After removal, the falsework will be returned to the stockyard for inspection by experienced workers. The purpose to repair the scaffold frames is to maintain the straightness of the components. The rust condition will decide whether the material is still good enough to be reused or not. One major supplier in Hong Kong has emphasised the importance of maintenance because of the labourers' carelessness which can cause undesirable damage to scaffolding materials during dismantling.

3.3 Control systems

As mentioned in section 3.2.1.3, a number of collapses have been reported for projects using the conventional control system of "Design by Contractor and Check by Engineer". Many failure investigation reports (Bragg 1975, BS5975 1996) and researchers have suggested modifications or changes in the control system are necessary to avoid failure recurrence. Two other principal control systems are discussed in the following sections.

3.3.1 Falsework Coordinator

In Bragg's Report (1975) on falsework failure investigations, proper procedures were recommended for the choice of parties, the design brief, checking of designs, acceptance of falsework drawings, loading of falsework and general site conditions. Further, at each stage of design and construction of falsework, a check or an inspection should be made by a technically competent person. Since many organisations are involved, correction of faults for example will require co-ordination between more than one of them (BS5975 1996). It was recommended that an individual in the construction organisation be given the duty of ensuring that all procedures and checks have been carried out. This person was described as the Temporary Works Coordinator. In order to fulfil mandatory duties, the Temporary Works Coordinator should have the authority to sign the permit to load and to strike the various units of the temporary works (Bragg 1975).

In BS5975, the appointment of Temporary Works Coordinator was renamed as Falsework Coordinator who is responsible for the narrower scope of temporary works. With the appointment made known to all parties concerned, the Falsework Coordinator should normally be directly responsible to the site manager and would have been given adequate authority to stop work if it has not been performed satisfactorily. The principal activities of the Falsework Coordinator are stated in section 2.5.2.2 of BS5975 and are listed below:

- coordinate all falsework activities;
- ensure that the various responsibilities have been allocated and accepted;
- ensure that a design brief which has been established with full consultation is adequate, and is in accord with the actual situation on site;
- ensure that a satisfactory falsework design is carried out;
- ensure that the design is independently checked for concept, structural adequacy and compliance with the brief;
- where appropriate, ensure that the design is made available to other interested parties, e.g. the structural designer;
- register or record the drawings, calculations and other relevant documents relating to the final design;
- ensure that those responsible for on-site supervision receive full details of the design, including any limitations associated with it;
- ensure that checks are made at appropriate stages covering the more critical factors;
- ensure that any proposed changes in materials or construction are checked against the original design and appropriate action taken;
- ensure that any agreed changes, or corrections of faults, are correctly carried out on site;
- ensure that during use all appropriate maintenance is carried out;
- after a final check, issue formal permission to load if this check proves satisfactory; and
- when it has been confirmed that the permanent structure has attained adequate strength, issue formal permission to dismantle the falsework.

It can thus be seen that the Falsework Coordinator's role is to ensure all activities associated with falsework are properly performed by the appropriate personnel with defined responsibilities. This is an effective way to prevent the recurrence of common failures which have been recorded from previous investigations.

3.3.2 Independent Checking Engineer

One of the most common causes for falsework failures is the lack of checking the design and construction (Bragg 1975, Hadipriono 1986b) which leads to the suggestion of employment of a professional engineer who is independent of the Contractor to cross check at some critical stages. In Hong Kong, an Independent Checking Engineer (ICE) has been required in major projects involving substantial temporary works. The ICE is concerned primarily with checking of the design and construction of the temporary works, which normally and very often includes falsework.

In a conventional contract system, the Engineer is accountable for the design of the permanent works and the Contractor is responsible for the construction; the Contractor is solely in charge of the design and specification of the temporary works. The ICE has to guarantee that the temporary works are constructed, used and removed without any adverse effects on the permanent works. Any examination, approval or consent by the Engineer on the documents submitted related to temporary works will not relieve the Contractor's responsibility (Hong Kong General Conditions of Contract 1992).

The Checking Engineer must be a suitable professionally qualified engineer who is able to act independently and is not associated with the design of the temporary works. If the ICE fails to perform the assigned duties properly, the Engineer has the authority to turn down such appointment. Normally, a consulting firm is employed by the Contractor as the ICE.

The temporary works design should be checked and certified as satisfactory by the Checking Engineer in which the effect of foundation, the construction method etc. have been taken into consideration in affecting the safety and stability of the temporary works during their construction, use and removal. Before erection of the temporary works, the Contractor should have submitted the certificate, to the Engineer, which has been signed jointly by the Contractor and the Checking Engineer confirming the works has been properly designed and checked. Another certificate is also required before loading or dismantling of the temporary works to confirm that the works have been constructed in accordance with the design. The autonomy of the Checking Engineer can ensure checking is performed in a more effective manner and with professional accountability.

3.4 The three control systems (Poon 1997)

The three principal control systems regarding the use of falsework, namely Conventional System, Falsework Coordinator System, and Checking Engineer System, have been reviewed in the previous sections. In accordance with the conditions of contract, unless otherwise stated the contractor is responsible for the design and construction of temporary works including falsework. For the conventional system, there has been much criticism of a lack of well-defined responsibility and accountability of the personnel involved in the design and construction of falsework. Both the Engineer and the Contractor have the feeling that the other party should and would have taken up, or shared the responsibility (Bragg 1975, Hadipriono 1985). The Falsework Coordinator system is to ensure that the Contractor has carried out appropriate checking at various stages of falsework activities and there will be effective coordination among the various parties to minimise the procedural errors which may lead to falsework failures (Bragg 1975). The Checking Engineer, being independent of the Contractor, is required to ensure that the design and construction of the falsework have been properly checked, in particular, at the critical loading and unloading events. The responsibility of various parties taking part in falsework activities is illustrated in Table 3.1, Table 3.2 and Table 3.3. They will be used in the procedural framework for assessing the likelihood of falsework failures in later chapters.

Table 3.1: Conventional System

Party\Stage	**Design**	**Erection**	**Use**	**Dismantle**	**Maintenance**
Engineer	Check * *	Check * *	Check * *	Check * *	
Contractor	**Design**	Supervise	Supervise	Supervise	
Sub-contractor			**Formwork** **Concreting** **Prestressing**		
Supplier	Preliminary design	**Erect**		**Dismantle**	**Maintain**

Note:

- Key falsework activities are bold in the table
- Checking responsibility level:
  - * for information;
  - ** without responsibility/accountability; and
  - *** with responsibility/accountability.

Table 3.2: Falsework Coordinator System

Party\ Stage	**Design**	**Erection**	**Use**	**Dismantle**	**Maintenance**
Engineer	Check *	Check *	Check *	Check *	
Contractor	**Design**	Supervise	Supervise	Supervise	
Falsework Coordinator	**Check ***** **Coordinate**	**Check ***** **Coordinate**	**Check ***** **Coordinate** **Issue permit**	**Check ***** **Coordinate** **Issue permit**	
Sub-contractor			**Formwork** **Concreting** **Prestressing**		
Supplier	Preliminary design	**Erect**		**Dismantle**	**Maintain**

Table 3.3: Checking Engineer System

Party\ Stage	**Design**	**Erection**	**Use**	**Dismantle**	**Maintenance**
Engineer	Check *	Check *	Check *	Check *	
Contractor	**Design**	Supervise	Supervise	Supervise	
Sub-contractor			**Formwork** **Concreting** **Prestressing**		
Supplier	Preliminary design	**Erect**		**Dismantle**	**Maintain**
Checking Engineer	**Check *****	**Check *****	**Issue permit**	**Issue permit**	

Each of the three types of control system mentioned earlier has its own merits and demerits. The conventional system which is still adopted on many projects, particularly in developing countries, has in general the least merits. The main deficiency of this system is that the Engineer has no accountability despite the fact that he or she may have checked or approved the Contractor's design and construction. In many cases, the Contractor's design is inadequate and a detailed checking of such design is always a painstaking process.

The adoption of a falsework coordinator employed by the contractor appears to be in close proximity to the ideal situation where someone will be full-time responsible for falsework activities. However, it is uncertain that whether the contractor has the resource to employ such experienced personnel, and whether he can act independently of the Contractor in reviewing and approving the falsework related activities.

The appointment of the independent checking engineer seems to get the best compromise by having an independent qualified personnel to oversee the whole matter. As this checking engineer is not resident on site, there can be misunderstandings in the communication of falsework activities and contractor's cutting corner cases in controlling the safety of falsework during construction have eventually led to falsework collapses. The collapse of the falsework supporting the two post-tensioned beams in Hong Kong in 1996 was the best example to illustrate (Poon 1997). The demerit of this system in the captioned case will be detailed in Chapter six.

The merits and demerits of the three systems are summarised in the following table:

Table 3.4: Merits and demerits of the three systems

(1). The conventional system commonly used in many developing countries	
Merits	The Engineer or Resident Engineer will concentrate on permanent works construction while the Contractor will be responsible for the design and construction of temporary works.
Demerits	Generally the Engineer or Resident Engineer will not formally approve the Contractors' falsework design. They are always reluctant to comment or give advice on temporary works design and construction, and have no responsibility whatsoever. As a result, many failures occurred as a result of the lack of proper control of temporary works by an appropriate party.
(2). System used in the United Kingdom – Falsework Coordinator	
Merits	The Contractor employs a Falsework Coordinator who is responsible for the checking of the design and construction of falsework. He is also responsible for coordination with other parties involved in falsework construction.
Demerits	He is not wholly independent of the Contractor's organisation. Small contractors may not be able to provide such personnel.
(3). System used in Hong Kong: Independent Checking Engineer (ICE)	
Merits	A consulting engineer, employed by the Contractor, checks the design and construction of falsework. His permit would be required at critical stages of construction.
Demerits	All checking and approval activities in connection with falsework will be undertaken by the ICE. However, the ICE is not working full-time on site and immediate control on Contractor's activity cannot be guaranteed as the Resident Engineer for this type of contract will always act passively.

In view of the above, there is a need to introduce a monitoring system which can help minimise or prevent the failure owing to communication problem between parties in particular when there are changes to be made swiftly during construction.

3.5 Construction (Design and Management) Regulations, UK

The Construction (Design and Management) Regulations (1994) was introduced in the UK because of an unacceptably high rate of death and injury associated with all types of project. The Regulations have an impact on all stages of planning and management of health and safety of a project and place duties on clients, designers and construction organisations. The designer includes engineers or architects for the permanent works design and temporary works engineers designing the formwork and falsework.

Designers may be the only people able to make the decision that will eliminate a foreseeable risk. They should be aware of the hierarchy of risk control which underlies the modern approach to health and safety management. It is best to prevent the hazard and alter the design to avoid the risk. If this is not reasonably practicable the risk should be combated at source. Failing this, priority should be given to controls that will protect all workers. The designers should look for ways of reducing and controlling the risks. To make judgements in a systematic way, designers need to adopt risk assessment.

3.6 Site Supervision Plan System, Hong Kong

The Hong Kong Building (Amendment) Ordinance gazetted in 1996 introduced a supervision plan system which focuses on the classification of the safety roles and duties of the professionals, namely the Authorised Person (mainly the architects), the Registered Structural Engineer and the Contractor who work together in a typical building contract. The three parties are now required to prepare a site supervision plan together before the commencement of the construction work.

The supervision plan system was introduced because there have been so many failures and accidents on building sites in Hong Kong and these incidences were not only due to the negligence of the workers, but also structural failures that were induced by the lack of supervision. The aim of the system is thus to provide safe working conditions for personnel working on site. It also proposes to increase the degree of self-regulation in the practices of professionals by clarifying the roles and duties of professionals in the safety aspects for a building project. Another requirement in satisfying the system is professionals are to assign technical competent persons to reside on the building site and to supervise key work activities including erection and dismantling of falsework.

Preliminary findings of implementing this system indicate that failures and accidents due to lack of communication and delineation of responsibility of personnel in building construction can be minimised (Ping 1998, Choy 1999).

3.7 Summary

Falsework construction commonly involves a number of parties - the supplier, the main contractor, the subcontractor, the Engineer, the Resident Engineer and sometimes the Independent Checking Engineer. Also three different systems have been used in controlling the falsework design and construction.

Under the conventional design by Engineer and construction by Contractor system, the Contractor's design was not always satisfactory and there was an absence of an effective checking system. The two modified systems involve the Falsework Coordinator and the Independent Checking Engineer. The Falsework Coordinator, as an employee of the contractor, is required to coordinate with other parties on falsework activities. The Independent Checking Engineer, appointed by the contractor in accordance with contract specification, is to check the falsework design and construction as well as to issue the approval to load the falsework and dismantle the temporary works.

In Hong Kong, both the Conventional Control System and the Independent Checking Engineer System are being used. The former is still adopted on small contracts whereas the latter has been required in recent years for major construction works. According to the conditions of contracts adopted in Hong Kong, the Engineer in both cases has no responsibility regarding the design and construction of the falsework. The Contractor will be responsible for the overall safety of the falsework. The Independent Checking Engineer is employed to check the design of the falsework and sometimes the erection of the falsework.

In recent years, in both the UK and Hong Kong, there have been new requirements on designers and professionals in exercising to follow a tighter control regarding site supervision and assessment on the likely risk of the construction work. It is apparent that the trend now is to follow a tighter proactive control of certain construction activities. Stringent control of falsework construction cannot be exempted in view of their frequent failures.

In the next chapter a study of the falsework failure reports will be undertaken.

CHAPTER FOUR

FALSEWORK FAILURE REPORTS

CHAPTER FOUR

FALSEWORK FAILURE REPORTS

4.1 Introduction

Falsework failures, like many construction failures, are spectacular and attract public attention. In many instances, the failures involved collapse of the partially built permanent works. The consequences always lead to not just a delay in completion, but also injuries and fatalities. This type of incidence has always been widely reported by the media.

In case of a failure, the media will give the public an account of what have happened. In Hong Kong, intensive investigation is required, in particular when there is a casualty, by the Labour Department. The Government Departments, if they are acting as the clients of the project, would also require an investigation and reports produced by both the Consultant and the Contractor, in order to explore the possible reasons and clarify the contractual and legal responsibilities. Expert reports are needed in case a court thinks it necessary in disputes for compensation or enforcement of the legislation. For severe incidences, the Government may set up a formal enquiry to investigate as well as to recommend for any remedial or preventive measures.

The different types of report on failures used in this research are:

- newspaper / television reports;
- engineering journals;
- professional reports;
- accident reports;
- court hearings; and
- formal commission enquiry.

4.2 Press / Television reports

Reports by the media have the fastest and most widespread impact in news announcement. Newspapers provide a written description which is enhanced by photographs of the accident; whereas television reports are verbal description with a closer look to reveal more detail. Though labelled with pictures or views, they are all short and brief descriptions only. Some report findings may be gathered through interviews with relevant personnel on site. They are plain descriptions by reporters who may not have the technical or professional knowledge to justify their findings. Though interviews are carried out on site, the views are unconfirmed and may lead to speculations without foundation. Some reporters tend to draw premature conclusions based on interviews. Most of these conclusions are unfounded as interviewers cannot judge the causes of the collapse due to a lack of investigation. Thus, these reports are of very low reliability. When citing the reports prepared by professionals, the content will only be reliable and relevant provided all the information quoted are complete, undistorted and without unfounded comments added.

In the case of the collapse at Tseung Kwan O, Hong Kong, the following observations were reported by the media.

- Academics suggested the rusted tabular scaffolds and the permanent support failure were causes in connection with the collapse of the beams; when interviewed by the press.
- The high rank government official, who was responsible for all public construction works, even mixed up the actual construction method.

The above ideas and comments were found to be contrary to the Court Hearings and the expert's investigation.

4.3 Engineering journals

From time to time, professional journals publish reports on accidents and structural collapses from places all over the world. Except incorporating the full reports they are not lengthy in description although diagrams and photographs are sometimes included.

The characteristics of these reports on accident can be similar to those found in newspapers or television reports which are brief, incomplete and sometimes bias. They roughly describe the accident scene with some unconfirmed hearsay. The reporters in many cases have not acquired the expertise in this field. No calculation or analysis is included in these reports. Descriptions are mainly based on observation and spokesman statement. Many comments given by professionals are based on observation solely and hence are subjective and unfounded. Sometimes, because of the Editorial Board's close contact with Professional's Association, professional report findings are available for publication. The journals may publish the available reports at different stages such as occurrence of the incidence, the course of preparation of reports, preliminary findings and even court settlements. The reliability of the contents published depends on the source of material available.

4.4 Professional reports

These are prepared by professionals generally involved in the project where an accident has occurred. The professionals include the Engineer together with the Resident Engineer, the Contractor with the subcontractor, the Independent Checking Engineer if appointed, and, in Hong Kong, the Labour Department if there is a serious injury or dangerous occurrence.

The Engineer, appointed by the client to supervise the construction work, would be required to compile the accident report based on the findings by the Resident Engineer and the Contractor. The Engineer has to report in particular the responsibilities and the activities leading to the accident. Naturally, this report presents information for judgement on contractual liability.

Often the Contractor is criticised for submitting an incomplete report with key information missing such as calculation, connection details or working drawing of the temporary works. Both the Resident Engineer and the Contractor may be required to produce their reports and are subject to questioning in the court for fatal cases.

The Resident Engineer's report is to include all necessary documents such as meeting minutes, contractors' submission of design calculation, drawings, comments or approval by the Resident Engineer, tests, and inspection results so as to give a complete picture of all relevant activities relating to the accident in an attempt to determine the fault and the responsibility.

While the Resident Engineer and the Contractor has the perception that their reports may be used for judgement on their responsibilities under the contract, some information which may be detrimental to their reputation would not be included deliberately in their report or so called "experts making false statements". The incompleteness of the report is often complained by the client or Government Department.

However, these reports, to a certain extent, serve as a reliable account of instances about the accident although they are not available to the public partly because of the nature of the content and partly because of the unresolved legal responsibility.

4.5 Accident reports by Labour Department

The Labour Department inspectorate prepares the report of industrial accidents. The report provides the following information.

- Information source - people or companies providing the information in compiling the report.
- Background information - the parties, the project and the work to be undertaken.
- Construction of the element in concern.
- Events before the collapse.
- The collapse.
- Observation and comments.
- Possible causes of the collapse.

- Recommendations.
- Appendices.

These inspectors, though have been trained and experienced to carry out investigation of general construction accidents, are not professionally qualified to judge and make recommendations on engineering failures. Furthermore, they lack objective analysis and tests to back up their argument. These reports may be presented to the court and a charge may impose on the party concerned should a breach of regulatory requirement be found.

4.6 Court hearings

Court hearings are necessary whenever a fatality has been reported or settlement for dispute over liabilities and compensation is required. Although information unfavourable to certain parties may not be disclosed or admitted in the court, the reliability of information presented is very high. Sometimes independent expert reports for both the plaintiff and defendant are needed despite a general accident report has been prepared by the Labour Department. In this report, the expert presents the professional investigation of the failure, and the view on the accident together with the failure causes identified and supported by objective assessment e.g. computer simulation, laboratory test etc.

Disputes are needed to be settled in the court for the following reasons.

- Coroner's court for investigation of death of a victim in an accident as a legislation requirement.
- Charges raised by the Labour Department in view of the breach of the regulation by the Contractor.
- Civil cases – When the injured worker or relatives of the victim seeks for compensation because of the injury or casualty. Legal aids are available to those who are eligible under the regulations.

The court will determine responsibilities and fines or punishment if appropriate. In the coroner's court, the judge has no authority to punish in law any person who has negligence in any operation, but to establish the reason of death.

In all these cases, the professional or personnel involved will be summoned by the court and questions will be raised by the Counsels. Reports prepared by professionals or experts would be read in court. Information presented during court hearings is reliable, in particular, the opinions expressed by professionals.

The expert's reports can be presented by both sides in a dispute but one hundred per cent independence is practically difficult to achieve. It is impossible to eliminate totally the bias of the expert towards the side asking for the report. The process of an accident or a failure may be simulated by retrospective analysis or use of computer software. A typical expert report contains the following information.

- Introduction including the information source.
- Background information extracted from documents.
- Sequence of events leading to the accident.
- Other relevant information related to accident.
- Probable cause of the accident.
- Safety procedures that should have been adopted.
- Safety regulations applicable and breaches of the regulation.

4.7 Formal enquiry

A formal enquiry was necessary after a major collapse such as the collapse of Hotel New World in Singapore in 1980, or as an intensive study of falsework in the UK in the nineteen seventies, when frequent collapses had been found. A commission of inquiry or a committee will be set up and may consist of a judge, academics, professionals and Government representatives. They are given the terms of reference in carrying out the investigation.

In the case of Singapore, the term of reference for the commission of enquiry was:

- to determine the cause of the collapse of the premises at 305 Serangoon Road on 13 March 1986; and
- to make recommendations for such appropriate measures that can be taken to prevent a similar occurrence.

The Report was published in 1987 with some of the recommendations listed as follows:

- all structural plans and calculations of a building should be independently checked;
- the system of voluntary registration of contractors should be expanded to cover projects in the private sector;
- proper supervision of construction work by qualified person should be enforced;
- various tests relating to structural work should be carried out under the supervision of a professional engineer;
- spot checks on the construction particularly at the critical stage of constructing the major structural elements should be carried out; and
- professional engineer's certificate on the structural plan is required for amended plans submitted by architects.

The findings of a formal investigation is very reliable with few bias and relatively little missing information. Firstly, the background leading to a failure would be reviewed and all witnesses will be summoned on the history of the project and contract conditions including well-defined duties and responsibilities. There is usually a theory for the failure and the report contains the failure re-construction including all enabling events, procedural errors and triggering events. The mode of failure can also be confirmed by computer simulation. Detailed analysis of loads, stresses, structural analysis would be undertaken to check against the actual factor of safety. The enquiry panel will make the judgment from all views and information, and include recommendations.

4.8 Summary

The publications which are pertinent to falsework failures have been reviewed. It is generally accepted that findings gathered from a formal enquiry are complete and authoritative. The Court hearings and professional reports including accident reports by Labour Department are deemed to be reliable. Descriptions in Engineering Journals and reports produced by the media, due to a lack of professional investigation, are of low reliability. Different degrees of reliability are attached to these failure reports and should be interpreted in analysing the failures from the reports. The overall degree of reliability of different reports of failures is summarised in the following table.

Table 4.1: Reliability of different accident reports

Type of report	Overall degree of reliability
Media	Very low - low
Engineering report	Medium
Professional report	High
Accident report	Medium – high
Court hearings	High
Formal enquiry	Very high

In the following chapter, the investigation and study of falsework by institutions will be presented.

CHAPTER FIVE

FALSEWORK GUIDELINES

CHAPTER FIVE

FALSEWORK GUIDELINES

5.1 Introduction

In the previous chapter, the different types of falsework failure reports have been reviewed and compared. Because of the frequent occurrence and disastrous effect of falsework failure, study reports and practice guidelines of falsework have been published by Institutions in the UK and Hong Kong. They include recommendations for professionals in enhancing good practices in falsework construction and preventing failures. As early as in the nineteen seventies, the report on Falsework by Concrete Society and the Report of the Advisory Committee on Falsework were published in the UK. In 1982, BS5975, the Code of Practice on Falsework was published. In Hong Kong, the Guidance Notes for Prevention of Falsework Failure and the Code of Practice for Metal Scaffolding were only available in recent years. This chapter gives an account of these publications.

5.2 Concrete Society Technical Report No. 4 – Falsework (1971)

In 1971, a Joint Committee appointed by the Concrete Society and the Institution of Structural Engineers in the UK published a report on falsework. The report represented a distillation of the knowledge and experience of the construction industry. Although it was not an approved Code of Practice, it was stressed that much of it could be used in this way. The followings are the major contents.

- Responsibility for falsework.
- Classes of falsework.
- Loadings.
- Permissible stresses.
- Design and detailing.
- Workmanship and inspection.

- Limit state design.
- Recommendations.

The report was aimed at producing guidelines to those professionals responsible for falsework activities such as the design, construction and use. It recommended the responsible person, from the Contractor, should have specialist knowledge and experience of the design and erection of falsework. The design, erection, control and maintenance of falsework should be the responsibility of the Contractor whereas the Engineer should be responsible for safeguarding the interests of the client.

5.3 Report of the Advisory Committee on Falsework (1975)

Because of the frequent collapses of falsework in the UK during the nineteen seventies, a committee was set up to investigate the causes. Chaired by S.L. Bragg, the Advisory Committee on Falsework was appointed on 13 March 1973 with the following terms of reference:

"To consider and advise on the technical, safety and other aspects of the design, manufacture, erection and maintenance of temporary load bearing falsework used to support formwork or permanent structures, particularly bridges, during construction, and, in particular, to:

- identify any inadequacies in present knowledge, standards and practices, recommend such steps as may be needed, and indicate an order of priority;
- draw up interim technical criteria, for use in advance of the publication of a British Standard Code of Practice, together with such procedural guidance as the Committee may consider appropriate;
- recommend what research and development should be carried out in the short and long term; and
- advise as to the training, organisational and manpower implications of the Committee's recommendations."

After extensive study of falsework failures and related topics, the Committee published an Interim Report and a Final Report in 1974 and 1975 respectively. The Final Report stated that the Committee had based their discussions on practice rather than on hypothesis and had tried to provide solutions that are realistic rather than utopian. The Report consisted of the following parts.

- Details of some of the collapses studied by the Committee.
- Commonest technical faults.
- Common inadequacy in procedure.
- Technical recommendation.
- Recommended procedures.
- Training and manpower.
- Implementation of recommendations.

Broadly speaking, technical reasons and procedural inadequacies were the main causes of falsework failures.

5.3.1 Technical reasons

The Final Report concluded that a single cause leading to the disasters was not common. In addition, there was no evidence to support that the reasons of failures were beyond existing knowledge. Technical failures could be classified into the following categories:

- applied loads different from design;
- inadequate design; and
- works not constructed to the design.

The principal technical causes extracted from the Report are described in the following sections.

(1) Stability in horizontal plane

Falseworks are designed to support vertical loads and to resist horizontal forces that may arise from wind, vibration, water waves etc. Too often the designer is preoccupied with vertical loads. Absence of adequate resistance to lateral forces is one of the major causes of failures.

Members out of plumb, whether by design or not, and concrete pressure on formwork will create horizontal components which must be allowed for at interconnecting points in the structure. Whereas accidental force such as impact by cranes if not considered in the design should be avoided or controlled on site.

Scaffold falseworks comprising standard components should be jointed properly into a coherent structure. Connection by friction only is absolutely inadequate and unreliable. Lateral forces may move the structure sideways causing disruption and failure.

(2) Progressive collapse

The falsework system should be designed to avoid the progressive collapse because of failure of a single component. One solution to avoid this type of disaster is to separate sections of the falsework into independent self-supporting structures.

(3) Overloads

Overloading can result from three reasons:

- inadequate design;
- applied loading is different from design; and
- loads are not applied as specified.

Inadequate design is a particularly very common problem on small jobs. Some small contractors may find it difficult to justify the employment of an experienced engineer in designing the falsework. For some apparently simple jobs, proper design and thorough checking by a competent person were ignored just because the design was too simple.

Actual applied loads can deviate greatly from those expected in the design office.

Underestimating the effect of floodwater causing the partial failure of the temporary foundation in the construction of a bridge over a river was an example. Different construction methods will create unexpected loading conditions in the structure. Effects of local stresses in particular must be carefully examined and allowed for.

(4) Inadequate foundations

It is important that the ground is strong enough to support the falsework and its loads. Information obtained from permanent works design may not be relevant for falsework design which is usually concerned with the ground surface. The changing environment effects such as surface water could weaken the soil overnight.

Experience has shown that many verticals are not properly founded and the loads are not well spread by use of timber sleepers. Badly compacted materials under the sleeper are potential areas of falsework failure. Furthermore, inclined supporting surfaces always require additional treatment. Restraints against the slipping down of the base plate must be sufficient. Small settlements can cause undesirable effects on the structures.

(5) Defective or inadequate materials

Use of unsuitable and substandard materials are causes of a number of falsework failures. Most scaffolding materials have been previously used and need inspection for damage or deterioration before reuse. Unauthorised substitution, perhaps because of the temptation to complete the job early while in short supply of materials, could form areas of weakness not considered in the design. A common serious error on site is the replacement of proper pins by reinforcing bars in the props.

(6) Dismantling

Dismantling of falsework should be planned and carried out so that the stresses are relieved safely while the permanent work takes up its own weight. Instability of separate sections during dismantling constitutes partial collapse. Similarly inadequate re-propping of the permanent structure supporting other falsework may result in slab floor collapse.

5.3.2 Procedural inadequacies

In addition to technical reasons causing falsework collapses, failures in procedure keep those weaknesses undetected or ill-treated. Procedural faults fall into the following two areas.

- Failure of communication due to lack of a proper brief, inadequate drawings and absence of feedback on site conditions.
- Failure of inspection when the design is not checked by a competent person and the structure is not inspected during and after erection.

Falsework construction involves a number of parties from many organisations, therefore, effective co-ordination is important in the execution of a scheme. The following sections describe the areas where inadequacies in procedure, communication or inspection would allow the technical faults to occur.

(1) Design brief

It is of utmost importance that the client prepares a comprehensive brief incorporating all features that must be considered in falsework design. Insufficient information tends to cause delay, unnecessary alterations and failures. For example, introduction of access openings after the initial design is complete can lead to unnecessary weakness.

(2) Design modification

Actual site conditions are never as ideal as the assumptions laid down in the design. Modification of the original design is sometimes inevitable. The need for changes should be communicated between the falsework designer and site staff. Any alteration made on site without notifying the parties involved could weaken the structure.

(3) Design error

Some failures are direct results of fundamental errors in design. If thorough checks have been made, the error could be detected and thus rectified. It has been found that the existing knowledge of construction professionals is sufficient to prevent the errors by an adequate checking procedure. However, a problem arises, when an error has been discovered, and the Engineer displays an inconsistent attitude or reaction. In various types of works, the Engineer's responsibility is defined in different ways.

In 1972 the falsework for a concrete bridge collapsed near London, killing three and injuring ten (Engineering News Record 2 Nov 1972). Later a report cited the causes as "an error in falsework calculation, said to be so simple that they were not rechecked".

(4) Site organisation

A sound design is not the end of the job. The design must be translated into detailed working drawings, erected with correct materials and dismantled safely. Most errors and omissions from design become apparent on site. An efficient and effective management system will safeguard the essentials of the success of a falsework scheme. The following are some of the principal recommendations.

- All falsework must be designed, even if it is a simple sketch on a small job.
- The Contractor must appoint a properly qualified Temporary Works Coordinator (TWC) whose duties are to ensure that all procedures have been followed, that all checks and inspections have been carried out and that any modifications or changes have been properly authorised. Falsework may not be loaded or struck without the written permission of the TWC.

5.4 Code of Practice for Falsework, UK (1982 & 1996)

In 1982, the British Standard Institution published the BSS975, the Code of Practice for Falsework known as the first of its kind in the world. It was deemed necessary because of the increase in scale, frequency and complexity of falsework. During the drafting of this Standard, the main document drawn upon was the Falsework Report of the Joint Committee of the Concrete Society and the Institution of Structural Engineers published in 1971 described in Section 5.2.

The Code has drawn together all those aspects that need to be considered when preparing a falsework design, including recommendations for materials, design and work on site. The following sections are included in the Code.

- General.
- Procedures.
- Materials and components.
- Loads applied to falsework.
- Foundations and ground conditions.
- Design of falsework.
- Work on site.
- Standard solutions.

The Code also stresses that success of falsework is closely tied up with its management, therefore procedures as well as technical aspects are included. It also endorses the Bragg's Report recommendation that a Temporary Works Coordinator needs to be appointed in order to ensure that all relevant procedures and checks have been carried out. However, the appointment is renamed as Falsework Coordinator so as to specify the duties to falsework activities only.

In 1996, the revised edition was published. It was not a full revision of 1982 edition but technical changes have been introduced to bring in line with BS5268 Part 2: Structural Use of Timber- Code of Practice for Permissible Stress Design, Materials and Workmanship (BS5975 1996).

5.5 Guidance Notes: Safety at Work (Falsework – Prevention of Collapse), Hong Kong (1998)

This Guidance Notes was published by the Occupational Safety and Health Branch of the Labour Department, Hong Kong, in November 1998. Although guidance on design, construction, use and dismantling of falsework can be found in the BS5975 (1996)- Code of Practice for Falsework, the Notes, as quoted, highlights the good practices sometimes overlooked by the contractor to prevent collapse of falsework on construction sites in Hong Kong. The Notes are intended to be read by site management personnel and competent engineers and consist of the following sections.

- Introduction.
- Responsibilities.
- Design stage.
- Construction stage.
- Dismantling stage.
- Useful information.

As duly specified, the guidelines should not be regarded as exhausting those matters which need to be covered under the relevant safety legislation. Compliance with the Notes does not confer immunity from relevant legal requirements. However, some important issues learnt from the local falsework failures have not been included in the Notes apart from its subtitle "prevention of collapse".

Firstly, the importance of checking the falsework design and construction has been left out. Such checking is often performed by the Independent Checking Engineer.

Secondly, consent of the Engineer or Independent Checking Engineer before loading the falsework is not stipulated. Also, before the dismantling of the falsework, the necessity of the approval and certification of the falsework and permanent works by the competent engineer are not specified.

This Guidance Notes only outlines some of the good practices which are sometimes overlooked by the industry but without incorporating those weaknesses commonly leading to falsework collapse (Poon 1999).

5.6 Code of Practice for Metal Scaffolding Safety, Labour Department, Hong Kong (2001)

This Code of Practice was published by Labour Department in June 2001. The drafting of the document is based on the revision of the previous code and consists of the sections listed below.

1. Introduction and the status of the Code.
2. Definition of terms commonly encountered in metal scaffolding.
3. A summary of the legislation and statutory provision in relation to safe metal scaffolding.
4. A safe management and a safe system of work including the following.
    - Design and initial planning.
    - Selection of subcontractor for metal scaffolding work.
    - Site management and procedures.
    - Working places and access.
    - Monitoring safety performance.
    - Training of metal scaffolders.
5. Technical requirements for safety in metal scaffolding covering the list below.
    - General requirements.
    - Tubular scaffolds.
    - Proprietary scaffold systems.
    - Falsework.
6. Inspection, maintenance and dismantling of metal scaffolding.

This Code stresses the importance of monitoring safety performance of metal scaffolding which is also commonly used in falsework construction, as illustrated in the following:

Section 4.5.1 "Requirements on safety and health, particularly those relating to compliance with safety legislation are advisable to be incorporated into the conditions of contract for engagement of subcontractor for metal scaffolding work or other subcontractors using the scaffold."

Section 4.5.2 "Records on the safety conditions of the scaffolding should be kept. Such records should consist of detailed information on work hazards, precautions taken, accident analysis and recommendations. These records should be constantly reviewed for hazard identification and for improvement of the scaffolding work."

Section 4.5.4 "A monitoring system should be developed, implemented and maintained on site for checking the safety performance of the subcontractor for metal scaffolding work or other subcontractors using the scaffold."

It is interesting to note that a monitoring system should be implemented on site to monitor the safety performance of personnel involved in metal scaffolding work. This Code comprises a thin section of falsework. It highlights the good practices sometimes overlooked in order to prevent collapse. However, the title of the Code does not indicate the inclusion of such important topic. In view of the importance and frequent collapse of falsework, a separate code of practice on falsework is recommended.

Based on the experience and study of the local failures, the following should have been included in the Code.

- The effectiveness of the liaison and control mechanism for falsework in the event of a change in the construction method of the permanent works.
- The inspection and approval requirement at critical stages of erection, loading and dismantling of falsework.

5.7 Summary

The Concrete Society Technical Report and Bragg's Committee Report had led to the publication of the BS5975, the Code of Practice for Falsework. This Code of Practice is a very comprehensive document providing recommendations not only on design but also the practice of falsework construction. On the contrary, the Guidance Notes and the Code of Practice published in Hong Kong are incomplete as weaknesses identified from failure reports have not been taken into consideration. However, all these reports and codes emphasise not just the importance of checking the design but also controlling the construction in preventing falsework failures. In the next chapter, case studies on falsework failures will be presented.

CHAPTER SIX

CASE STUDIES OF FALSEWORK FAILURES

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CASE STUDIES OF FALSEWORK FAILURES

6.1 Introduction

In general, case studies are the preferred strategy when "how" or "why" questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life content (Yin 1994). In order to study the causes and to collect relevant information regarding falsework failures, site visits were made to failures in Hong Kong and nearby places. Between 1986 and 2001, there were seventeen known major falsework failures. Nine occurred in Hong Kong, two in Taiwan, four in Southern China and one each in Macao and Singapore. This chapter presents the findings of failure cases investigated. Cases with relatively few information available are grouped in one section. The significance of having the site visit will also be discussed.

6.2 Case study 1 - May 1986, Hong Kong

The failure occurred at the Tsing Yi North Bridge Site where square-prop falsework was used for the construction of a post-tensioned concrete bridge deck. The falsework for one span of the deck had been erected the day before the incident. Because of the strong gusty winds at night, workers discovered that some props were found out of plumb early next morning. The workers then rectified the verticals. Suddenly, part of the erected falsework collapsed and caused one death and one injury. Formal access to the construction site was not allowed in this case, which is similar to many other cases, due to a number of reasons which are listed as follows.

- Workers may still have been trapped under the wreckage and only parties such as firemen or police can get access to the scene.
- Investigation is still underway by related parties such as the Engineer, the

Contractor, the Labour Department, the insurance company and the Police if there is any question of a criminal offence.

- While busy in dealing with other parties, the Contractor will not like to entertain outside visitors at this particular instance of time.
- Conditions of contract usually do not allow any trespassers for security and safety reasons.
- Usually the Contractor will not release any information because people regard accidents particularly structural failures may cause damages to the Contractor's reputation.

Photos of the collapsed falsework together with the accident report prepared by the Labour Department were being studied. The major cause for the collapse was the absence of a proper procedure for rectifying the falsework. There was neither proper inspection nor suggestion given by the Professional Engineer regarding the safety procedures to be followed during rectification.

6.2.1 The bridge (Labour Department 1986)

The highway bridge was known as Tsing Yi North Bridge. It consisted of two carriageways, the north and the south, spanning across the Channel. The main span was supported by two major columns. There were five piers, E1 to E5, with four of them E2 to E5 completed, all on one side of the Channel.

6.2.2 Falsework

Square props were used as the falsework for the concrete bridge deck between Piers E3 and E4 of the north carriageway. It consisted of four tubes, and made up of intermediate sections of various lengths (Figure 6.1). Each prop rested on a concrete slab.

On top of the topmost section was a U-head which would hold the steel I-beams transversely. Another layer of I-beams was placed longitudinally on top of the first layer.

Wooden formwork would then be erected at the top.

On the day before the incident, the erection of Stage 1 (Figure 6.2) falsework was completed and fixing of wooden formwork had already commenced. The erection of Stage 2 falsework had started three days earlier. The square supports of Stage 1 were tied both transversely and longitudinally at five levels. The six rows of Stage 2 falsework were erected upright on site. They were tied horizontally both in the transverse and longitudinal direction at two levels near the top and the bottom.

6.2.3 The collapse

At 7:40 a.m., on 14th May 1986, the Stage 2 falsework (Figure 6.3) was found leaning in a southerly direction. The leaning falsework was allowed to rest against the jib of a crawler crane parked nearby. At about 9:00 a.m., the contractor and falsework subcontractor agreed to lift the leaned temporary works to its upright position first. The crawler crane was used to lift the falsework. Two chain blocks were anchored at the North to pull the temporary structure with the aid of two wire ropes which were secured to the top part of the leaned falsework.

During the course of the remedial work, one foreman and five workers from the falsework subcontractor were mobilised. They needed to climb up the falsework to check the clamp joints for damages, then fastened or adjusted the coupling between bracing and secured additional bracing as necessary. One worker stayed on ground to check the verticality of the props.

At 10:00 a.m., the foreman ordered the workers to release the wire ropes and chain blocks which were used to secure the top part of the falsework and pull the falsework northerly. At about 11:00 a.m. most of the work was nearly completed. Only two workers remained on top of the falsework in order to finish the last bit of the work. Suddenly the whole of the Stage 2 and part of the Stage 1 falsework collapsed in the south-east direction. The two workers fell with the props. One of them, being trapped by the collapsed props, was certified dead later.

The collapsed area was about 24m in length and 12m in width. A total of ten rows of props with each row consisted of eight individual props fell. The height of the props was about 14.5 m and 16 m for Stage 1 and Stage 2 props respectively.

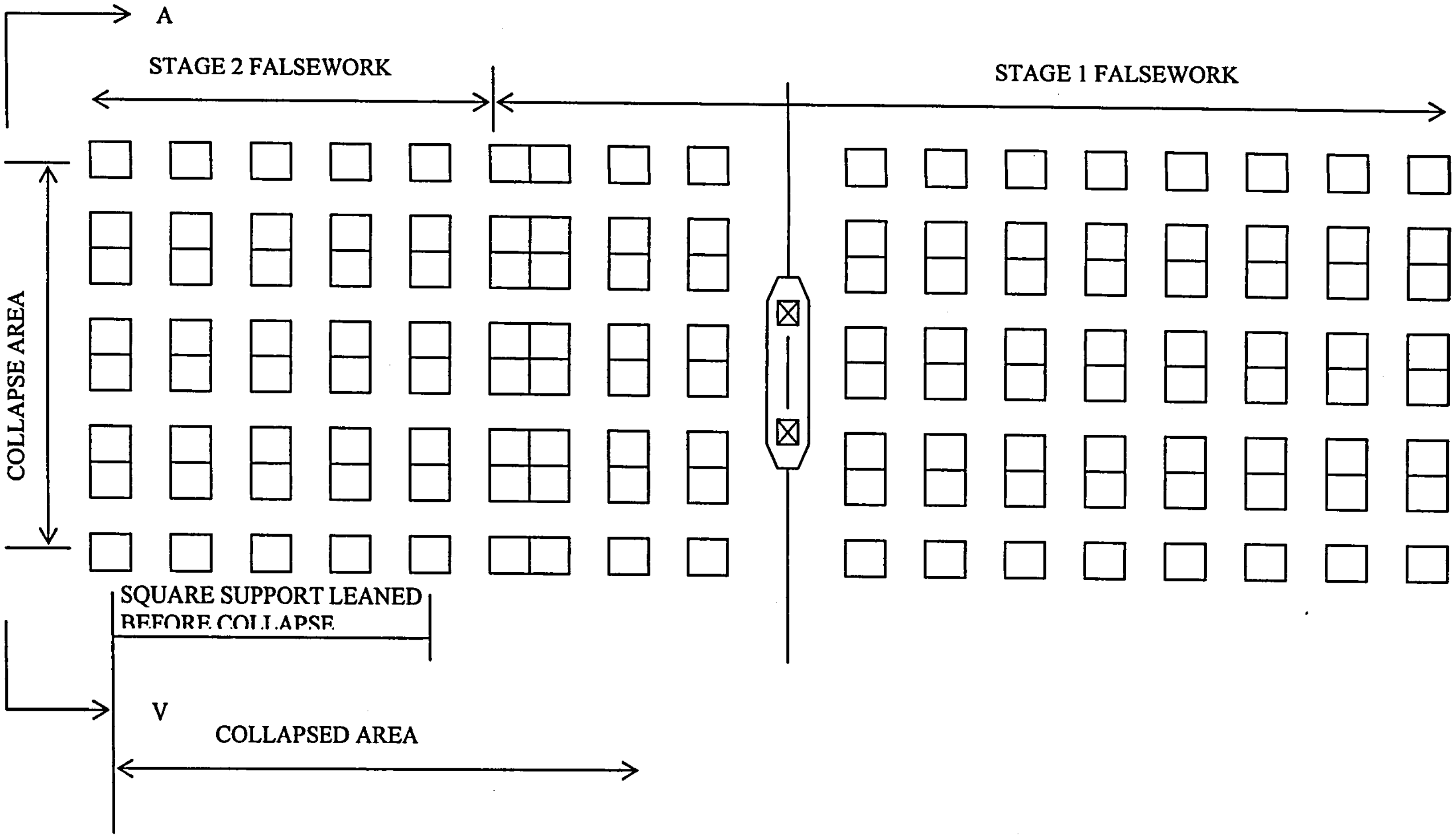

Figure 6.1: Layout plan of falsework supports, Tsing Yi, Hong Kong

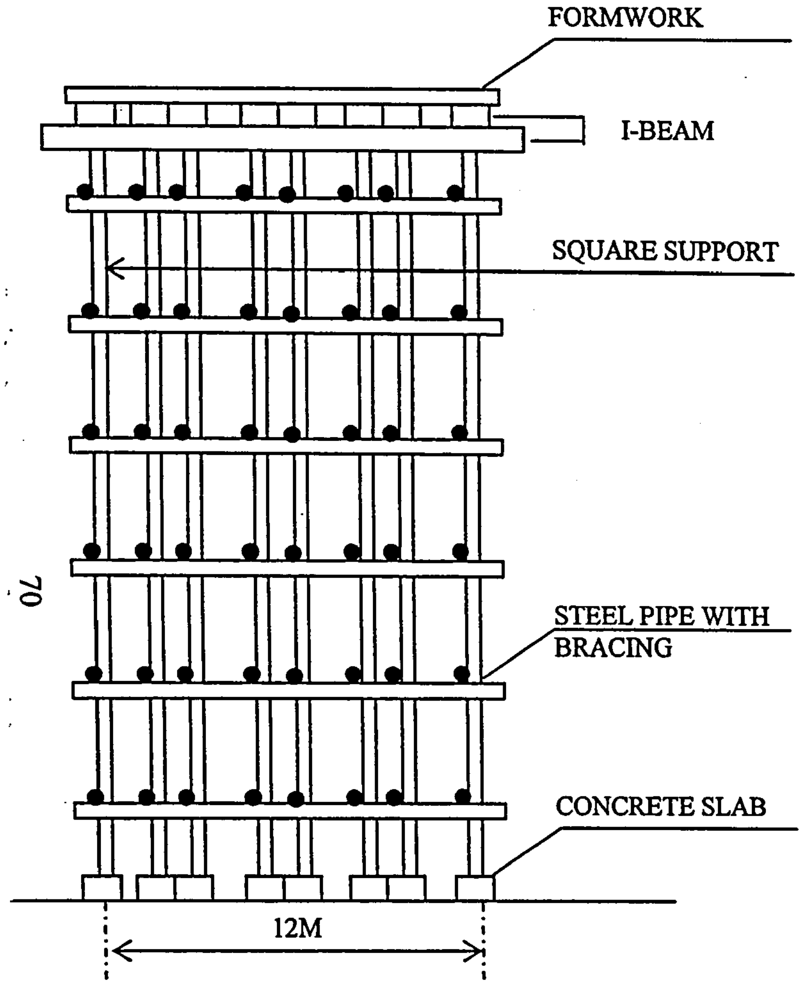

Figure 6.2:
CONDITIONS OF STAGE 1 FALSEWORK BEFORE COLLAPSE

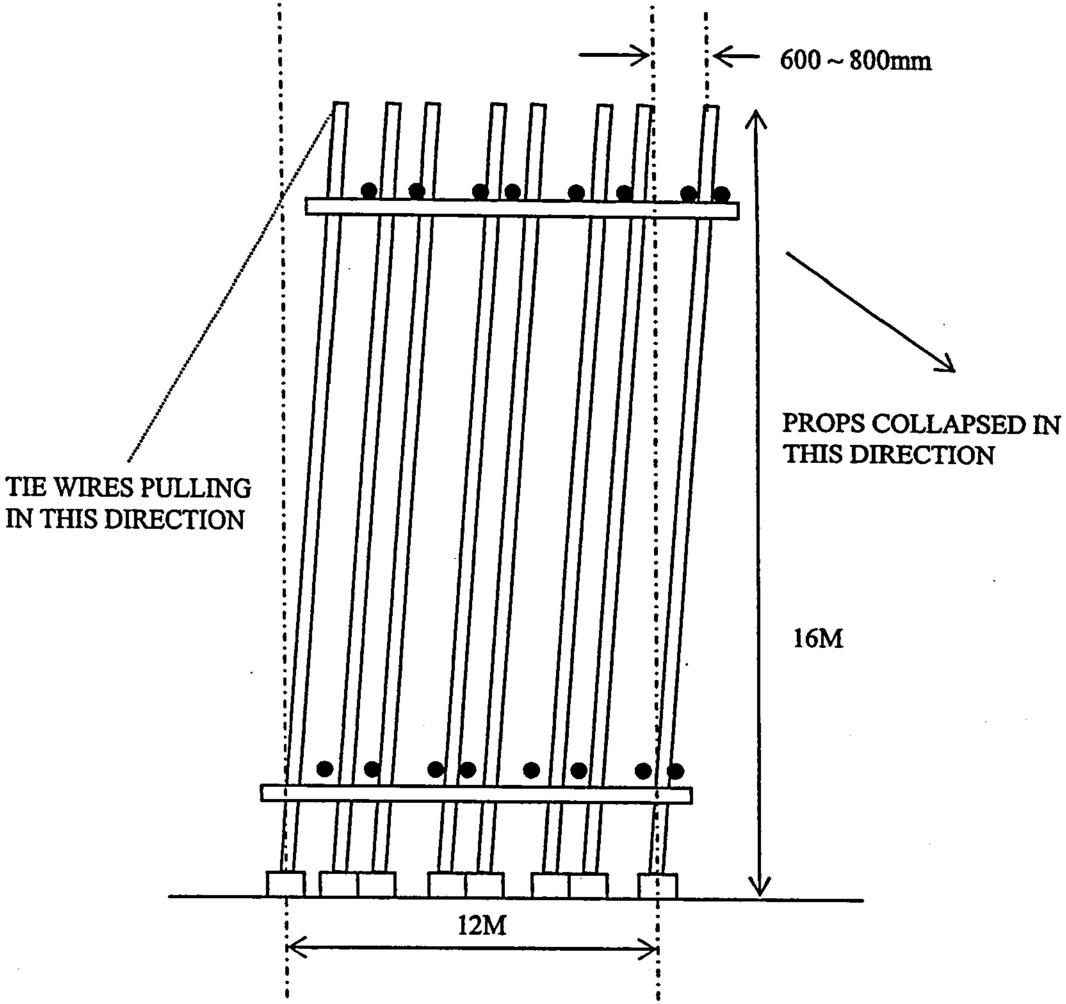

Figure 6.3:
STAGE 2 FALSEWORK LEANED TO SOUTH

6.2.4 Design and supervision

The drawings and calculations of the collapsed falsework were based on those which had been accepted for use at the other spans previously constructed in the same project. Features unique to the Stage 1 falsework had been reviewed by the Engineer, however, no drawings nor calculations had been submitted for the Stage 2 falsework.

A total of sixteen bays of the bridge deck had been concreted by using the same kind of falsework in the same contract. No adverse effect had been reported so far before the collapse.

According to the contract requirement, the contractor must satisfy the Engineer that the completed falsework would perform its function safely and satisfactorily. The day-to-day management of the erection was supervised and under the control of the contractor. The completed falsework required the Engineer's consent before it was being put into use. According to the Labour Department's Report, staff from the Resident Engineer's office did observe the leaning of the falsework and workers' performance of remedial work, but it was difficult to discern the communications between the contractor/ subcontractor and the Engineer/ Resident Engineer regarding the method of remedial work.

6.2.5 Causes

The bracings of the square supports of Stage 2 falsework at two levels only were far from the requirement as stipulated in the design. Thus, they would be easily displaced and tilted by any foreign force. It was reported that strong winds and thunderstorm affected the site area in the night before the accident. The maximum gust of wind recorded was 43 km/hr.

The use of the crawler crane and tie-wires to stabilise the falsework appeared to be reasonable to achieve temporary stability for the falsework. However, the subsequent premature release of the tie-wires and the tie with the crane was unwise before adequate diagonal bracing had been installed.

6.2.6 Recommendations

The props should be braced adequately in every stage of erection in order to prevent displacement effected by any foreign force. Critical assessment and detailed procedures on remedial work should be made before any action could be conducted. Any remedial work should be approved and supervised by qualified professionals specialized in falsework and the devised procedure must be strictly adhered to.

6.3 Case Study 2 - December 1987 & April 1988, Taipei, Taiwan (Poon 1989)

6.3.1 The bridge

The highway bridge was located along the central part of Hsinhai Road at the southern part of Taipei City. The bridge was designed as two parallel structures, running from East to West, connected by a tied beam or separated by an expansion joint. The collapsed portion of the bridge deck was the northern part of four continuous spans about 120m in length and was of post-tensioned concrete construction as shown in Figure 6.4. The average longitudinal fall was 3.5 per cent and the height of the soffit above ground varied with a maximum of around 6m.

The bridge deck was a box girder constructed in two stages (Figure 6.5). The bottom slab together with the vertical stems were cast first. Formwork was then erected across the tops of the stems to form the hollow cells. The top slab was concreted across the cells and made integral with the stems. A number of access openings of 800mm square were left in the top slab for ease of removing the shuttering and, afterwards, to be refilled with concrete using suspended forms.

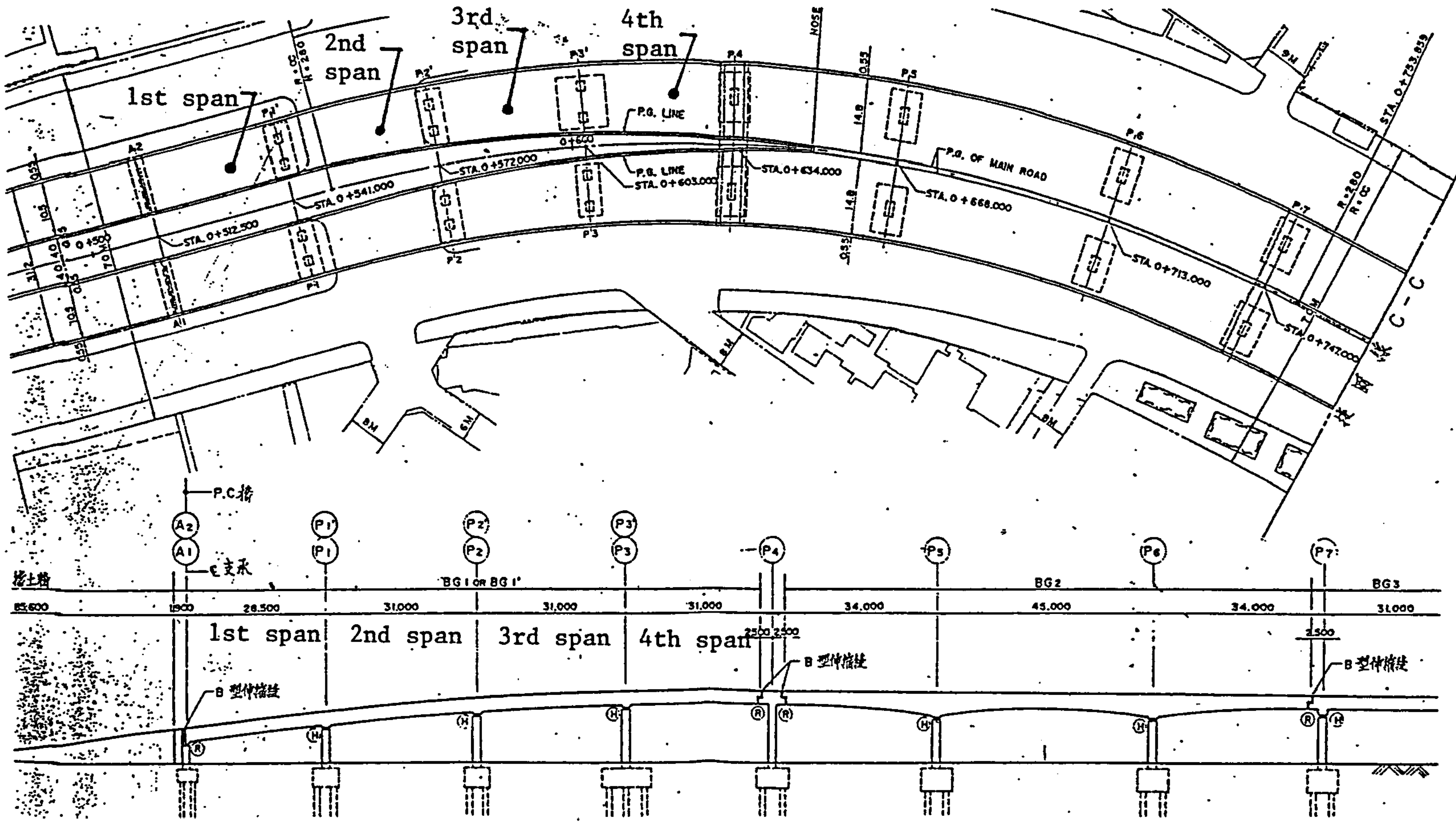

Figure 6.4: Layout plan of collapse in Taipei, Taiwan

6.3.2 The falsework

The falsework supporting the concrete deck were of two structural forms. The lower portion was system scaffolding or steel frame structures depending on whether the access was required below the deck during construction. At the top, there was a planked platform laid above which timber posts and beams were nailed to fix the formwork.

The vertical load carried by tubular uprights of the frames was spread in a conventional way through a 40mm thick timber sole plate placed on the ground. The stanchions of the steel frame structure, bearing higher loads, were supported by plies of steel plate on either concrete plinths or directly laid on the ground.

6.3.3 The collapse

The collapse occurred during casting of the top slab. The concrete pouring which started from the lowest span and working towards the top was about completed. Initially, the third span dropped to the ground as a loss of support from the tubular scaffold from below. Consequently, the other three spans collapsed after a chain reaction.

The fourth span, being the uppermost and with tubular scaffolding below, rotated about the continuous support and fell to the ground. The second span was retained by the much stronger steel frame structure which was erected to provide access below the deck during construction. The first span, which was at a greater distance away, had had similar damages as the second one. Fortunately and miraculously, no one was hurt during the collapse.

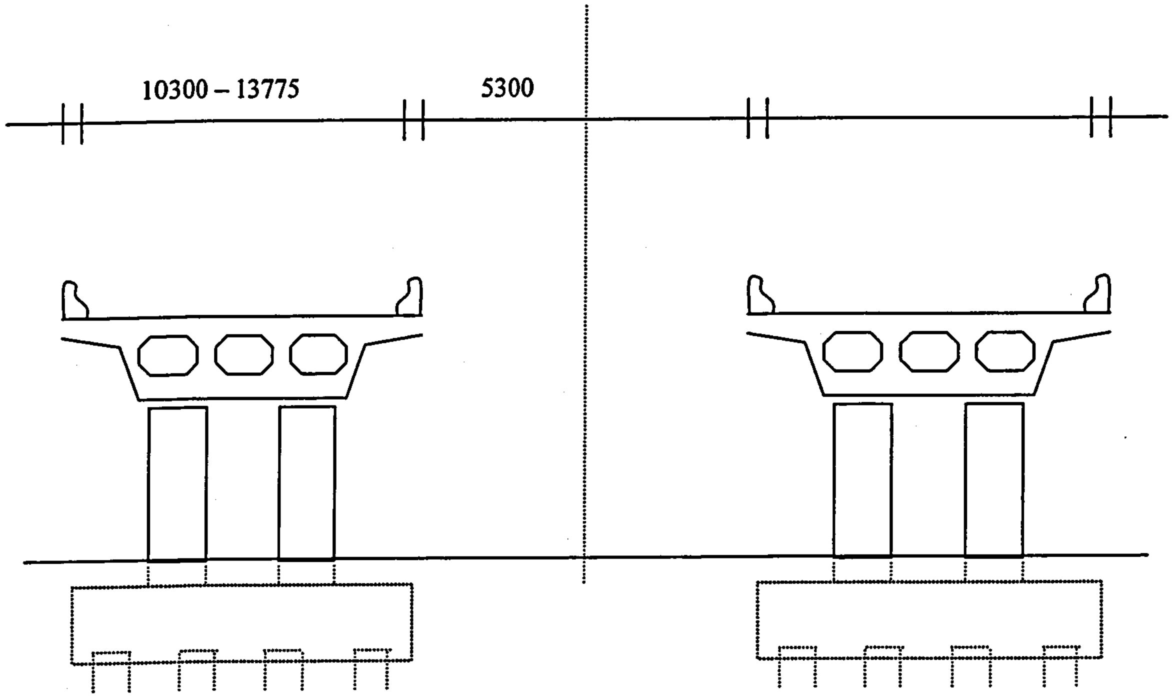

Figure 6.5: Section of the collapsed bridge, Taipei, Taiwan

6.3.4 The causes

As pointed out in the Bragg's Report (1975), there can be many causes for most falsework failures. Based on the field observation and the discussion with the consultant for the project and other professionals, the collapsed falsework had the following weaknesses.

- Absence of a proper and an adequate design with checking by competent persons.
- Lack of bracing members both longitudinally and transversely.
- Overloading of the slender tubular scaffolds.
- Horizontal forces, such as those due to concrete pumping had not been allowed for in the design, which may be negligible only in small works and in a sheltered location.
- Settlement of the ground was not taken into account.

Immediate remedial work after the incident such as strengthening the remaining scaffolds by adding timber struts and diagonal braces justified some of the above-mentioned points.

According to Tsai & Hadipriono (1990), the failure of deck BG1 was caused by the insufficient support of the falsework and this accident prompted the Department of Public Works to request the contractor to replace the falsework scaffolds by structural steel members. However, since the contractor had already completed the falsework foundation, they simply strengthened the existing falsework scaffolds by adding timber struts.

In April 1988, the deck BG3 collapsed only two weeks after concrete pouring was completed (Tsai & Hadipriono 1990).

An independent investigation performed by a commission appointed by the Department of Public Works concluded that the following were the enabling causes:

- weak connections of the steel pipes (frames);
- weak timber structure at the upper level of the falsework;
- inadequately spliced and incompletely installed cross bracings; and
- weak foundation for the falsework.

The following were identified as triggering causes.

- Several days of heavy rain that resulted in water ponding on the top parts of the falsework.
- Differential settlement of the soil beneath.

The request of the Department of Public Works to replace the steel scaffolds with stronger components such as H-beams or columns was ignored by the contractor, as the contractor had already completed the falsework foundation.

6.3.5 Second failure

Five months later another deck BG3 of the same bridge collapsed after concrete pouring. The two collapsed spans were supported by similar falsework scaffolds, though the second one was reinforced by additional timber struts. However, this second deck BG3 collapsed due to a number of inherent causes which had been identified from the study of the first deck BG1 failure. Had the parties learnt from the first failure and taken immediate preventive measures, the second collapse should have been avoided.

6.3.6 Control system used for this project

According to Mr. Tsang of China Engineering Consultants, who was the Consulting Engineer for the highway project, the contractor should provide the following for the Resident Engineer's (staff from the Department of Public Works) approval before commencement of the works:

- material, machinery and plant to match the actual site conditions;
- associated construction method; and

- design of the falsework including drawings and details.

This control system is similar to the conventional one, i.e. the contractor is required to design and construct the temporary works including the falsework, whereas the Engineer will approve the design and construction of the temporary works but without responsibility.

6.4 Case study 3 - July 1988, Chongqing, Sichuan Province, China (Poon, 1989)

6.4.1 The bridge

The eight-span highway bridge was about 150m in length running from South to North. The maximum soffit clearance at mid-length was six metres and two rising ramps at the two ends accommodated the difference in level between the bridge deck and the existing ground. The span length varied between 16m and 20m and the deck comprised ten T-shaped prestressed beams simply supported at their ends.

Before the collapse, three spans each at both the South and the North end had been substantially completed. The beams were either cast in situ at their final positions, or those from the adjacent spans were elevated temporarily 2m above the bearings by tubular steel falsework. Steel shuttering was used for the soffit of the beam, whereas timber board was shaped to form the varying height of the web along the length of the beam. The difference in levels between beams of adjacent spans during such temporary arrangement enabled the prestressing operation to be performed at the beam ends. Thereafter, the elevated beams would be lowered to their ultimate position.

In general the site was poorly managed and water ponding was found everywhere particularly near the pier foundation. The whole site had not been fenced, thus permitting people to obtain access right across and below the bridge deck under construction.

6.4.2 The falsework

The falsework used for this bridge construction was tubular steel of 38mm external diameter and 3mm thick. The height of the scaffolding varied and many members were rusted, twisted or bent, signifying the prolonged absence of repairs and maintenance. The steel tubes were erected directly on the ground without a base, or on some hard material such as pieces of stone or timber. No adjustable U-heads were used at the top. The supporting level was adjusted by altering the fixing of the horizontal transom. The load carrying capacity of the falsework scaffold was thus based on the bending strength of the transom, the shear capacity of the couplers and the compressive strength of the uprights with respect to their effective height.

The falsework should be designed to support the weight of the concrete beams not only before but also after prestressing, and until the beams were lowered to their final positions. After prestressing, the uprights at both ends would take up the weight of the beam as there would be an upward deflection at mid span after post-tensioning.

6.4.3 The collapse

Shortly after 5:00p.m. in one afternoon of July, 1989, the third span from the South end of the bridge collapsed. The concrete beams fell and rotated about their North ends which were still retained by the pier. About thirty workers were trapped below the falling beams. Fifteen were injured and three were reported dead.

6.4.4 The causes

Based on the field inspection, discussion with the site personnel and the analysis of the recommendation issued by the Authority concerned after the incident, the possible reasons for the collapse were shown as follows:

- overloading the supporting falsework due to uneven load distribution;
- instability of the falsework because of ground settlement, out of plumb of the

uprights and lack of bracing members to distribute the horizontal loads; and

- removal of the props intentionally or accidentally by workers, who were inexperienced in prestressed concrete works, from the villages.

Instructions issued by the Construction Planning Authority after the collapse of the bridge were as follows.

- All leading parties must establish quality first, safety first concept. Any improper procedure and irrational behaviour for progress which do not take health and safety into consideration must be prohibited. All departments are to build up the responsibility for quality and safety, and leaders have to be appointed for checking the safety and quality of works.
- For large span tunnels, precasting and cast in-situ work, specially appointed staff are required to control the construction. Working procedures without scrutiny by design professionals will not be allowed.
- Exercise stringent control over construction workers. Subcontractors from the village are not permitted to construct large span beams and tunnel projects.

6.4.5 Lessons learnt

The falsework should be properly designed and constructed with adequate materials. Furthermore, it is crucial to lay down proper procedures so that staff will find it easier to cope with critical events such as prestressing and removal of falsework.

6.4.6 Construction supervision

The supervision system adopted in China is generally in line with the traditional "Design by Engineer and Construction by Contractor" method i.e. the design is done by the Engineer while the construction of the permanent and the temporary works is performed by the Contractor. However, there is no checking of the temporary works by any third party.

6.5 Case study 4 - February 1995, Hong Kong (South China Morning Post 1995, Coroner's Court Hearing)

There was a report released by the media that a 75-tonne concrete bridge segment crashed through a supporting scaffold during placing to the bridge pier at the Route 3 Highway Bridge construction site.

The collapse section was a part of the Route 3 of the Airport Core Program. The bridge deck was either a single cell section or a twin cell section. The sections were cast on a falsework scaffold and subsequently moved to the bridge piers. A number of such single cell units had been cast and placed successfully before standard procedures had been followed and checked where appropriate by the Independent Checking Engineer (ICE).

The section collapsed was a twin cell unit which weighed about 80 tons. Initially, the launching beam method was proposed. However, due to the headroom restriction, partial lift method was then used, i.e. the section after casting and cured, would slide via two steel beams at the top of the scaffold towards the pier. The scaffold was 3.65 m high with bracing. The individual component was tested after the accident and it had a 6.5-ton safe load with a F.O.S. of two. The scaffold was erected on 20 February 1995.

The method statements without detailed sliding mechanism and design calculation of temporary works were sent to the Engineer and, before commencement, to the ICE. As it was the first time to install the twin cell segment, the Resident Engineer had reminded the Contractor to submit the temporary works design. It was later found that the collapsed scaffold was erected in accordance with drawings for other scaffolds. The construction method had been changed but there was no revised method statement, and certainly without formal approval.

The erection work and moving of the segment were undertaken by Thai workers. They did not understand English although it was claimed that they had undergone a three-hour introductory training course. The two technical managers of the Contractor, who had overall planning and controlling responsibility, left Hong Kong after the accident. The Contractor's foreman and Thai foreman supervising the Thai workers were absent from site on the day before and on the day of accident. There was no inspection of the scaffold to ascertain whether it was suitable for use or not and there were no instructions given to Thai workers. While the workers were moving the segment towards the pier, the segment crashed through the supporting scaffold and injured the workers.

The possible causes of the collapse were:

- poor ground support;
- eccentricity of load;
- uneven distribution of load on the scaffold; and
- the scaffold was not designed.

The procedural causes included:

- no approval by the ICE;
- unconventional construction method; and
- communication flaws such as workers proceeded construction work without approval.

At the Coroner's Court, the Judge concluded:

- the scaffold was not erected according to proper design drawings approved by the ICE;
- during erection, there was no proper supervision;
- after erection, there was no inspection or checking by the Engineer, the Resident Engineer or the ICE; and
- there was no approval by any supervisor in moving the segment to the pier by Thai workers.

6.6 Case study 5 - January 1996, Hong Kong (Poon 1997)

6.6.1 The footbridge

In January 1996, in Hong Kong, two precast and prestressed concrete beams collapsed during construction of a footbridge. The collapsed 34m span footbridge was designed to straddle Po Ning Toad, Tseung Kwan O, Hong Kong. It was formed by first installing two concrete beams of rectangular cross section 0.65m x 1.95m. Each beam was about 110 tonnes by weight. The 3m wide deck and the roof were then built on the two beams. (Figure 6.6).

6.6.2 Construction method

The two beams could either be precast or cast in situ. Since the top of the beam was designed to be in line with that of the permanent piers that were first built at the two ends, it was impossible to prestress the beams if they were cast in situ at their final positions.

The beams could be precast off site, and then delivered and lifted into their positions. But this operation would involve closing of the road below the footbridge at mid-night. As the road was required to be kept open to traffic twenty-four hours a day because of the operation of a landfill site nearby, off-site casting was out of the question.

The only option left was casting the concrete beams about 2m above their final positions using temporary supports. Prestressing operations would then be carried out and thereafter the beams were to be lowered to the bearings on the piers.

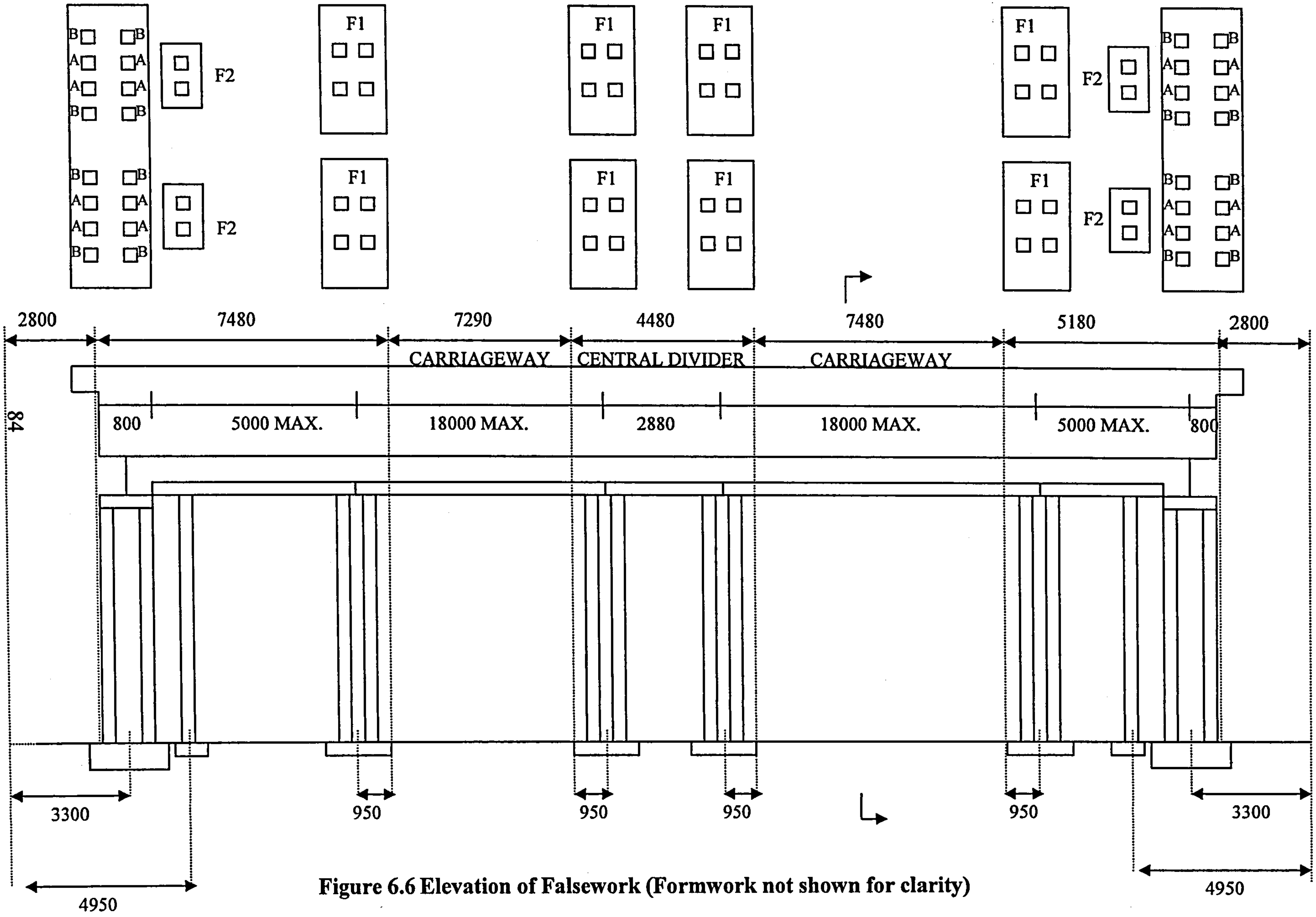

Figure 6.6 Elevation of Falsework (Formwork not shown for clarity)

6.6.3 Falsework

Timber formwork was used for casting the beams. Steel transverse I-beams and channels were erected to spread the concrete load onto the longitudinal steel beams. The vertical supports were quadshores consisting of four tubular steel members which were connected to the temporary concrete footings by bolts (Figure 6.6).

6.6.4 Lowering of the concrete beams

After post-tensioning, the two concrete beams were supported by the falsework at both ends. Since the beams were cast at a height of 2m above the bearings, a method for their descending was required owing to the fact that there was no hydraulic jack with sufficient capacity available to lower the beams in one single operation.

At both ends, a pair of steel I-beams was placed transversely underneath the concrete beams. Below, two sets of props, A and B, with sets of I-beams fixed at the top, were erected to support the concrete beams in turn. After prestressing, the two concrete beams were supported by the A props. Another set of props, B, was later erected. The plan layout would then consist of two rows of props of the pattern B-A-A-B-B-A-A-B. (Figure 6.7)

Initially, eight hydraulic jacks were scheduled to be placed at B props at both ends. However, by placing the jacks above two A props, the number of jacks could be reduced to four. So there was a change in the construction method. When B props were providing the support, the hydraulic jacks would be placed on A props. By activating the hydraulic jacks, the intermediate I-beams on B props could subsequently be removed. Similarly, the intermediate I-beams on A props were removed when B props were in support. By repeating the processes, the two concrete beams would finally be lowered to the bearings without using the cranes and closing of the road below (Figure 6.7).

6.6.5 The collapse

Having completed the erection of B props, the workers attempted to remove the intermediate I-beams on A props. While they were striking the last screw jack of the A props at the North end of the bridge, the two concrete beams fell, rotating about their longitudinal axis. Three workers on site were injured and a lorry driver was crushed to death by the falling beams.

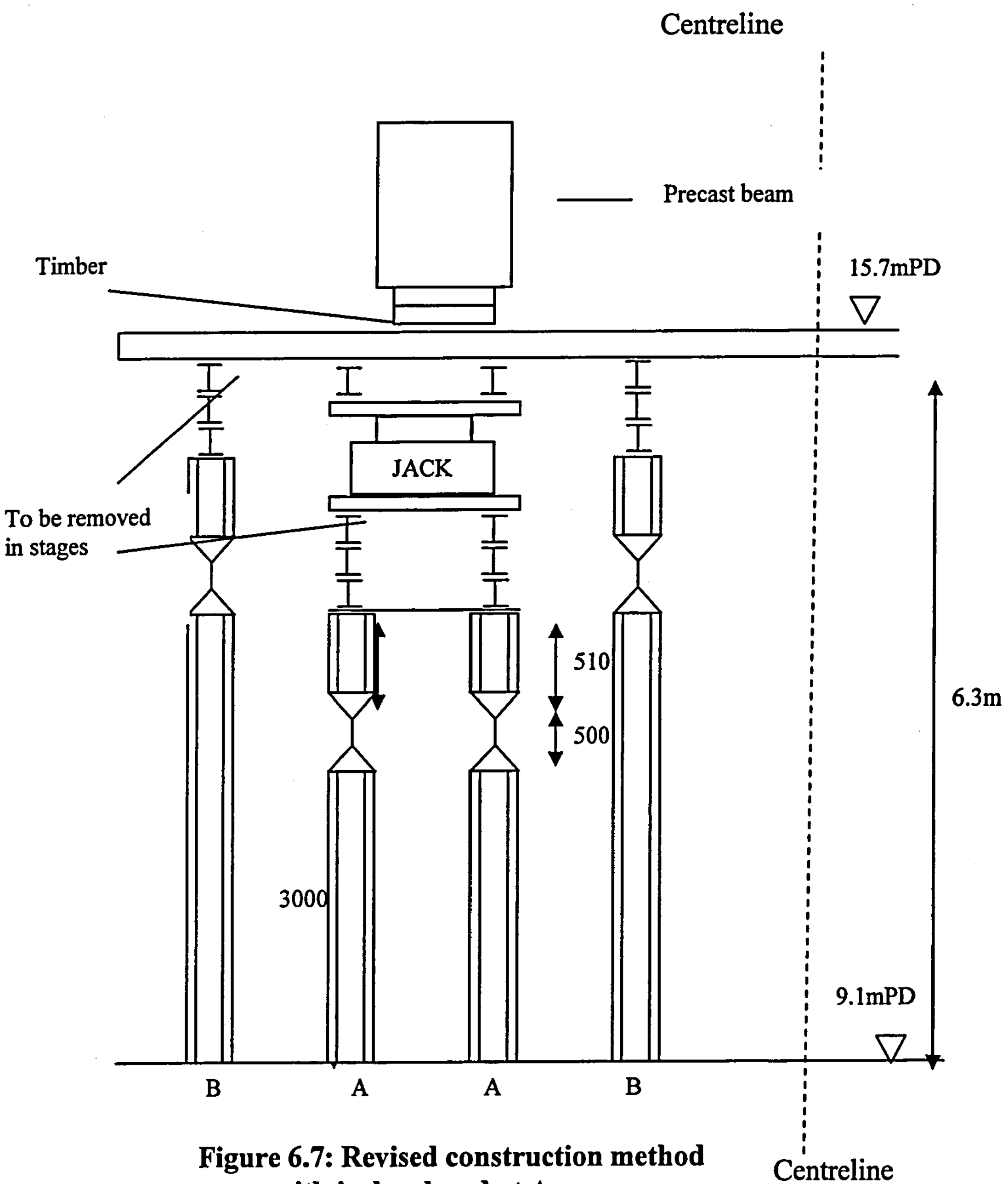

Figure 6.7: Revised construction method with jacks placed at A props

6.6.6 Possible causes

When concrete was being placed for the casting of the two beams, the I-beams on the props at the North end had shifted. Due to the post-tensioning of the beams, there was a re-distribution of loads on the I-beams and the props. Unfortunately, the loads were not evenly distributed. In addition, the I-beams on A props had been stiffened whereas those on the B props were unstiffened and could not be able to support the increased loads.

The failure sequence was as follows:

(1) short longitudinal I-beams failed in buckling;
(2) transverse I-beams started to fall;
(3) concrete beams fell; and
(4) eccentric loading on quadshores at the other end led to failure and collapse of the falsework.

6.6.7 Procedural inadequacies

The following are the inadequacies of the procedures.

- The steel I-beams were not properly checked for misalignment after concreting and their ability to support the concrete beam loads.
- The main contractor failed to provide detailed drawings for the falsework construction.
- The workers were removing the A props without the ICE's approval on the construction of the B props to receive the loads from the concrete beams.
- Consultant's site staff showed little concern about the work being carried out by workers prior to the collapse.

6.6.8 Recommendation

As for traditional construction contracts, the Resident Engineer claimed that they had no liability regarding the construction of the temporary works except receiving the approval certificate submitted by the ICE and the Contractor. The Contractor and the consultant's site staff claimed that they did not know the workers employed by the subcontractor had started to remove the A props, but the consultant's works supervisor was on the deck prior to the collapse of the beams. However, the Contractor or the subcontractor had proceeded the construction work i.e. removing the A props while the beams were transferred to B props before inspection and approval by the Checking Engineer.

The situation exposed the deficiency in the control of the temporary works during their construction. There was supervision but held no position of responsibility by the consultant's resident staff, and the Contractor left all the checking responsibility to the Checking Engineer. Furthermore, the Checking Engineer was not working full time on site. This implied that there was no control with responsibility by any competent professional when the workers were in operation.

It is therefore recommended that the Checking Engineer should be appointed to check and supervise the construction of the temporary works, not just to certify that they have been erected in accordance with the design drawings. Also, the Contractor should appoint a member of his staff to be responsible for the co-ordination of the design and construction of temporary works. The consultant's site staff should also pay more attention to the temporary works construction although they contractually have no liability.

6.6.9 Conclusion

Control should be tightened with the appointment of the ICE who is responsible for checking and approving the design and construction of, and loading on the temporary works. However, as shown from the above mentioned collapse case, there was no control over the Contractor's work during the erection and loading of the falsework. To prevent future failures caused by unauthorised work being carried out by the Contractor or subcontractor, the Checking Engineer should be appointed to supervise the whole erection stage particularly those activities which would be immediately followed by loading on the works. The Contractor should appoint staff to be responsible for the co-ordination of the temporary works and the consultant's site staff should be more alert to the critical activities.

6.7 Case studies 6 - December 1996, Ru Yuan, Guangdong, China (Poon et al. 1998)

6.7.1 Introduction

A severe accident occurred at a bridge construction site during concrete pouring in December 1996, near Ru Yuan Town, Guangdong, China. It was a box arch bridge of reinforced concrete construction in a highway construction project. The beams forming the arch were twisted and collapsed totally to the bottom of the valley. Thirty-four workers died and twenty-seven severely wounded in the accident.

It was one of the most severe construction failures in recent years in China. Initially, the press did not release any cause from detailed investigations. The original drawings and related information of the bridge were kept confidential by the authority. Even visiting the site within one month after the failure occurrence was strictly forbidden. The author made great efforts to visit the site twice. The first time was one week and the second one was three months after the accident. Information was collected by visiting the site and interviewing the workers. The possible causes for the failure were identified such as poor site management, lack of safety control and instability of falsework.

6.7.2 Review of the information collected

Among of all types of bridges built in China, the arch has been widely used for highway bridges because of its large spanning capacity. Around seventy per cent of highway bridges are arches which are especially suitable for long-span bridges.

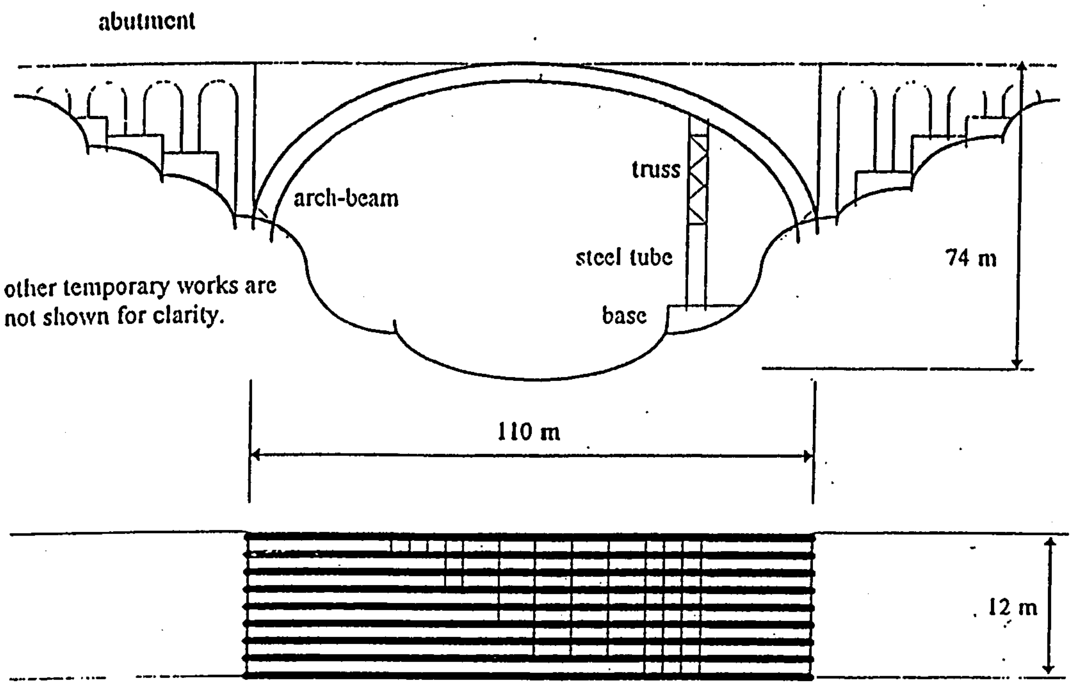

Figure 6.8 Elevation and plan of the arch bridge

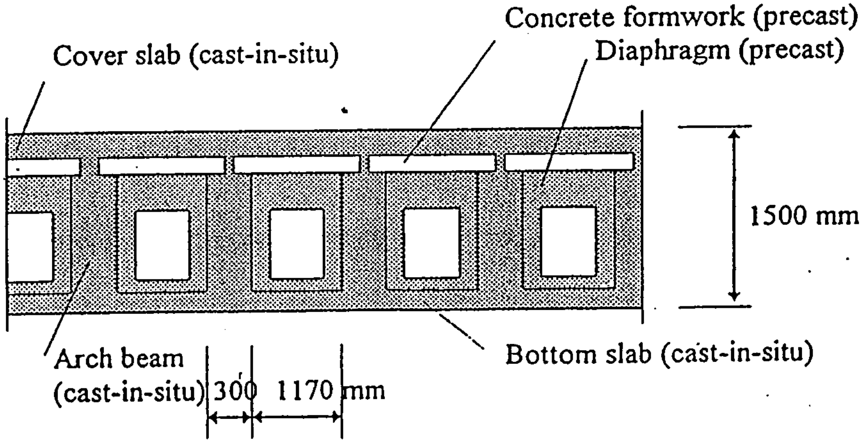

Figure 6.9: Cross-section of the box arch

This bridge was one of the two main arches in a highway joint-venture project which was scheduled to be completed by March 1997. The bridge was 12m wide and 163m long. The top part of the 110m centre span would be 74m above the valley. The height of the arch was about 17m which means the ratio of height to span was 1/6.5. Details of the bridge are shown in Figure 6.8. The bridge deck comprised nine arch beams to form eight boxes by the bottom slab, cover slab and diaphragms (Figure 6.9). The reinforced concrete arch beams were constructed in situ. The precast concrete diaphragms spaced at a certain distance were used to increase the stability and stiffness of the arch.

The procedures of the arch construction are shown in Figure 6.10. The failure happened during concrete pouring of the top part of the arch. The concrete abutments to both sides had been completed earlier and remained the same after the collapse. Falsework erection was the key activity in the arch bridge construction. Concrete was produced by three mixers nearby. A steel truss tower was erected near each abutment to support several steel cables which were attached with two trolleys and suspending hooks for the transportation of materials across the valley.

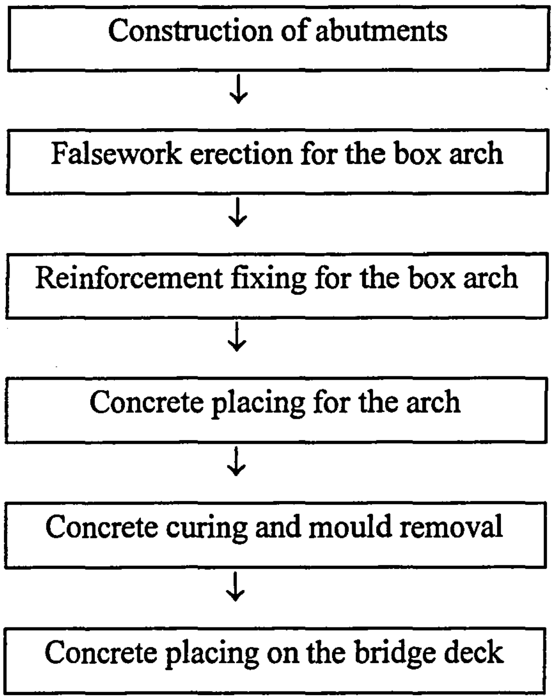

Figure 6.10: Flow diagram of the bridge construction

Timber forms and lattice frames were supported by columns made up of steel tubes and small trusses when forming the arch. Concrete should be poured in a continuous process according to the design. Workers were divided in groups for the non-stop concreting work. A couple of days before the accident, displacement of the forms had been noticed. The problem was solved by simply raising and restoring the forms at their required positions with the suspending hooks. This operation might have loosened the falsework connections and buried the root of the tragedy.

After several days' hard work in concreting, there was an area of less than 10m long at the top and near the centre of the arch yet to be concreted. On 20 December 1996, over one hundred labourers and technicians were scattered on the work surface of the bridge with the last efforts of concrete pouring in that morning. According to the press, at about 9:10 a.m., a labourer standing at the west edge of the newly placed concrete heard a strange noise under his feet. He instantly threw himself to the opposite side and grasped the steel bars of the arch. The west part of the work surface suddenly twisted and then crashed with the whole arch to the bottom of the valley.

6.7.3 Possible causes of the failure

Falsework failures occur often at the end of concrete pouring due to the biggest loading during construction. The design of the arch bridge was adequate according to the official results released. Investigation confirmed that the main causes can be attributed to the following aspects during construction.

(1) Falsework failure

- The falsework consisted of a variety of components which were made of different materials and shapes. Any displacement, loosening, breaking in any part of the system would lead to the redistribution of stress and falsework failure.
- Loosening of falsework and settlement of temporary foundations.
  It was observed that the natural surface of the valley was of highly weathered rocks. A few places were selected as the bases for falsework erection. The use of the

700mm x 700mm concrete blocks as temporary foundations appeared to be over-simplified.

- Joint failure of the falsework

  The falsework was supported by trusses (600mm x 600mm) which were made of angle steel (50mm x 50mm) and U-section (80mm x 40mm) and steel tubes (600mm diameter). The connections of the parts were not complicated. Steel tubes were placed on the base without sufficient connection. The trusses were linked by tubes and the connection between them was by welding four pieces of steel bars. Small steel tubes were also used as the supporting falsework.

- Strength failure of the falsework

  Using the worn and insufficient materials was a popular means for contractors to reduce the cost in construction. As a result, use of inadequate materials may lead to a failure in falsework.

- Instability of the falsework

  The ratios of length to section size of the supporting columns were large and this could easily affect the stability of the falsework. Horizontal forces during construction could trigger the collapse of the falsework.

(2) Poor management on site

It was reported that there had been a lack of concepts of quality assurance and safety control on site. The contractor had ignored the warning displacement of forms which happened a few days ago before the collapse. The resolution of the latent dangers was questionable. As it was close to the Chinese New Year, the contractor and the workers wanted to complete the work quickly so that they could go home before the festival. Taking chances and cutting corners could lead to failures.

According to the official announcement on 1 November 1997 by China's Central TV

Station, the failure was due to inadequate design of the falsework.

6.8 Brief reports

There were failure cases with no detailed investigation reports available. They are grouped and described in the following sections.

6.8.1 Case study 7 - 1991, Singapore

The falsework scaffold supporting the concrete slab of the first level of a car park collapsed during concreting. A visit was made to the site. However, there was no disclosure of information by anyone in connection with the accident.

6.8.2 Case study 8 - June 1994, Macao

A 20m x 10m bridge deck collapsed during concreting for the construction of a flyover linking to the new airport terminal building. The concrete deck was supported by falsework scaffolding. A visit was made to the site after the incident. No information was made known to the public and later it was released by the press media that the collapse was attributed to soil settlement.

6.8.3 Case study 9 - 30 December 1997, Guangzhou, Guangdong, China

The collapsed deck was a span connecting a highway and another bridge. Three were killed and over thirty workers were injured during concreting of the deck.

There were over thirty workers involved in the concreting operation. Below the deck, five workers were inspecting the falsework. One worker responsible for falsework inspection recalled that, before the accident, he discovered a few timber falsework had cracked or broken. He then went to find four timber posts as reinforcement. Before he started the installation, he found more steel props and falsework supporting the bridge deck had already buckled and twisted. He managed to run away from the deck, while the other four workers were buried by the collapsed deck.

According to the news reports, the 800mm thick reinforced concrete deck should have been cast in two stages. The top 400mm would not be placed until the bottom 400mm slab had been cured sufficiently. The falsework would not be able to support the casting of the full thickness of the bridge deck in one pour. However, the deck was poured to 800mm full depth in one go.

As reported by the media, similar accidents happened in Guangzhou in 1993 and 1994 with nine injuries in the former and seven dead plus eleven injuries in the latter case.

6.8.4 Case study 10 - 12 November 1998, Tsing Yi, Hong Kong

The collapsed bridge ramp, 6m wide and 10m span, was a part of a 100m long vehicular bridge connecting a car park of a new development and the public road on Tsing Yi Island. The deck was about 5m above ground and was of reinforced concrete in situ construction.

Apparently, the falsework used was of the heavy type system scaffolding. From the photographs, it can be clearly seen that there was a lack of bracing members for the remaining scaffolds. According to the news reports, concrete had been laid down as the first layer on that morning.

Shortly after 12:00 noon, the workers resumed casting of the slab but found a movement and a strange sound when the first skip of concrete was loaded onto the deck. The deck then dropped to the ground with the loss of support from the falsework below.

The existing legislation and requirement for building work do not require:

- submission of temporary work design and construction information; and
- independent checking on the design and construction of falsework.

Other inherent weakness as identified from the photographs include:

- the ramp was sloping – significant horizontal forces could have been present; and
- no bracing for other remaining scaffolds was seen from the photographs showing similar absence in fixings might have been the case for the collapsed portion.

Official report by Buildings Department would remain confidential and normally would not be released to the public whatsoever.

6.8.5 Case study 11 - February 1999, Chai Wan, Hong Kong

A 16m x 16m concave reinforced concrete canopy over a stage collapsed during concreting and killed a worker who was vibrating the concrete.

The reinforced concrete canopy, 5m above ground, was supported by timber formwork and system scaffolding. Before the accident, five truck-loads of ready-mixed concrete, i.e. about 30 cubic metres had been laid. The worker, who was killed in the incident, was vibrating the concrete near the centre of the roof. Concrete was delivered by a skip suspended from a crane.

One of the workers, who was at the rooftop, recalled that when he could feel the vibration of the roof, he quickly jumped off the roof. The roof was then found to collapse towards the centre in a V-shape. The workers vibrating the concrete were buried by the concrete.

This project was part of the improvement scheme of a commercial complex nearby. The structure was designed by the Architect and the Engineering Consultant. It was believed that the conventional control had been adopted, i.e. the temporary works were designed and constructed by the Contractor, subject to checking by the Architect or Engineer who bore no responsibility.

6.9 Usefulness of the visits

There had been difficulties in paying visits to sites where failure had occurred. The problem and experience gained from the trips are summarised as follows.

- Time lag - As soon as the accident was reported in the press media, some hours might have passed if the collapse occurred locally. For accidents occurred in other cities, the delay could be a couple of days.
- Transportation - Some cities could not be reached on the same day of accident announcement. Direct air flights might not be available within the shortest possible time.
- Site closure - In most cases the site concerned was close to the public. Finding a suitable place to view the scene would depend on the site surrounding.
- Information inaccessible - For a number of reasons, the personnel concerned would not be willing to disclose any information. Sometimes no report would be published or available to the public despite that there was an investigation undertaken by the authority.
- Evidence lost - Quite often the evidence relating to the cause for the collapse could have been undermined or mingled due to the quick removal of the wreckage in order to rescue the entrapped workers.

Despite the problems encountered, there are merits for visiting the site soon after the accidents occurred. They are listed as follows.

- Acquaintance - It was much better to get the actual feeling of the construction by visiting the site. The construction method, the type of permanent structures and the completed works, the scale of works and any other related construction works on site could be better understood than interpreting the description solely from the reports.
- Clue finding - Some of the causes for the collapse could still be traced or observed on site. For example, the existence of any similar works might provide valuable evidence.
- Interview - Opinions regarding the stage and the cause of the failure could be

obtained from workers on site or people living nearby. These people might have noticed the happenings related to the incident and they would be willing to tell. After the accident, instructions given from the senior level could reveal the causes although no official announcement of the reasons was available.

- Cross checking - Information collected in an informal way served to cross check the material collected from other sources. For example, the remedial works erected to the remaining falsework provided some sort of evidence to the announcement by the parties involved.

6.10 Summary

This chapter reveals the investigation of major falsework collapses occurred in Hong Kong and nearby cities since 1986. Most of the sites were visited with an aim of finding out the possible causes of the failure. There were lots of problems and difficulties while collecting the fact and information as an individual investigator. Certainly the information collected would be far from the complete picture without the assistance from the authorities concerned. However, the visits did provide valuable opportunities to understand the incidents and to pinpoint or confirm the possible causes of the falsework failure besides the available reports.

Use of inadequate materials has been identified as one of the causes of falsework failure. The assessment of performance of falsework scaffolding will be detailed in the following chapter.

CHAPTER SEVEN

PERFORMANCE OF FALSEWORK SCAFFOLD SYSTEMS

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PERFORMANCE OF FALSEWORK SCAFFOLD SYSTEMS

7.1 Introduction

One of the reasons for falsework failure as identified from reports was using materials of lower strength than they should have been. In Hong Kong, falsework scaffolds are generally available from suppliers. The large contracting firms may be able to own and stock certain amount of components if they see there is a good chance of continuation of their uses. The suppliers may be simply trading companies only or equipped with an in-house department to provide technical and engineering services. Scaffold systems available in Hong Kong are mostly imported. Due to variation in quality and origin of the scaffold systems, there is a need to ascertain their loadbearing capacity (Poon 1994, Lee 1998). This chapter presents the findings on the performance assessment of common scaffold systems used in Hong Kong.

7.2 Scaffold suppliers

There are about twenty plus falsework scaffold suppliers in Hong Kong. Some of them are mainly traders dealing with import of the components and providing the materials hiring services in the construction industry. The others, besides acting as agents for some proprietary systems, have set up the in-house engineering departments to support the necessary technical and engineering services. A couple of subsidaries of well known proprietary systems suppliers such as Scaffolding Great Britain (SGB) has established the branch service in Hong Kong for quite some time.

The products provided by the suppliers are varied. The SGB provides the well known Cuplock System besides other common components. These companies also receive vital backup support from their parent company or headquarters such as computerised analysis and design. If new systems are to be introduced they can be duly tested in a full scale manner at their headquarters. Thus, the quality of their products is more reliable.

Others, in particular the trading companies, provide mainly the most common system, i.e. the frame for use by the contracting firms. They purchase the products which are manufactured in the South East Asia, particularly the Southern China. Load test of these systems may have been performed at the place of their manufacturing when they are new. The other main sources of materials are used systems imported from Japan where a tighter control of used construction equipment has been implemented.

7.3 Scaffold types and loadbearing capacity

The most common type of falsework scaffold used in Hong Kong is the frame type. They are made of steel tubes welded together. The light duty systems are often used for building construction where loadings are always not excessive and overall height is limited. The heavy duty scaffolds are required for bridgeworks where the concrete weight to be supported is considerable. For high headroom situations, the shoring systems which combine three or four steel tubes together to provide a more concentrated and stronger support are used.

The catalogues available from the suppliers regarding the common frame system are very similar in the content and layout. For the light duty scaffolds, the maximum failure load per frame is quoted as 100kN and the recommended working load is 50kN, i.e. 25kN per leg with a factor of safety of two. For the heavy duty frames, the recommended failure load per frame is 178kN with a factor of safety of three.

One problem emerges when using these falsework scaffolds is whether the information provided by the suppliers is reliable or not. Studies about the resistance capacity of steel scaffolds were performed around the world. Wu (1991), Jan (1989) and Peng (1994) have done some research work on the theoretical model analysis in this field. Most of these studies were based on theoretical analysis, and the research in experiments were much less (Yen 1995). Theoretical analysis are complicated and one major problem is how to determine the boundary conditions of each member (Yen 1995). With this in mind it was the main reason of establishing the failure load of the scaffolds by load tests (Lee 1998). Furthermore, there is great uncertainty of the strength of the used materials which are not available from the suppliers' catalogues. There is one recommendation derived from the permissible stresses of the used materials compared with the new condition in BS5975. From Table 23 in BS5975, it can be derived that the reduction factor is 0.85 when used steel scaffold tubes are used. But can this factor be verified, for example, from the actual load tests of scaffolds?

7.4 Load test equipment

The aim of performing the tests was to load the scaffolds until they failed to take on any further loads. The loading equipment was basically a hydraulic jack which was hung from a steel frame in the structural laboratory of Department of Civil Engineering, the University of Hong Kong. The loading from the jack was transferred to the frames through a loading platform, comprising 305x152x65.1 I-beams and 150x150x14 angles jointed by 22mm diameter high tension bolts, suspended from above and rested on top of the scaffold under testing (Photo 7.1).

Due to the limited headroom available in the laboratory, the scaffolds were erected in one lift and were regarded as the smallest unit in building up the whole scaffold on site. The scaffolds were braced in accordance with the supplier's catalogue. Twenty to thirty strain gauges were glued on the surface of the tubes of the frames. They were used in pairs and fixed in perpendicular directions to record the strains and deflections. Electronic devices were installed to measure the horizontal deflections of the four legs at their mid-height, and vertical deflection of the frame until collapse of the tower. Both strain gauges and electronic devices were connected to a central terminal so that readings could be taken through the monitor during the test. To avoid damages to the electronic devices, they were removed before failure of the tower occurred or when the extension had reached their capacity. However, due to the time needed to prepare the gauges, only horizontal deflections were measured from the seventh test and onwards.

Photo 7.1 Test equipment

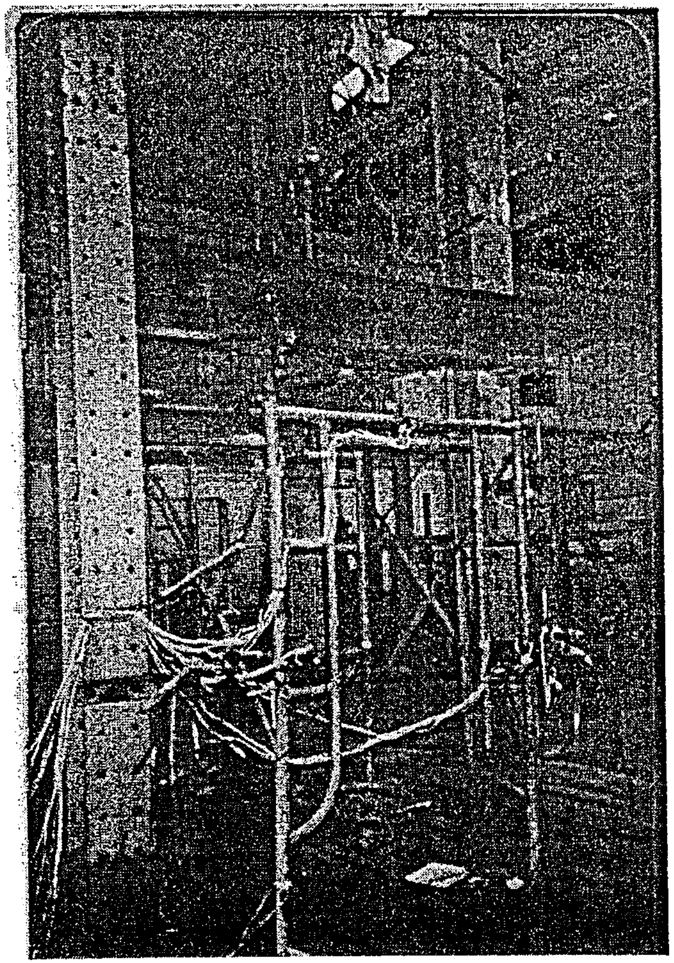
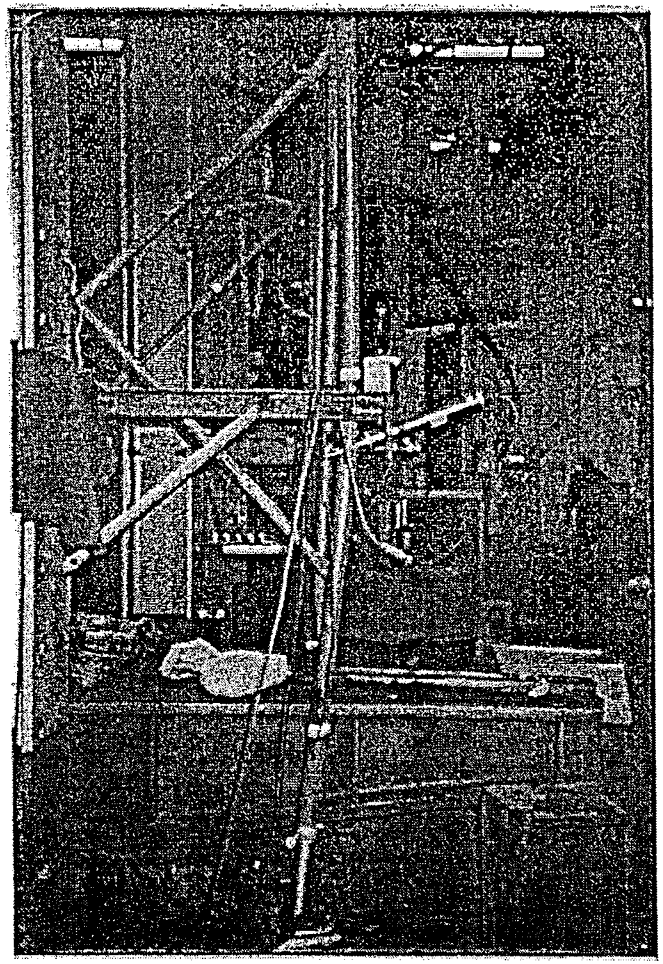


Photo 7.2 Failure of scaffold



A hydraulic jack of 500KN capacity was used to provide a vertical load to the platform which in turn transferred the load through the forkheads to the frames. Plywood pads were placed in the forkheads and underneath the base plates at the legs so as to produce a good contact and simulate the loading condition on site as far as possible. The load was increased continuously until the maximum attainable load was reached or until the deformation of the tower was such that no further load could be applied (Photo 7.2). The test was performed as much as possible in accordance with the Draft British Standard DD 89: Methods for Testing and Assessing the Performance of Prefabricated Heavy Duty Support Towers (BSI DD89 1983).

7.5 Tensile tests

After the loading tests, specimens of 127mm x 13mm were cut from the frames during the first six tests. A total of twelve samples had been prepared for tensile tests. By the use of an extensometer with the MTS machine, the tensile load was applied until fracture of the specimen. A stress and elongation graph was automatically plotted and from the graph the direct stress and strain were determined. A mild steel specimen of 6mm cross section diameter was also tested for comparison.

7.6 Test samples

Altogether, thirty-three pairs of frames were tested. Materials in both the new and used condition, but ready to be used on site were obtained from six major suppliers. They were:

- Modern (International) Plants & Machineries Ltd.
- Canyon Engineering Works, the agent for Acrow products.
- Scaffolding Engineering Co.
- Joint Constructional Plants & Machineries Co. Ltd. and Joint Formwork Co. Ltd.
- Vector Scaffolding Ltd.
- Advance Equipment Service.

The frames were mostly originated from China and Japan. Several of them could not been identified for their origin but were believed to be imported from Singapore and South Korea. Most of them were painted frames except two pairs from Japan were galvanised. Tubes with bracings in two directions, but without transom members jointed in the usual case, were also erected and tested for four times. Only two tests were performed on the heavy duty systems.

7.7 Discussion of test results

According to the usage condition, the configuration of the frames, the suppliers and the origins, the test results were classified into eleven groups in which at least two tests were performed. In all groups, it was found that the minimum failure load was between 79 per cent and 98 per cent of the maximum failure load. The average failure load derived from the test results was compared with the supplier's failure load. Also, against the working load as recommended by the suppliers, the actual factor of safety (F.O.S.) was calculated. The results are tabulated in Table 7.1.

Table 7.1 Performance of falsework scaffolding

Group No.	Origin	Age (Years)	Type of Frames	Actual Failure Loads (kN)	Actual Mean Failure Loads (kN)	Supplier Failure Loads (kN)	Supplier F.O.S.	Actual F.O.S.
1	China (1)	New	L.D.	201 196 196	198	200	2	1.98
2	China (2)	New	L.D.	176 204 204	195	200	2	1.95
3	China	2 Yrs	L.D.	179 171 186	179	200	2	1.79
4	China	Used Age Unknown	Tubes only	140 147 133 146	142	200	2	1.42
5	Japan	Used Age Unknown	L.D.	142 246 206	226	200	2	2.26
6	Japan	Used 9 Yrs	L.D. Galvanised	166 182	174	200	2	1.74
7	Japan	Used 7 Yrs	L.D.	129 155	142	200	2	1.42
8	Japan	Used 6 Yrs	L.D.	172 178 181	182	200	2	1.82
9	Japan	Used 5 Yrs	L.D.	224 181 176	194	200	2	1.94
10	Cannot be identified	Used Age not known	L.D.	185 183 155 184	177	200	2	1.77
11	China	New	H.D.	352 359	356	534	3	2.0

Notes:

China (1)	- Swatow, Guangdong Province
China (2)	- Guanxi Province
L.D.	- Light Duty
H.D.	- Heavy Duty

The performance of the frames are summarised according to their origins, whether they are of light or heavy duty type, and new or used condition.

(1) Products from China

Light duty frames of both new and used condition, and heavy duty frames of new condition were tested.

- Light duty frames - For new frames the loadbearing capacity was very close to the quoted strength in the supplier's catalogue. The used frames of two years old had a strength of 0.9 of those of the new frames. Whereas, the untypical used tubes with bracings only achieved only 0.7 is obvious due to absence of the strengthening by transom members.
- Heavy duty frames - They had a factor of safety of two only instead of three as stated in the supplier's catalogue.

(2) Products from Japan

Only light duty frames of used condition were available for testing as new frames from Japan were not available. The test results were mixed and varied. Apparently, the failure loads reduced with age of the frames. The galvanised frames with a F.O.S of 1.74 though not commonly available in Hong Kong had a high strength than expected despite the nine years old age.

(3) Sources unidentifiable

These samples were not able for identification of both the origin and age. They had on average a factor of safety of 1.77.

7.8 Correlation of loadbearing capacity of scaffold frames with age

The actual factor of safety of the scaffold frames was plotted against their age in Figure 7.1. The correlation was discussed with respect to their origin, i.e. either China or Japan.

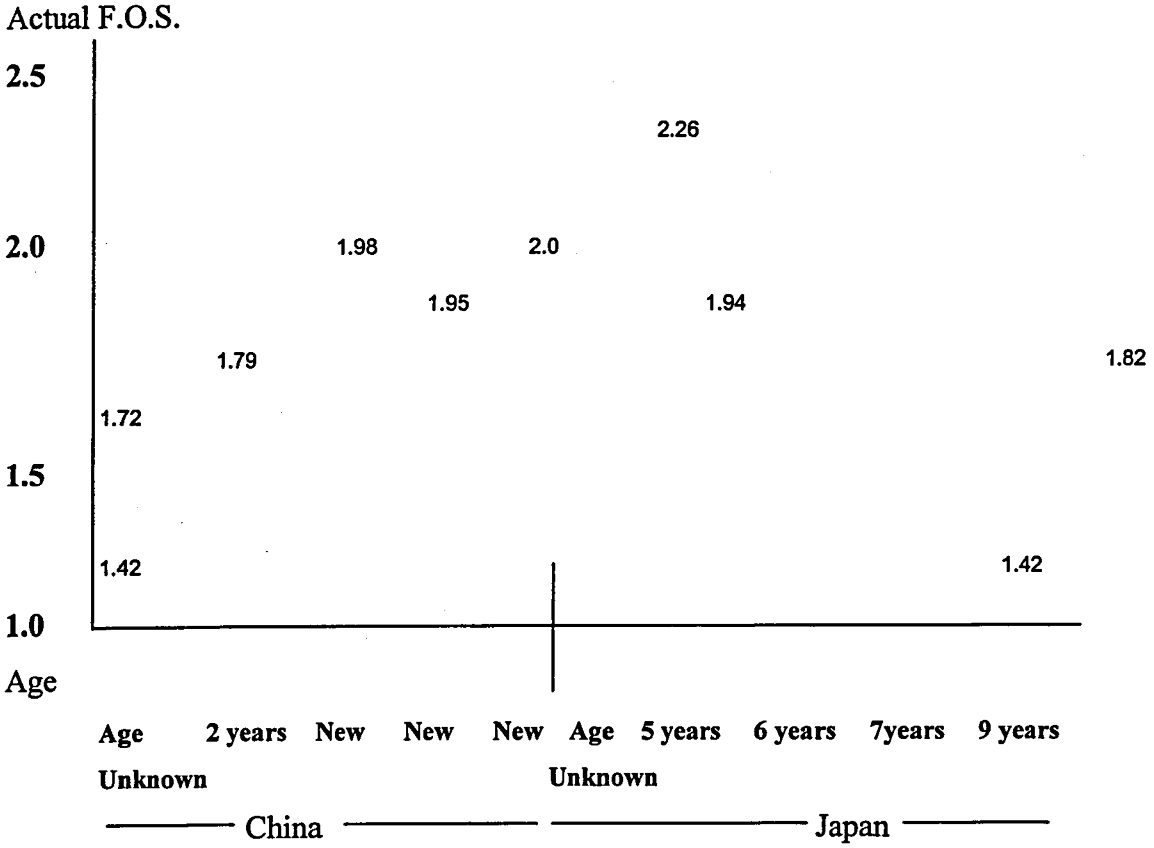


Figure 7.1: Actual factor of safety vs age of scaffold frame

(1) Products from China

The new light duty frames from China achieved a failure load comparable to supplier's recommendation whereas the new heavy duty systems gave a surprisingly much lower factor of safety. The new light duty frames had achieved a factor of safety of 2 and the used frames of two years old had a reduction factor of 0.9. Both satisfied the requirement specified in Section 23.4 and the implication for used materials in Table 23 of BS5975 respectively.

(2) Products from Japan

The used frames from Japan showed strong indication that the capacity would reduce with increase in age as depicted in the following table.

Table 7.2: Age and reduction factor for loadbearing capacity of used frames from Japan

Age in Years	5	6	7
Reduction Factor	0.97	0.91	0.71

Apparenty, for used frames of not older than six years old, the 0.85 reduction factor can be safely applied. However, the falsework designer must keep in mind when using the used frames, the 0.85 factor must be decided with known conditions of the scaffold materials.

7.9 Summary

This chapter presents the load test results of scaffold frames commonly available in Hong Kong. The results have shown that the new light duty frames from China generally achieved the performance as provided by the suppliers. The used materials from China and Japan should be reduced by 0.85 as recommended by BS5975. However, for materials of higher age the reduction factor must be decided with care. There was a big difference in assessing the performance of the new heavy duty systems from China as the supplier's F.O.S. could not be justified by the two tests undertaken.

To summarise, the failure loads and F.O.S. quoted by the suppliers are not reliable although they can produce a certificate of the test performed at the place of their manufacturing. Therefore the loadbearing capacity of falsework must be carefully ascertained before use. For the second hand and used frames, the test certificate if available only refers to the new and unused condition. The thirty-three test results provide a better understanding of the performance of the frames commonly used for falsework scaffolding in Hong Kong. In particular, when using the used frames, the designer must reduce the quoted loadbearing capacity of the frames with care.

Inadequate design is a common cause of falsework failure. To ensure an adequate design, the strength and loadbearing capacity of falsework material must be established. For used materials, the minimum F.O.S. as recommended by relevant standard must be maintained by adopting a lower working load in design.

There are many other reasons for falsework failures besides the inadequate materials used in construction. The failure needed to be analysed and causes are identified so as to prevent their recurrence. The next chapter will cover analysis, prevention and prediction of failures.

CHAPTER EIGHT

REVIEW OF FAILURE ANALYSIS, PREVENTION AND PREDICTION

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REVIEW OF FAILURE ANALYSIS, PREVENTION AND PREDICTION

8.1 Introduction

In the nineteen seventies, a large-scale study of falsework failures was undertaken in the UK by the Bragg's Committee (1975). Technical reasons and procedural inadequacies were identified as the two main causes. A study of 60 bridge collapses (Poon 1996) revealed that over 50 per cent were falsework related failures and the most common causes were inadequate review of falsework design, inadequate control during construction and improper procedures in falsework removal. This chapter reviews extensively previous research work on analysis and prediction of failures, in particular falsework failures, and their recommendation for preventive measures. The first part will concentrate on failure analysis and precaution suggestion and the second part will cover failure prediction.

8.2 Failure Analysis and Prevention

A number of researchers have studied falsework failures since 1973. The following is an account, presented chronologically, of investigation of failures and recommendations for preventive measures.

8.2.1 Elliot 1973

Elliot (1973) described seven collapses occurred within two years in California and he recommended that, among the others, the contractor is required to have a licensed engineer's check on the design of the falsework.

8.2.2 Bragg 1975

As technical reasons and procedural inadequacies were identified as the main causes, the Bragg's Final Report recommended that the Temporary Works Coordinator should be appointed to ensure at each stage of the design and construction of falsework, a check or an inspection would be performed. Such appointment was renamed as Falsework Coordinator in BS 5975 which was first published in 1982.

8.2.3 Smith 1976

Smith (1976) studied 143 bridge failures happened since 1877. Twenty-three of them happened during bridge construction and about 40 per cent of these were due to the failure of temporary supports.

8.2.4 Fraczek, Hausers 1979

Fraczek (1979) reported the American Concrete Institute's survey of 277 cases of concrete structure errors. The errors occurred during the design and construction phase were fifty-seven per cent and fifty per cent respectively of the total cases. In the same year, Hauser published his investigation of 800 European failures and concluded that only very few errors were unavoidable and a primary deficiency in structural safety was data checking.

8.2.5 Hadipriono et al. 1985

During the nineteen eighties, Hadipriono and his researchers did a lot of work in studying falsework failures. Hadipriono and Wang analysed 126 falsework failures in concrete structures happened during the previous twenty-three years. Forty-two per cent of them were related to bridge construction. Falsework collapses during construction stage were summarised and about half of these 85 cases occurred during concrete pouring.

According to Hadipriono, three types of causes, i.e. the enabling, triggering and procedural causes, were classified. The enabling causes are events that contribute to the deficiencies in the design and construction of falsework. The triggering causes are usually external events that can initiate a falsework collapse. Procedural causes are hidden events that lead to the enabling and, quite often, the triggering event as well.

It was also revealed that most of the enabling and triggering causes were stemmed from inadequate procedural methods. Evaluation of these factors is generally only available in more detailed investigation reports. The most noticeable cause is lack of review of falsework design or construction, and a significant number of monitoring problems were found in connection with concreting procedures. It was also found that unqualified person was commonly employed to monitor the erection procedures. A lack of supervision in monitoring changes during construction was also identified as a significant factor for most collapses.

Hadipriono concluded that the most often repeated enabling and triggering causes were generated from inadequacies in the procedures. In his paper "Analysis of events in recent structural failures", Hadipriono (1985) further identified external events and deficiencies in both the design and construction were the principal sources of 150 major structural failures. From the events surveyed, he revealed that the enabling events, in particular, were caused by inadequacy in the institutional and procedural methods in the project phases. The inadequacies were reflected in the interrelationships between the parties involved in the operations such as confusion that occurred at interfaces between contractors, subcontractors, construction managers, design engineers, architects and the client's representatives. Consequently, they resulted in inadequate design review and improper construction monitoring.

Many failures were stemmed from inadequate design review procedures. In some instances, design calculations subcontracted to a professional were not thoroughly checked. Others like detailing of important components or the design of a complex falsework were performed without fully verified (Bragg 1975).

Another trend being spotted in the study of failure was a lack of monitoring during construction phases. This trend seems to be more significant in developing countries. Frequently, inspection was performed in superficial ways and proper erection procedures were not adhered to. Also, lack of expertise and facilities in performing unconventional construction processes were very common.

In summary, Hadipriono suggested three problems.

- There is a need to analyse potential problems occurred in the past. When a potential problem for a typical structure is suspected, performance data of similar structures can be retrieved from these sources. Thus, preventive measures and effective quality control process may be implemented. Besides, appropriate safety measures would be undertaken.

- In order to avoid confusions among parties involved, improvement in procedural considerations during design and construction processes such as proper delineation of each party's responsibility should be extended throughout the construction stage. The structural design and details should be reviewed by an independent party to reduce the possibility of a structural failure and to show evidence that the design is in compliance with the criteria.

- There is also a need for adequate risk analysis for structures in services and during construction. Risk analysis of potential problems during construction can be employed to select methods and procedures that have lower probabilities of failure, to institute control in preventing initiation of failure, and to monitor the critical aspects during construction.

8.2.6 Ellingwood 1987

Ellingwood (1987) concluded that the majority of structural failures in ordinary construction occurred as a consequence of errors in planning, design, construction and utilisation. Only about ten per cent of failures were traceable to stochastic variability in loads and capacities. The remaining ninety per cent were due to other causes, including design and construction errors, modeling and analysis uncertainties.

8.2.7 Holloway 1990

Holloway (1990) recognised the potentially serious effects of rule violations on plant safety, a methodology was therefore developed for the qualitative investigation of such violations. The method covers identification of violations and their effects on safety, and qualitative assessment of the incentive and disincentives for such violations, including the degree to which violations would be recorded.

The method was intended to provide an approximate ranking of the importance of violations, but does not offer a numerical quantification of probabilities. Its use was limited to qualitative investigations intended to identify violation worthy of further analysis or to anticipate preventive measures. Violation of rules has been important contributors in major accidents. Had the rules not been violated, most if not all of the accidents would have been prevented.

Holloway's "SURVIVE" methodology involves a survey of rules which constrain the human elements in plant safety, and an assessment of violations of those rules which could seriously degrade safety. The following are the stages in the overall process.

(1) Identify those rules which, if violated, will allow a fairly immediate and significant degradation of safety to arise. The possible violations are given against each identified rule.

(2) For each violation, the magnitude of the effect on safety is assessed. The effect may be assessed in terms of increased probabilities of accidents, and consequences of accidents or the combination.

$$\text{Effect} = \text{Probabilities} \times \text{Consequence}$$

(3) For each violation, the incentives and disincentives for the violation are assessed.

(4) The particular disincentives associated with recording of violations are assessed.

(5) The overall ratings of the Effects, Incentives and Disincentives are combined in a final assessment.

Comment: The violation of rules on safety of a plant is thus very similar to inadequate procedures for construction of falsework.

8.2.8 Lucas 1990

Lucas (1990) suggested one outcome of investigating the failures is that we must learn from experience to prevent future crises from occurring. The fundamental concept is to find out the cause, to derive effective remedies and to prevent future accidents.

He describes a stage model of accident investigation in which any casual analysis is used merely to apportion blame, and the learning process from the accident analysis is non-existent. An alternative process model of accident investigation is placing an emphasis on monitoring of remedial actions and hence on learning from the unfortunate experience of the incident. The conclusion is that it is better to be process rather than stage oriented.

Comment: The process model of accident reporting would be a good reference for the model to be developed later and is quite relevant to the Event Sequence Diagram approach.

8.2.9 Pidgeon et al. 1990

Pidgeon et al. (1990) described the work in developing an intelligent knowledge based system for safety management in the construction industry. Case history material of past incidents is acquired by a process of knowledge elicitation, and the information derived is represented in a knowledge base using Event Sequence Diagram.

In the knowledge representation, the case histories can be conceived of as stories which need to be converted into a structured representation. The form chosen is the Event Sequence Diagram (ESD) which is similar to event tree technique. The diagram provides a powerful means of representing and accessing information about the sequences of events preceding a failure or near-miss incident. The ESD shows the temporal order and relationship of events leading to a particular outcome.

Comment: In view of the identifiable procedures in falsework activities, the Event Sequence Diagram is probably the most suitable method to analyse falsework failures.

8.2.10 Whittingham 1990

Whittingham (1990) described a method of retrospective analysis of safety significant events to identify the root causes. An accident may in retrospect be considered as a sequence of interconnected events. It usually comprises equipment and human failures linked together by cause and effect relationships. Accident causes are classified as:

- direct (immediate) causes; and
- root (underlying) causes.

Direct causes are usually trigger events or latent failures. Trigger events are occurrences which set off the accident sequence e.g. concreting in falsework failures. Latent failures are unrevealed failures of components of a system which remain undetected and uncorrected until a demand occurs on the failed component e.g. lower strength, inadequate design.

The root cause of an accident can be defined as the most basic reason for the accident which, if corrected, will prevent a future recurrence of the accident.

Three methods of retrospective analysis are as follows.

(1) Hypothesis approach

A number of alternative hypotheses are advanced to explain how the accident may have been caused. The objective is to ensure that the widest possible range of solutions to the problem are explored.

(2) "What if" approach

The probable cause of the accident is known with some certainty and the investigation will generate slightly divergent scenarios from the one originally selected and test the effect of fairly subtle changes in the circumstances of the accident. The objective of this approach is to allow an assessment to be made of the influence of the various components on the course of the accident. It can quickly determine whether the component concerned is a possible cause or not.

(3) Change Analysis approach

The principle of this approach is that a decline in a formerly acceptable standard of performance suggests that something has changed. The method sets out an effective means of sorting through numerous and diverse changes which might have occurred, some of which may have given rise to the problem which is required to solve. This approach provides a systematic basis for identifying and analysing the causes.

Using the Change Analysis approach, the following areas require changes to be identified.

- Design / Intent – The mode of operation of the system as designed or intended.
- Normal practice – The normal operation mode of the system.
- Actual practice – The mode of operation of the system just prior to the accident.

The propositions in investigating the effects of change are as follows.

- Design intent versus normal practice = Root causes.
- Normal practice versus actual practice = Direct causes.

Comments: The root causes and direct causes are similar to the procedural and enabling plus triggering causes as classified by Hadipriono. However, the two propositions do not seem to be fit for assessment of falsework failures and are more suitable for plant failure only. The retrospective analysis for procedural causes certainly is a very useful tool to help reduce future risk levels of similar projects.

8.2.11 Turner 1992

Turner (1992), based on an initial study of disasters in Britain over an eleven-year period, identified a pattern which suggests that large scale accidents are caused by many sources rather than a single source and that their preconditions build up over a period of time, rather than springing into existence instantaneously. The model points to the way in which crises and disasters developed is a covert and unnoticed fashion during an incubation period.

From an initial situation when the circumstances of the project in question are notionally normal, the incubation period starts to develop at the point at which circumstances start to deviate, covertly, from that which is believed to be the case. This state of affairs continues to develop until it is terminated by a trigger event which combines the predisposing factors into a single occurrence. Usually an unanticipated discharge of energy of some kind provokes the onset of a system failure. Events within the incubation can be reconstructed in retrospect as event sequence diagrams, a treelike structure of contributory incidents with the trigger event and the onset of the failure at its focus. Event sequence diagrams can be used to summarise the events associated with a failure and to relate inquiring findings and lessons learned. The sequence of system failure is:

- situation notionally normal;
- incubation period;
- trigger event;
- onset;

- rescue and salvage; and
- full cultural readjustment.

Comment: This system of investigating and analysing failures can be used for analysing falsework failure.

8.2.12 Stewart and Fortune 1995

Stewart and Fortune (1995) suggested all project lifecycles consist of a sequence of stages and activities and there is always a degree of risk associated with each stage. Blockley, Humphreys and Thomas (1991) commented that project managers should be sensitive to potential sources of risk. They should be able to anticipate their occurrence and appreciate their potential impacts on the project objectives and to reduce their future impact through appropriate risk action management strategies. Therefore, risk identification and development of implementation of risk management strategies must be carried out throughout the life of a project.

Systems methods and techniques (such as the use of rich pictures, systems maps, influence diagrams, systems models in building up holistic pictures that emphasise interconnectedness) enable problem themes to be identified. Two areas require further investigation are listed below.

- Interactions in particular those within the project team and between the team and its clients.
- Human aspects such as conflicts of objectives, motivation problems and poor communication which may hinder the success of the project.

The holistic techniques include the following.

(1) Soft systems analysis is an approach which does not only deal with hard tangible information but also with soft complexity that arises because people are involved. It takes account of the feelings, attitudes, perceptions as well as potential conflict between people.

(2) Systems map is a diagram showing a snapshot of the structure of the area under consideration being conceptualized as a system. The structure is particularly emphasised.

(3) Influence diagrams explore the important relationships between components within a system and between the system and its environment. They are concerned with relationships.

(4) Formal system model (FSM) is a model of a robust system that is capable of purposeful activity without failure, and coordinates a number of key systems concepts within an organized framework. The formal system itself comprises a decision making subsystems and elements which carry out the tasks of the system and thus effect its transformations by converting inputs into outputs.

(5) History files are a rich source of information about which strategies were effective, what problems occurred and whether contingency plans were successful.

(6) The systems failures method is a systemic method for the analysis of failures which can be used to look back at events, activities and situations with a view to identifying any significant failures that occurred and coming to an achieving understanding of those failures. It has two key features:
   - conceptualisation and modeling of the situation as a system; and
   - comparison of that system, first with FSM, and subsequently with other models based on typical failures.

Information about failures in past projects can be used to identify potential risk areas for future projects.

Stewart and Fortune further argued that by using systems approaches, it is possible to identify potential risks which would not otherwise be predicted. In addition, application of systems thinking at the end of a project can enable lessons from outcomes to be used to improve performance on future projects.

8.2.13 Dias and Blockley 1995

Dias and Blockley (1995) agreed that engineering students and practising engineers could upgrade their knowledge vastly by learning from case histories of design and construction, and of failure. Reflection on failures will result in improved design and construction. Event sequence diagrams can represent the essential preconditions to failure.

8.3 Failure Prediction

Similarly, an account of researchers' work on failure prediction is presented chronologically in the following sections.

8.3.1 Pugsley 1973

In 1973, Pugsley outlined an approach to the problem of assessing the proneness to structural accidents. It seeks to distill from experience of past structural failures a number of significant parameters, by the assessment of which for a new structure its proneness to accidents could be broadly judged. The parameters of significance in accident history are:

- new or unusual materials;
- new or unusual methods of construction;
- new or unusual types of structure;
- experience and organisation of design and construction team;
- research and development background;
- industrial climate;
- financial climate; and
- political climate.

Pugsley's paper argues that a small group of engineers of rich experience would have a good chance of assessing in broad terms its accident proneness, as weakness in any one of the parameters would suggest such proneness and merit more attention to reduce any proneness to accidents.

8.3.2 Blockley 1975

Blockley (1975) outlined a possible approach to the problem of predicting the likelihood of a structure failure due to causes other than stochastic variations in loads and strength. Fuzzy set analysis was used in the formulation of the method. A failure occurs because there is a major error and/or several smaller errors combine to eliminate the factor of safety. These factors or safety parameters are difficult to quantify. However, they may be measured using fuzzy linguistic variables. Six main parameters used include materials, type of structure, design experience, time, construction and externals. Each parameter is assigned the gravity and consequence rating. The overall effect is then related to a safety index.

8.3.3 Blockley 1977

Blockley (1977) presented a classification of basic types of structural failure. The classification is expanded into a set of parameter statements which could be assessed subjectively in a prediction process. This process is intended to account for a structure failure due to causes other than stochastic variations in load and strength. The parameters are assessed for twenty-three major structural accidents and one existing structure, and are analysed using a simple numerical interpretation. The accidents are ranked in their order of inevitability.

From the assessments, human errors were proved to be the dominant reasons for the failures. A simplified form of the proposed procedure for predicting the likelihood of structural accidents was also outlined in which concept of fuzzy set was used and applied to the twenty-four accident parameter assessments. Problems such as poor site control, errors of judgment, time and financial pressure which are difficult or impossible to be included into mathematical models were highlighted. From the assessments, it was shown that the human errors were predominant in causing the failures. Human errors during the construction phase can be prevented by good communications between all parties concerned and by well-defined responsibilities under the contract (and well-defined procedures). Fuzzy set analysis is used to assess the parameters, thus giving a better illustration of the inevitability to failure for the cases.

Comments: The parameters are assessed in giving an overall score only. No account has been taken of the importance of various stages, and no warnings are to be given at appropriate stages so as precautions can then be taken to avoid the failures.

8.3.4 Melchers 1978

Melchers (1978) gave comments on the contents of various failure reports ranging from the formal government inquiry reports to professional magazines and noted that non-technical problems such as human errors were not always included in failure reports. The objective of his paper was to identify problems, which may interfere with successful project completion and operation, at an early stage in order to reduce them to a minimum. To illustrate that organisational matters can be influential in bringing about project failure, the following are problems identified from four well-known bridge failures.

- Failure to appoint an experienced bridge engineer, reflecting that there is a loose and inefficient supervision.
- Negligence in checking the falsework design and failure to submit to the Engineer the falsework drawings.
- Failure of the consulting engineers in requiring the contractor to submit details of falsework for approval.
- Routine design work is commonly done by inexperienced engineers although it is a usual practice for the more experienced personnel to supervise the work.

Melchers suggested a complementary approach on the in-depth study of the failed projects, i.e. a pathological approach so that projects would be studied from an organisation as well as a technical viewpoint.

Comments: Normally the company concerned would not welcome study of their projects by an outside body unless it is required by law. Even this is the case, important but controversial information may not be easily released. Further, some information are not allowed to be made known because of the legal proceedings applied to recent failures.

8.3.5 Yao 1981

Yao (1981) summarised and examined the state of the art of damage identification of existing structures. The application of fuzzy set in assessing the damaged state of existing structures was explored. There was a gap between the calculated probability of failure (10^{-6}) and Brown's perceived failure rate (10^{-3}) for a certain type of structure. In his example, two subjective factors, namely, the design and construction factors were assessed for their gravity and consequence. The failure probability index was found to be of the order of 10^{-4}, if the objective failure probability was 10^{-6}, which was closer to Brown's perception. Collaboration of expert is required to establish the various membership functions.

8.3.6 Melchers et al. 1983

Melchers et al. (1983) summarised the experience gained from the study of structural failures and satisfactory construction, and commented on the accuracy and completeness of reporting. Comparison of the findings on a number of investigations was made according to the type of failure mode, structural elements affected, time of failure, prime cause of failure, reasons for their occurrence and their consequential cost. Most failures could be attributed to human errors. The nature of these errors was discussed and the requirement for the evaluation of experience in the future was considered. One important and additional requirement for future experience evaluation was, amongst the others, determination of appropriate procedures for analysing structural failures. Of the greatest importance was the need for a means of assessing the effectiveness in controlling the changes in both the design and construction process on the occurrence of gross human errors.

8.3.7 Hadipriono 1985

Hadipriono (1985) pointed out human based uncertainties are abundant in falsework construction but are seldom included in the assessment of falsework performance. A method based on fuzzy set concept has been developed to assess falsework adequacy. The concept interprets in mathematical terms the linguistic variables of subjective appraisals of falsework which include the enabling and triggering events, and their consequences. Graphical displays are constructed from the final assessment and presented as a guide to determine the overall falsework performance. The method developed can be used as a tool for quality control processes. Reduction of enabling and triggering events can be conducted to achieve a desired level of overall falsework performance.

Comments: Procedural errors are not included in the assessment.

8.3.8 Ellingwood 1987

Ellingwood outlined a simple model of the effect of error on structural reliability developed from the event tree. This model contained the important notions of error consequence, detectability (and correction) and resulting consequence. The equations showed that structural safety could be managed by controlling the incidence of errors, the impact and consequences of the errors on structural performance. To include a human error multiplier on the classical limit state probability which varied from 4.4 to 10 and this increase was consistent with available data comparing failure rates of buildings and bridges with those predicted by classical reliability analysis. One important strategy for mitigation and control was to consider technical measures which included independent reviews of fundamental design concept and assumption. Identification and formulation of hazard scenarios could be helpful in planning quality assurance programs. Fault and event trees could serve as useful analytical tools. Independent control stops should be instituted at key decision points in the project, especially where responsibility for project phases changes hands.

8.3.9 Blockley 1992

Blockley (1992) commented on Turner's model which describes that most system failures are not caused by a single factor and that conditions for failure do not develop instantaneously. Multiple casual factors accumulate, unnoticed or not fully understood over a considerable period of time which is called the incubation period.

The following are types of conditions that can be found within the incubation period.

- Events unnoticed or misunderstood because of wrong assumptions about their significance.
- Dangerous preconditions unnoticed because of poor communications.
- Uncertainty about how to deal with formal violations of outdated safety regulations.
- When things started to go wrong, the outcomes are worse because people tend to minimise danger or believe that the failure would not happen.

The incubation period is brought to a conclusion either by taking preventive measures to remove the dangerous conditions or by a trigger event to release the harmful energy. The previously hidden factors are then reviewed for assessment of the reasons for failure. There would be adjustment of precaution to avoid recurrence of similar incidents in the future.

Blockley made an analogy of development of a failure to the inflation of a balloon. The start of the process is when air is first blown into the balloon while the first precondition for the accident is established. The pressure of air inside the balloon is similar to the proneness to failure of the project. Events accumulate to increase the predisposition to failure. The size of the balloon can be reduced by lowering the pressure and letting the air out, and this parallels the effects of management decisions that remove some predisposing events and thus reduce the proneness to failure. If the pressure of such events build up until the balloon is very stretched then only a small trigger event is needed to release the energy confined in the system. The trigger may not be the most important factor. The over stretched balloon represents an accident is about to occur. When it comes to accident prevention, it is important to recognise the preconditions, i.e. the development of the pressures in the balloon. The symptoms that characterize the incubation of an accident need to be identified and checked.

8.3.10 Construction (Design and Management) Regulations 1994

(1) Introduction

The Construction (Design and Management) Regulations in the UK place new duties upon clients, client's agents, designers and Contractors to re-think their approach to health and safety so that health and safety is taken into account, and then coordinates and manages effectively throughout all stages of a construction project. They are needed because of the unacceptably high rate of death and injury associated with all types of project. The Regulations have an impact on all stages of the planning and management of health and safety of a project, and place duties on clients, designers and construction organisations.

(2) How can designers contribute to health and safety?

- Accidents are resulted from a combination of circumstances, some of which are related to design. An analysis on falsework failures indicated over fifty per cent were design faults (Poon 1996).
- Few designers have carried out systematic and routine reviews of the safety aspects of their designs. Opportunities to reduce risks at the design stage have not been generally acknowledged. Normal practice is to leave the issues to contractors, but the chances to reduce risks at the design stage cannot be

guaranteed. The first step designers can take is to recognise the risks involved in construction work.

- Design defines the work to be done. Designers may be the only people who are able to make the decision that will eliminate a foreseeable risk. Designers should be aware of the hierarchy of risk control which underlies the modern approach to health and safety management. It is best to prevent the hazard and alter the design to avoid the risk. If the design cannot be changed at once, the risk should be combated at source. Priority should be given to controls that will protect all workers.
- The designers should look for ways of reducing and controlling the risks. To make judgments in a systematic way, designers need to carry out risk assessment.

(3) Designer's duties

The designer includes engineers or architects for the permanent works design and temporary works engineer designing the formwork and falsework.

The following are items that should be given adequate resources:

- familiarity with construction process;
- knowledge of the impact of design on health and safety;
- awareness of health and safety legislation and appropriate risk assessment methods;
- suitable practices and procedures which take account of health and safety in design and communicate information to the planning supervisor;
- train staff and provide access to advice;
- adequate time and other resources allowed for the work;
- support facilities such as access to current health and safety information; and
- clear method of dealing with design changes and suitable methods of communicating revised information.

(4) Hazards and risks in construction work

Hazard is the potential to cause harm, and risk is the likelihood that harm will occur. A precise estimate of risk is not required because of the limitation of time and lack of data. The simplest method for assessing risk arising from a hazard depends on two elements:

- the likely severity of harm caused (consequence); and
- the likelihood that harm will occur (frequency).

The likely severity of harm caused by the hazard can be assessed by Low, Medium or High.

- High – Fatal, long term disability.
- Medium – Injury, short term disability.
- Low – Others.

The crude qualitative judgment on the likelihood that harm will occur is as follows.

- High – Certain or near certain to occur.
- Medium – Reasonably likely to occur.
- Low – Very seldom or never occurs.

In assessing both severity and likelihood, the product of the two elements will give some measures of the assessed risk which, in turn, can be seen as exerting a pressure on designers to alter the design. Clearly, a "high" x "high" risk exerts a very high degree of pressure, "low" x "low" virtually none.

Designers may conclude that design alteration is not practicable, but they should be prepared to justify their choice in the light of the particular risk assessment. This regulation does emphasise the important roles of the designer, not just for the permanent works but also for the temporary works.

(5) Role of CDM in Hong Kong

At present, the provisions of CDM are not effective in Hong Kong although the regulation is known to many professionals for some years.

In 2001 the report of the Construction Industry Review Committee chaired by Henry Tang has emphasised the importance and use of the CDM. The Hong Kong government is setting up committees to explore the probabilities of implementing the CDM in Hong Kong and a number of government projects have been selected for the trial run of the application of the CDM regulations.

8.3.11 Site Supervision Plan System 1997

In Hong Kong, the Buildings Department has implemented the Site Supervision Plan System (SSPS) since end of year 1997. The aim is to improve safety of building works and to minimise safety hazards on building sites.

The objectives of the SSPS are:

- to improve safety on, or adjacent to, private building construction sites in Hong Kong;
- to ensure building works carried out are complied with Buildings Ordinance and allied regulations; and
- to control hazards from building works so as to mitigate the risk to the workers on site, all persons around the sites, and adjoining buildings, structures and land.

The supervision plan is defined as a plan setting out the safety management of building works or street works, which will be lodged by an Authorised Person with the Building Authority. The salient features of a supervision plan (Lau 1998) include the following.

- Classes of supervision as appropriate to the specific type of building works or street works to be carried out, at various stages and sequences.

- The manpower and level of supervision required for the classes of supervision to be provided.
- The management structure, the quantity and quality of personnel involved and specific task assignments associated in each element of the management structure.
- Method statements of various operations at various stages of the building works or street works, and types of precautionary and protective measures to be undertaken for the safety of the site, the workers and the public.

The Authorised Person, i.e. the Architect, Registered Structural Engineer and Registered Contractor who work together in a typical building contract have overall responsibility and accountability for their respective functional streams. They are required to prepare a site supervision plan together right before the commencement of works. The lodging of the plan by the Authorised Person becomes one of the pre-requisites for the issue of the consent for commencement for works, by the Building Authority.

The supervision plan system is somehow different from other safety stipulation produced by the Labour Department, such as the Factory and Industrial Undertakings Ordinance and its subsidiary regulations. The latter concerns mainly the occupational safety and health of workers, i.e. they aim to enhance the safety awareness of the workers through the power of legislation. On the contrary, the Site Supervision Plan System does not touch the worker side. Instead, it intends to get the parties to the project involved in the safety issues from very beginning of the project. However, the supervision plans submitted do not require the formal approval from the Building Authority. These plans would be selected randomly for audit checks to ensure that they are properly prepared and that the management structures as documented are provided on sites.

Under the Ordinance, a Technical Memorandum for Supervision Plans was introduced. Enacted on 12 December 1997, it can be regarded as a guideline that provides an administration framework for putting the site safety management system in place and stating the principles, requirements and operation of site supervision plans. The principles are as follows.

- The framework and purpose of the site safety management system.
- The roles and responsibilities of the parties concerned.
- The two types of safety supervision: engineering safety supervision and routine safety supervision.
- The deployment of technically competent persons.
- The preparation of supervision plans.

The Code of Practice for Site Safety Supervision was also issued to incorporate the detailed requirements and guidance on the preparation of supervision plans. It describes the principles and important safety related activities that require special attention and monitoring. It explains:

- how to deal with special features;
- how to establish the degree of complexity of various types of works;
- how to approach method statements, precautionary and protective measures;
- how to establish the class of supervision;
- how Technically Competent Persons (TCPs) may best be deployed and how their duties may be combined;
- the management structure within each functional stream and the responsibilities for communication; and
- the specific tasks of TCPs in carrying out safety supervision.

The Supervision Plan is a plan for safety management of building works or street works. According to the Technical Memorandum, safety management comprises the traditional quality supervision and the new site safety supervision. Quality supervision means that the practitioners have to ensure that the building works or street works are carried out in accordance with the provisions of the Building Ordinances and Regulations. Site safety supervision, on the contrary, is not a common practice in the Hong Kong construction industry. It requires the three parties' supervision in a building project.

Site safety supervision can be further classified into two types of supervision, the engineering safety supervision and routine safety supervision.

(1) Engineering safety supervision requires judgement and includes:

- considering the suitability of the principles of working methods being used on site;
- examining the compliance of specified aspects of work with the design requirements where these are related to site safety;
- checking that site works are in conformity with the supervision plan, including the method statements and the precautionary and protective measures;
- verifying the validity of the provisions of method statements and precautionary and protective methods on site;
- notifying the designer of method statements and precautionary and protective measures when site conditions are inconsistent with assumptions made in the designer's design; and
- ensuring the proper execution of the safety supervision.

(2) Routine safety supervision involves:

- the monitoring of site operations and working methods so as to meet the safety standards in the Buildings Ordinance and relevant Codes of Practice;
- the inspection of the safety aspects of the works is properly carried out; and
- the checking of the compliance of the works with the approved method statements and the precautionary and protective means.

There are five different grades of TCPs, termed T1 to T5 accordingly, for each functional stream. Their respective responsibilities are defined in the Technical Memorandum and are further amplified in the Code of Practice. They should exercise all reasonable skill, care and diligence in carrying out the duties and specific tasks, and undertake the responsibilities which are set down in the two documents. Different grades reflect the differences in qualification and experience between TCPs. T1 to T3 are the technical grade in which the T1 and T2 are the operative-supervisory layer while the T3 is the managerial layer. They are required to carry out the routine safety supervision. T1 would supervise routine and general building works such as superstructure works whereas T2 would supervise the demolition and piling works. The T4 and T5 are the professional grade in which they belong to the decision-making levels and responsible for the engineering safety supervision. TCPs of lower grades are not able to carry out such supervision responsibility. The general responsibilities of the five grades of TCPs are listed in Table 8.1.

Table 8.1: General Responsibilities of the Technically Competent Persons

TCP Grade	General Responsibilities
T1	Check on a routine basis that the work on site complies with general site safety requirements and that the minor site safety aspects of building works are properly carried out.
T2	Check that identified specialist aspects of site work comply with safety requirements.
T3	Monitor the activities of subordinate TCPs to ensure that routine checks are being carried out at the frequency set out in the Code of Practice and that reports are properly prepared and filed.
T4	Check that specified aspects of site work comply with the design requirements where these are related to site safety and with the supervision plan including method statements, precautionary and protective measures. Check that systems are in place and followed to record that site safety supervision has been properly executed.
T5	Check that site operations and installations meet safety requirements. Where the design of temporary and / or permanent works relies for safety on assumed conditions being present on site, validate those assumptions by checking the actual site conditions and taking necessary follow up action. Direct subordinate TCPs in priorities and identify aspects of works, which require special care and supervision.

Source: The Buildings Department, Hong Kong (1997)

The Code of Practice on Site Supervision Plan specifies the division of responsibility between Registered Structural Engineer (RSE) and Contractor for temporary work as below.

- When the prescribed plans stipulate temporary works and the sequence of construction or method statements are also shown on prescribed plans, the RSE has the responsibility of supervising the carrying out of the works in accordance with the approved plans.
- When the temporary works, the sequence of construction or method statements are not required to be shown on prescribed plans and in cases when these have no effect on the permanent structure, the contractor has the sole responsibility of ensuring the integrity of temporary works and that the carrying out of temporary works should be safe and should not endanger the workers on site, the public and adjoining buildings.
- In cases when the temporary works or the sequence of construction or method statements are not required to be shown on the prescribed plans but have a potential effect on the integrity or serviceability of the permanent structure whether during construction or completed, the demarcation of responsibilities between the RSE and the Contractor on supervision of carrying out of the temporary works and the sequences of construction are as shown in the flow chart attached in Appendix A.

Comment: To a certain extent, this system is quite similar to the Checking Engineer system. However, it also possesses the weakness that there is no continuous supervision by the third party during the temporary works construction.

8.4 Summary

A number of researchers have undertaken studies on failure analysis and proposed prediction methods. The shortcomings of falsework failure analysis and prediction models are:

- procedural inadequacy has not been considered and assessed, particularly at the interface of operations and activities in view of different parties involved with different roles and responsibilities; and
- most of the models can only be used to assess the likelihood of an eventual failure without evaluating aggregates of the (safety) condition at various stages of the falsework construction.

After taking into account the recommendations made by researchers on failure analysis and from private investigations, the characteristics of a procedural framework for falsework failure analysis and failure prediction should include the following.

- The key and critical activities of falsework are grouped under the five essential stages i.e. the design, erection, loading, taking down and anew stages, and presented by event sequence diagram.
- Different sub-models are derived and used in accordance with the type of control or contract used, e.g. the conventional, independent checking engineer and falsework coordinator system.
- Controls regarding the following common critical activities are included in the model.
    (1) Construction method of the permanent works and its relevance or relationship with the risk of falsework collapse.
    (2) Changes in falsework design concept and construction method.
- The activity or procedure performance can include the effect of personnel's characteristics such as experience and qualification.
- Communications between parties are shown in the flow diagram e.g. duly inspection, receiving an approval certificate etc.

Based on the above, falsework failures will be studied for the development of a procedural framework in analysing and predicting falsework failures in the following chapter.

CHAPTER NINE

FALSEWORK FAILURE ANALYSIS

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FALSEWORK FAILURE ANALYSIS

9.1 Introduction

In the previous chapter, the shortcomings of many falsework failure analysis and prediction models have been discussed. It was found that there was an absence of assessment on procedural inadequacies. In this chapter, procedure will be defined and procedural inadequacy will be retrieved from a study of fifty falsework failures using event sequence diagram and content analysis.

Flow charts showing the essential procedures will be developed for the three control systems. The analysis of the failures will provide data for the procedural framework in monitoring the safety of falsework at various stages.

9.2 Falsework failure analysis

Many researchers have developed models to analyse and predict falsework failures. However, no model has included the assessment of procedural inadequacy although errors in procedure accumulate and lead to the failure of the falsework (Bragg 1975, Hadipriono 1985, Blockley 1975 & 1992). In the following sections, the essential procedures will be defined for the design and construction of falsework, and procedural inadequacy will be extracted from literature review and failure cases. Flow charts based on event sequence diagram will be developed for analysis of falsework failures.

9.2.1 Procedures

Definition:

Procedures will detail the purpose and scope of an activity, and will also identify how, when, where and by whom the activity is to be carried out (Stebbing 1989). In this research, a procedure is taken as an activity or a series of activities at the end of which an intended task is to be completed.

A procedure will consist of enabling events and triggering events leading to failures (Hadipriono 1985). Deviation during the course of a procedure due to inadequacy or inadequate fulfillment of specific task requirements will result in the lowering of factor of safety of the falsework. The following are examples.

- Checking and reviewing of falsework design.
- Application and receiving of approvals for certain key operations.
- Supervision during erection and removal of falsework.
- Supervision during loading the falsework.

If procedures are properly carried out, it will minimise the errors to be made so that the intended factor of safety in the design will not be reduced undesirably and unexpectedly by procedural inadequacy.

9.2.2 Essential procedures in the five stages

Table 9.1 shows the essential procedures in the five critical stages based on the practice of falsework scaffolding in Hong Kong (Chapter 3), review of the falsework failure reports (Chapter 4) and falsework guidelines (Chapter 5). The inadequate procedures which have been identified from failure reports are also included.

The five stages are listed below.

- D – Design.
- E – Erection.
- L – Load.
- T – Taking down.
- A – Anew.

Table 9.1: Essential operations and procedural inadequacies

Essential Operations	Procedural Inadequacies (Poon 1996, Hadipriono 1986)
D - Design Stage	
Analysis, design and detailing of falsework to suit the permanent works and the construction method. Need: • proper analysis; • adequate design incorporating a sufficient Factor of Safety; • experienced designers or design being carried out under competent supervision; and • proper checking of the design.	• Inadequate falsework design (including foundation) – underestimate the loads. • Inexperienced designer without competent supervision. • Inadequate checking by a competent engineer. • Ignore lateral forces due to out of plumb.
E - Erection Stage	
Use of suitable and adequate materials for falsework erection. Need: • proper construction method; appropriate materials and components; and • proper erection procedure.	• Use of unsuitable or inferior materials. • Inadequate falsework construction including foundation, bracing and falsework components. • Lack of supervision during erection. • Not in accordance with the drawings.
L - Loading Stage	
Apply load to the falsework due to: • formwork and steel bars; • concrete placing; and • post-tensioning. Need: • proper loading method (construction	Improper loading procedures due to: • improper concrete placing method; and • uneven or unexpected load distribution arising from post-tensioning.

method); and • even load distribution as assumed in the design.	
T - Taking Down Stage	
Dismantle the falsework when the permanent work is self-supporting. Need to: • check the permanent work has matured; and • follow proper dismantling procedures with proper supervision.	Improper dismantling procedures due to: • premature removal of falsework without approval; • improper dismantling procedures; and • lack of competent supervision.
A - Anew Stage	
Repair and maintain the materials/ components for re-use. Need to: • check or inspect; and • repair or replace.	Improper or inadequate maintenance of falsework materials and components will result in a lower Factor of Safety than assumed in the design.

9.2.3 Graphical illustration of procedural inadequacy in the five stages of failures

In the last section, it has been shown that errors occur at different stages of the falsework activities. The effect of the errors would accumulate and carry over to another stage. Failure can occur at certain stages depending on the magnitude of the error accumulation. The following figures illustrate the procedural inadequacy in different stages. The failure line represents the maximum stress that the falsework can resist, i.e. two (factor of safety) times the allowable stress.

(1) The design error can singly lead to failure during error or loading stage.

The errors in designs can accumulate and can lead to failure under normal load or no failure, depending on the magnitude of the design error. Figure 9.1 shows the accumulated errors exceed the ultimate capacity of the falsework and resulting in a failure. It is assumed that the erection error is small and normal load is acting.

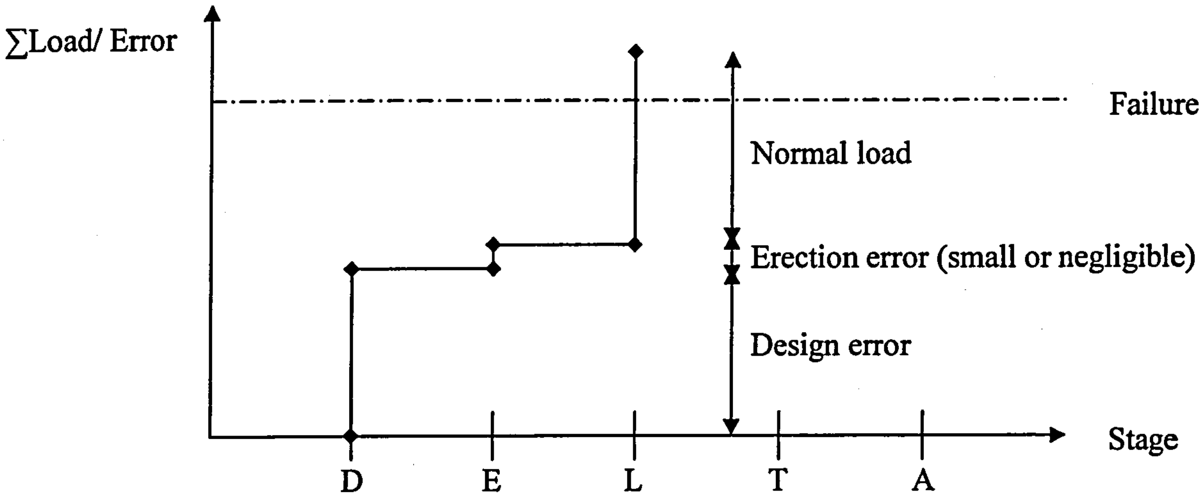


Figure 9.1 Design error

(2) The erection error can also singly lead to failure during erection or loading stage.

In figure 9.2, it is assumed that the design error is small or negligible and the erection errors can lead to failure or no failure, when normal load is acting.

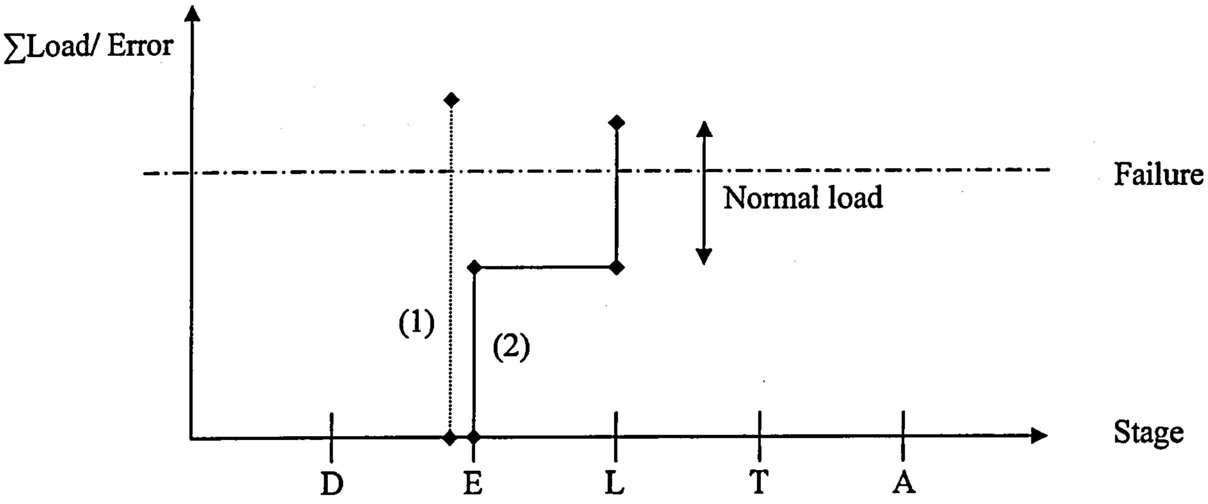


Figure 9.2 Erection error

(3) The loading error alone can also contribute to a failure.

Figure 9.3 shows the accumulation of the small errors in the design and the erection stage. The normal load and the loading error can trigger the failure, or there will be no failure, depending on their magnitude.

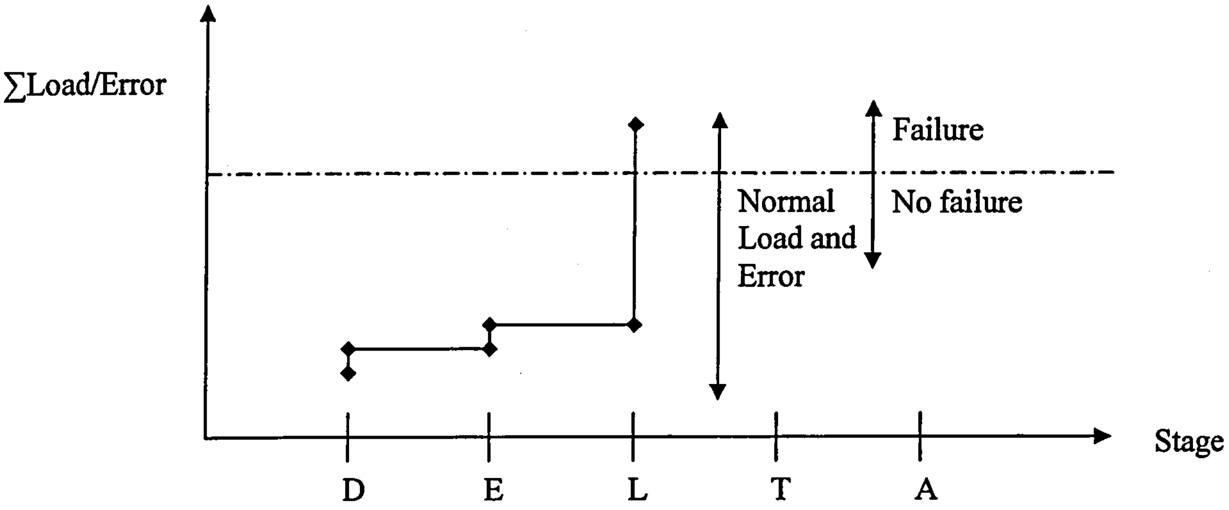


Figure 9.3 Loading error

(4) Accumulation of the design, erection and loading error leading to failure.

As shown in Figure 9.4, the combination of the design, erection and loading error can lead to collapse at the loading stage – result of accumulation of errors which individually can or cannot lead to failure, depending on their magnitude.

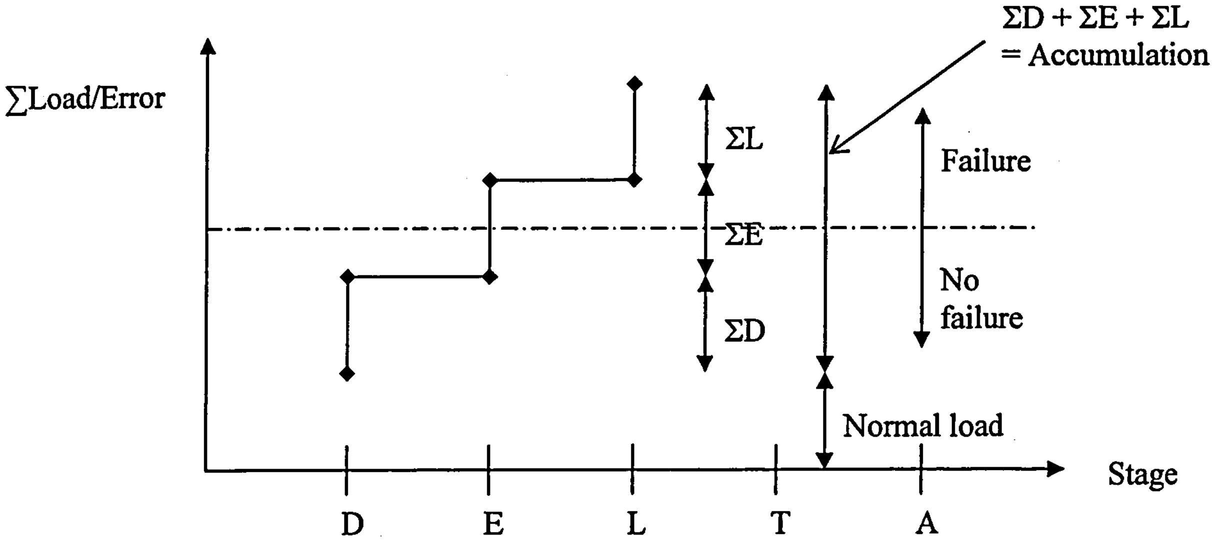


Figure 9.4 Combination of design, erection and loading error

(5) Improper taking down procedures can also lead to collapse of the falsework.

In Figure 9.5, the error during taking down procedures can trigger the failure and cause the collapse.

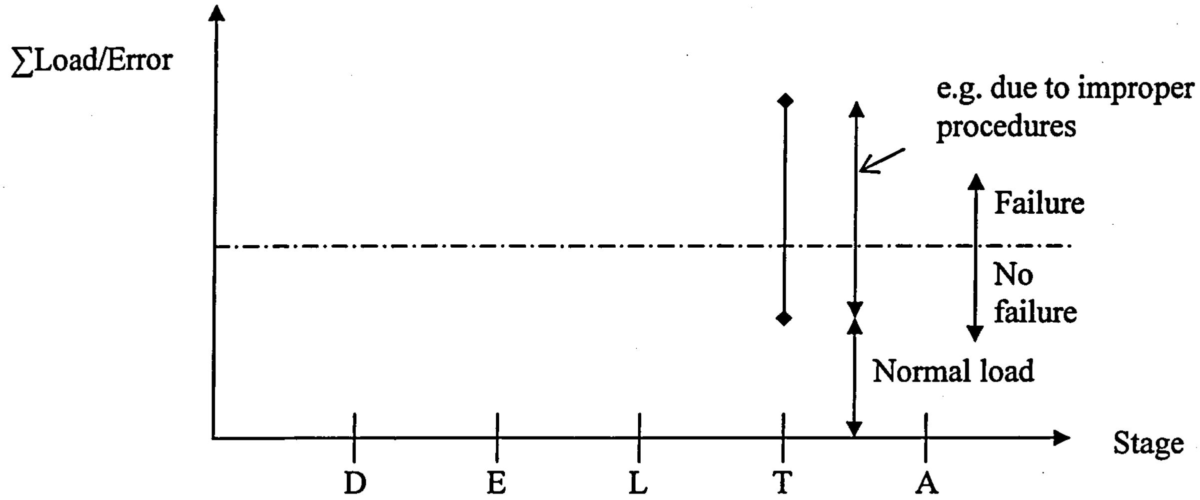


Figure 9.5 Improper taking down

(6) The inadequate repair and maintenance of falsework materials will lower the F.O.S. and move down the failure line.

As shown in Figure 9.6, the failure line will move up or down depending on the condition and quality of the falsework scaffolding material. Normally for new materials a F.O.S. of two is assumed. For used and improper maintained materials, the F.O.S. is less than two and the failure line will move down.

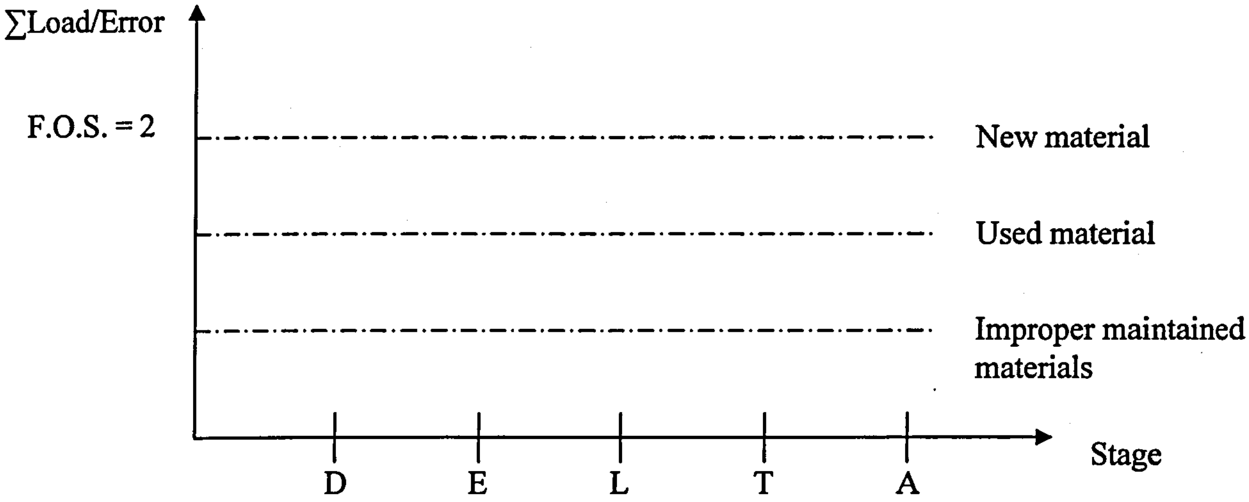


Figure 9.6 Inadequate repair and maintenance

The plotting of error accumulation at various stages can be shown in the following graph.

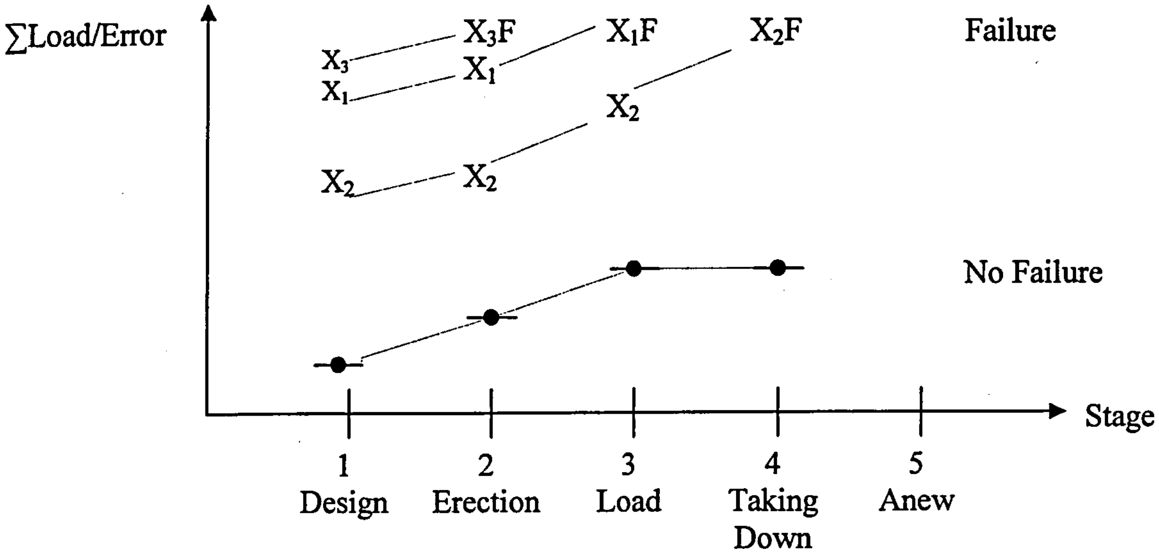


Figure 9.7 Errors at different stages

Note: X_1,......X_1F Shows the line of failure

—●— Assessment of successful project conditions by Engineers

Any score lies between the failure and successful envelope would indicate the proneness to failure or not.

The score would have an inverse relationship with the Factor of Safety (F.O.S.) of the falsework construction. The higher the scores, the lower will be the F.O.S. (safety margin).

9.3 Development of flow chart of essential procedures for three control systems

In Chapter 3, the three control systems for falsework design and construction have been explained in detail. For the conventional system, the Engineer or Resident Engineer (R.E.) will not formally approve the Contractor's falsework design. They may check and approve but without accountability. The Independent Checking Engineer will check the design and construction of the falsework. However, this

Checking Engineer will not work full time on site and immediate control on contractor's activity cannot be guaranteed. The Falsework Coordinator, as an employer of the contractor, will be responsible for all activities related to falsework. Such appointment is not wholly independent of the Contractor's organisation.

Taking into account of characteristics of the three systems, the essential procedures in the form of flow charts under three control systems are developed and illustrated in the following Figures 9.8 to 9.10.

(1) Conventional Control System (Figure 9.8)

The contractor will be responsible for the design of the falsework whereas the Engineer/ R.E. will check the design but bears no accountability as specified in the contract. Also the contractor will be wholly responsible for the safety of the falsework during erection, loading and dismantling. The Engineer/ R.E. will only carry out the routine supervision at every stage of the falsework construction.

(2) Independent Checking Engineer (ICE) System (Figure 9.9)

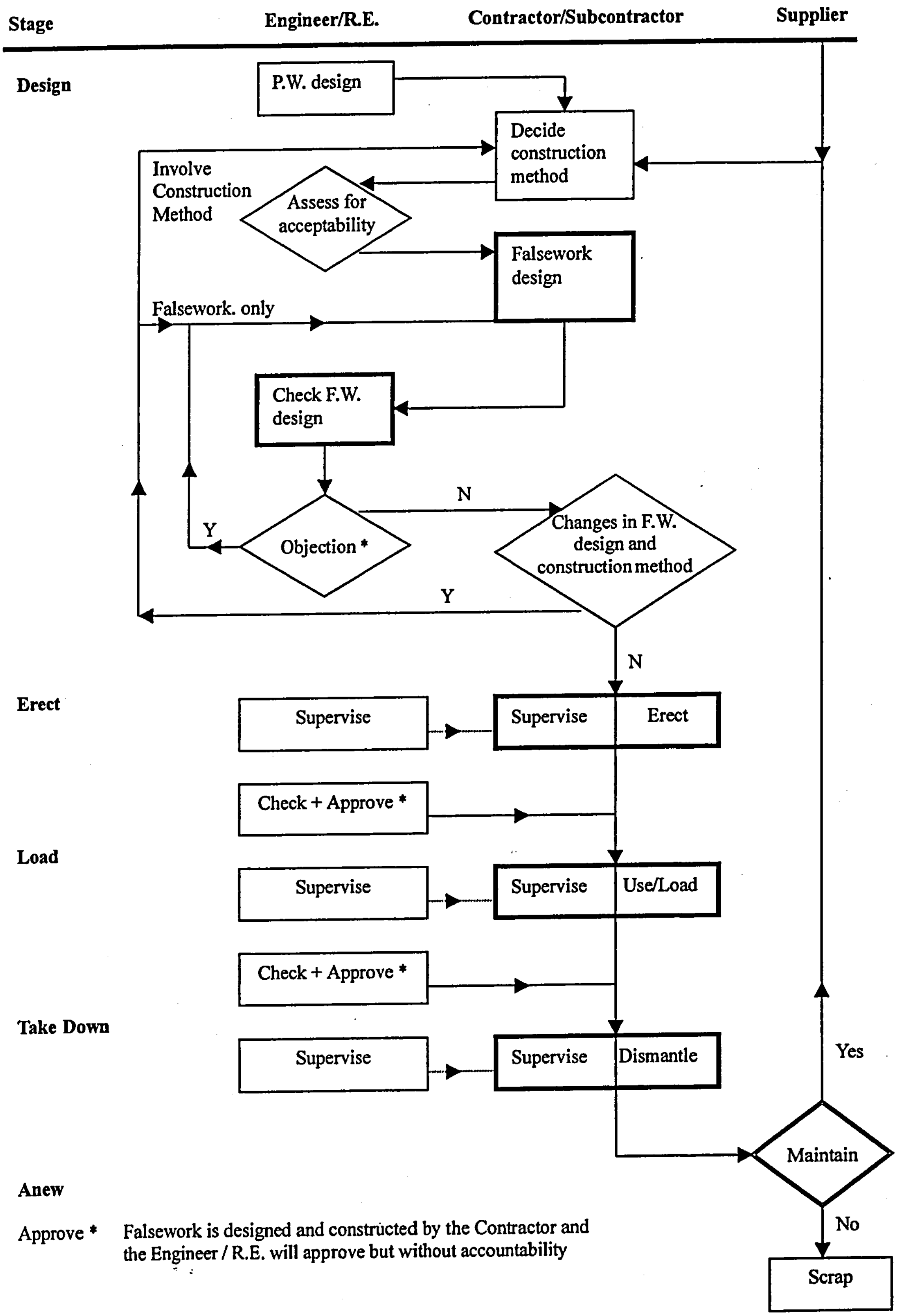
The ICE is employed by the Contractor for checking and approving the design of the falsework. After checking, the ICE will sign jointly with the Contractor a certificate for submission to the R.E. Falsework erection will not be allowed to proceed on site without receiving the certificate by the Engineer.

After the erection, the ICE is required to check the falsework in accordance with the design drawings. The approval certificate signed by the ICE will be received by the Engineer before the Contractor applies the load to the falsework. Similarly dismantling should not proceed without checking and approval by the ICE and certification received by the R.E.

This system has the merit of ensuring the design, erection, loading and dismantling of the falsework to be checked and approved by the ICE, who is independent of the contractor and whose role will cover the passive and inadequate involvement of the Engineer/ R.E. in the supervision of temporary works.

(3) Falsework Coordinator System (Figure 9.10)

The Falsework Coordinator carries out the checking and approving activities as undertaken by the ICE. The difference is that the Coordinator is the direct employee of the Contractor and no approval certificate is required to be submitted to the R.E. by the Coordinator.



Approve * Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical Stages

Figure 9.8: Conventional Control System

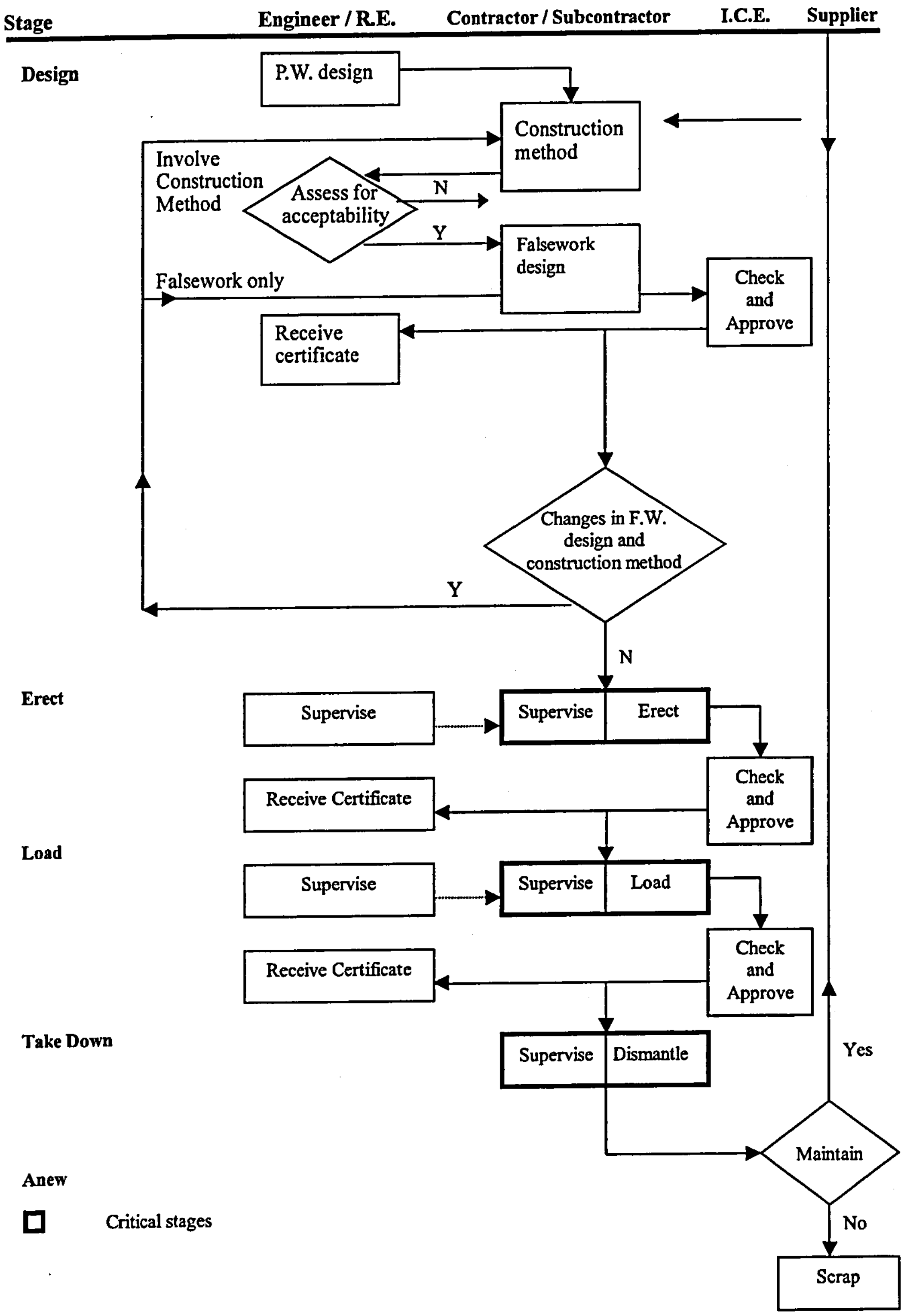


Figure 9.9: Independent Checking Engineer (ICE) System

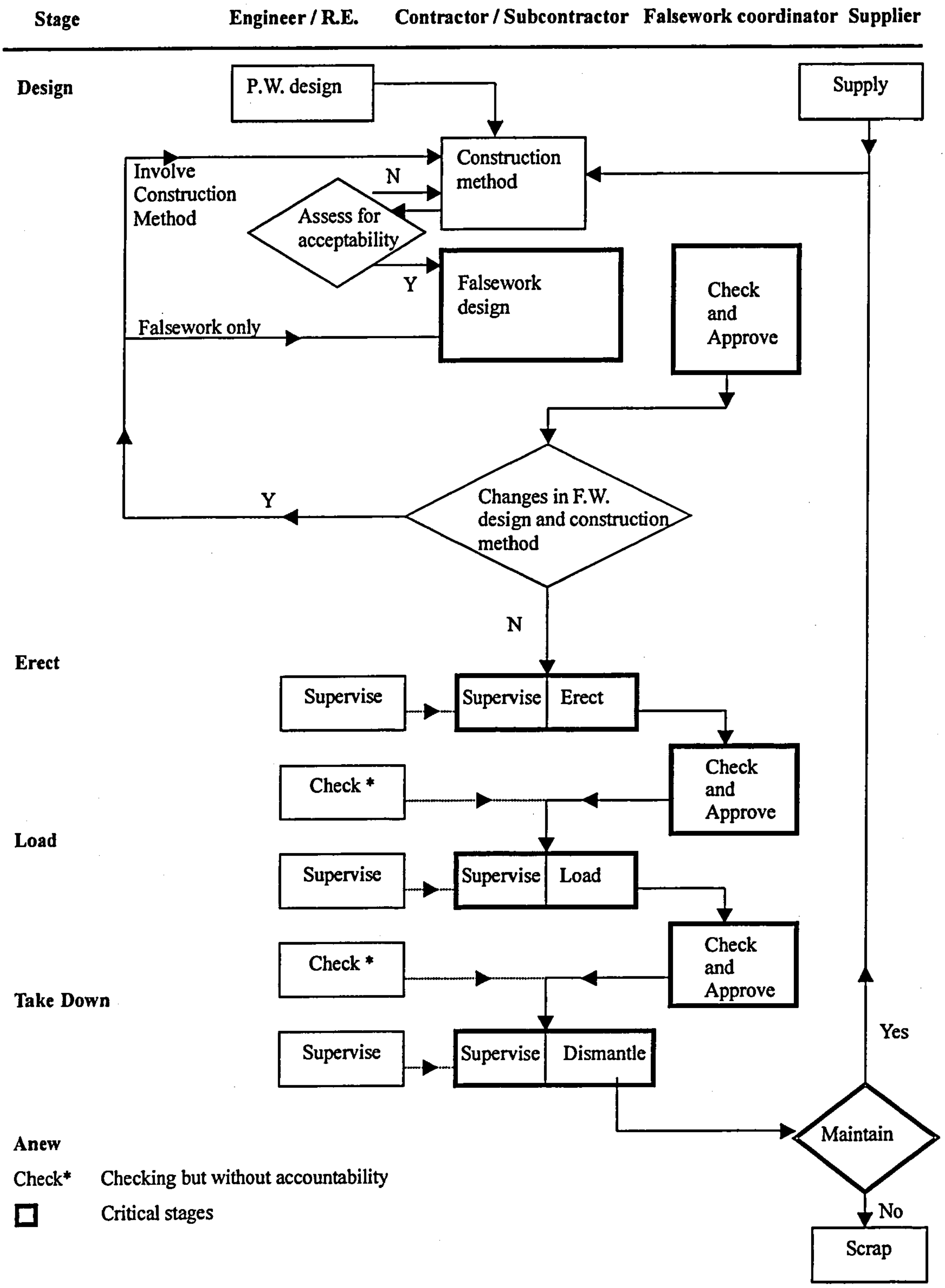


Figure 9.10: Falsework Coordinator System (BS 5975)

9.4 The fifty falsework failures

Between 1958 and 2000, a total of 50 falsework failures have been recorded in various forms. The description of the failures is abstracted from the reports. Visit to some of these sites have been made as described in Chapter 6.

Table 9.2: Fifty falsework failures

Failure	Date	Bridge	Type of Failure	Casualty
1	11/00	Shenzhen China *	30m wide x 50m long bridge section collapsed during concreting due to inadequate transverse bracing	60 injured
2	3/99	Castle Peak Hong Kong	A section of 4m x 10m podium collapsed during concrete pumping	5 injured
3	2/99	Siu Sai Wan Hong Kong *	A canopy of 96m^2 collapsed while vibrating the concrete due to extensive extension of foreheads	1 killed
4	12/98	Sai Wan Ho Hong Kong	A platform of 10ft x 25ft collapsed during concreting	3 injured
5	11/98	Tsing Yi Island Hong Kong	An 8m R.C. section of a ramp supported by tubular steels collapsed during concreting	7 injured
6	12/97	Guangzhou China	A highway bridge deck supported by timber falsework collapsed during concreting	3 killed 3 injured
7	12/96	Ru Yuan Guangdong China *	A 100m span R.C. arch bridge collapsed during concreting	34 killed 27 injured
8	9/96	Kwai Chung Hong Kong	A ramp leading to a carpark collapsed during concreting	3 injured
9	3/96	Jakarta Indonesia	A 30m long simply supported in-situ concrete span collapsed due to premature removal of falsework	3 killed 18 injured
10	1/96	Tseung Kwan O Hong Kong *#	A 34m long footbridge formed by two precast and prestressed concrete beams collapsed as a result of a change in the construction procedures	1 killed 4 injured

11	2/95	Route 3 Hong Kong #	A 75-ton concrete bridge segment crashed through the supporting scaffold which had not been designed and checked during placing to the bridge pier	2 killed 4 injured
12	6/94	Airport Flyover Macao *	20m x 10m bridge deck collapsed during concreting owing to soil settlement under the falsework	16 injured
13	3/94	Telaviv Israel	The falsework supporting the 100-ton precast concrete beam collapsed due to uneven load distribution	3 killed
14	4/90	St. Paul Bridge Minn. USA	Concrete arch bridge collapsed after concrete pumping due to buckling of an under-designed steel beam	1 killed
15	8/89	Route 198 Maryland USA	Post-tensioned concrete highway bridge collapsed during concreting owing to the use of screw jacks below the capacity specified	14 injured
16	7/88	Jiang Pei Flyover Chongqing, Sichuan, China *	Post-tensioned concrete beams collapsed as a result of premature removal of suporting falsework	3 killed 15 injured
17 & 18	4/88 & 12/87	Hsinhai Road Flyover, Taipei Taiwan *	Post-tensioned concrete bridge collapsed during concrete pumping due to under-design of the falsework scaffolding	Nil
19	5/86	North Tsing Yi Bridge Hong Kong *	Square-prop falsework collapsed during rectification after wind	1 killed 1 injured
20	1/86	Taiwan	Post tensioned concrete beams collapsed due to removal of formwork / falsework before pre-stressing	1 killed 2 injured
21	12/85	Heidelbery West Germany	Falsework failed during lowering of the steel girder	Nil
22	10/85	Viaduct across Interstate 25, Denver, Colo. USA	Concrete girders collapsed during placing onto a partially completed pier table because of misunderstanding in construction sequence	1killed 4 injured
23	10/84	Taiwan	Bridge collapsed during concreting due to insufficient formwork support	1 killed 1 injured

24	8/84	Sunshine Skyway Bridge, Florida USA	100m launch truss buckled during installation of a 216-ton precast concrete pier top due to inadequate structural analysis of the temporary support	4 injured
25	2/83	Taiwan	Bridge pier working platform collapsed as a result of overload from construction plant and formwork	3 injured
26	11/82	Overbridge on Route 36, Kansas USA	R.C. slab overbridge collapsed during concreting by pumping and skips when timber falsework collapsed	1 killed 8 injured
27	4/82	East Chicago Expressway, Indiana USA	Box girder road deck swing during concreting by skips due to collapse of the shoring towers on inadequate pad foundations	13 killed 15 injured
28	3/82	Tuen Mun Highway Hong Kong	The pier head collapsed during concrete pumping due to under-design of the falsework scaffolding	1 killed
29	1/82	Riyadh Outer Ring Road, Saudi Arabia	43m post tensioned concrete deck buckled and collapsed 8 days after concreting due to compression force in the cut-outs in the deck section during post tensioning	Not stated
30	9/80	Bombay India	Cast T-beams but not yet prestressed fell due to inadequate trestle support made up of steel cribs and timber sleepers	Nil
31	2/79	Jalan Eunos Flyover Singapore	65m long post tensioned concrete flyover collapsed as a result of inadequate design to accommodate the boxout and premature removal of falsework	Nil
32	5/75	Auckland New Zealand	212 ft span prestressed concrete bridge collapsed after prestressing due to changed weight distribution on the falsework	Not stated

33	6/74	Meuse River Belgium	42 ft long cantilever of post tensioned concrete girder bridge failed during curing because of the failure of the tubular steel falsework	Not stated
34	4/74	Leubas Bridge Kempten West Germany	72 ft long center post tensioned concrete span collapsed during concreting owing to ignorance of lateral forces induced by the cross-fall on the falsework	9 killed 13 injured
35	5/73	Sao Paulo Brazil	131 ft center span of a reinforced concrete girder collapsed during concreting because of shifting of wooden falsework after rain	6 injured
36	10/72	River Lodden Berkshire UK	110 ft post tensioned concrete bridge span collapsed during concrete pumping as a result of inadequate design and construction of the falsework	3 killed 10 injured
37	10/72	Arroyo Seco Bridge, Pasadena Calif. USA	150 ft expressway bridge collapsed during concrete placing with a conveyor because of inadequate formwork and falsework design	6 killed 6 injured
38	9/72	Koblenz West Germany	A section of elevated prestressed concrete bridge collapsed during concrete pumping due to insufficient reinforcing of a crossbeam in the steel falsework	6 killed 15 injured
39	8/72	Route 50, Sacramento, Calif. USA	Steel falsework collapsed during dismantling	10 injured
40	7/72	Dallas, Texas USA	An elevated highway deck slab collapsed during casting due to movement of the formwork / falsework	2 injured
41	12/71	Elgin, Ill. USA	A small concrete arch bridge collapsed during construction as a result of stress reversal when the forms were stripped	Not stated

42	4/71	San Bruno, Calif. USA	15 precast prestressed concrete T-beams fell during placing because of buckling or lateral movement of the steel scaffolding	2 injured
43	3/71	Birling Road Overbridge, Kent UK	138 ft long center span of a post-tensioned concrete highway overpass collapsed during concrete pumping due to the collapse of the tubular scaffolding	1 killed 17 injured
44	9/70	Kazerne Viaduct, Johannesburg S. Africa	The post-tensioned concrete span collapsed as a result of inadequate anchorage of the temporary stays	A few injured
45	8/67	Calder, Yorks UK	76m concrete span collapsed due to low strength and inadequate bracing of steel beams in temporary supports	4 killed
46	8/66	Heron Road Bridge, Ontario Canada	The concrete bridge collapsed during concreting because of buckling failure of inadequately braced timber falsework	Not stated
47	8/66	Welshpool Road Overpass, West Australia	Prestressed concrete bridge collapsed during concreting as a result of the buckling of falsework	Not stated
48	6/62	Fife UK	Superstructure of road overbridge collapsed due to buckling of temporary support after concrete they were supporting had set	3 killed
49	2/59	Barton, Lancs UK	Steel girders fell owing to buckling of temporary supports	4 killed
50	6/58	Second Narrows, Vancouver Canada	Steel truss spans collapsed due to inadequate base of temporary column	18 killed

Notes:

* - with site visit

- with court hearings

9.4.1 Analysis of fifty failures using Event Sequence Diagram and Content Analysis from reports

The falsework activities of the fifty failure cases under three control systems are presented by event sequence analysis shown in Figure C.1 to Figure C.50 in Appendix C. By applying the event sequence diagram and content analysis to fifty failure reports, the major procedural causes are identified. The procedural causes of the fifty cases together with other relevant information are summarised in Table 9.3. Details of application of event sequence diagram and content analysis have been discussed in section 2.3 and section 8.2.9 respectively.

The event sequence diagram (Pidgeon et al. 1990) is applied in presenting the information in the temporal order of the events. The content analysis technique (Berelson 1952, Holsti 1969) is used to extract information from the falsework failure reports to fit the format of causes preceding the event and the consequence.

Table 9.3 Procedural causes of fifty falsework failures

Case No.	No.	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
Site Visit		✓		✓		✓		✓			✓		✓				✓		✓	✓						
Type of report		D	D	D	D	D	D	D	D	D/C	B/D	B/D	D	C/A	C/B	C/B	D/B	D/B	D/B	D/B	C	C	C/B	C	C/B	C
DESIGN – Inadequate design	15							✓			✓	✓		✓	✓			✓	✓							✓
– Inadequate supervision	2										●															
– Inadequate checking	9										●	●		●	●			●	●							
ERECTION – Inadequate construction	20	✓				✓					✓	✓				✓		✓	✓	✓				✓		
Lack of supervision	3										●	●								●						
Inadequate foundation	5											●	●					●	●							
Inadequate bracing	10	●				●							●					●	●	●						
Inadequate components connection	8															●		●	●					●		
Lack of stage communication	2										●	●														
Rectification	1																			●						
LOADING – Failure occurs/ improper loading	43	*	*	*	*	*	*	*	*		*	*	*	*	*	*		*	*			*	*	*	*	*
Segment/ concrete placing	37		●	●	●	●	●	●	●			●	●	●	●	●		●	●			●	●	●	●	●
Pre-stressing	2																									
Jacking method	2										●											●				
Excessive construction load	1																									●
Stage communication	2										●	●														
TAKING DOWN	6									✓							✓				✓					
Premature removal	4									●							●				●					
Improper removal procedures	2																●									
OTHERS – Communication across stages/ parties	6						●				●	●											●			
EXACT REASON UNKNOWN	16		●						●				●									●				
Failure of permanent works	3																									
Warning given	9					●	●	●						●					●							

Case No.	No.	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Type of report		C	B/C	B/C	C	B/C	C	C	C	B/C	B/C	B/C	C	B/C	C	C	C	C	C	B	C	B/C	B/C	C	C	B/C
DESIGN – Inadequate design	15			✓				✓		✓		✓	✓									✓				✓
– Inadequate supervision	2			●																						
– Inadequate checking	9			●						●																●
ERECTION – Inadequate construction	20	✓	✓	✓							✓	✓		✓						✓	✓		✓			
Lack of supervision	3																									
Inadequate foundation	5		●	●							●															
Inadequate bracing	10	●	●									●								●	●	●				
Inadequate components connection	8		●			●						●		●							●					
Lack of stage communication	2																									
Rectification	1																									
LOADING – Failure occurs/ improper loading	43/	*	*	*	*	*		*	*	*	*	*	*	*		*		*	*	*	*	*	*	*	*	*
Segment/ concrete placing	37	●	●	●		●			●	●	●	●	●	●		●		●	●			●	●	●	●	●
Pre-stressing	2				●			●																		
Jacking method	2																									
Excessive construction load	1																									
Stage communication	2																									
TAKING DOWN	6						✓								✓		✓									
Premature removal	4						●										●									
Improper removal procedures	2																									
OTHERS – Communication across stages/	6						●			●																
EXACT REASON UNKNOWN	16	●				●			●		●	●	●		●	●		●	●					●	●	
Failure of permanent works	3				●		●													●						
Warning given	9					●							●						●	●						

✓ Gross errors ● Procedural inadequate * Failure stage
A Formal enquiry B Court hearings, accident reports, Professional reports
C Engineering journals D Newspapers

9.4.2 Summary of procedural causes of fifty falsework failures

The analysis of procedural causes are as follows.

(1) Type of reports

As shown in Table 9.4, forty per cent of the failures were in the form of the professional reports, accident reports and court hearings which require a longer time to prepare and are not always available to the public, as discussed in Chapter 4. Another forty per cent of failures were obtained from engineering journals. The more recent failures were mostly reported by the media (18 per cent).

Table 9.4 Type of reports

Type	Report description	Number	Per cent
A	Formal enquiry	1	2
B	Court hearings, accident reports, professional reports	20	40
C	Engineering journals	20	40
D	Media: newspapers	9	18
	Total	50	100

(2) Type of collapsed falsework

The common materials used in the collapsed falsework were metal scaffolding (54%) and steel frame (20%) with the latter more appropriate for heavier loads and longer spans (Table 9.5). Four cases involved the use of timber which has a lower load-bearing capacity yet timber was still used in many developing countries.

Table 9.5 Type of collapsed falsework

Principal type of material	Number	Per cent
Tubular steel/metal scaffolding	27	54
Steel frame	10	20
Timber	4	8
Not stated	9	18
Total	50	100

(3) Type of failed permanent works

Table 9.6 shows that in situ concrete construction with post tensioning was the most frequent type (38%) in falsework failures. Bridges are often of long span supporting heavy vehicle loads, thus post tensioning concrete is very suitable for bridge deck construction. Thirty per cent of the failures were of in situ reinforced concrete construction which is more appropriate for medium and short span bridges. Falseworks are also required to support the precast elements requiring post tensioning. The uneven stress distribution during placing of the elements and as a result of post tensioning could easily lead to overstress of the falsework.

Table 9.6 Type of failed permanent works

Permanent works construction	**Number**	**Per cent**
In situ reinforced concrete	15	30
In situ concrete with post tensioning	19	38
Precast and post tensioned elements	8	16
Steel	3	6
Not stated	5	10
Total	50	100

(4) Failure stages

From Table 9.7, the majority of failures (74%) occurred during concrete casting particularly towards the end of concrete pouring and placing of precast concrete segment. At these instances the falsework would subject to the full design load. The erosion of factor of safety of the falsework due to procedural inadequacies would lead to a collapse. It should be noted that twelve per cent of failures occurred during removal or dismantling of formwork and falsework. The distribution of the causes correlates well with the findings by Hadipriono in 1986.

Table 9.7 Failure stages

Construction stage	Number	Per cent	Per cent *
During erection	1	2	4
Before concrete pouring	1	2	9
During concrete pouring	24	48	49
Post concrete pouring (No post tensioning)	2	4	12
Post concrete pouring (Prior to post tensioning)	2	4	7
Post concrete pouring (after post tensioning)	3	6	4
During formwork/falsework removal	6	12	12
During precast concrete/segment placing	9	18	1
Unspecified	2	4	0
Total	50	100	100

Note: * Data from Hadipriono's analysis of causes of falsework failures in concrete structures (1986).

(5) Stage inadequacy

Out of the fifty cases, thirty-five cases have been provided with reasons of failure. Some cases have more than one stage inadequacies. Most of the errors (45%) occurred in the erection stage because of the inadequate bracing and inadequate components for the falsework. About one third of the failures were due to the errors in design where inadequate design and checking have been very common.

Table 9.8 Stage inadequacy

Stage	Number	Per cent
Design	15	33.3
Erection	20	44.5
Loading	4	8.9
Taking down	6	13.3
Total	45	100

9.5 Three case studies

The flow charts can be used to identify the procedural inadequacies in falsework failures. Three cases of different control systems are used to illustrate the application of the flow charts.

Case Study 1: Minnesota, USA (1990)

Information:

- Main Contractor – McCrossan.
- Main Consultant – Rehder-wenzel designed the falsework.
- Client – MDOT - had a copy of falsework design for information only.
- It was common not to check the falsework design by the client. The contract required a Registered Engineer (not the Contractor) to carry out the temporary works design. Design was performed by the Contractor's consultant but without checking by any third party.
- Cause of failure – Web-bucking of an I-beam falsework.
- Control / Prevention – no independent third party checking of the design which was carried out by the Contractor's Consultant.
- Triggering event – concrete pouring.

- Event sequence diagram of procedural causes is shown below.

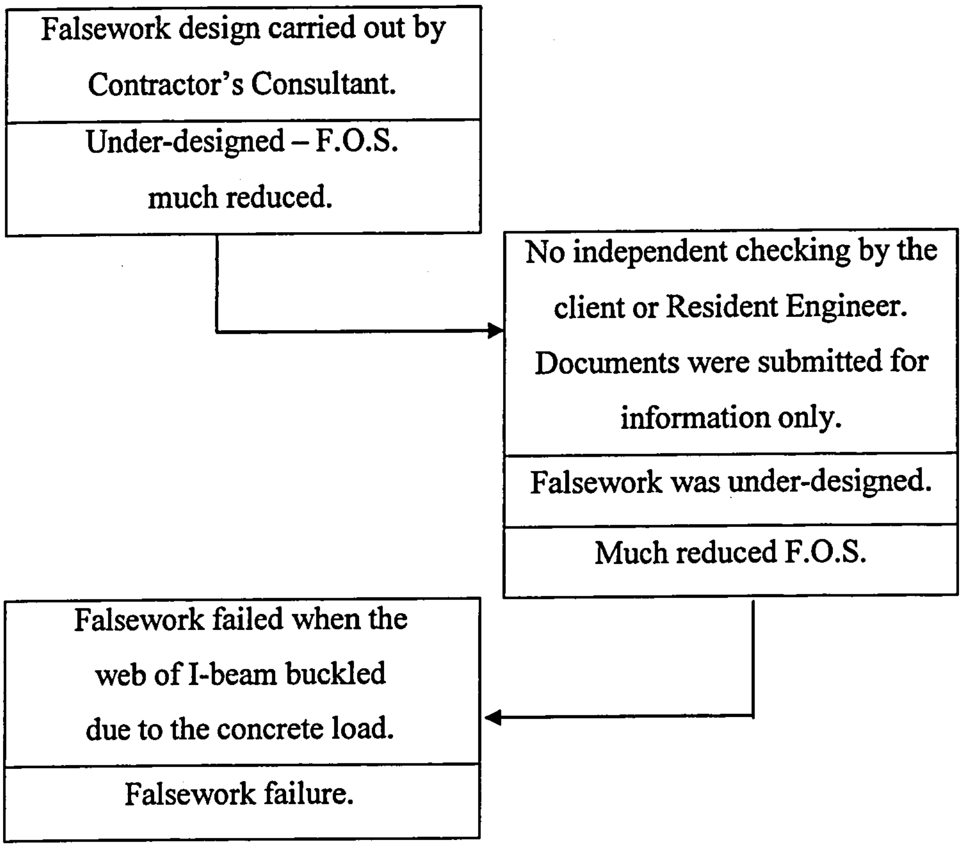


Figure 9.11 Case study 1- Event sequence diagram

- This was a typical case that the design was inadequate and there was no independent checking.

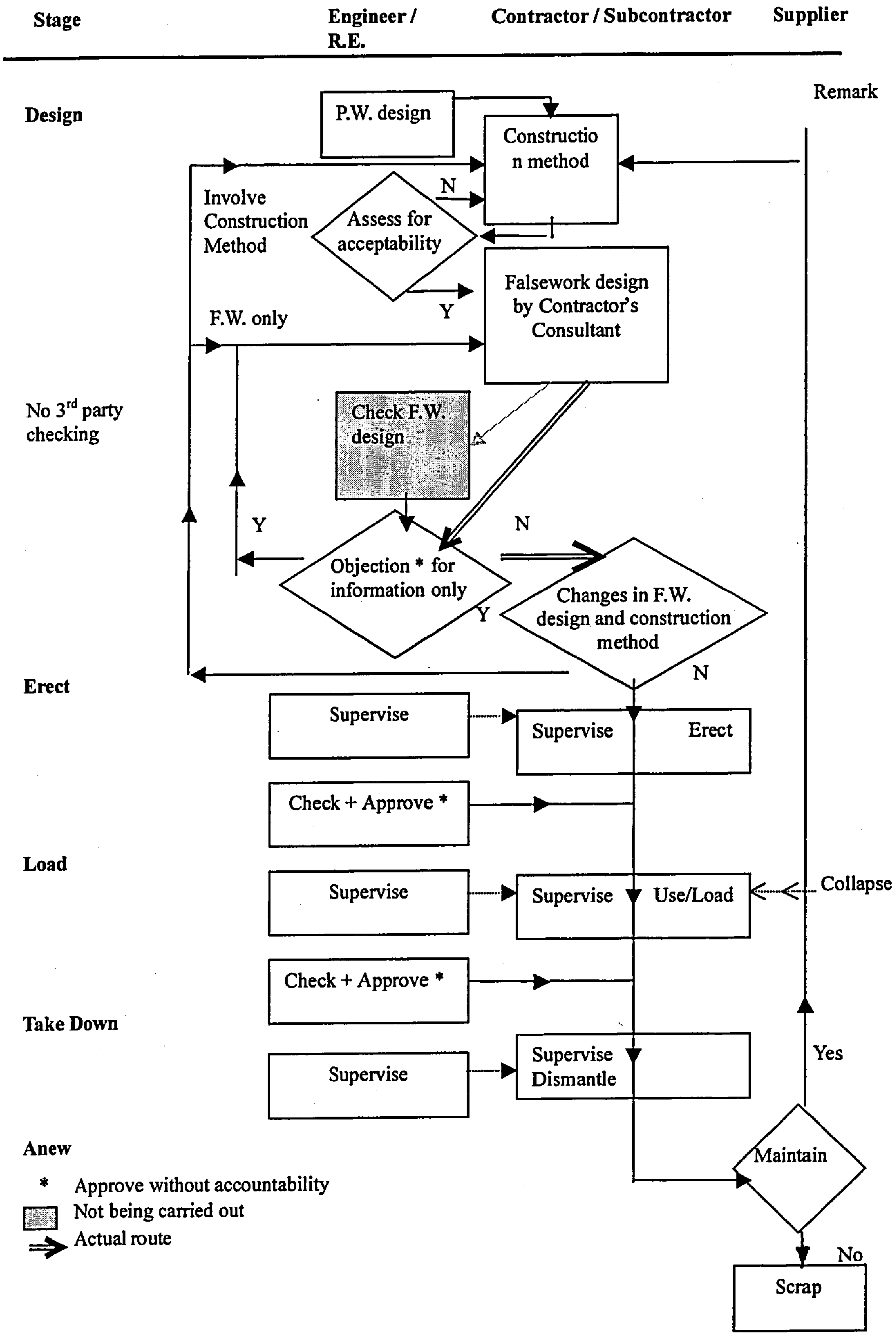


Figure 9.12: Case Study 1: Minnesota, USA (1990) – Conventional Control System

Case Study 2: Israel (1994)

Information:

- Construction: A precast beam of 100-ton was resting on the falsework before tensioning and making connection to permanent supports.
- Client: Public Works Department.
- Contractor: Sollel Boneh.
- Client's responsibility – designed the bridge and supervised the construction work.
- Contractor's responsibility –the construction.
- The failure investigation report quoted "The load was not evenly distributed as assumed in the design."
- Cause – Falsework was overloaded due to uneven load distribution contrary to the assumption in the design.
- Procedural – No third party verification of the falsework design.
- Construction method – Concrete beam to be post tensioned.
- Triggering event – Load of the beam supported by the falsework.
- Event sequence of diagram of Procedural causes:

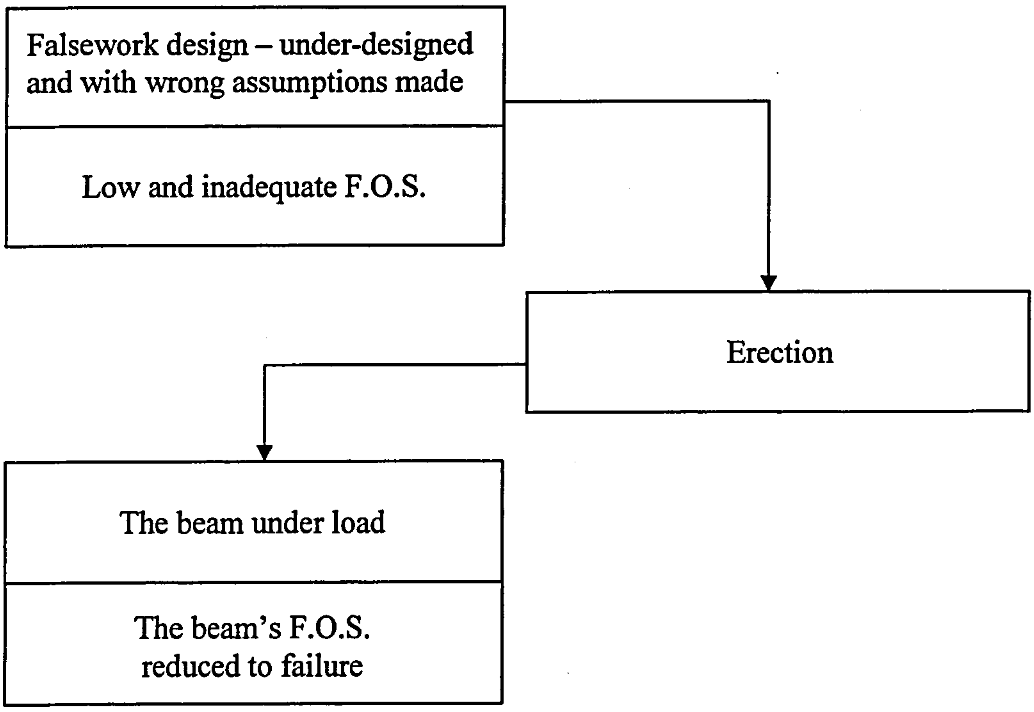


Figure 9.13: Case study 2 – Event sequence diagram

- This was a typical case of no checking of falsework design.

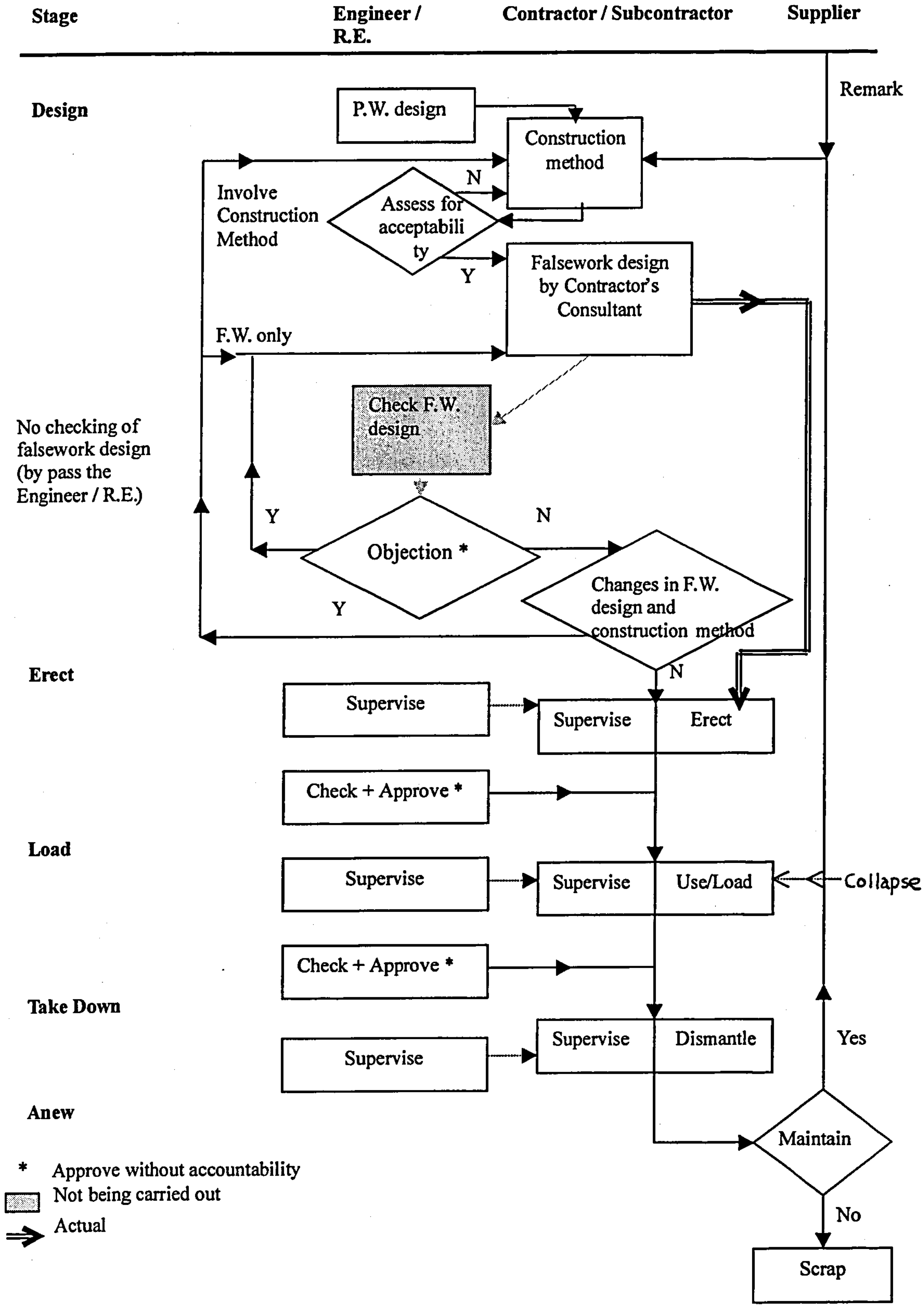
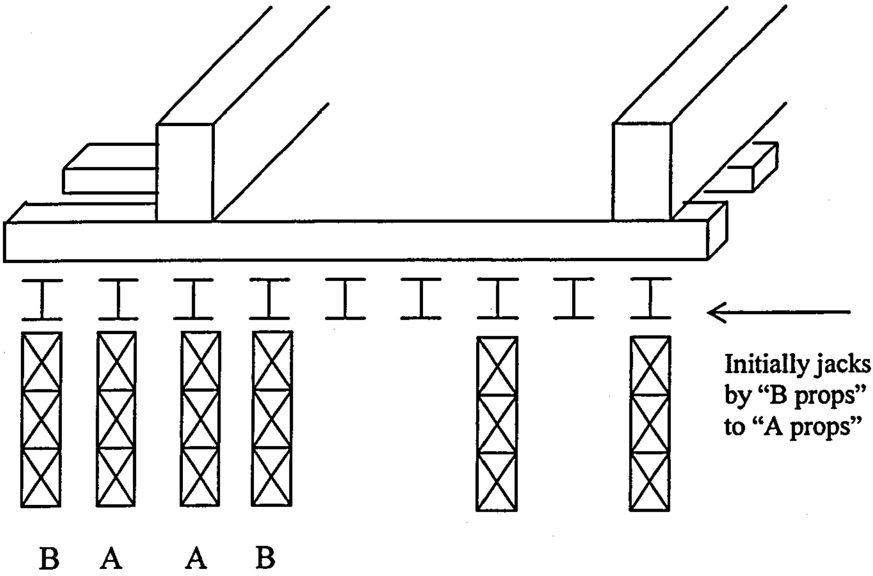


Figure 9.14: Case Study 2: Israel (1994) – Conventional Control System

Case Study 3: Tseung Kwan O Hong Kong (1996)



Initially jacks were supported by "B props" and moved later to "A props"

Figure 9.15: Props A and B, Tseung Kwan O, Hong Kong

Information:

- Initially hydraulic jacks were placed at "B Props" in supporting and lowering the post-tensioning beams. A change in construction method required fixing of jacks at "A Props" but this had not been independently checked and certified. The loading certification had not been completed when failure occurred.
- Supports by "A Props" were almost totally removed while the revised construction method statement was still being verified by the Independent Checking Engineer.
- No supervision by Resident Engineer's staff during the loading of the beams onto the props.
- Sketches for falsework erection were inadequate.
- Enabling causes:

  Shifting of I-beams after post-tensioning has led to uneven load distribution on the props.
- Triggering causes:

  Remove top part of A Props and transfer load to B Props.
- Procedural causes:

(1) High potential risk in the new construction method –required stringent supervision.

(2) Inadequate inspection of falsework after post tensioning by ICE, Resident Engineer and Contractor.

(3) Proceed erection and loading without Resident Engineer's and Independent Checking Engineer's inspection and approval.

(4) Inadequate review / checking / approval of falsework due to a change in construction method.

- Event sequence diagram of procedural causes is shown in Figure 9.16.

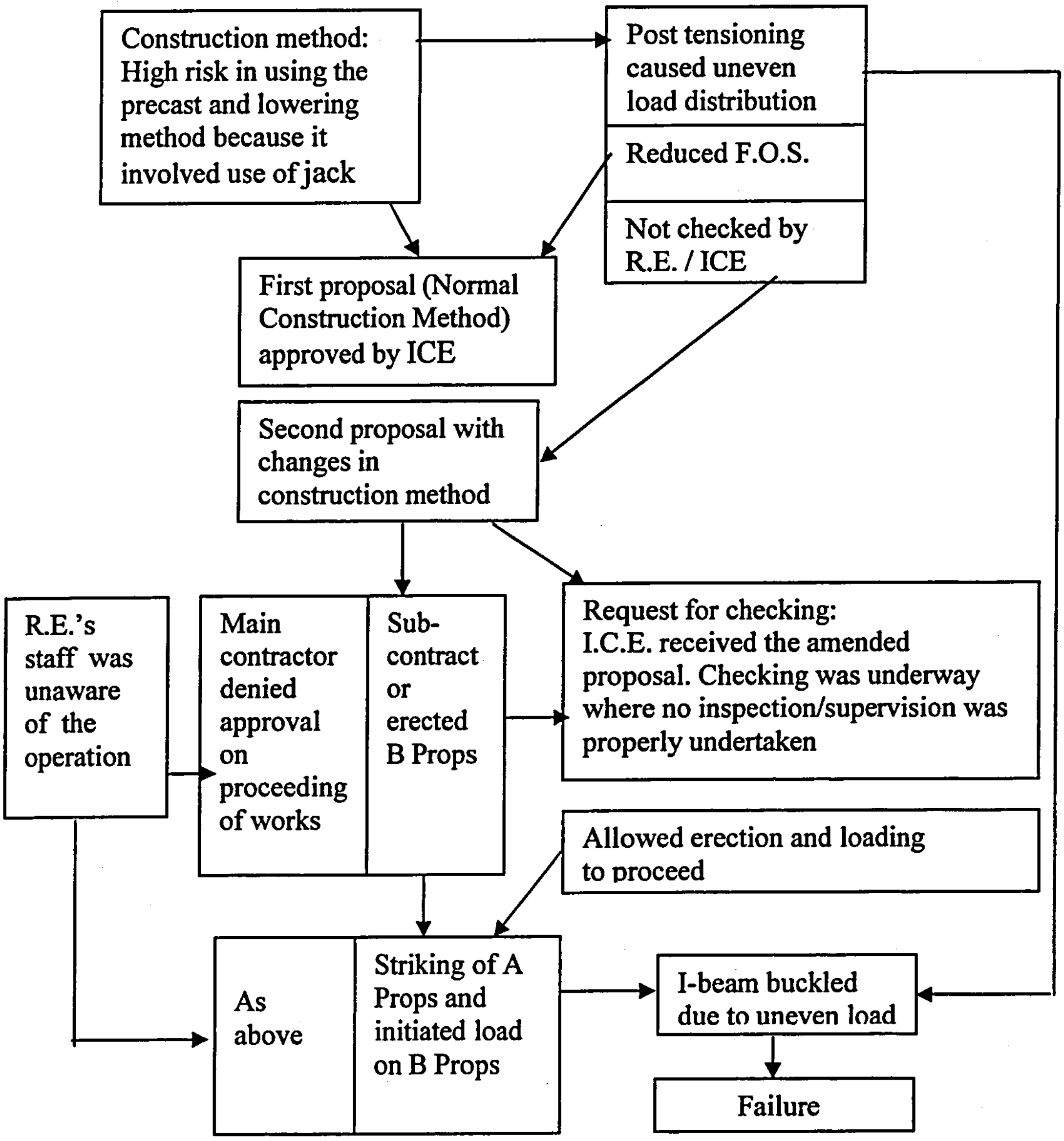


Figure 9.16: Case study 3 – Event sequence diagram

- This was a failure case involving the employment of Independent Checking Engineer. The construction method changed and proceeded without approval of the Independent Checking Engineer.

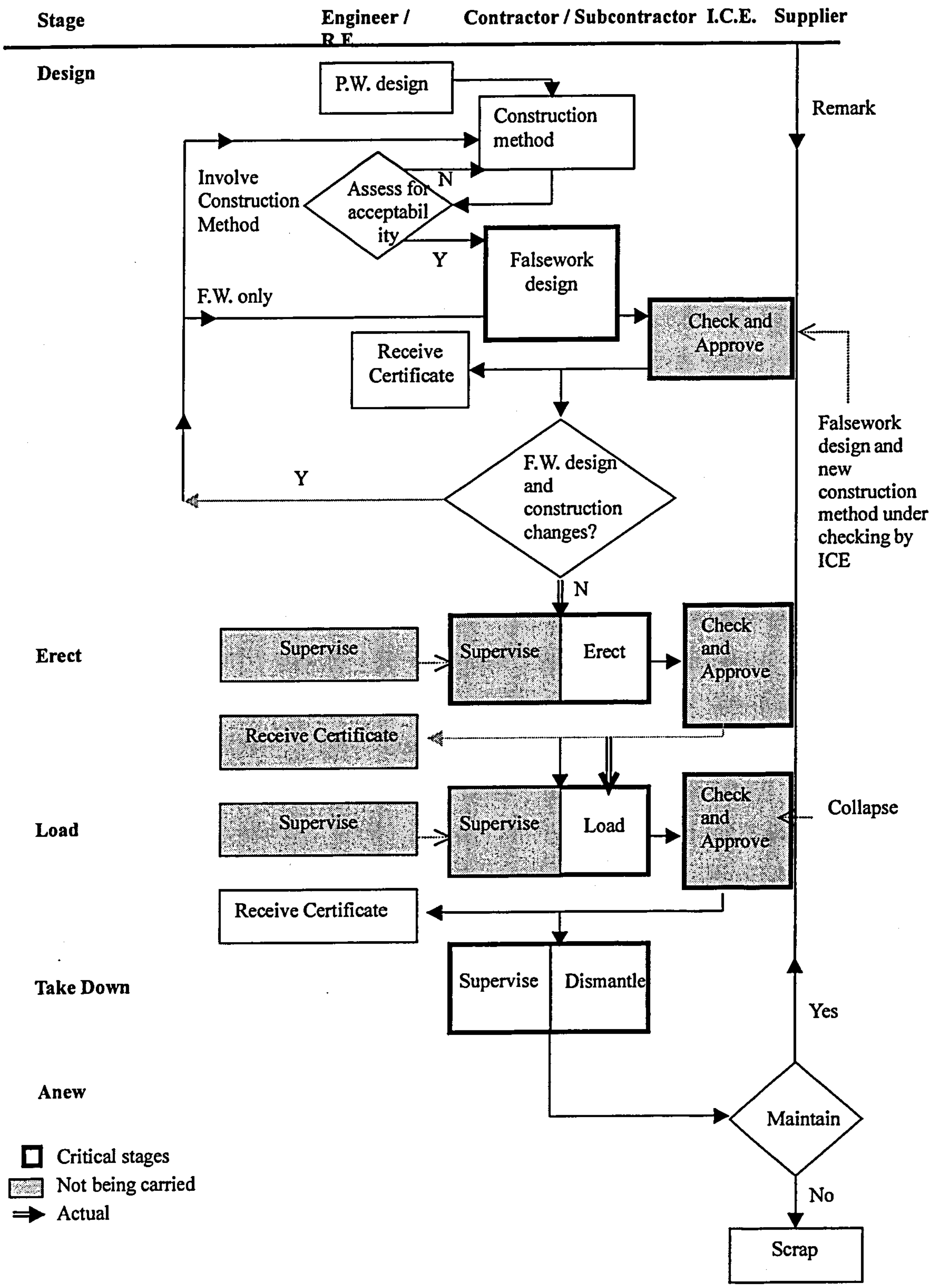


Figure 9.17: Case Study 3: Hong Kong (1996) – Independent Checking Engineer (ICE) System

9.6 Summary

After the review of the practices of falsework scaffolding in Hong Kong and the relevant codes of practice and guidelines, the essential procedures in the five critical stages of falsework construction have been established. The inadequate procedures commonly found in the failure reports are also listed. A flow chart based on event sequence diagram in listing the key activities and roles of parties who take part in falsework construction was developed. Modifications have been made to cater for the differences in the three control systems, namely the conventional, falsework coordinator and independent checking engineer systems. The charts have been used in analysing the three failures in detail.

Based on the content analysis and event sequence diagram, fifty falsework failure reports have been analysed. Forty per cent of the reports were from engineering journals and another forty per cent from accident reports, professional reports and court hearings. Eighteen per cent of the reports were of more recent cases and were available only from the media.

The principal types of material for failed falsework were tubular steel or metal scaffolding (54%) and steel frames (20%). Thirty-eight per cent of the failures were in situ concrete construction with post tensioning, which is a typical choice for long span bridge construction. Thirty per cent of the failures were in situ reinforced construction, mainly for medium and short span bridges. Another twenty-two per cent were for the falsework supporting precast elements followed by post tensioning or steel members.

Most of the failures (82%) occurred during concrete casting particularly near the end of pouring and placing of precast segments at which the falsework would be subject to the full design load. Ten per cent of the failures occurred during dismantling or removal of the falsework.

Regarding the procedural inadequacies, forty-five per cent of the substantial errors occurred in the erection stage, thirty-three per cent occurred in the design stage, thirteen per cent in the taking down stage and nine per cent in the loading stage. A tighter control in the design and erection stage is thus necessary in preventing the falsework failures.

In the next chapter, the procedural framework for analysing and predicting falsework failure will be developed.

CHAPTER TEN

PROCEDURAL FRAMEWORK FOR ANALYSING AND PREDICTING FALSEWORK FAILURE

CHAPTER TEN

PROCEDURAL FRAMEWORK FOR ANALYSING AND PREDICTING FALSEWORK FAILURE

10.1 Introduction

In Chapter 9, flow charts were developed and the fifty failure cases were analysed based on content analysis and event sequence diagram. It was revealed that the majority of falsework failures occurred during concreting or loading stage. The identification of causes is essential in developing a procedural framework for analysing and predicting the falsework failures. A procedural framework for assessing the procedural inadequacy based on the event sequence diagram and the Balloon theory will be discussed. This chapter presents the development and validation of the procedural framework.

10.2 Accumulation of errors leading to failures

The two main approaches to increase the proneness (i.e. the pressure) of falsework failures by procedural errors are as follows.

(1) Lowering the loadbearing capacity of falsework

Procedural errors often lower the loadbearing capacity of the falsework and cause the failure. Examples of failure extracted from fifty cases and the relevant inadequate procedures are shown in Table 10.1.

(2) Increasing the stress (instability) of falsework

Improper procedures can increase the stress or instability of the falsework and lead to ultimate collapse. The failures taken from the falsework failure cases and the corresponding procedural inadequacy are illustrated in Table 10.2.

Table 10.1: Lowering loadbearing capacity

Failure	Procedural inadequacy
Buckling stress dominates due to lack of bracing as a result of an increased effective length.	Inadequacy in construction / design.
Reduction in loadbearing capacity of falsework materials due to inadequate maintenance of the aged / used material. BS 5975 recommends 15% reduction in bearing capacity for used materials.	Inadequate control in maintenance and inadequate consideration of the used material in design.
The web of the I-beam has not been stiffened and has not been properly checked for buckling failure.	Inadequate design or review.
Falsework foundation design and construction are inadequate.	Inadequate design / construction of foundation.
Lateral instability due to wind.	Inadequate bracing in design/ construction.

Table 10.2: Increasing the stress / instability

Failure	Procedural inadequacy
Under-estimate the loads acting on the falsework due to uneven load distribution.	Inadequate design / analysis or inadequate review of construction method.
Erection of falsework is not in accordance with the drawing or supplier's recommendation causing uneven or unexpected load distribution.	Inadequate checking in erection with respect to drawings.
Unexpected construction load acting on falsework.	Inadequate control of changes in construction method on site or inadequate inspection.
Premature or improper removal of falsework.	Inadequate control for falsework dismantling.

In the above cases, the factor of safety of the falsework has been lowered by a reduction in loadbearing capacity and/or the increase in load.

$$\text{Factor of Safety} = \frac{\text{Capacity}}{\text{Stress / Load}}$$

Effect of procedural inadequacy in eroding the factor of safety is aggregated upon the end of a particular stage (assuming failure has not occurred yet). The five stages for falsework activities are design, erection, loading, taking down and anew. If at any point of time the total effect of the inadequacy exceeds the bearing capacity, the falsework would fail. The extent of inadequacies which increase the stress or instability of the falsework (with a decrease in the Factor of Safety) is carried forward to the next stage depending on the effectiveness of control at the critical points (Figure 10.1). The more effective the control, the less additional stress or instability will be carried forward to the next procedure. This approach is also matching with the emphasis of appreciating the accumulative effect the risk would have on other packages in the project put forward by Wirba et al. (1996).

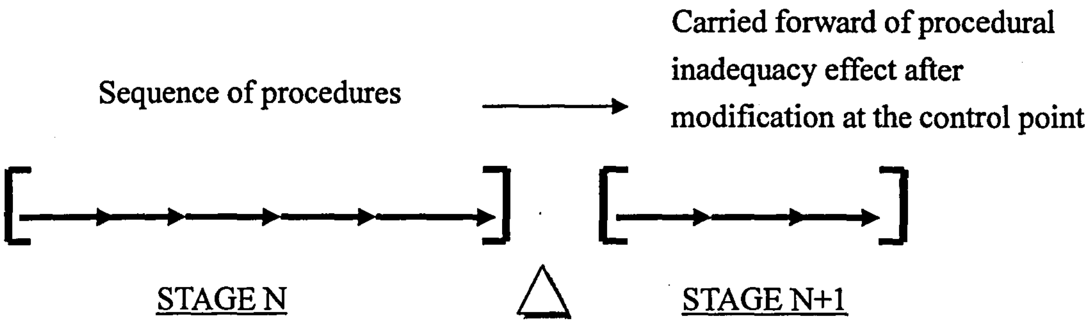


Figure 10.1: Accumulation of procedural inadequacy and control point

→ activity

△ end or beginning of a stage

Note:

The range of control factor = 0 ~ 1

very effective = 0 (no carry forward of procedural inadequacy)

no control = 1 (full carry forward of all procedural inadequacy)

As quoted by Bragg's Report (1975), a falsework failure is often due to the aggregation of numerous minor errors. This is similar to accumulation of pressure inside a balloon. The occurrence of a failure when the bearing capacity of falsework is reduced and overwhelmed by the accumulation of the load or stress is equivalent to the bursting of a balloon. The Balloon Theory is thus appropriate to illustrate the falsework failure.

Balloon Theory (Blockley 1992)

Air pressure inside a balloon increases until the balloon bursts. The maximum stretching of the balloon is pre-determined based on the strength of the material. Likewise, the strength of the falsework scaffolding is normally taken as two (factor of safety) x allowable stress. The whole process of accumulating the procedural inadequacies until falsework collapse is similar to the increase of air pressure inside the balloon until the balloon bursts.

Chaos Theory

Chaos Theory is concerned with those instances when doing the obvious thing does not produce the obvious desired outcome. It is concerned with behavior that varies in such a complicated way that one cannot predict exactly what will happen in the future (Cutright 2001). Chaos Theory examines natural systems that are governed by simple laws yet can evolve into extremely complex and volatile behaviour. While both natural and human systems or organisations appear to have stable or consistent patterns which allow some degree of accurate prediction, these systems are in fact unpredictable because they are unstable: "make a slight change to the way a system is by a small amount at one time, and the later behaviour of the system may soon become completely different (Hawking 1994, Cutright 2001)". The theory also highlights that the future will not be simply a linear extrapolation of the past and that the small events happening today will cause unexpected new patterns to develop downstream.

There are similarity and difference between the Balloon Theory and Chaos Theory.

(1) Similarity

Small events happening today will cause failure in future. At certain points small changes within the system will produce great and unpredictable results. Both theories can be applied to predict falsework failure based on accumulation of small errors.

(2) Difference

Using Balloon Theory, the same errors if repeated can lead to another falsework failure. Based on the Chaos Theory, the failure outcome would have no resemblance to the past.

10.3 Graphical presentation of errors accumulation

The following illustrates graphically the accumulation of pressure/ errors leading to failures at different stages of falsework design and construction.

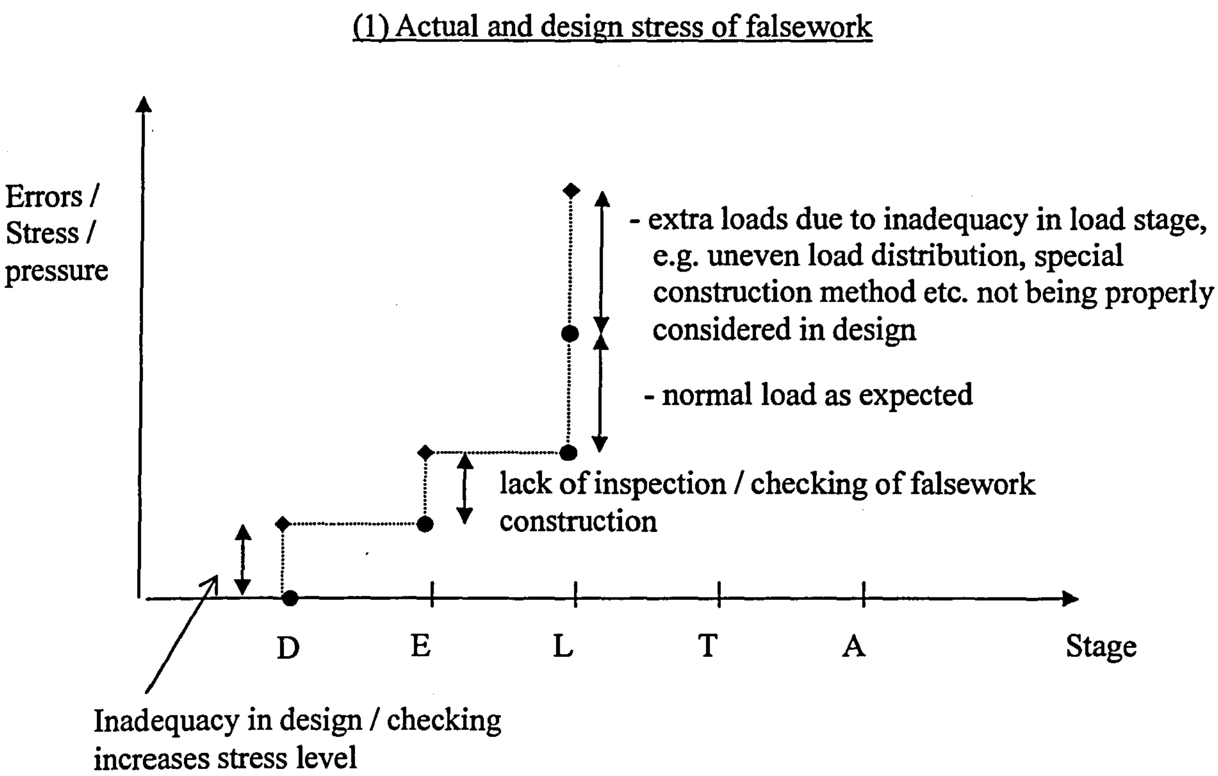


Figure 10.2: Accumulation of stress applied to falsework at different stages

During the taking down stage, improper procedures, depending on the degree of completion and self-supporting of permanent works, can cause a failure. In the anew stage, the degree of maintenance and repair applied to falsework material influences the maximum allowable stress and hence the actual factor of safety.

(2) Typical failure at erection (4% by stage)

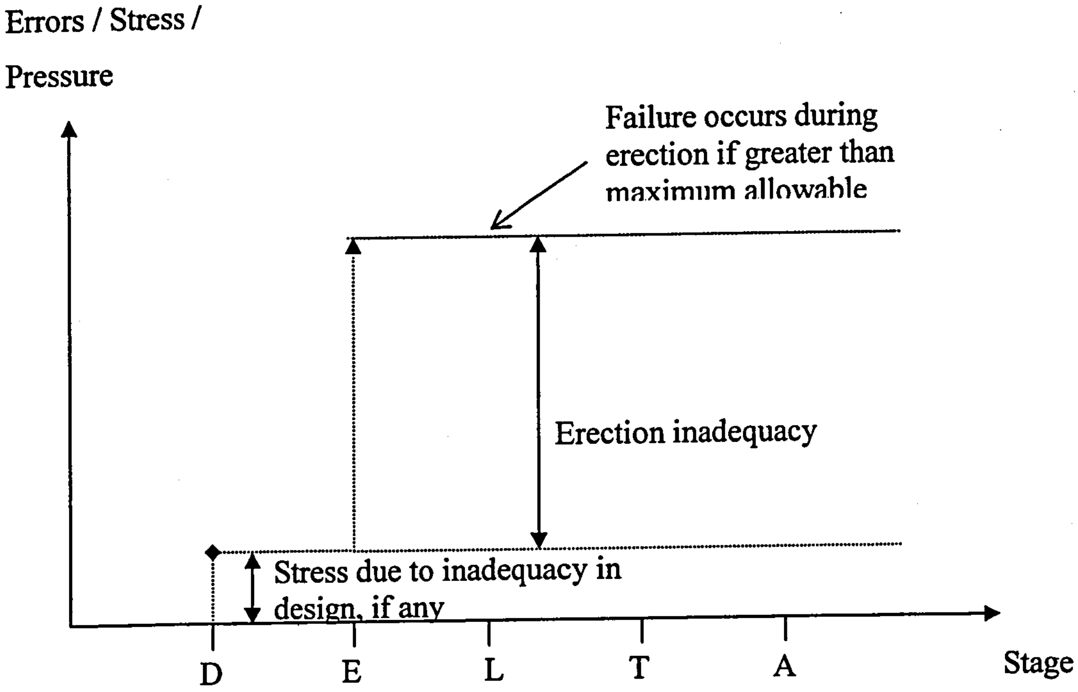


Figure 10.3: Typical failure at erection

During and or after erection, but before loading, failure will occur if the summation of stresses from the design and erection exceeds the load bearing capacity. This is the case of failure occurred in Shenzhen, China in November 2000.

(3) Typical failure at load / use (82% by stage)

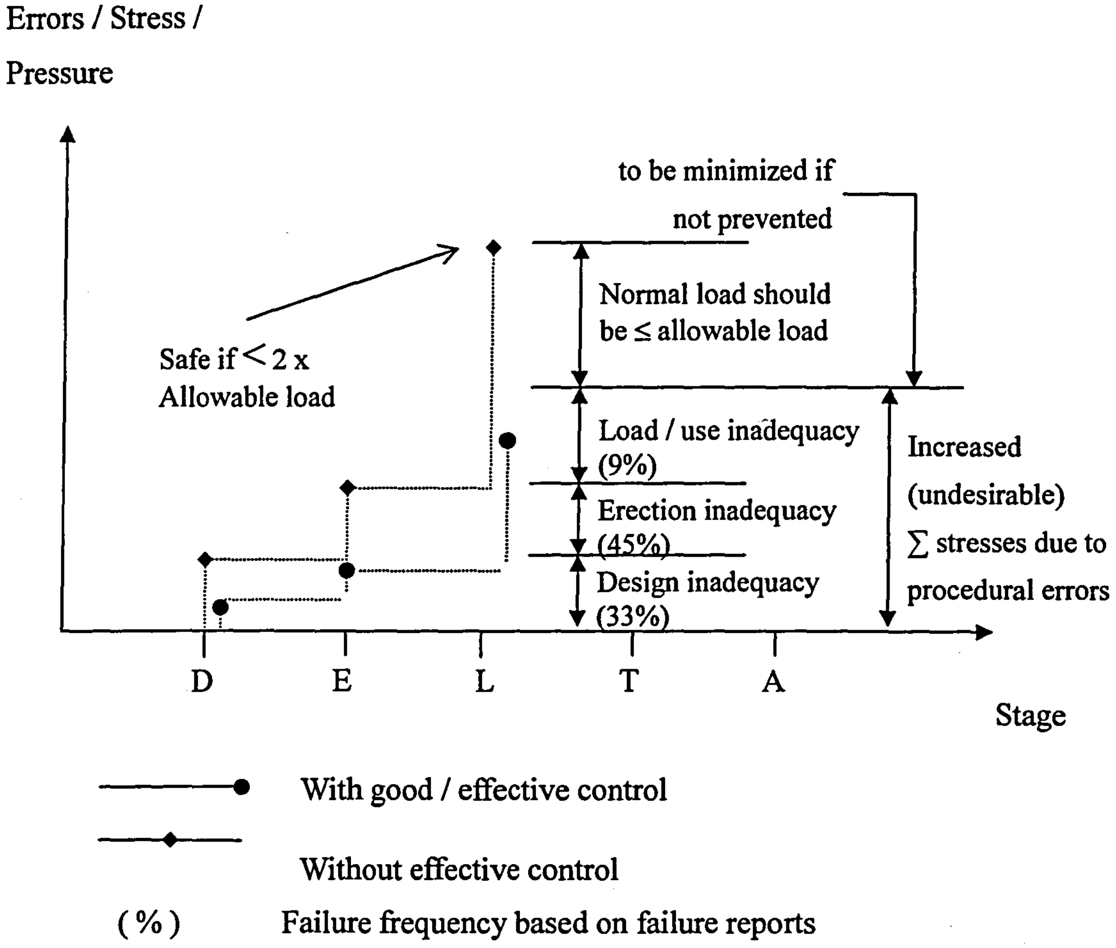


Figure 10.4: Typical failure at load / use

Effective control at various stages can reduce the errors. In Figure 10.4, the two summations indicate the difference if effective control has been implemented or not.

Falsework is often designed with a Factor of Safety of two. Normally the load applied to the falsework will be about equal to one allowable load. For failures to occur, the summation of the unexpected loads should be at least one allowable load.

(4) Typical failure at Taking down (12% by stage, 13% by reason)

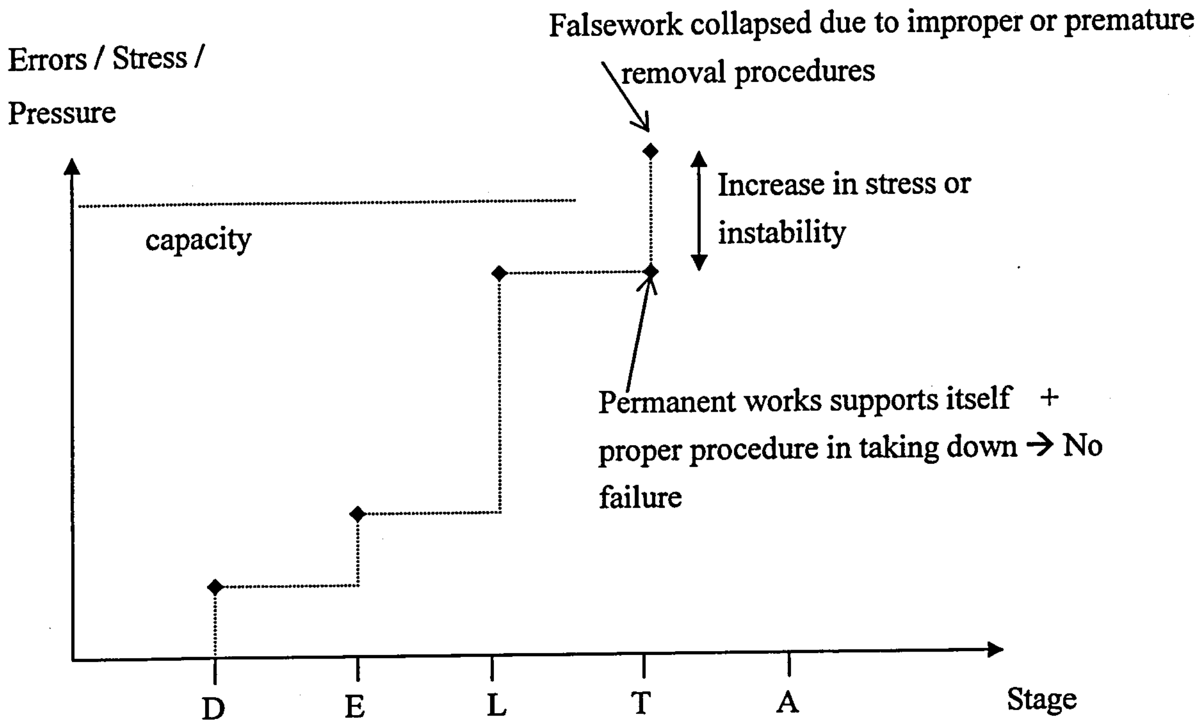


Figure 10.5: Typical failure at Taking down stage

Failure at Taking Down stage depends on:

- whether the permanent works is properly constructed and is self-supporting; and
- a proper dismantling procedure for falsework has been followed.

Premature dismantling or improper procedures will lower the bearing capacity, or increase stress or instability of falsework.

10.4 Assessment of pressure / risk based on Balloon Theory

Risk can be assessed as the product of Consequence and Frequency. Inadequacy in each activity of any stage in falsework construction would and could contribute to higher risk of falsework collapse.

Risk of falsework collapse = Consequence x Frequency **Equation 10.1**

In the case of a cause with high impact and high frequency, the risk will be very high.

i.e.Risk = High impact x High frequency
= Very high

If a cause of very low impact and with a very low frequency of occurrence, the risk would be very low.

i.e.Risk = Low impact x Low frequency
= Very low

The product of two risk factors is shown in Table 10.3.

Table 10.3 Product of two risk factors

Risk factor				
H	M	H	VH	
M	L	M	H	
L	VL	L	M	
	L	M	H	Risk factor

Note:

L – Low VL – Very Low
M – Medium
H – High VH – Very High

Consequence can be regarded as degree of severity of the impact with respect to a specific cause, which will increase the pressure or risk. The risk can be modified by the effectiveness in controlling the operations. The more effective the control, the lower will be the risk.

The procedural framework illustrates the development of a failure as an analogy to the inflation of a balloon. The accumulation of procedural errors is the pressure of the air. If the pressure or errors of the events build up until the balloon is very stretched then a triggering event would cause the balloon to burst. The pressure (or risk) from the event or cause = Consequence x Frequency.

In the case of an actual failure due to one particular cause, both consequence and frequency are of very high value and should be equal to 1, i.e. risk = 1 × 1=1. Similarly, for low impact and of low frequency, risk = 0.

In other words, the range for risk lies within 0 and 1. For existing projects, subjective assessment for consequence and frequency is required. Reference can and should be made to the analysis of failure reports and the characteristics of the activity concerned for appropriate values of consequence and frequency.

The following are cases illustrating the severe conditions that have led to failure of falsework including the permanent works under construction. The principle is that if there is no effective checking for a particular procedure and its frequency and consequence towards failure of falsework is very high, the assessment score would be 1 x 1 x 1= 1.0 (no checking x frequency x consequence). A very careless but important design without checking (factor = 1) can easily lead to collapse of falsework if occurrence of such happening is very frequent. So the likely severity of harm (i.e. the consequence) is collapse i.e. 1, and frequency is 1, therefore 1 (no control) x 1 (severity of harm) x 1 (very frequent) = 1.0 (risk is very high)

Failure due to dominant factors at different stages:

Case 1: Gross error at design stage with falsework failure at load / use

If the procedure inadequacy occurs substantially at the design stage, then the overall aggregate of ΣD = 1.0 (minimum) implies that a failure would occur in later stages even only normal load as allowed in the design will be acting on the falsework later, and the falsework would be erected according to the drawings. (Assume the error is small at erection stage).

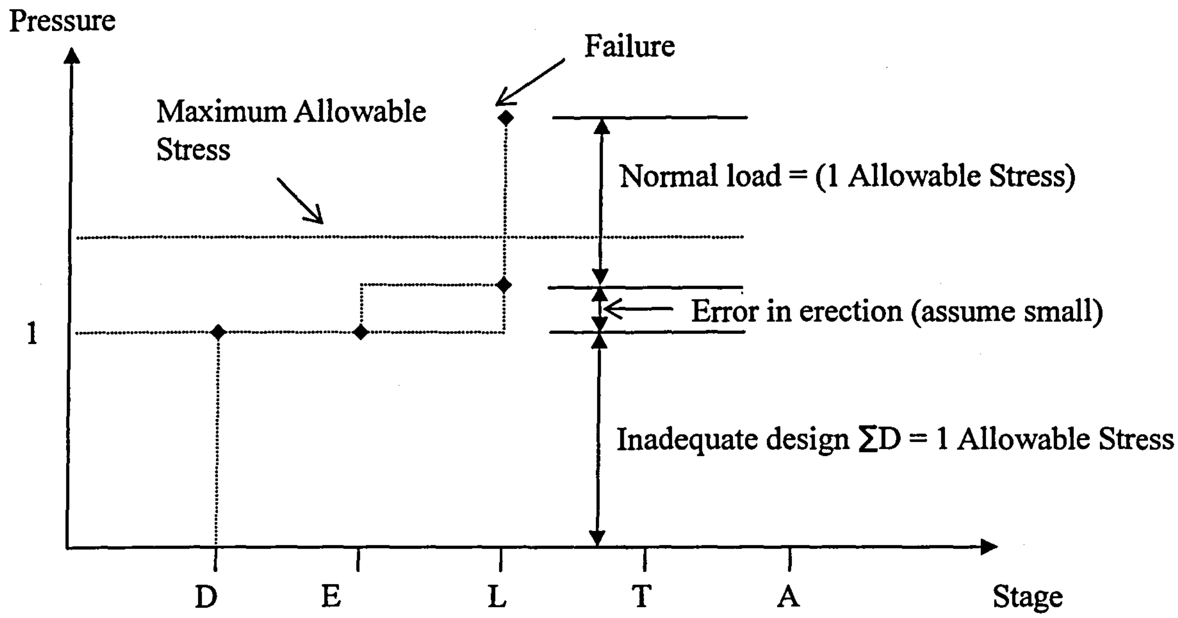


Figure 10.6: Gross error at design stage

Reference cases:

No. 11 Israel (1994)	ΣD = 1 Allowable Stress
No. 7 Guangdong, China (1996)	ΣD = 1 Allowable Stress
No. 28 Tuen Mun Highway, Hong Kong (1992)	ΣD = 1 Allowable Stress

Case 2: Gross error at erection stage with falsework failure at erection stage (1) or at loading stage (2)

If failure occurs because crucial errors occur at the erection stage i.e. $\Sigma E = 2.0$ which guarantees an instant failure at this stage e.g. the falsework for Tsing Yi – North Bridge, collapsed during rectification of falsework, not necessarily including any errors that might have been brought forward from the design stage. The failure could occur later during the loading stage. Similarly the falsework collapsed in Shenzhen, China after erection but before loading.

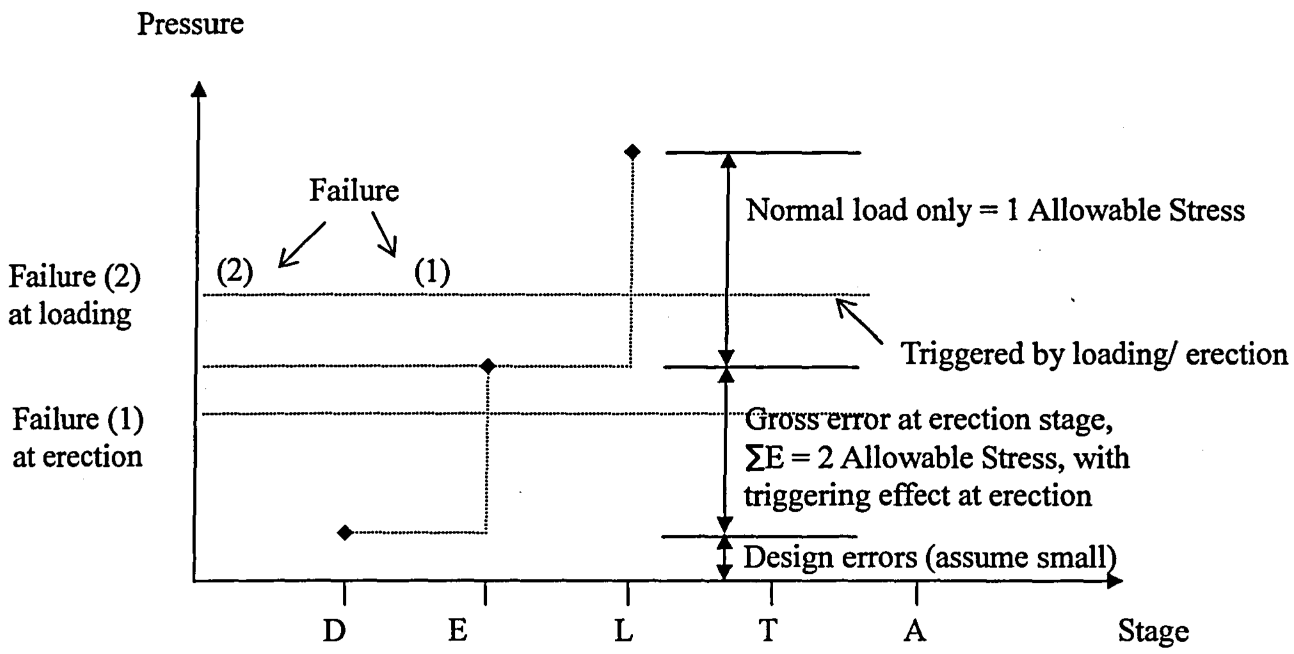


Figure 10.7: Gross error at erection stage

Reference cases:

No. 1	Shenzhen, China (2000)	$\Sigma E = 2 \times$ Allowable stress
No. 19	North Tsing Yi Bridge, Hong Kong (1986)	$\Sigma E = 2 \times$ Allowable stress

Case 3: Gross error at loading / use stage leading to falsework failure

If failure occurs at the loading stage and because there is insufficient consideration of the loads acting on the falsework, the score ∑L = 1.0 irrespective of the errors that may have been brought forward from the design and erection stage.

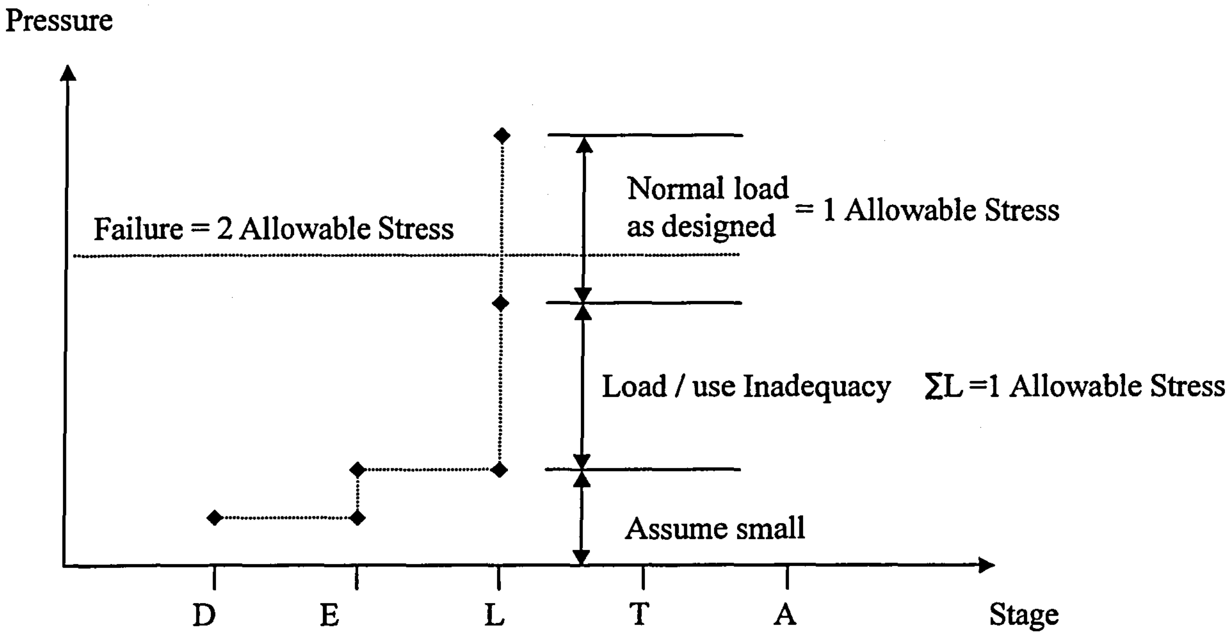


Figure 10.8: Gross error at loading stage

Reference cases:

No. 10	Tseung Kwan O, Hong Kong (1996)	∑L = 1 Allowable Stress
No. 6	Guangzhou, China (1997)	∑L = 1 Allowable Stress
No. 13	Telaviv, Israel (1994)	∑L = 1 Allowable Stress

Case 4: Accumulation of errors from various stages

For cases where individual stage error is less than 1 but the aggregate of errors from previous stages can lead to collapse if $\Sigma D + \Sigma E + \Sigma L > 1$. This has been suggested by the Bragg's Report (1975).

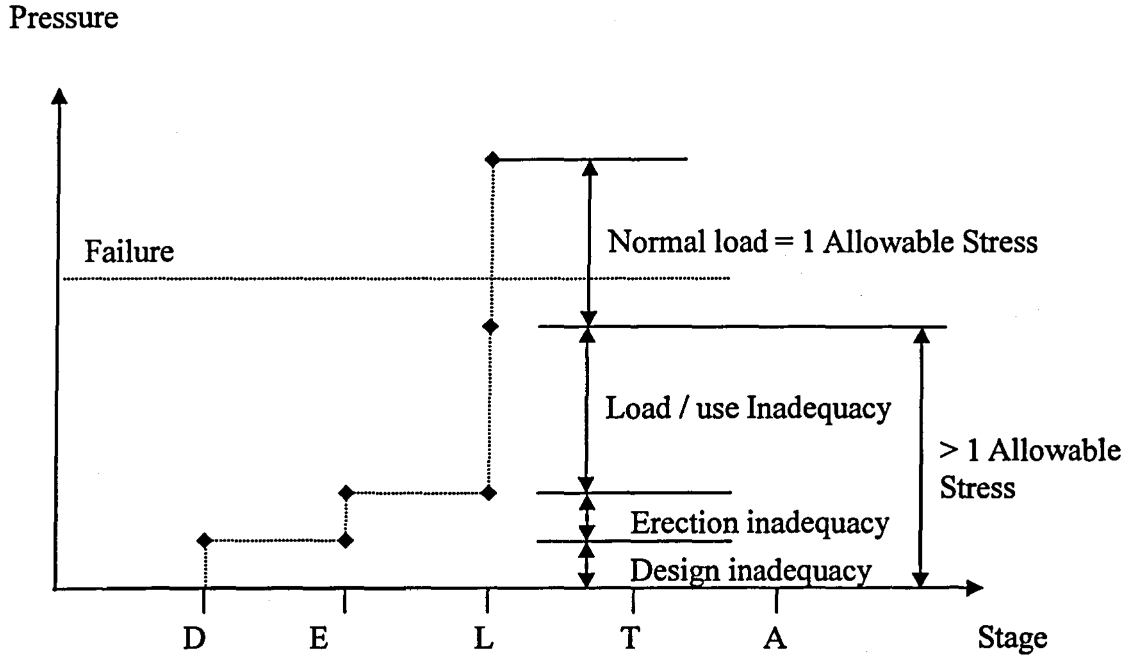


Figure 10.9: Accumulation of errors

Reference cases:

No. 36 Route 3, Hong Kong (1995) Σ (D+E+ L) = 1 Allowable Stress

This is the case when individual error from the design, erection or loading stage would not be able to cause the failure. However, the aggregation of the errors would be in excess of one Allowable Stress.

Case 5: Gross error at taking down stage

Failure occurs during taking down stages.

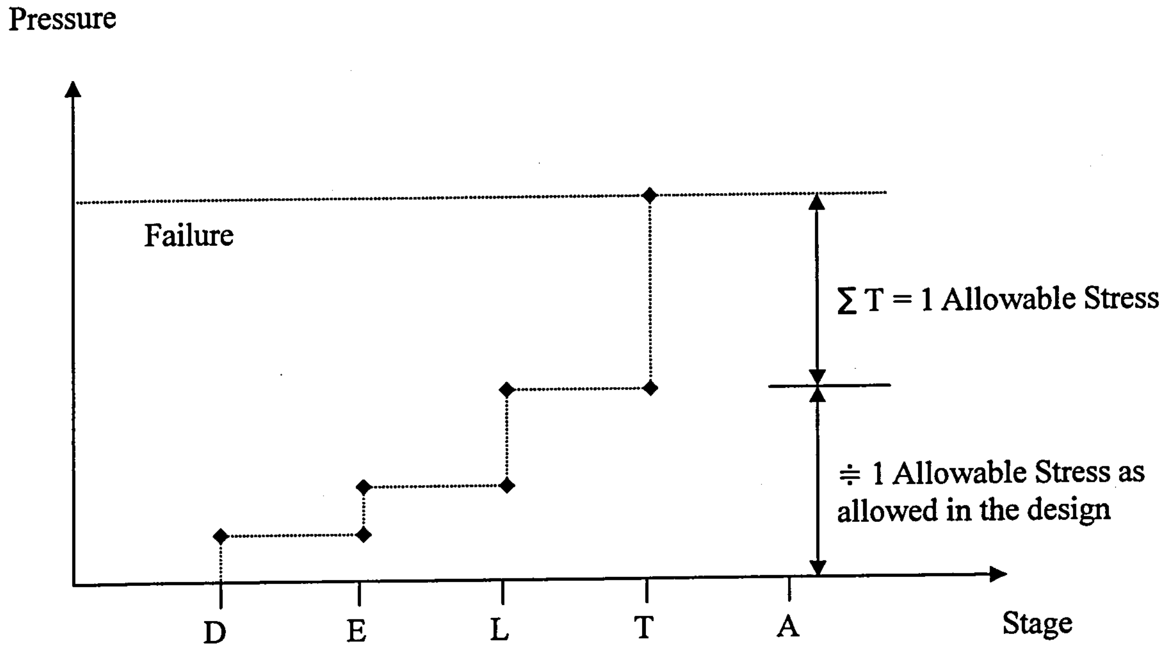


Figure 10.10: Gross error at taking down stage

Reference cases:

No. 9 Jakarta, Indonesia (1996)	Σ T = 1 Allowable Stress
No. 16 Chongqing, China (1988)	Σ T = 1 Allowable Stress

The falsework before taking down should have been supporting a load of one Allowable Stress. The error caused by this stage would be equal to at least one Allowable Stress.

For a particular procedure, the risk (pressure or Degree of Inadequacy) is to be assessed in two aspects:

(1) The consequence of such inadequacy towards collapse

		Score (Range between zero and one)
Ranking	– very important	1
	– important	0.5
	– not important	0.2

(2) Frequency of collapse due to such reason

		Score (Range between zero and one)
Ranking	– very high	1
	– average	0.5
	– very low	0.2

Risk of collapse = (1) x (2)
= pressure (in the Balloon)

From simple failure reports, usually only one or two reasons would be given as the major causes. The minor causes are always hidden as they are difficult to identify or quantify. In detailed reports / investigations, there may be elaboration of more causes, i.e. with major and minor causes included after a thorough study of the failure.

The overall score of a procedure or a stage would be modified by the degree of effectiveness of control. For example, when the effective third party checking and approval is employed, then the factor will be 0 or close to 0. For conventional R.E. checking, it varies between 0 to 1.0 (i.e. from very effective to not effective).

10.5 Back analysis of failure using the procedural framework

From each failure report, the following factors are identified:

1. Causes
2. Weight (risk)
3. Frequency = 1 for actual case

The explanation of the assignment of Weight / Risk / Score is as follows.

(1) If there is only one substantial cause, the weight should be minimum 1.0 (one allowable stress in Hong Kong).

(2) If there are 2 causes (described as major and if there is no difference made between them), the major weight should be 0.5 ~ 0.7 = 0.6, say 0.6 x 2 > 1.

(3) Other suspected or minor causes, the weight should be 0.2 ~ 0.4, say = 0.3

(4) Very minor causes, the weight should be 0.05 ~ 0.1, say = 0.1.

Categorisation of the causes will depend on content analysis and subjective interpretation. For the failure cases in Hong Kong, all summation of the scores will be greater than one allowable stress or two depending on the collapse stage. This can be a back checking method to assure that there are sufficient substantial, major or minor causes identified from the failure reports for a failure to occur. A scale factor, i.e. the degree of reliability of various types of reports might be applied to the results and check their degree of sensitivity.

Based on the above principle, the assignment of procedural inadequacies for five failures in Hong Kong is shown in the following table.

Table 10.4: Procedural errors

Case No.	Design	Erect	Load	Take Down	Anew	Failure stage	Σ=
5		Substantial				Loading	1
10	Major	Major	Major			Loading	1
11	Substantial	Minor	Major			Loading	1
19		Substantial				Erection	2
28	Substantial	Minor				Loading	1

Case No. 5

This involved the construction of a cast in-situ ramp and was a typical inadequate erection without proper checking and failed during concreting. The conventional control system was adopted.

Case No. 10

The falsework was used to support two long bridge beams at a height of 2m above their final support. A change in construction method with inadequate design and construction supervision led to failure during loading. Independent Checking Engineer's approval of the design changes should be required.

Case No. 11

This is a case of providing support to a precast concrete bridge segment. The falsework failed due to the absence of checking the design and no supervision during loading, although Independent Checking Engineer system was used.

Case No.19

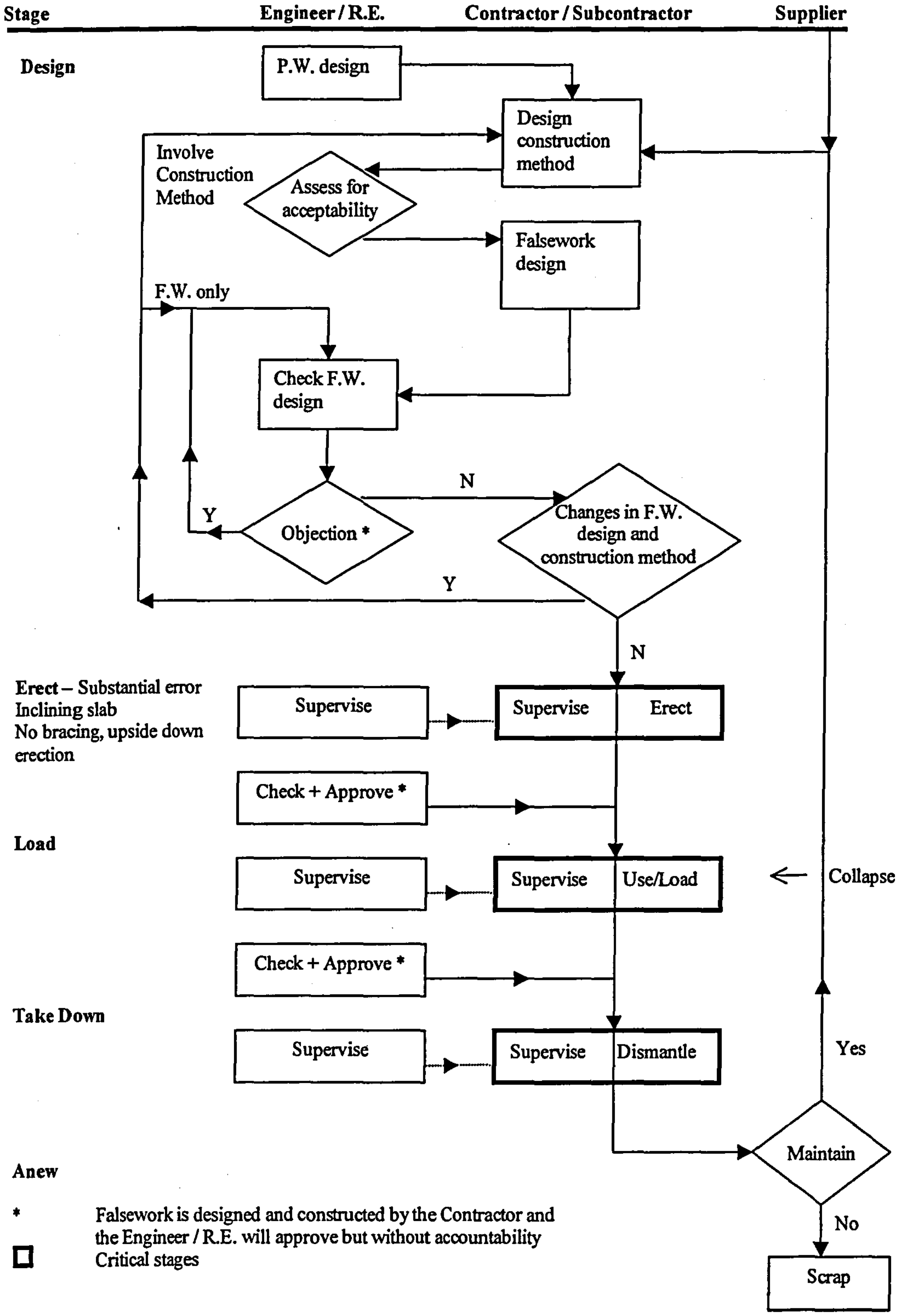
This was an improper rectification of falsework without supervision during erection, which caused the failure.

Case No. 28

The conventional control system was adopted. There was inadequate design without proper checking and site supervision. The falsework collapsed towards the end of concreting operation.

Hence, the five cases in Hong Kong is a fairly good representation of different failure cases in the design, erection and loading stages. The flow charts for the above cases are shown in the following pages.

Procedural framework 1: Conventional Control System



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Figure 10.11: Case No. 5, Tsing Yi, Hong Kong

Procedural framework 2: Independent Checking Engineer System (ICE)

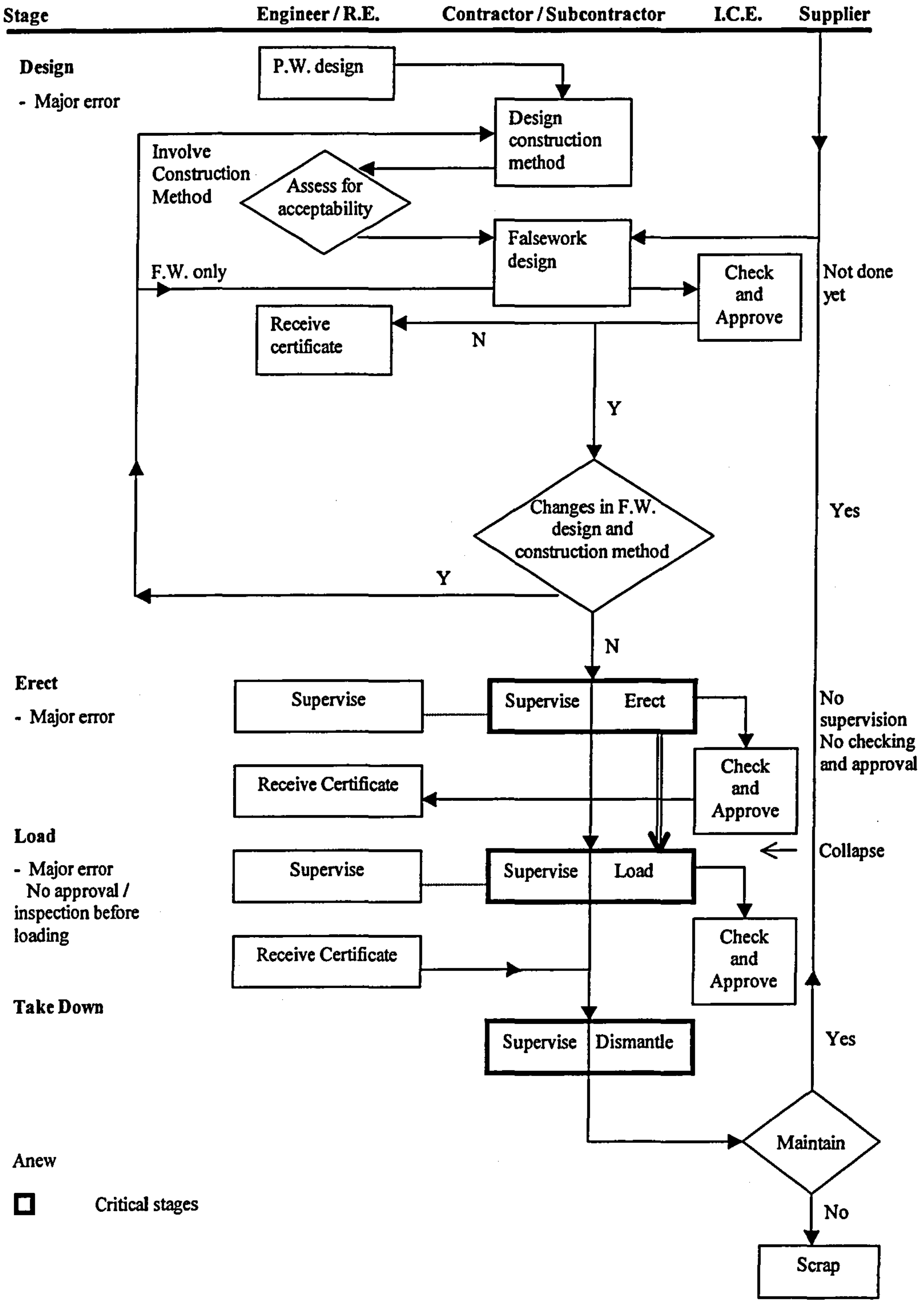


Figure 10.12: Case No. 10, Tseung Kwan O, Hong Kong

Procedural framework 2: Independent Checking Engineer System (ICE)

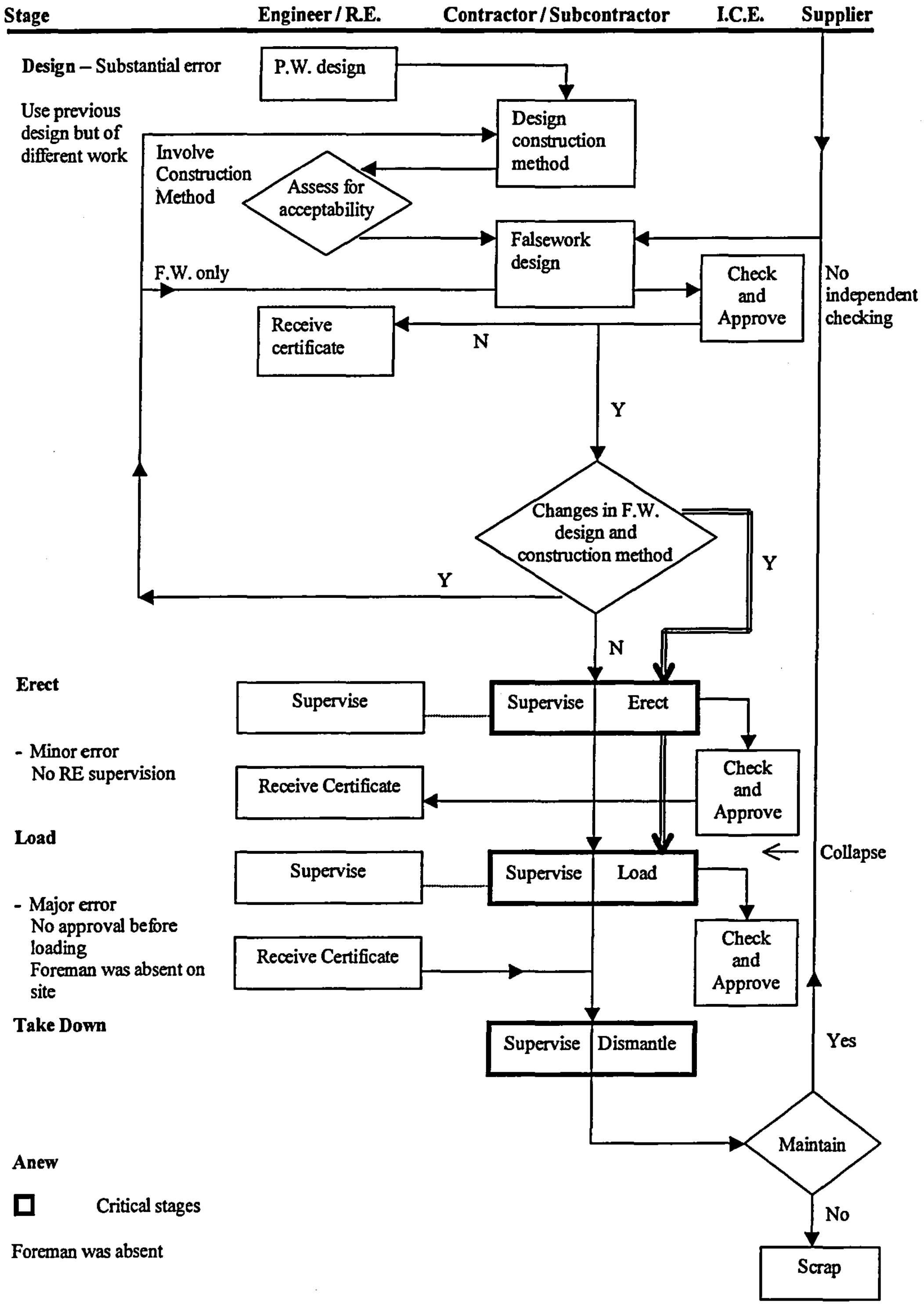
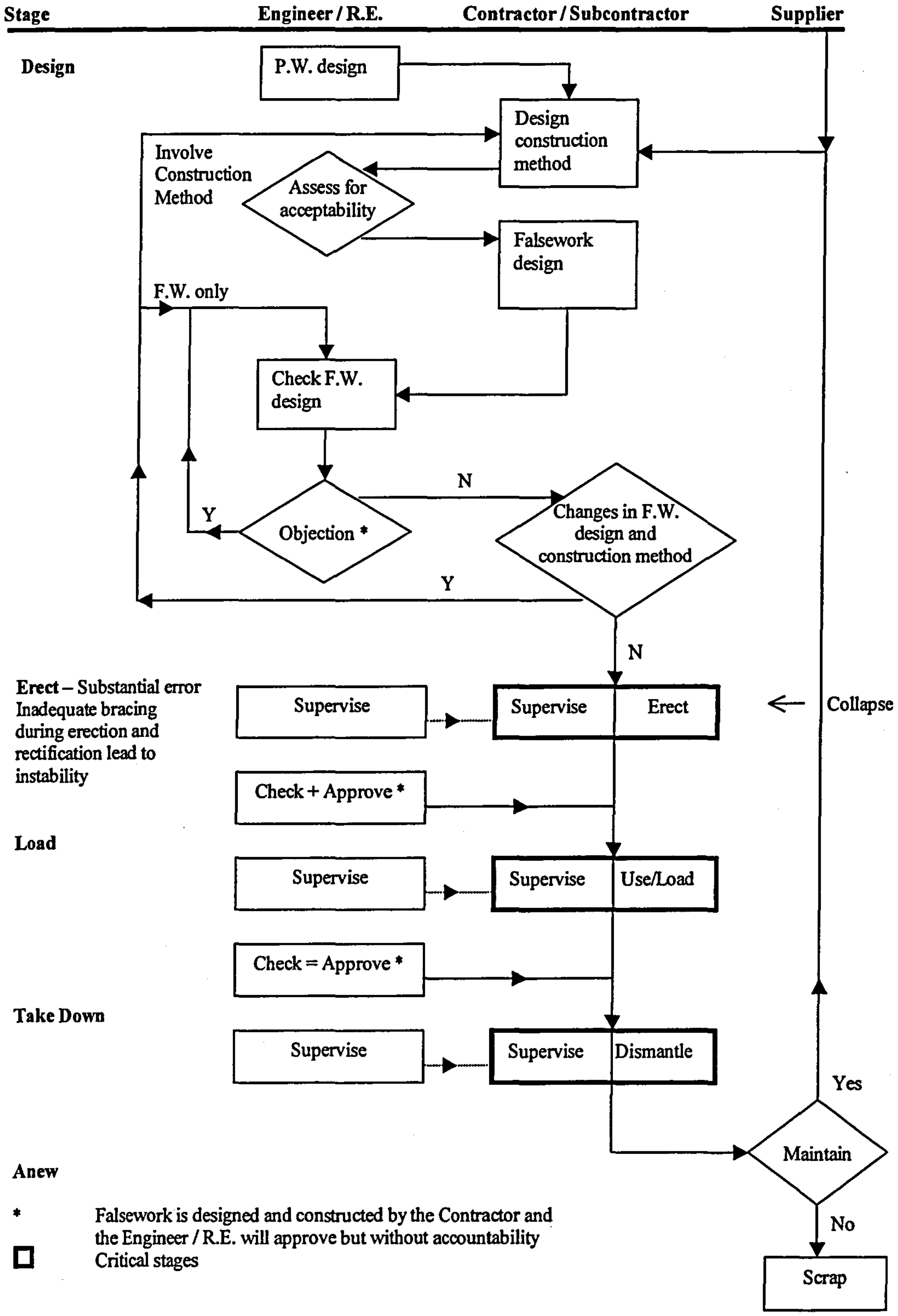


Figure 10.13: Case No. 11, Route 3, Hong Kong

Procedural framework 1: Conventional Control System

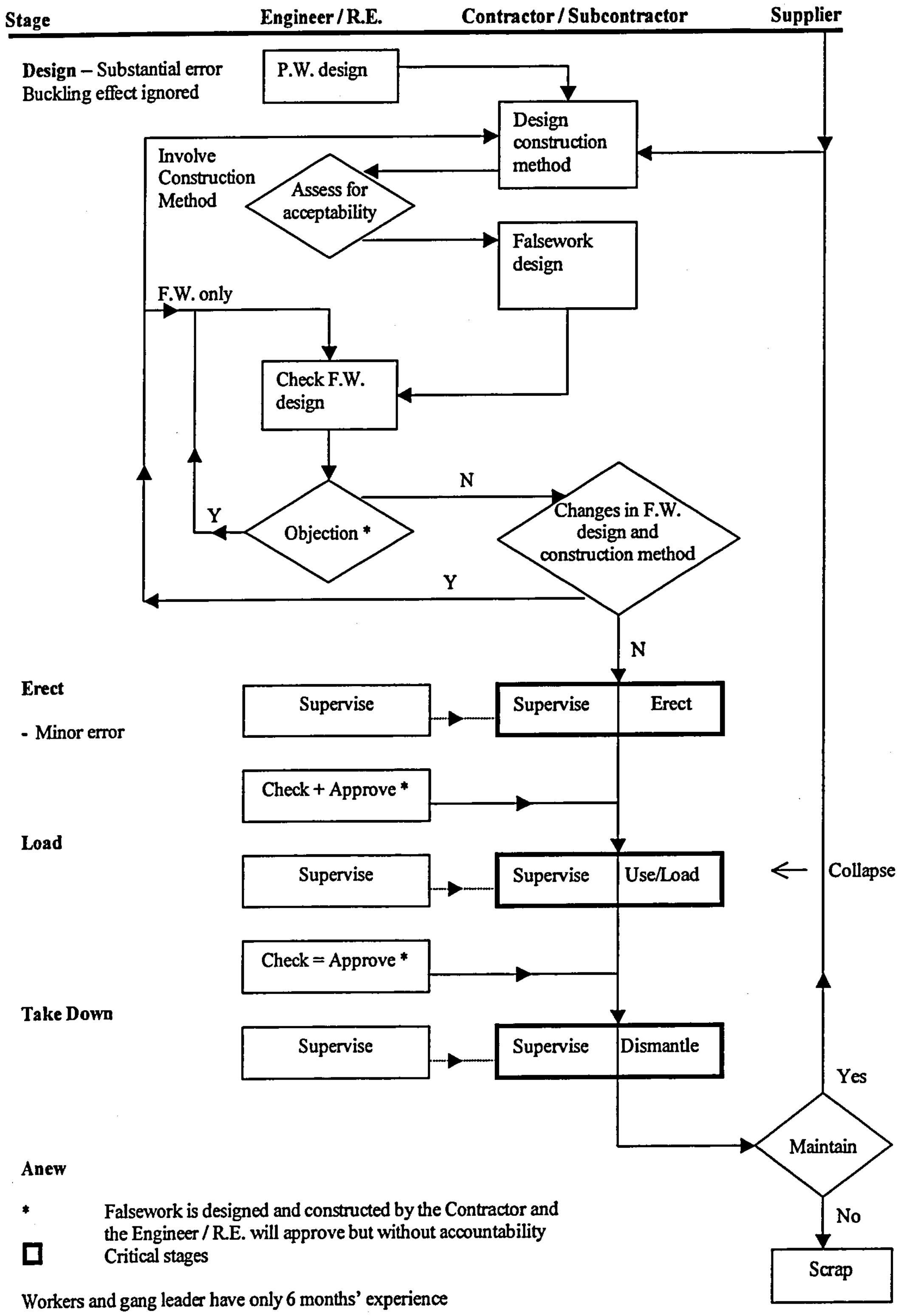


* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Figure 10.14: Case No. 19, Tsing Yi, Hong Kong

Procedural framework 1: Conventional Control System



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Workers and gang leader have only 6 months' experience

Figure 10:15: Case No.28, Tuen Mun, Hong Kong

To assess the magnitude of errors, the method of equating the errors to the allowable stress is adopted.

From case No. 5 in Table 10.5, a substantial error should be at least equivalent to one allowable stress. From case No. 10, the value of the major error should be 0.4 allowable stress. The minor error cannot be established due to a lack of sufficient data. The values of the errors are shown in Table 10.6.

Table 10.5: Summation of the causes

Case No.	Assignment of causes			Allowable stress
5/ 19	1 Substantial			≧ 1/2
10	1 Major	1 Major	1 Major	≧ 1
11	1 Substantial	1 Minor	1 Major	≧ 1
28	1 Substantial	1 Minor		≧ 1

Table 10.6: Assessment of errors in procedures

Overall Procedure Analysis	Degree of Error	Erosion of Allowable stress	Other Factors
Content Analysis of failure reports	Substantial	Minimum 1.0	For actual failures: Frequency = 1 Control = 1
	Major	Minimum 0.4	
	Minor	Cannot establish	

Correlation between degree of error and erosion of allowable stress can be confirmed by back analysis of failures with Σ errors > 1 in the loading stage or 2 in the erection stage.

For failure prediction purpose, the conditions of an existing project at all stages are checked against the corresponding condition of failure cases as shown in Table 10.7, 10.8 and 10.9:

Table 10.7: Content analysis for design errors (Hong Kong cases)

Case No.	Design Stage	Degree of Error
10	Checking of design not completed by ICE.	Major to substantial
11	No design for this falsework.	Substantial
28	Design not checked with buckling effect ignored. Note: Inexperienced designer and without proper supervision.	Substantial

Table 10.8: Content analysis for erection errors (Hong Kong cases)

Case No.	Erection Stage	Degree of Error
5	No bracing and poor foundation construction.	Substantial
10	No supervision, no checking and no approval of the erection. No R.E. supervision.	Major
11	Inadequate communication with workers (who did not speak English).	Minor
19	Inadequate bracing and no supervision during Rectification.	Substantial $\sum$=2
28	Lack of bracing.	Minor – Major

Table 10.9 Content analysis for loading errors (Hong Kong cases)

Case No.	Loading Stage	Degree of Error
10	No approval / inspection before loading.	Major
11	No approval of design and construction method before loading. No supervision by foreman.	Major

Similar categorisation of causes derived from failures can be used as a reference when prediction of proneness of failure is required. Relevant design errors are extracted from all failure cases and are shown in Table 10.10.

Table 10.10: Content analysis for design errors (from all cases)

Case No.	Design Error	Degree of error / Degree of Erosion of F.O.S.	Control by	
			R.E.	I.C.E.
7	Inadequate design	Substantial	No	
10	Design not checked / approved	Major – Substantial		Yes, but not on time.
11	Used previous design but for different work	Substantial		Yes, but by-pass I.C.E.
12	Inadequate foundation	Substantial	No	
13	Wrong assumption of even load distribution	Substantial	No	
14	Inadequate design for I-beam buckling failure	Substantial	No	
17	Design inadequacies	Substantial	No	

Other categorisation may include:

- types of construction e.g. post-tensioning, cast in-situ, precast segments;
- places of construction;
- conventional separate design and construction contract or I.C.E. system; and
- failure causes at different stages such as design, erection, loading and taking down.

For prediction purposes, each procedure is assessed with reference to the content analysis of failures and the degree of error, thus the anticipated eroded allowable stress is assigned. Accumulation of Σ errors is then plotted to indicate the proneness of failure.

For frequency calculation, refer to the analysis of failure reports plus subjective judgment. The following is recommended by Blockley (1975).

Frequency: Very High = 1.0
High = 0.8
Moderate = 0.6
Low = 0.4
Very Low = 0.2

The overall assessment of risk of any procedure = C x F x E **Equation 10.2**

Notes: C = Consequence
F = Frequency
E = Effectiveness in control

Values for C and F are based on the content analysis of all failures and E is determined from analysis of failure reports or subjective judgement.

The assessment of existing projects compared with failures can be shown in Figure 10.16.

Assessment on Existing Project

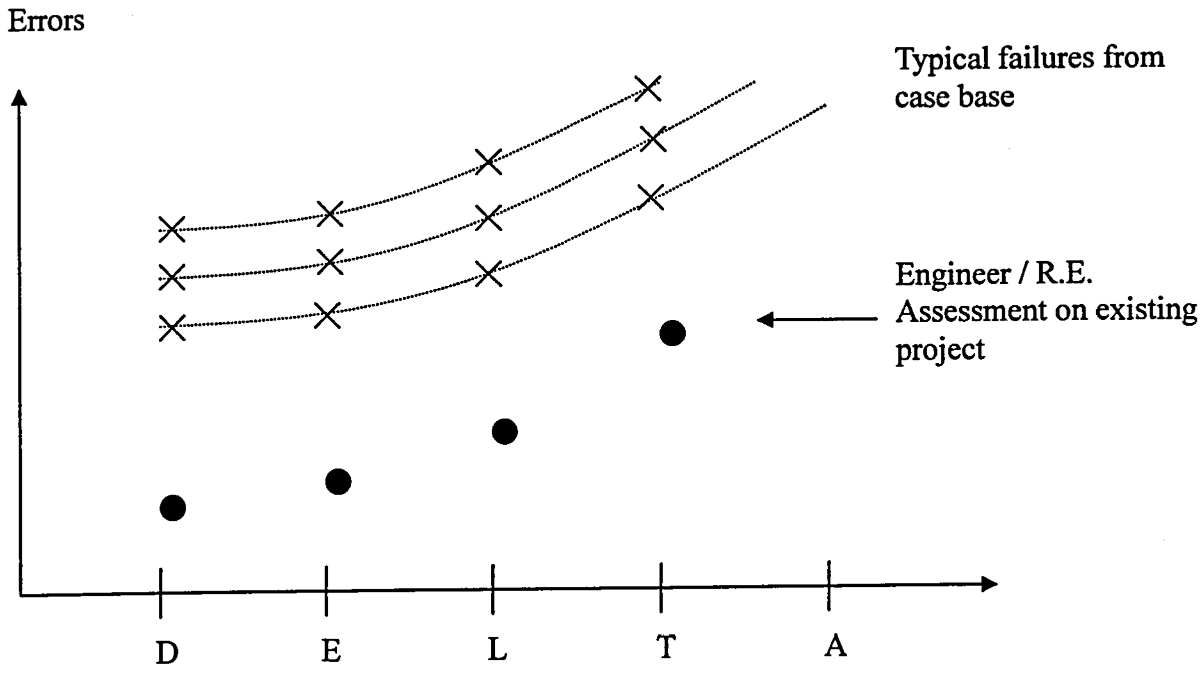


Figure 10.16: Comparison between successful projects and failures

This method can be used to assess and compare the effectiveness of different control systems, i.e. the conventional, Independent Checking Engineer and Falsework Coordinator System, if sufficient data is available. Professionals of a project involving falsework construction can assess in accordance with the principles established and check against the previous failure cases. The graph is useful in gauging the safety conditions at various stages of an existing or a future project (Wirba et al. 1996), and to give warnings of the likelihood of a failure well before it occurs.

One condition for the above to realize is to gather sufficient related failure reports. Sufficient data about description of the project, characteristics of construction works, construction method, control mechanism and effectiveness in control will be required and stored in a case base. The development of the procedural framework is represented in the following chart.

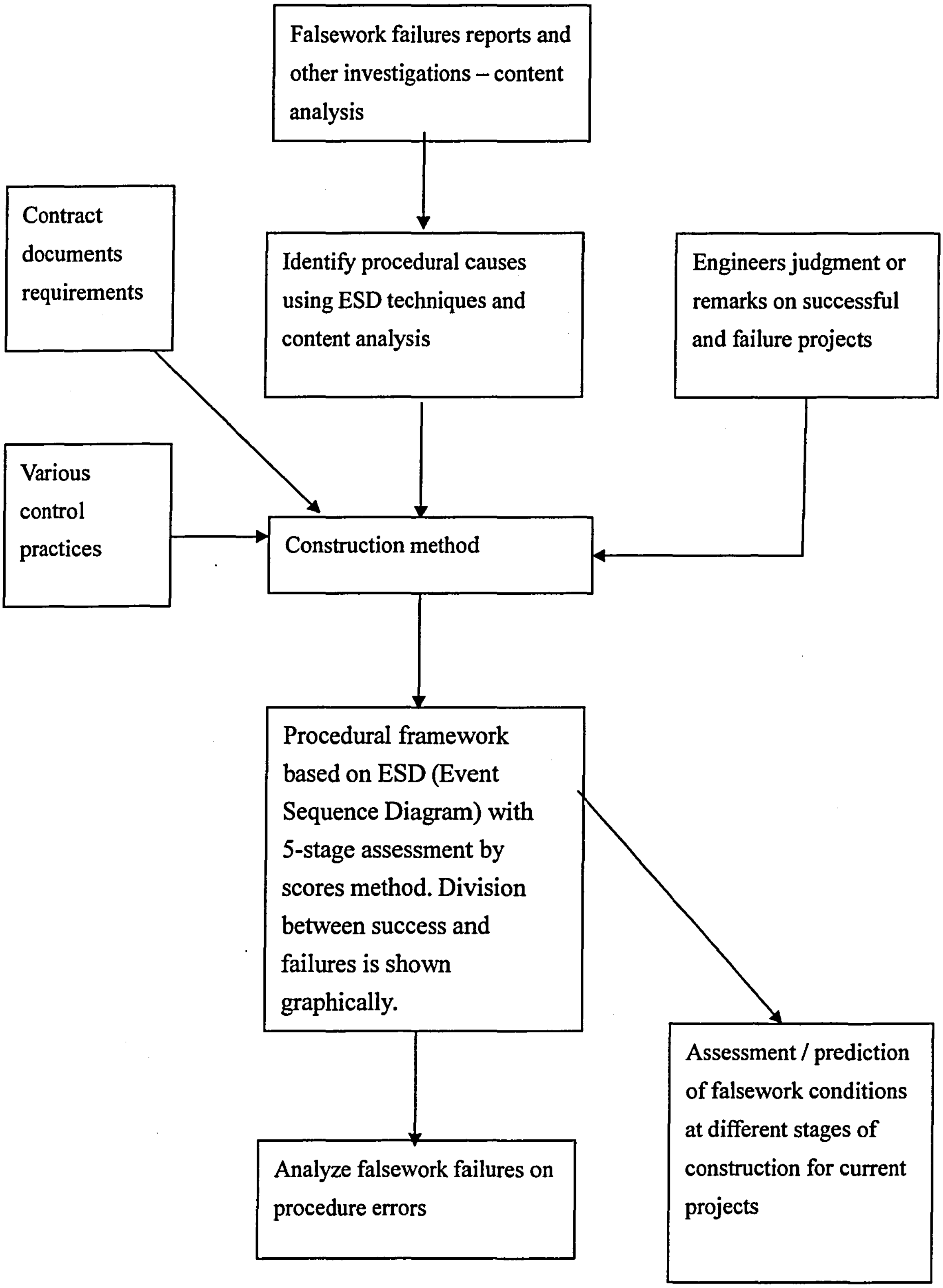


Chart 10.1: Development of the procedural framework

10.6 Summary of the procedural framework

The structure of the procedural framework consists of the following components.

(1) Graphs of error accumulation

These illustrate the accumulation of procedural errors at various stages and also the stages at which failure occurs.

(2) Flow charts

These charts present the essential activities and roles of personnel involved in falsework design and construction. Different charts are developed for the Conventional Control System, Falsework Coordinator and Independent Checking Engineer system.

(3) Summation of procedural errors from falsework failure reports

Procedural errors are assigned to failure causes and are summed to equal to a failure.

(4) Assessment of possible causes

Based on failure causes and professional judgement the severity of procedural errors is assessed to analyse the failure or predict the proneness to failure.

Literature findings incorporated in the procedural framework include the following.

- Essential activities of falsework design and construction.
- Grouping of activities into five stages.
- Role of personnel involved in falsework activities.
- Causes of falsework failures and their severity.
- Analysis and prediction methods for failures.

A checklist can be attached to the flow chart for use by relevant parties particularly the Contractor in falsework selection. The checklist should include the following:

- construction method for the permanent works;
- type and loadbearing capacity of falsework required and available;
- new or used materials; and
- particular requirements in erection and dismantling.

10.7 Validation of the procedural framework developed

The analysis and prediction procedural framework for falsework failure needs to be validated in order to justify its usefulness and application. Construction professionals were interviewed and were presented the flow charts and the procedural framework. They were asked to:

- confirm the flow of activities and the role of various parties;
- comment on the use of the flowchart; and
- comment on the problems of the existing control system.

A total of eleven interviews with fifteen professionals were conducted. Each interview lasted on average one hour. The following is the summary of the interview findings:

(1) Dr. A is a professional engineer who has extensive experience in temporary works design and construction. He has involved in over 100 jobs and, since 1992, has been employed as ICE for falsework construction. He has also investigated collapse cases and undertaken remedial works. He commented many contractors in the industry has attempts to lower the F.O.S. in the design, thus control of falsework design is very important and essential. He agreed fully with the flow charts developed for the three control systems. Based on his experience and knowledge, he commented that the F.O.S. of falsework generally would drop from 1.6 – 1.7 in the design stage to about 1.2 in loading stage. He also commented that only if R.E. insists, the approval certificate will be prepared by the ICE, otherwise no professional engineer's checking would be required. He also predicted that twenty to thirty percent of falsework would have failed if without third party checking.

(2) Mr. B and Mr. C are Principal and Assistant Engineer respectively of a Consulting Firm performing as an Independent Checking Engineer for about fifteen years. Mr. B has involved in over thirty-five cases of falsework design checking and Mr. C has experience of twenty falsework jobs. They commented they very often the young graduates of the contractor designed the falsework and there are often inconsistency between the design and the erected falsework. They both agreed that falsework is often designed with a factor of safety of two. The loadbearing

capacity indicated in the falsework product brochure is often used in the design unless the ICE specifically requires the scaffold materials to be tested. They shared the view that errors mostly occur in the erecting stage with the failures mainly happened in the loading stage. Based on their professional judgement, most falsework could only have a F.O.S. of 1.2 after loading if without proper checking by the ICE.

(3) Mr. D, Mr. E and Dr. F were staff of a major scaffolding material supplier in Hong Kong. Mr. D was the general manager who set up the company and has twenty-seven years of falsework construction related experience. Mr. E is project engineer with twelve years experience and Dr. F has two years experience in falsework design.

During the interview with the captioned professionals, they endorsed the flow charts of the Conventional Control and the ICE system and have the following comments.

- Very often the ICE only certifies the falsework design and not the construction, and checking of the falsework erection will be left to the contractor's staff who are most likely foremen and not engineers.
- There is a lack of a monitoring system or a checklist for site staff to assess the safety of the falsework.

(4) Mr. G is a senior structural engineer now working in a government department. He has over twenty-three years design and construction experience, particularly in the investigation of structural failures during the recent years. He has been involved in the drafting of the Code of Practice for Metal Scaffolding Safety.

While being presented the graphical illustration of the procedural errors leading to collapse of falsework, he agreed very much on the principle of error accumulation leading to failures.

He had particularly emphasised the common inadequacy during falsework erection. Based on his experiences of investigating the collapses, he suggested the common causes are as follows.

- Design stage
  - No calculation.
  - Horizontal load was not considered.
  - No checking of calculation.
  - No drawings.
- Erection stage
  - No manual for erection.
  - Wrong material was used.
  - Wrong erection method.

Also, he regarded the factor of safety, usually specified as two in the catalogues is unreliable and should be reduced for used materials.

To conclude, he considered safety management of the falsework design and construction is very important and the present views of the construction professional towards falsework as a kind of unimportant temporary works would substantially reduce the factor of safety of falsework.

(5) Mr. H has thirty-five years experience in construction safety since he started his career in the Labour Department. He was the Founder President of the Society of Registered Safety Officer in Hong Kong in 1991 and established his consulting firm three years ago. He has taken part in investigating construction accidents including falsework failures. His experience was largely related to implementing and complying with the safety regulations. He held the view that the preparation of a checklist based on the failure causes would be useful for site staff in order to avoid failures. He also agreed that proactive assessment of risk and safety condition on site has become a trend and should apply to falsework construction in view of so many collapses in recent years.

(6) Mr. I is a recently qualified professional engineer who is presently working as an Assistant Resident Engineer on a civil engineering construction site. He has eight years experience including two falsework designs and six jobs of falsework construction. He agreed the activities shown in the flow chart presented to him.

He opined that the R.E. should have professional conduct in supervising the site works, although they had no responsibility in checking the temporary works.

However, there was not a checklist available for site staff to follow in checking the falsework. The works supervisor normally checks according to the drawings or sketches available.

He considered the loophole of the ICE system was that the ICE had no knowledge of the erection process and could only check the "as constructed" falsework. He agreed that the accumulation of errors at different stages would lead to collapse and errors during erection were the major concern particularly when there was a lack of site supervision.

(7) Mr. J is a professional engineer with 20 years construction experience. He has been a Project Manager for 15 years. He has come across five to six falsework collapses. The major reasons of the failure were communication problem and no checking by professional engineer. Most of the failures occurred during concreting. Other common weaknesses were no design checking by the third party and removal of bracing member without replacement. He agreed that the flow chart is useful in delineating the responsibility of various parties and he commented that in general falsework construction would only have a F.O.S. of 1.5 after loading.

(8)Messrs. K and L are now working as Project Manager (15 years experience) and site agent (6 years experience) respectively. They have come across minor defects in falsework construction but not actual collapses. They both agreed with the flow charts and proposed that falsework would have a F.O.S. of about 1.5 after loading due to accumulation errors in procedures.

(9)Ms. M is procurement manager of a large construction firm and has 20 years experience in construction. She has involved in falsework construction during the last six years. She commented "no design", "no checking" and "no ICE checking" were common errors. The design and stability of falsework are very important but are frequently ignored. She commented that the procedural framework is very useful in predicting and warning the possible failures, and is a good indication of concern of safety. She estimated that the F.O.S. of falsework would have been reduced by 20 per cent after erection.

(10)Mr. N is the director and general manager of a building construction firm. He has over 17 years experience of falsework construction. He has witnessed falsework failures and undertaken urgent remedial measures. He agreed that collapse normally occurred during concrete casting or near completion of the concreting operation. He suggested the F.O.S. of falsework would be reduced by 20 per cent after erection and stressed that the design is very important but is often not properly checked.

(11) Mr. O is a Senior Engineer of Shenzhen Construction Safety Supervision Station in China. He has over twenty years experience in construction. He briefed that the employment of the safety supervision engineer in China is similar to the Resident Engineer in Hong Kong in ensuring the works are constructed in accordance with the design drawings and in a safely manner. He quoted the collapse of falsework in Shenzhen in 2000 was because of the lack of lateral bracing members. In that project, the supervision engineer was not independent because the client, the design engineer, the construction firm as well as the supervision engineer were all belong to the same government enterprise. He commented that the design of the temporary works prepared by the design engineer should have been checked by the government department and on site by the safety supervision engineer. He agreed that the flowchart of the "Conventional Control Type" is currently adopted for projects in Shenzhen and assessment of safety of falsework at various stages would prevent the falsework collapse.

The qualification and experience of the interviewees are listed in Table 10.11.

Table 10.11 Qualification and experience of interviewees

No.	Name	Qualification/ Present Title	Experience
1	Dr. A	Independent Checking Engineer	100 falsework jobs
2	Mr. B	Independent Checking Engineer	30 years construction experience 15 years with falsework design checking 35 falsework jobs
3	Mr. C	Independent Checking Engineer	4 years ICE experience 20 falsework jobs
4	Mr. D	Scaffolding Material Supplier	27 years experience

5	Mr. E	Project Engineer	12 years of falsework design and construction experience
6	Dr. F	Project Engineer	2 years design experience
7	Mr. G	Senior Structural Engineer	23 years experience particularly in falsework failures in recent years
8	Mr. H	Safety Officer and Safety Consultant	35 years in implementing safety regulations and accident investigation
9	Mr. I	Assistant Resident Engineer	6 years falsework construction 2 designs of falsework
10	Mr. J	Project Manager	20 years
11	Mr. K	Project Manager	15 years
12	Mr. L	Site Agent	6 years
13	Ms. M	Procurement Manager	20 years (6 years falsework experience)
14	Mr. N	Director and General Manager	17 years of falsework construction
15	Mr. O	Senior Safety Supervision Engineer	20 years of construction

The interviewees can be classified as different key parties involved in falsework construction and are categorised in Table 10.12.

Table 10.12 Categorisation of interviewees

Party	**Number**
Independent Checking Engineer	3
Falsework Supplier and Project Engineer	3
Government Structural Engineer	1
Safety Officer and Consultant	1
R.E./ Safety Supervision Engineer	2
Contractor – Project Engineer or above	5
Total	15

The fifteen professional interviewed generally agreed with the followings:

- the flow charts to indicate the activities and the roles of various parties involved in falsework construction;

- the usefulness of the flow chart in analysing the failures;
- the erosion of factor of safety at different stages of falsework construction would eventually lead to failure; and
- the usefulness of the procedural framework in providing warning about proneness to failures.

Some of the certified findings and the full name of the interviewees are included in Appendix D.

10.8 Summary

The two approaches to increase the proneness of falsework failures include lowering the loadbearing capacity of the falsework and increasing the stress (or instability) of falsework. Inadequacy in procedures will lead to either way and reduce the factor of safety of the falsework designed. Such effect can be aggregated in a particular stage and be carried forward to the next stage in the absence of an effective control system. The accumulation of the stress or pressure would eventually lead to failures when the loadbearing capacity of the falsework is exceeded.

Taking the similarity of bursting a balloon when pressure inside it is increased, the Balloon Theory is adopted to illustrate the falsework failure due to accumulation of pressure or errors because of the procedural inadequacies.

Pressure or Risk = Consequence x Frequency x Effectiveness in Control
(R) (C) (F) (E)

Using the score method, the range of scores for R, C, F and E is between zero and one. The risk can be modified by effectiveness of the control system adopted. For actual failures with only one principal cause, C=1, F=1, E=1, and R=1.

Falsework failures due to gross errors at different stages are illustrated graphically. They include the following.

- Gross error at design stage with failure at loading stage.
- Gross error at erection stage with failure at erection or loading stage.

- Gross error at loading stage causing the failure.
- Accumulation of errors for failure at loading stage.
- Gross error at taking down stage.

In practice, the scaffolding material is often designated with a factor of safety of two and is often designed to resist the allowable stress. The minimum stress or pressure for a failure to occur due to procedural inadequacy would be at least equal to one allowable stress in loading and two during erection stage.

For each failure, the causes, weight or consequence of the cause and the frequency (equal to one for actual cases) are identified or extracted from available reports. Assignment of scores to causes can be classified as substantial, major, minor or very minor. They are classified according to their description in the reports. From the analysis of the five typical failure cases in Hong Kong, the substantial and major causes would erode one and 0.4 of allowable stress respectively. The recommended values for minor causes, however, cannot be established because of the lack of data.

For prediction purposes, each project is checked against the causes in the case base with respect to relevant conditions. The case base should contain all failure analysis using the flow charts developed in Chapter 9. All procedures as far as possible are checked against the similar known conditions and assigned the appropriate impact. Their relevant scores are then aggregated to indicate the proneness of failure at various stages of the falsework construction. The frequency would be established from the failure cases analysis or assigned subjectively from experience.

Interviews with fifteen construction personnel who have involved in falsework construction were conducted. They were asked to comment on the usefulness and application of the procedural framework. They endorsed the usefulness of the flow charts in illustrating the activities and responsibility of various parties involved and the approach in assessing the erosion of allowable stress of falsework as developed in the procedural framework. One interviewee in Shenzhen of China, indicated that the control system currently used in Shenzhen was similar to the conventional control system. Thus the procedural framework developed could be applied in assessing the safety of falsework construction in Southern China.

CHAPTER ELEVEN

CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH

CHAPTER ELEVEN
CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH

11.1 Introduction

The previous chapter discusses the assessment of procedural errors which would lead to failures in falsework construction. The errors can be identified by the developed flow chart which illustrates the key activities and roles of different parties. The analysis of five major falsework failures in Hong Kong has established the assignment of causes to erode the allowable stress and initiate the failure. The procedural framework was validated by fifteen construction professionals who regarded it a very useful tool in assessing the safety condition of falsework which is commonly required in concrete construction in Hong Kong.

During the last six years, a total of eight major falsework collapses occurred in Hong Kong with five people killed and twenty-six injured. Within the same period in Guangdong, the province in China next to Hong Kong, three severe collapses had resulted in forty deaths and ninety-five injuries. Because of the absence of research on falsework failures in Hong Kong, the aim of this research was to develop a procedural framework that will assess the safety condition and the proneness to failure at different stages of designing and constructing the falsework with the following objectives:

- to review the practices of falsework scaffolding in Hong Kong;
- to determine the impact on safety of the falsework by adopting different control systems on the design and construction of the falsework;
- to analyse the causes of falsework failures; and
- to devise a procedural framework to assess the safety condition for the falsework at different stages.

The aim and objectives of this research study were achieved by:

- an extensive literature review of the topic and interviews with professionals to determine the essential activities and the scope of professional's responsibility;
- conducting thirty-three tests on the falsework scaffolding systems commonly available in Hong Kong;
- collecting data by visiting nine sites in Hong Kong, China, Taiwan and Singapore when failures had occurred;
- extracting and analysing the failure causes from fifty failure reports;
- developing a procedural framework for assessing the safety condition of the falsework at different stages; and
- interviewing fifteen construction professionals for their views on the application of the procedural framework developed.

The conclusions drawn from the research are presented below.

11.2 Conclusions

From Chapter 3 to Chapter 5, an extensive literature review on falsework design and construction and unstructured interviews with professionals were undertaken to establish the essential activities for falsework construction, taking into consideration the differences of the three different control systems. Chapter 6 presented the experience in visiting and collecting data from sites where falsework failures had occurred. Discussion and recommendation on the performance of scaffolding systems were presented in Chapter 7. Identification of causes from other research work together with characteristics of a procedural framework was discussed in Chapter 8. Chapter 9 presented the analysis of procedural errors from fifty failure cases and Chapter 10 developed the procedural framework for analysing and predicting falsework failures. The following are conclusions drawn from above chapters.

11.2.1 Review of practices

A comprehensive study on falsework was first undertaken in the nineteen seventies in the UK. In 1998, the Labour Department of Hong Kong published its first falsework

Guidance Notes: Safety at Work (Falsework – Prevention of Collapse). The Notes highlights the good practices frequently overlooked by contractors on site but it does not include the important issues learnt from falsework failures. In 2001, a Code of Practice of Metal Scaffolding Safety was published by the same department. This document includes a section on consideration for falsework construction and emphases the importance of falsework monitoring. However, two important aspects have not been included. They are:

- the effectiveness of the control system for falsework; and
- the approval requirement at various critical stages of falsework activities.

In construction, the conventional 'Design by Contractor and Check by Engineer" control system has been widely adopted. In view of contractor's deficiency in fulfilling the role of designing and constructing the temporary works, the "Independent Checking Engineer" (ICE) system has been adopted during the last decade, notably for large projects. However, the ICE is not resident full time on site to supervise and control the construction particularly when changes in construction method are implemented. The falsework collapse in Tseung Kwan O, Hong Kong, in 1996 has exposed the loophole of this system.

A more proactive approach to prevent failures on site has been adopted in both the UK and Hong Kong since the mid-nineties. The Construction (Design and Management) Regulations and Site Supervision Plan System require the designer during the design stage to take up responsibility in health and safety throughout the project, and to assess and minimise if necessary the risk of the construction work. Such approach is in line with the aim of this research in the development of a procedural framework for assessing the safety condition of falsework at various stages of the construction.

One uncertainty arises from the use of scaffolding material for falsework construction. These materials, largely imported from near by places, are varied in quality. The only source of their loadbearing capacity is the quotation in the supplier's catalogue. Thus there is a need to investigate their performance under load.

Altogether thirty-three tests of different scaffolding systems were performed in the structures laboratory to determine their loadbearing capacity. Most materials have a factor of safety of two when they are new, as recommended in the catalogues. The used material should be reduced by a factor of 0.85, as suggested in the British Standard BS5975.

In practice, new scaffolding materials are designed to resist the allowable stress with a factor of safety of two, as confirmed by tests. It implies that the procedural errors would erode at least one allowable stress in initiating a failure. In other words, the effect of the procedural inadequacies is at least equivalent to the effect of the design load acting on to the falsework.

11.2.2 Falsework failure analysis

Many researchers have studied construction failures including falsework collapse. Some models have also been devised for failure prediction. Taking into account of the characteristics of falsework construction activities, these models do not consider or assess the procedural adequacies, particularly at the interface of operations where different parties with different roles are involved. Also these models are only used to assess the likelihood of an eventual failure without evaluating the safety conditions at various stages of the construction.

A procedural framework for failure analysis and prediction, thus, should include the following characteristics.

- Safety of the falsework at different stages, i.e. the design, erection, load, taking down and anew stages are assessed.
- The different roles played by the professionals under different control systems are considered.
- The common critical activities as identified from failure reports are being appraised.
- Personnel's experience and qualification can be included in the assessment.
- Effectiveness of critical communication and control activity are checked in the procedural framework.

Incorporating these characteristics together with the practices of falsework scaffolding, and the identification of critical procedural causes from other research studies, a flow chart based on event sequence diagram was developed. Modifications are made in the flow charts for different control systems.

Based on the content analysis and the use of the flow chart, fifty falsework failures were analysed. These are derived mainly from professional reports, accident reports, court hearings and reports in the engineering journals. They are of medium level of reliability. The recent failures are only available from newspapers which considered to be of low reliability due to a lack of investigation by professionals. On the other hand the formal enquiry, bearing the highest level of trustworthy, would be set up only for disastrous cases.

The analysis reveals that tubular steel and metal scaffolding were the most common materials used in these failures. Steel frames had also been used for supporting long spans and heavier loads. One third of the failures were cast in situ concrete construction with post tensioning, presumably used for long span bridges. A little fewer than the former cases were cast in situ reinforced concrete construction typically used for medium and short span bridges. Failures involving timber as the falsework was infrequent because timber was not popular due to its relatively low strength.

About eighty per cent of the failures occurred when concreting operation was near completion or upon placing of the precast segment on to the falsework. About ten per cent of failures arose from dismantling of the falsework. Although the gross errors arising from these two stages were around ten per cent each, the loading and dismantling stages would require proper supervision as these are the instances when the falsework would be supporting the full design load.

Forty-five per cent of the failures have gross errors stemmed from the erection stage and one third was rooted in the design stage. Also ten per cent were in connection with the dismantling operation. Thus, the Independent Checking Engineer should be employed to prevent the accumulation of procedural errors, particularly in the design and erection stage, which could be brought forward to the loading stage.

In spite of the frequent occurrence of falsework failures, detailed failure reports are difficult to obtain largely for the reason of confidentiality during legal proceedings or submission of claims for compensation. Similar obstacles were experienced in visiting sites where falsework failures had occurred. However, the visits did provide valuable opportunities to understand the incidents, to appreciate the scale and organisation of the construction site, and to confirm the possible causes of the failure whenever possible.

11.2.3 Procedural framework for analysing and predicting falsework failures

Procedural errors can reduce the loadbearing capacity of falsework or increase the undesirable stresses leading to the reduction of factor of safety of the falsework. Only an effective control system can prevent the accumulation of errors. The failure of the falsework due to accumulation of procedural errors is similar to the bursting of the balloon when pressure inside the balloon increases.

The Pressure or Risk is the product of Consequence, Frequency and Effectiveness in Control. Using the score method, these factors lie between zero and one. For an actual failure with only one principal cause, the impact of the cause, the frequency and the poor control are all equal to one. The Pressure or Risk is then one.

Failures occurring at different stages have been illustrated graphically. Gross errors can start at the design, erection, loading or taking down stage whereas a failure can happen during erection, loading or dismantling. Accumulation of minor errors from various stages can cause the failure at a later stage such as during loading.

From the failure reports, the causes, the impact or the degree of error of the cause can be identified and then stored in a case base. The degree of the error can be classified as substantial, major, minor or very minor, depending on the description in the reports. From the analysis of five major failures in Hong Kong, the substantial and major causes will be equivalent to at least one and 0.4 of the allowable stress respectively. The magnitude for the minor or very minor causes cannot be established due to a lack of sufficient data.

For failure prediction purposes, each project is assessed with its known or assumed condition against the procedural causes in the case base with respect to the relevant conditions. All appropriate procedures are checked against the similar known conditions or decided subjectively by experience. The scores are aggregated to give the indication of proneness of failure at various stages.

The developed procedural framework has been validated through interviews with fifteen construction professionals who have substantial experience in falsework construction and failure investigation. They have endorsed the flow chart as a very useful tool in illustrating the activities and roles of the parties. They also endorsed the approach of assessing the erosion of allowable stress by procedural errors in analysing a failure or predicting the proneness of a collapse.

11.3 Recommendations

This research analysed the fifty falsework failure reports and developed a procedural framework that professionals can use for assessing the safety conditions of the falsework construction. The procedural framework can be used for analysing the failures in identifying the procedural errors and predicting the likelihood of a failure. It has been scrutinised by fifteen professionals experienced in falsework construction. They endorsed the flow chart as correct and simple to use. They also agreed on the approach of assessing the procedural errors in determining the likelihood of a failure.

It is recommended that the Contractor, the Engineer and their site staff, and the Independent Checking Engineer, if applicable, use the flow chart for monitoring the safety of the falsework construction. This is one of the recommendations in the Code of Practice for Metal Scaffolding Safety.

Regarding the control system to be used, the Independent Checking Engineer (ICE) should be adopted as far as possible. The additional consideration is to employ the ICE on site shortly before and during the loading stage of the falsework. This will assure no cut-corners by other parties that would lead to failures.

To ensure sufficient cases available for assessment of procedural errors, the government departments should set up a central pool of failure cases collected locally and from abroad.

In view of the frequent and severe occurrence of falsework failures and the wide use of the conventional control system in China, it is recommended to introduce the procedural framework to the professionals in China for monitoring the falsework safety.

11.4 Recommendations for further research

The development of the procedural framework in this research was based on the analysis of fifty falsework failures. The information gathered is insufficient to produce a sophisticated procedural framework with a higher degree of reliability in analysing and predicting failures. To set up a case base for assessing the procedural inadequacy, more detailed failure reports are required though they are difficult to obtain due to a variety of reasons. Also more professional views and judgement on the adequacy of procedures with respect to erosion of the allowable stress is needed in order to differentiate the successful and failed falsework construction. Further, fuzzy set approach can be applied in assessing the erosion of the allowable stress instead of the score method.

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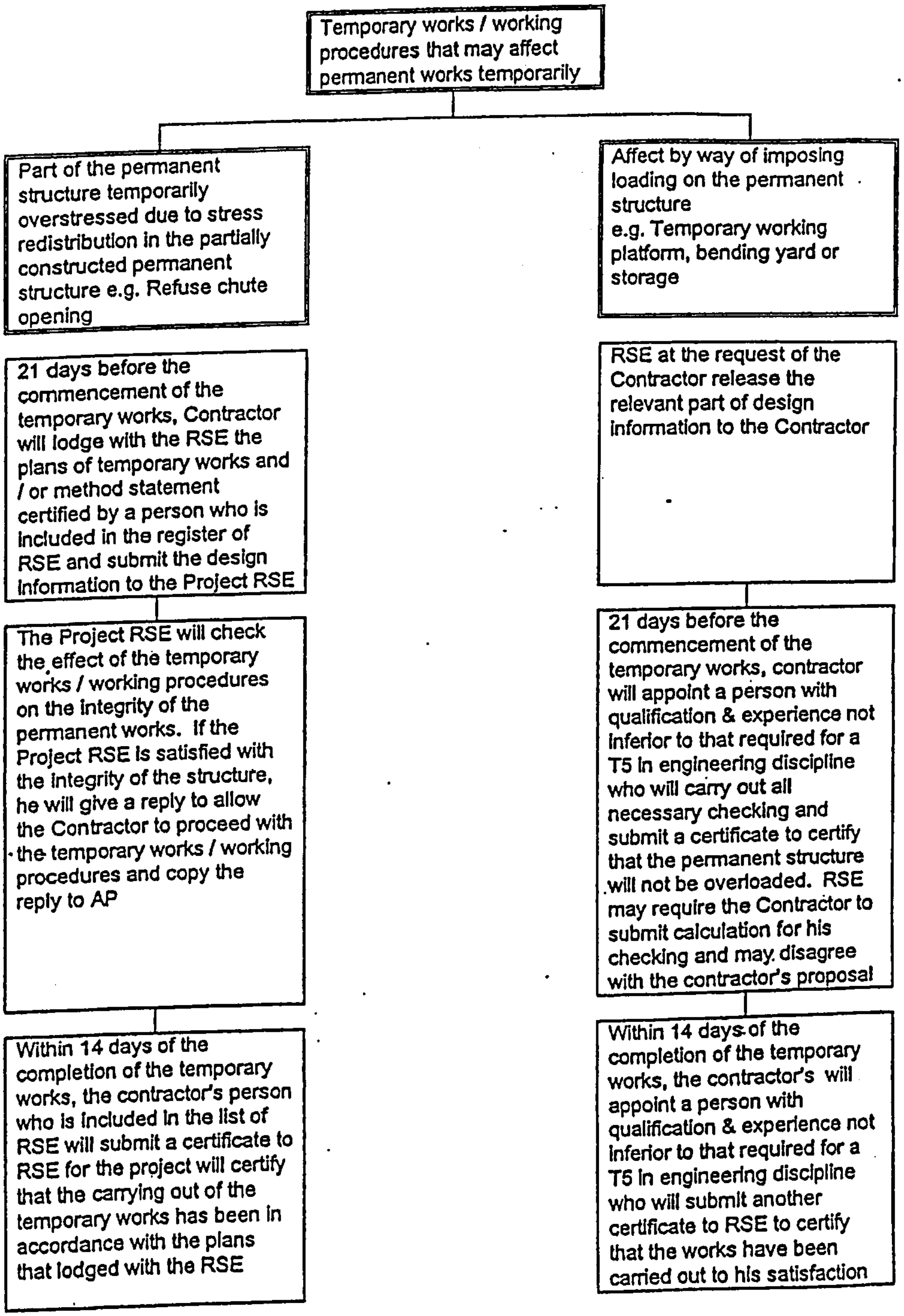
APPENDICES

APPENDIX A

Division of Responsibilities Between Registered Structural Engineers and Constructors for Temporary Works or Working Procedurals That are Not Required to Be Shown on Prescribed Plans But That May Affect Permanent Works (Site Supervision Plan System – Hong Kong Government Buildings Department)

Table 5.4 - **Division of Responsibility Between RSE and Contractor for Temporary Works or Working Procedures That Are Not Required To Be Shown On Prescribed Plans But That May Affect Permanent**



Temporary works / working procedures that may affect permanent works temporarily

Part of the permanent structure temporarily overstressed due to stress redistribution in the partially constructed permanent structure e.g. Refuse chute opening

21 days before the commencement of the temporary works, Contractor will lodge with the RSE the plans of temporary works and / or method statement certified by a person who is included in the register of RSE and submit the design information to the Project RSE

The Project RSE will check the effect of the temporary works / working procedures on the integrity of the permanent works. If the Project RSE is satisfied with the integrity of the structure, he will give a reply to allow the Contractor to proceed with the temporary works / working procedures and copy the reply to AP

Within 14 days of the completion of the temporary works, the contractor's person who is included in the list of RSE will submit a certificate to RSE for the project will certify that the carrying out of the temporary works has been in accordance with the plans that lodged with the RSE

Affect by way of imposing loading on the permanent structure
e.g. Temporary working platform, bending yard or storage

RSE at the request of the Contractor release the relevant part of design information to the Contractor

21 days before the commencement of the temporary works, contractor will appoint a person with qualification & experience not inferior to that required for a T5 in engineering discipline who will carry out all necessary checking and submit a certificate to certify that the permanent structure will not be overloaded. RSE may require the Contractor to submit calculation for his checking and may disagree with the contractor's proposal

Within 14 days of the completion of the temporary works, the contractor's will appoint a person with qualification & experience not inferior to that required for a T5 in engineering discipline who will submit another certificate to RSE to certify that the works have been carried out to his satisfaction

Note: The contractor has the sole responsibility to ensure the integrity of the temporary structure itself and the associated fixing methods.

APPENDIX B

Falsework Failure Reports From Newspapers and Engineering Journals

Case Ref. No. 1 Shenzhen, China
Source: 29th November, 2000, China Daily, Hong Kong Edition

NOVEMBER 29, 2000 HONG KONG/GUANGDONG CHINA DAILY HONG KONG EDITION

Probe as 30 hurt in bridge collapse

Project part of US$240m highway to spur Shenzhen economy, tourism

By XU XIAODAN
China Daily staff

SHENZHEN: Thirty workers were injured, five seriously, when a bridge collapsed as part of construction of the Yantian-Bagang Expressway.

An investigation into the cause of the accident on Monday evening began yesterday, said Shenzhen municipal government, which is taking charge of the investigation.

The expressway is one of the key construction projects in Shenzhen, Guangdong Province, South China.

The collapse was suspected to have been caused by damaged cast iron in the south of the bridge, but it has not been confirmed whether bad workmanship or a mishap in design were to blame.

The bridge was designed by the Design Institute of Shenzhen under the Ministry of Railways and was constructed by a company of the China Railway Construction Group.

The bridge, which was still under construction near Yantian port, Yantian District, caved in at 9:45 pm on Monday.

Witnesses said a 30-metre-wide and 50-metre-long section of the bridge broke into a V-shape.

Sixty workers on the bridge fell to the ground where some were pinned under fallen iron beams.

The injured were rescued immediately and treated in local hospitals.

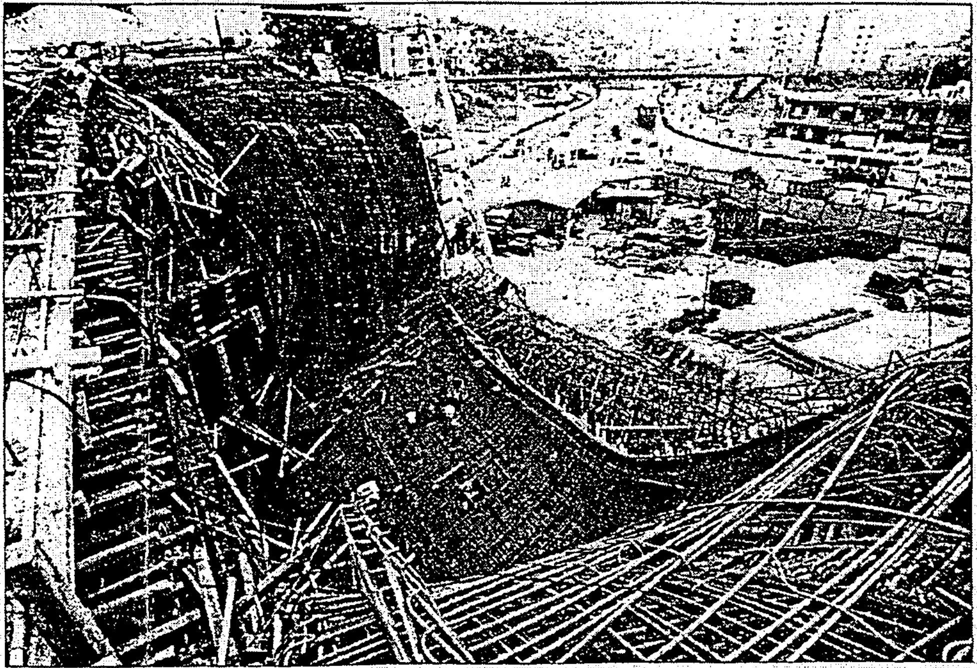
Tan Guoxiang, a Shenzhen government official, said the rescue operation was swift and efficient.

More than 10 ambulances, police and transportation officers arrived to help with the rescue.

The bridge was located at the beginning of the expressway, which aims to improve transport conditions in eastern Shenzhen when its first phase is completed before the end of the year.

The 26.9-kilometre expressway links the port of Yantian and the city of Huizhou.

The nearly 2-billion-yuan (US$240 million) project is expected to boost tourism and the economy in Shenzhen's eastern areas.



CNS

Toppled structure: A bridge under construction near Yanlian port in Shenzhen collapsed on Monday night, injuring 30 workers, 5 seriously.

Case Ref. No.2 Castle Peak Road, HK
Source: 11th March, 1999, Ming Pao Newspaper

1999年3月11日 星期四

港聞

平台支架下塌

五地盤工灌石屎墮地傷

【本報專訊】青山公路帝濤灣建築地盤，昨午發生工業意外，逾十名工人在上址平台進行灌石屎工程時，疑平台部分支架不勝負荷下塌，其中五名男女工人，隨石塊墮下四米路面，幸五人未被困瓦礫，消防到場，迅速將五人救出送院，經醫治後，情況穩定。

送院敷藥後情況穩定

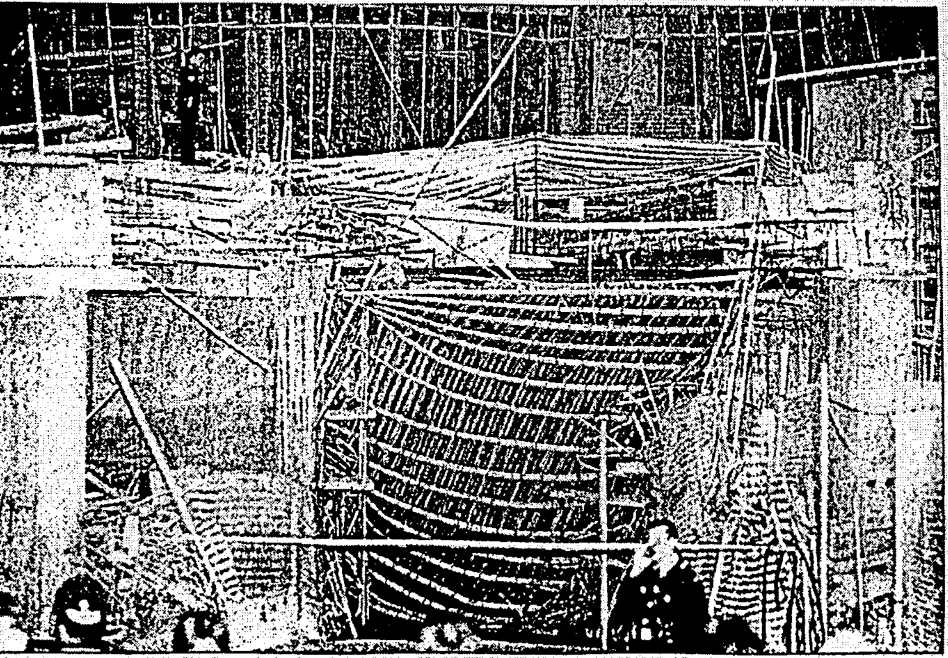
受傷五名石屎工人分別陳金印（五十五歲）、沈子恆（四十五歲）、楊錦廣（四十六歲）、莊光華（四十一歲）及女子葉惠珍（四十四歲），五人分別頭部及手腳被鐵支插傷，幸傷勢輕微，送院經敷藥後，情況穩定。

現場爲青山公路小欖段帝濤灣建築地盤，上址正興建九幢住宅大廈，一樓則爲相連九座樓宇的平台，現正進行平台灌石屎工程，預計下月尾建成。

四米乘十米範圍下塌

昨午五時十四分，十五名工人正於上址三期對出平台工作，平台下則以鐵支架承托，工人當時正以一條石屎喉進行灌漿工序，其間，疑支架不勝負荷，引致四米乘十米範圍出現下塌，平台工人即爭相走避，其中五男女工人卻走避不及，連隨平台塌下四米地面，幸各人未有被困瓦礫中，其他工友見狀，立即上前拯救及報警。

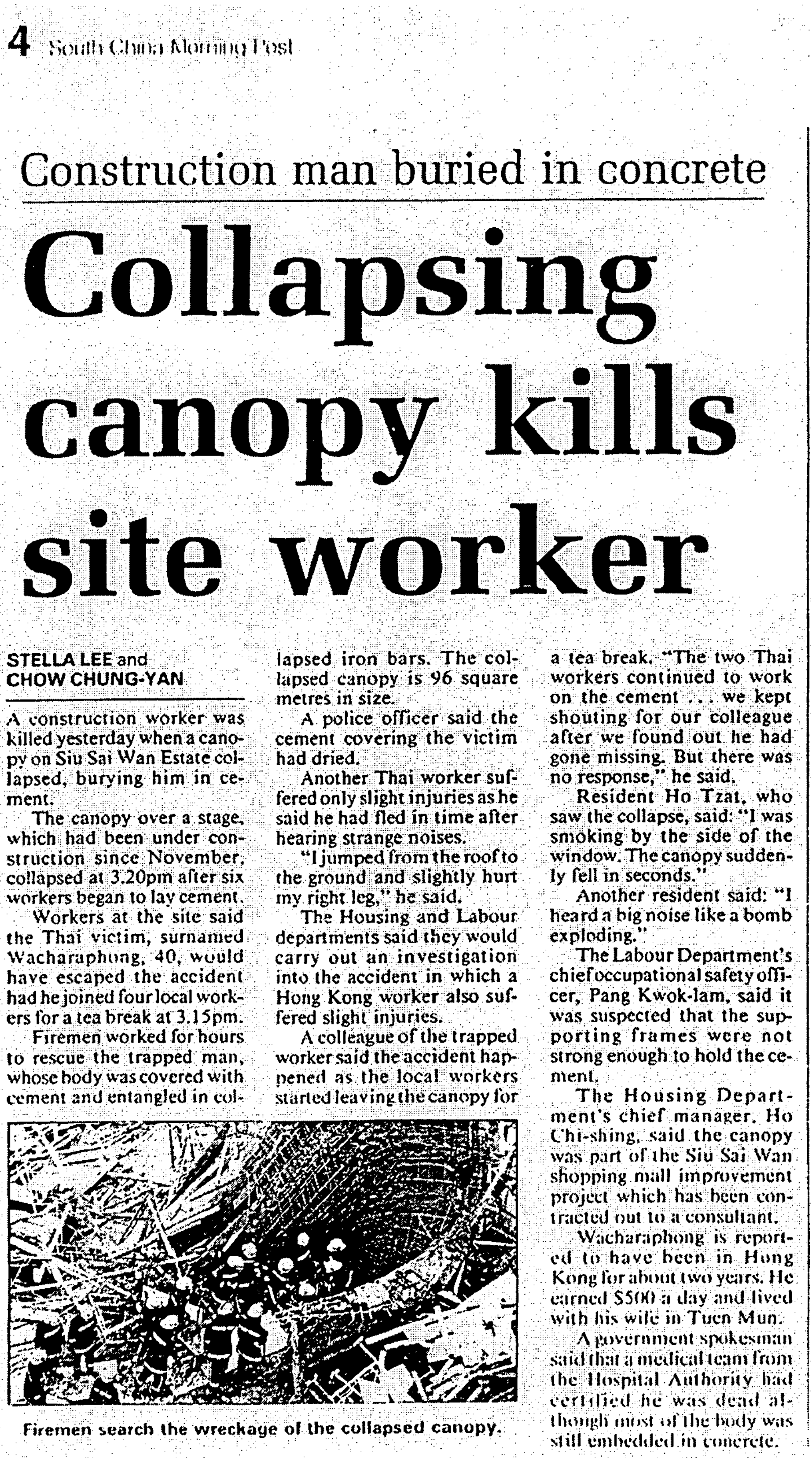
警方及消防員接報到場，立即將五名傷者救出送院，警員並將現場封鎖調查。稍後，勞工處及屋宇署亦到場了解情況。



屯門帝濤灣地盤工傷意外發生後，警方封鎖現場進行調查。（郭慶輝攝）

Case Ref. No. 3 Siu Sai Wan, HK

Source: 13th February 1999, South China Morning Post



4 South China Morning Post

Construction man buried in concrete

Collapsing canopy kills site worker

STELLA LEE and CHOW CHUNG-YAN

A construction worker was killed yesterday when a canopy on Siu Sai Wan Estate collapsed, burying him in cement.

The canopy over a stage, which had been under construction since November, collapsed at 3.20pm after six workers began to lay cement.

Workers at the site said the Thai victim, surnamed Wacharaphong, 40, would have escaped the accident had he joined four local workers for a tea break at 3.15pm.

Firemen worked for hours to rescue the trapped man, whose body was covered with cement and entangled in collapsed iron bars. The collapsed canopy is 96 square metres in size.

A police officer said the cement covering the victim had dried.

Another Thai worker suffered only slight injuries as he said he had fled in time after hearing strange noises.

"I jumped from the roof to the ground and slightly hurt my right leg," he said.

The Housing and Labour departments said they would carry out an investigation into the accident in which a Hong Kong worker also suffered slight injuries.

A colleague of the trapped worker said the accident happened as the local workers started leaving the canopy for a tea break. "The two Thai workers continued to work on the cement . . . we kept shouting for our colleague after we found out he had gone missing. But there was no response," he said.

Resident Ho Tzat, who saw the collapse, said: "I was smoking by the side of the window. The canopy suddenly fell in seconds."

Another resident said: "I heard a big noise like a bomb exploding."

The Labour Department's chief occupational safety officer, Pang Kwok-lam, said it was suspected that the supporting frames were not strong enough to hold the cement.

The Housing Department's chief manager, Ho Chi-shing, said the canopy was part of the Siu Sai Wan shopping mall improvement project which has been contracted out to a consultant.

Wacharaphong is reported to have been in Hong Kong for about two years. He earned $500 a day and lived with his wife in Tuen Mun.

A government spokesman said that a medical team from the Hospital Authority had certified he was dead although most of the body was still embedded in concrete.

Firemen search the wreckage of the collapsed canopy.

Case Ref. No.4 Sai Wan Ho, HK
Source: 22nd December 1998, Apple Daily Newspaper

建電影資料館 支撐鋼架不穩

地盤塌地台三人墮地庫

■西灣河地盤塌地台工人被救起送院。

【本報訊】港島西灣河建築中的「香港電影資料館」，昨日發生地台塌下意外，一批工人在倒石屎鋪設地台時，懷疑支撐鋼架不穩，三名工人連倒塌地台跌下三米深地庫，幸僅受輕傷，勞工處對意外已展開調查。

工人正進行地台灌漿

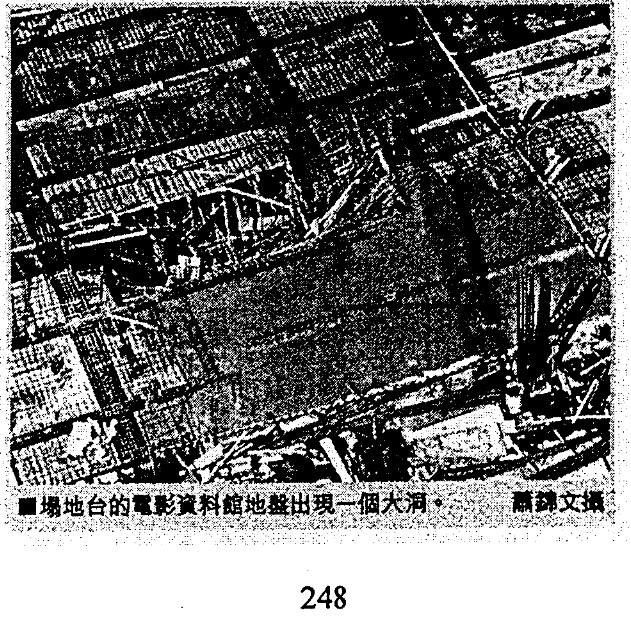
現場為西灣河鯉景道臨時市政局[illegible]下的「香港電影資料館及西灣河康[illegible]中心」地盤，佔地六千平方呎，預[illegible]興建五層高樓宇，已完成平整地基[illegible]程，目前正鋪設地台。

昨日上午十一時半左右，工人[illegible]天秤吊運石屎進行地台灌漿，地台[illegible]鋪有木板和鋼筋，而下面則是裝有鋼架支撐地台的地庫。

昨日事發時，懷疑支撐地台的鋼架不穩，出現移位，一列約十呎乘二十五呎的地台突然塌下，在上面工作的六名工人，其中三人站立不穩，隨平台倒下，直跌落三米深的地庫，其他工人見狀報警。

稍後，救援人員到場將三名傷者救起送院，其中姓張四十歲工人敷治後出院，而姓蔡（四十七歲）和姓施（四十歲）經治理後，均情況穩定。

耗資二億元的電影資料館，樓高五層，設冷藏片庫、展覽廳及迷你戲院，預計二〇〇〇年四月落成。



■塌地台的電影資料館地盤出現一個大洞。 蕭錦文攝

Case Ref. No. 5 Tsing Yi, HK

Source: 13th November 1998, Ming Pao Newspaper

灌漿期間 5米高橋面下塌

青衣地盤塌橋 七工人傷

【本報專訊】青衣東北路一個正在興建中的行車天橋昨午進行灌漿工序時，其中一段模板突然塌下，七名正在天橋上的工人連人帶械跌落五米下地面受傷。消防員到場，以生命探測器搜索，證實無人被壓。屋宇署及勞工處事後派員到場，調查塌橋的原因。

五人擦傷二人留院

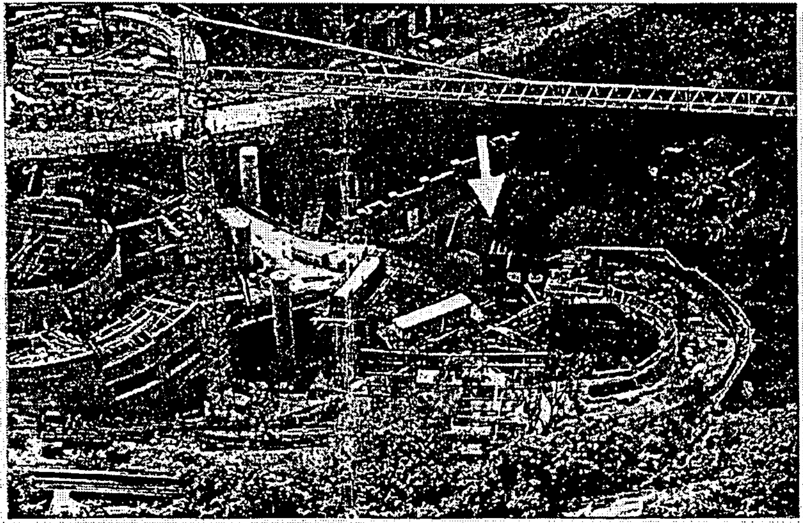
七名受傷的工人，年齡由二十八至四十四歲，事後被送往醫院診治，其中五人僅擦傷手腳，敷藥後出院，另兩名分別三十九歲何×邦，頭部及下顎均有受傷，四十四歲梁×根則被鐵枝插傷胸部，兩人經診治後情況穩定。

塌橋現場為青衣東北路私人屋苑曉峰園的建築地盤，兩年前開始興建，而天橋工程則於半年前開始動工，塌下的天橋是一條「U」形的行車天橋，離地五米高，用作連接東北路與曉峰園大廈平台的停車場。由於天橋仍在興建中，下塌一段仍未完成灌漿工序，僅由鋼筋及木板搭成，底部以鋁架支撐，工人昨晨八時開始，以天秤運載石屎漿，進行十多米橋面的灌漿工程。

至下午一時，工人午飯後繼續灌漿工程，七名工人當時站在橋面上，另一人則持控天秤將第一斗石屎灌下橋面後，一幅十米乘五米的橋面突然下陷成「V」字形，天橋的鋼筋、木板隨即塌下，七名工人如坐滑梯般沿橋面滑下。意外發生後，部分工人從塌下的木板及鋁架中自行爬出，其他工人見狀，立即上前搬開塌下的木板，將被壓的工人救出，滿身泥漿的工人事後仍能保持清醒，大部分僅擦傷手腳。

承建商曾違例遭控

事後塌橋位置被封鎖，待有關部門進一步調查。屋宇署及勞工處特派人到場，勞工處署理總職業安全主任彭國材表示，現正調查事件中是否有人違反安全法例。他稱，勞工處的安全主任於過去兩年內，共巡查該地盤十二次，並曾就有關高空工作的項目控告承建商。



青衣一個地盤昨日發生塌橋意外，箭嘴所指處即為下塌部分。　（何耀勤攝）

模板承托力不足出事

初步估計

對於青衣昨日發生的塌橋事件，屋宇署初步確認是在灌漿工程中用以承托石屎的模板倒塌，而事發後地盤監察組人員已到場了解詳情，調查事發原因。

屋宇署發言人指出，按署有關人員巡查地盤，認可的工程師須在建築過程中定期提交報告，根據《建築物條例》，承建商聘請的工程師在法律上有責任確保工程符合條例。

石屎成分規範不清

是次事件暴露了私人屋苑內行車天橋建築規範含糊的問題，根據規則，事發的行車天橋由屋苑通往屋苑範圍外的東北路。

理工大學土木及結構工程系講師陳鴻天指出，此類屋苑的行車天橋的石屎成分規範不如一般的行車天橋，但所採用的交通負載標準卻與一般行車天橋無異。

陳氏表示，較之於外國的行車橋石屎成分規範清晰，香港現有的法例明顯存有灰色地帶。

此外，屋宇署自今年開始分三期對此類私人建築工程實施地盤監工計劃，但要加強監管這次事件涉及的基礎及上層結構工程，則要在今年底才開始實施。

陳鴻天認為這次事件可能是因為支架負荷太重而出事，由於在「落石屎」過程中，支架的負重增加，用以支撐模板的系統承托力不足，或支撐點的結構出現問題致造成意外。

該座天橋由金門及怡輝建築公司負責承建，怡輝建築有限公司昨日在聲明中表示，將按勞工法例向傷者作出賠償，但未有解釋意外發生的成因及詳情。

Case Ref. No. 6 Guangzhou, China
Source: 3rd December 1997, Ming Pao Newspaper

3/12/97

迄今三死一垂危兩輕傷

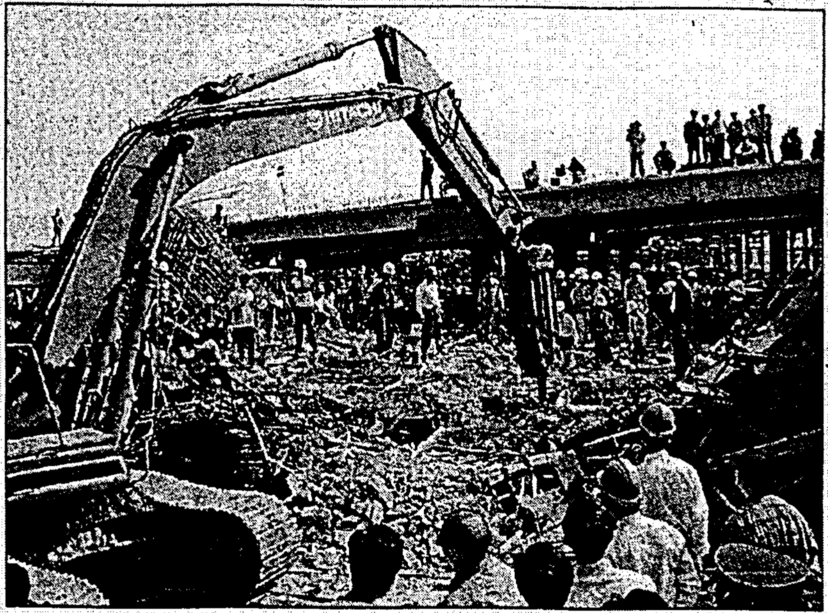
廣州塌橋疑負荷過重

【本報專訊】發生塌橋事故的廣州市東圃環市東立交橋施工現場，昨日已經停止屍體的挖掘，四名被塌橋壓住的民工已全部被挖掘出來。至昨天下午爲止，證實有三人死亡，一人重傷垂危，二人輕傷。塌橋的原因仍在調查中，有關專家初步認爲事故和橋樑負重過重，及施工程序有誤差有關。

發生塌橋事故的廣州東圃環市東立橋引橋現場現已封閉，由市政府官員及有關專家組成的事故調查小組和善後小組在現場調查事故的原因。

至昨天下午爲止，事故中共有三人死亡，一人重傷，二人輕傷。目前傷者正在廣州市華僑醫院接受醫療，重傷者情況危險，輕傷者則仍需留院觀察。

事故原因仍未有調查結論，但有關專家認爲，事故原因和橋身負重過荷有關。專家指出，該橋八十公分厚的混凝土本應分兩次倒，等第一層厚四十公分的混凝土凝固後，橋樑鋼筋能承受部分重量，才能倒第二層混凝土。但調查顯示，施工過程中，八十公分的混凝土是一次過就傾倒下的，致使橋身過重，橋樑下支撑的木方斷裂，引致塌橋事故。



在廣州東圃高速公路塌橋意外現場，搶救隊調來液壓破碎機參加挖掘工作。

（中新社）

Case Ref. No. 7 Ru Yuan Guangdong, China

Source: 23rd December 1996, South China Morning Post

Pouring cement caused tragedy, says hurt worker

Eight still missing in bridge collapse

MUNN TAM in Shaoguan

One of the workers badly injured in the Guangdong bridge collapse that killed 29 people yesterday said the accident was caused by cement being poured into a mould to form the bridge surface.

Tan Monglin (譚夢林) said the bridge collapsed because the iron scaffolding failed to support the weight of the cement.

Eight workers were still missing yesterday after the collapse near Shaoguan in which more than 60 people were injured.

The accident happened in a gorge between Pinshi and Ruyuan counties.

Mr Tan, a 26-year-old Sichuan worker, travelled to Guangdong in search of a job this year.

He has severe injuries to the upper body and is unlikely to recover totally.

Some of his close friends died in the accident.

Mr Tan said Sichuan workers went to Guangdong as pay for migrant workers in the province was much higher than at home.

He and five other badly injured workers were still being treated at the First Shaoguan People's Hospital last night. Another six workers with similar injuries were being treated at Yuebei Hospital in Shaoguan.

Twelve more seriously injured workers were sent to hospitals in Shaoguan, a major city in northern Guangdong.

One Sichuan worker treated at Yuebei Hospital said he would go back to Sichuan once he recovered and never return to Guangdong.

The less seriously injured were taken to hospitals in Ruyuan.

More than 100 workers were on the bridge, which spans a 100-metre-deep valley. Many fell into the valley when it collapsed.

Nobody was available to comment on the engineering work yesterday.

The work formed part of a highway linking Ruyuan, a poverty-stricken county, and Pinshi.

Authorities planned to alleviate the poverty problems in Ruyuan by directing more traffic through the town after scheduled completion of the highway before the Lunar New Year.

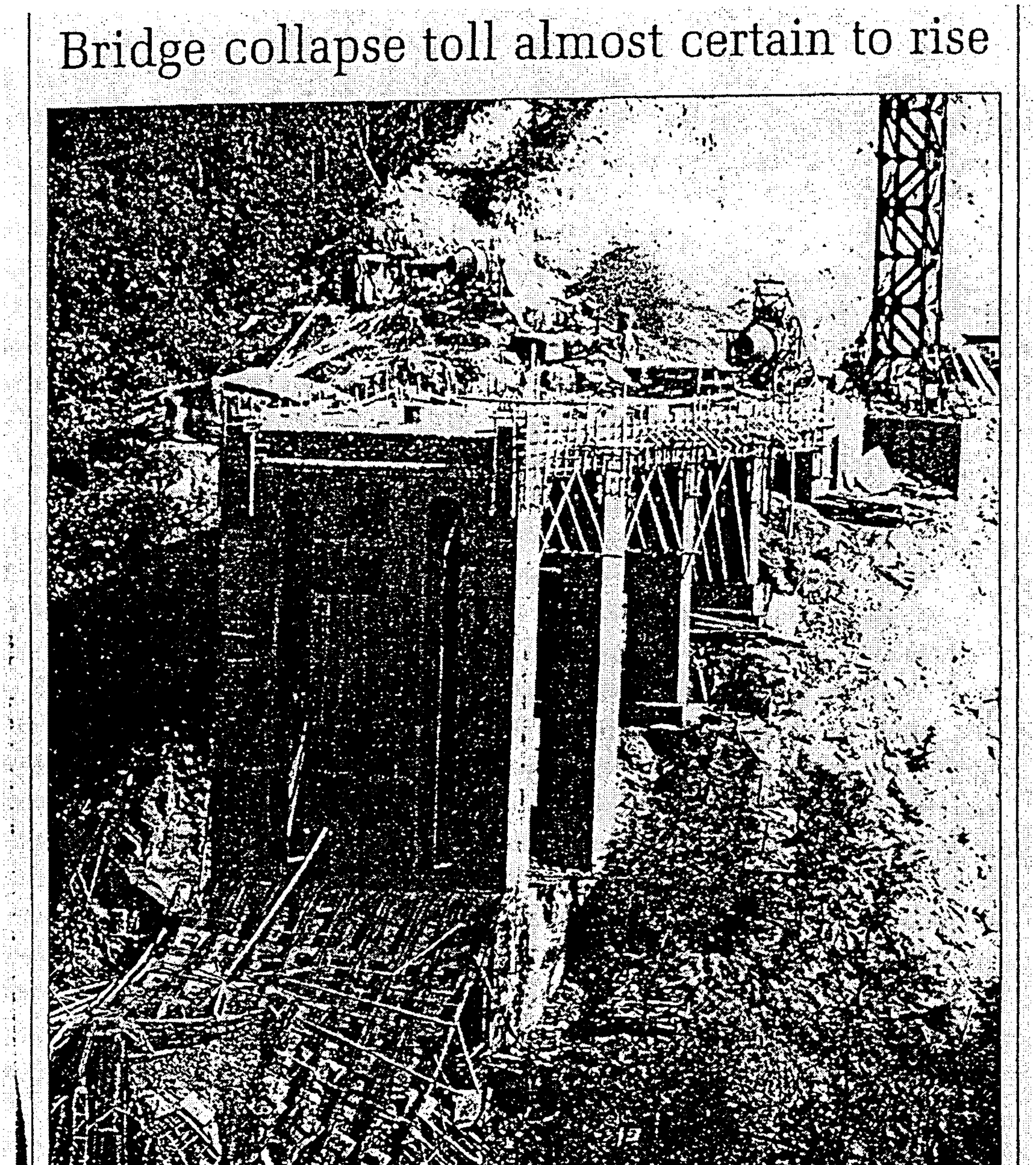
To meet the schedule workers, mainly from Sichuan with others from Hubei, Henan and Guangdong, were required to work at night.

The *Shaoquan Daily* reported Friday's accident next day without reporting the death toll or the number of wounded.

Several people, said to be relatives, burned incense and paper money near the scene after receiving telexes about the tragedy.

Case Ref. No. 7 Ru Yuan Guangdong, China

Source: 23 December 1996, South China Morning Post



Bridge collapse toll almost certain to rise

K. Y. Cheng

An eerie silence pervaded the scene yesterday at Shaoguan, in northern Guangdong province, where 29 people died when a bridge collapsed on Friday. Rescuers warned that the death toll was almost certain to rise, with at least eight workers still missing.

Full report – Page 7

Case Ref. No. 8 Kwai Chung, HK

Source: 30 September 1996,Ming Pao Newspaper

數噸水泥壓塌鐵架傷三人

消防員在已塌下的地盤內，使用生命探測器，找尋還有沒有被困的地盤工友。 （梁偉年攝）

【本報專訊】葵涌葵福道一個建築地盤昨日下午發生工業意外。地盤工人進行灌漿工程期間，水泥下的鐵架疑因不勝負荷，引致未凝固的水泥塌下，釀成三名工人輕傷。

傷者分別爲陳進聰，三十六歲，地盤雜工，撞傷頭部、右肩，左手擦傷，需要留院觀察；另外兩名傷者是石屎工人，分別是五十二歲的陳煥章及張裕波，敷藥後已經出院。

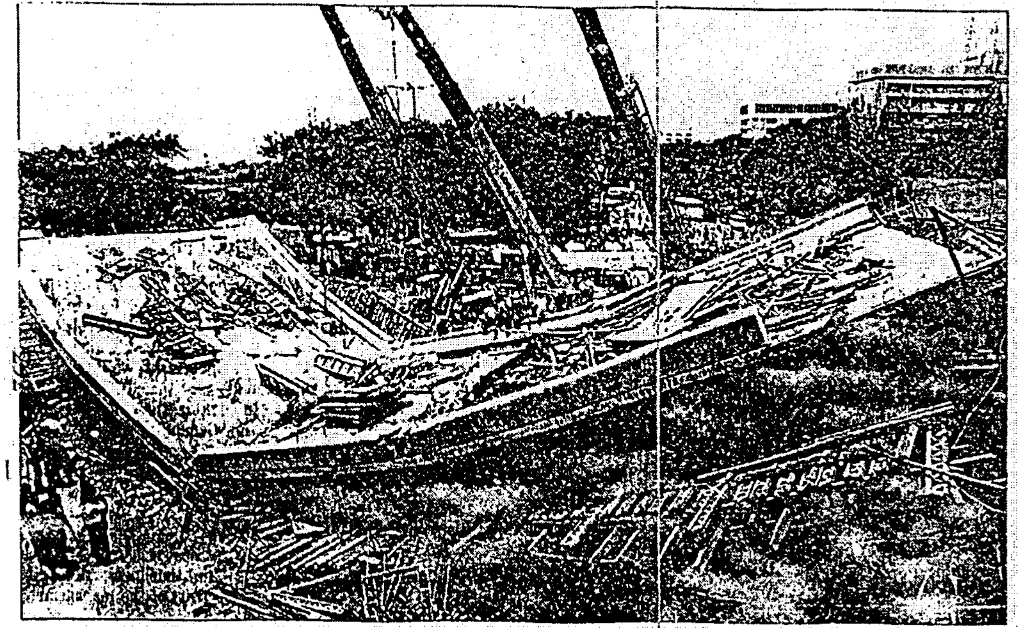
現場是葵涌葵福路晉昇工業中心隔鄰的地盤，工程已進行至停車場二至三樓車路迴旋處的部分，工人已搭建三米高的鐵架，再鋪以木板及鋼筋，預計灌約五百平方米的水泥。

葵涌消防局局長李建日表示，塌下石屎的範圍約十米乘四十米，地台約一米高。全個地盤共六十七名工人，包括石屎工人及雜工，負責在迴旋處灌水泥的工人則有二十五人。由昨晨八時起，工人不斷灌以水泥，共灌約四百平方米的水泥，估計重量以噸計。

約四時半左右，在地盤的二樓和三樓間的停車場迴旋處，正進行灌漿工程。地下的工人突然聽到石屎塌下的聲音，發現連接二樓和三樓間的迴旋處的鐵架疑不勝負荷，致剛灌漿尚未凝固的水泥及木板塌下，三名工人因走避不及故被水泥濺傷。

Case Ref. No. 9 Jakarta, Indonesia

Source: 28th March 1996, New Civil Engineer



Falsework blamed for road span fall

PREMATURE FALSEWORK removal is being blamed for the collapse of one span of a tollroad access ramp in Jakarta, Indonesia, last Friday.

Three workers died and 18 were injured when the 30m long simply-supported insitu concrete span crashed down at 8am. Survivors claimed they had been told to remove the falsework four days early by their supervisor from main contractor Korean-based Han Bo.

First reports said workers were struggling to jack the sagging span back up again when the collapse occurred. One survivor is said to have attributed his escape to having refused to work beneath the slab after cracks developed in the concrete following the earlier removal of part of the falsework.

A rescue operation ended on Monday when the last two bodies were uncovered. The remains of the 600t slab have now been cut into seven pieces and lifted away.

The 250m long access ramp was being constructed in Grogol, West Jakarta, as part of the Grogol-Pluit toll road project which is designed to improve access to Soekarno-Hatta international airport.

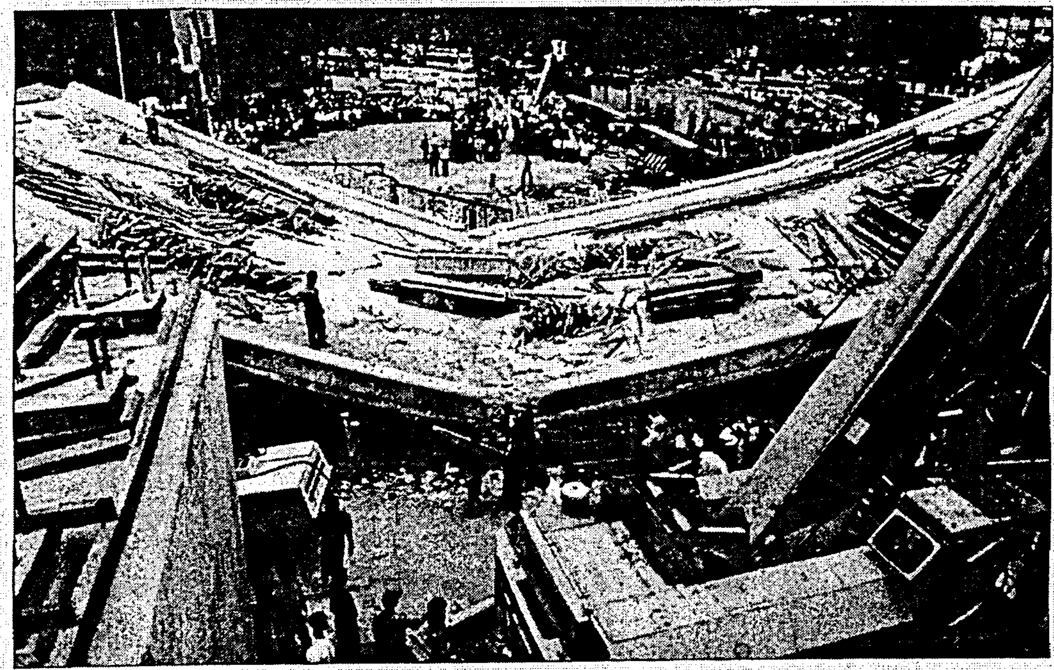
Han Bo is in joint venture with local contractor PT Bumi Karaya, and lead structural consultant was said to be Tokyo-based PCI & Yec.

Work on the project began last March and was due to be completed at the end of next month. Officials of the Indonesian Ministry of Public Works launched an immediate investigation, and a preliminary report was promised within 10 days.

Case Ref. No. 9 Jakarta, Indonesia

Source: 23rd March 1990, South China Morning Post

ASIA



Fatal flaw

Reuter

Four construction workers died and three more were buried and feared dead when an unfinished overpass collapsed in western Jakarta. At least 18 were injured when the road fell on workers after iron scaffolding was removed ahead of schedule.

Case Ref. No. 10 Tseung Kwan O, HK

Source: 21st January 1997, South China Morning Post

Fatal bridge collapse as props unscrewed

MICHELLE CHIN

Contractors had begun unauthorised procedures to remove props supporting a Tseung Kwan O footbridge last January – the day it collapsed and killed a driver, an inquest heard yesterday.

A section of the 200-tonne footbridge in Po Ning Road, outside Hau Tak Estate, collapsed on January 26, crushing a lorry. The driver was killed and four other site workers injured.

The body of Cheung Kwok-fai, 46, was recovered five hours later after heavy cranes lifted the footbridge.

Medical reports said Cheung had died immediately.

Chow Po-ki, a site engineer employed by Maunsell Consultants to monitor the project, said main contractor Wan Hin started to remove four positioning jacks on temporary scaffolding that day without the task being approved by an independent engineer.

The Coroner's Court heard that after the positioning jacks had been unscrewed, two precast concrete beams could then be lowered to the bridge's deck.

Mr Chow said no certificate endorsed by another engineer had been received to approve the works.

"Wan Hin didn't give us a detailed proposal about lowering the beams. It had mentioned the procedure during a meeting but didn't hand over detailed plans," he said.

Leung Sai-cheong, 41, an on-site construction worker, said he was taking out the positioning jacks when the bridge collapsed.

"There was no warning. It shook a little bit and fell down all of a sudden. It was like an earthquake," he said.

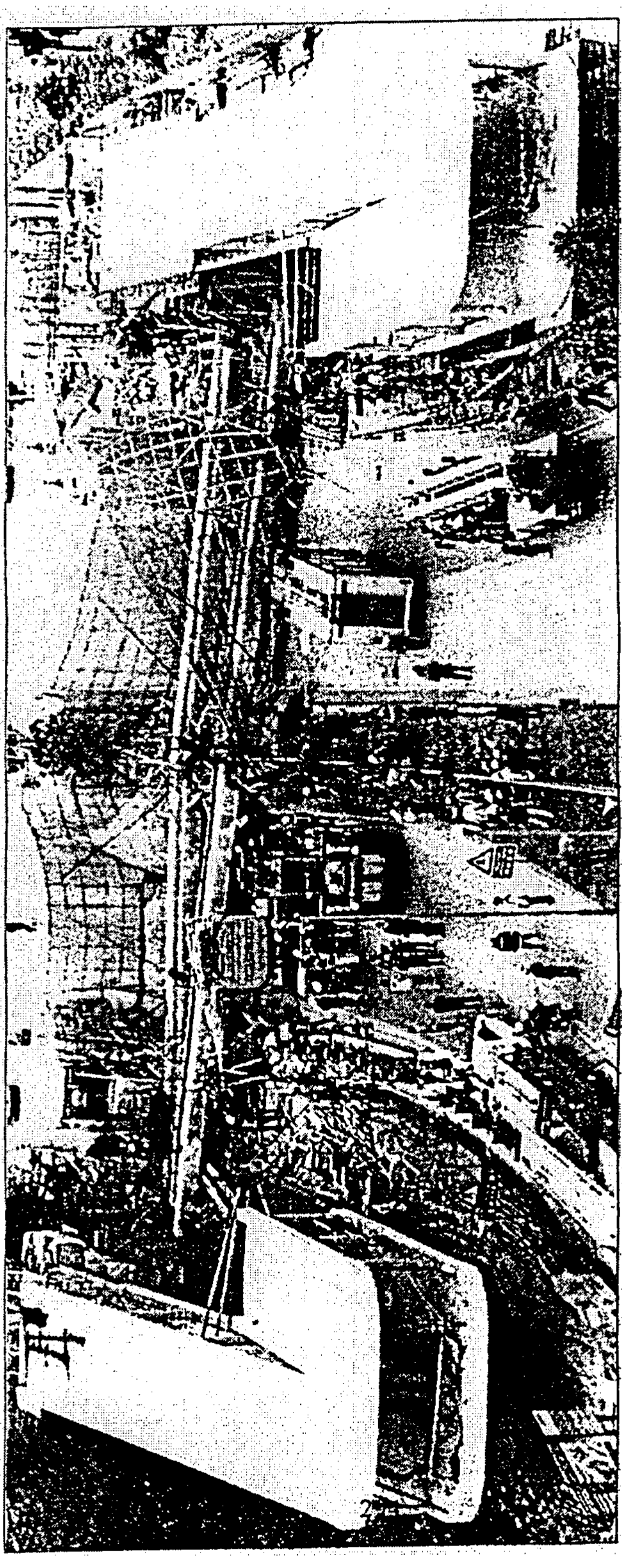
Mr Leung, who had worked on the bridge's scaffolding since November 1995, said he did not consider the procedure to be unsafe. He suffered internal bleeding in the accident and has been unable to work since.

Wan Hin and its manager each face two summonses of failing to ensure safety at a workplace and failing to ensure workers' wellbeing. Their trial has been fixed for May 5.

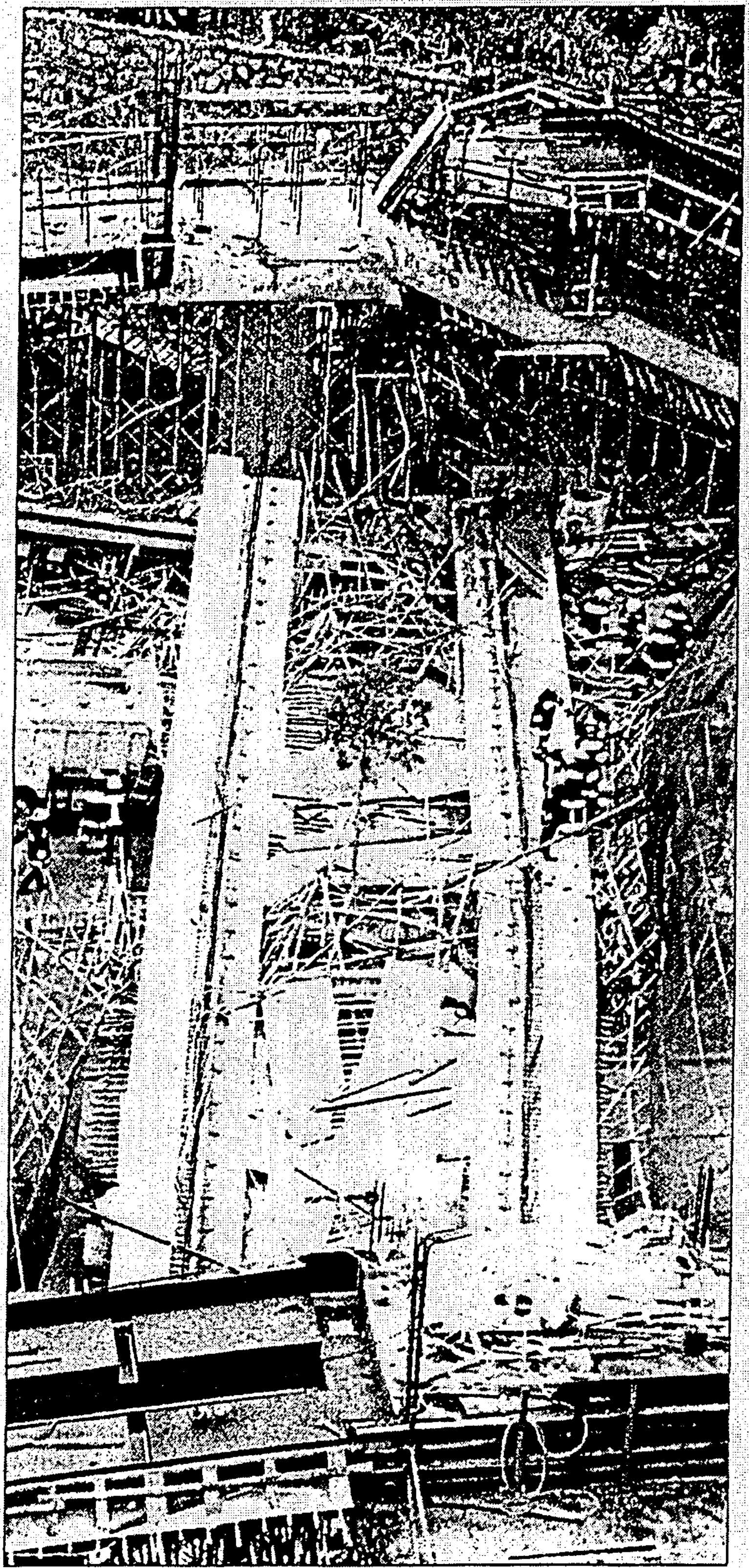
Yesterday Cheung's wife, Tong Ling-yuk, 39, an Indonesian-Chinese, listened to the hearing aided by an interpreter. The inquest continues before Coroner Richard Day today.

Case Ref. No. 10 Tseung Kwan O, HK

Source: 21st January 1997, South China Morning Post



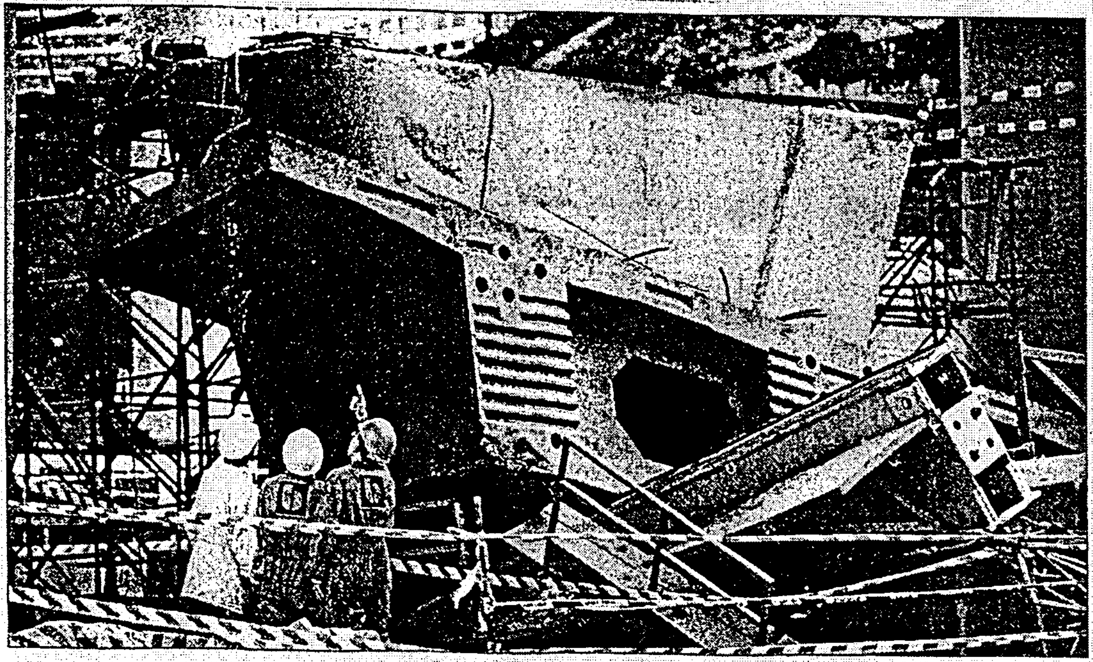
Case Ref. No. 10 Tseung Kwan O, HK



Case Ref. No. 11 Route 3, HK

Source: 24th February 1995, South China Morning Post

Two workers killed as flyover collapses



K.Y. Cheng

Bridge of death . . . inspectors examine the collapsed concrete section that killed two Thai workers at the troubled Kwai Chung viaduct project.

By KEITH WALLIS

TWO Thai workers died and four were injured yesterday when a 75-tonne concrete bridge section crashed through scaffolding at a construction site in Kwai Chung.

The accident happened at 3.40 pm on the troubled Kwai Chung viaduct contract.

The dead and injured were taken to Princess Margaret Hospital. Sritharارat Somphong, 36, died after a one-hour emergency treatment, and another unidentified worker was found to be dead at the scene.

The injured workers, Namuvn Gkun, 22, Vthat Knamtan, 42, Bumsom Kuson, 34, and Phinit Czk Nok, 36 suffered broken hands or legs.

They are on a one-year contract and are paid about $10,000 a month. About 100 Thai construction workers have been imported for the project.

Campenot Bernard/Franki Contractors (CBF) project manager Rohan Shorland said the workers' families would be contacted and flown from Thailand.

"They all worked for the joint venture. Some of them had worked for us for years [in Thailand on similar projects]," Mr Shorland said.

"There is a technical inquiry. The segnent is on the ground surrounded by scaffolding and other material. It is far too early to guess what caused it," he said.

CBF safety manager Wong Yun-yin said the scaffolding should have been able to support the weight of the segment which was being moved by special equipment.

CBF and the Labour Department have launched separate investigations.

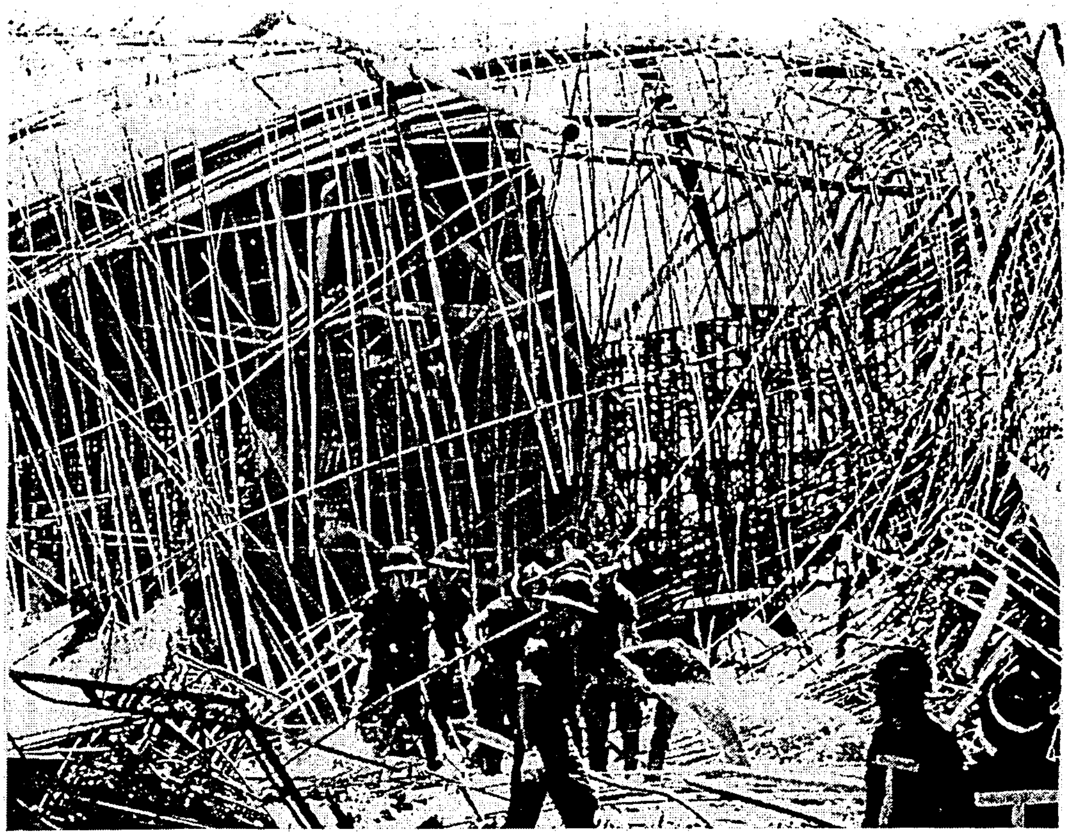
The collapsed section is part of a four-kilometre elevated viaduct for airport-bound road and rail traffic being built next to the Kwai Chung container port. Mr Wong said the segment that fell was for the railway portion of the project.

CBF won its $2.3 billion contract in May 1993, but the project ran into serious trouble last year after design difficulties.

As a result, in December last year joint venture partner Franki Contractors said it expected to make a $645 million loss by the time the contract finished at the end of next year.

Case Ref. No. 12 Macao

June 1994



Case Ref. No. 13 Israel

Source: April 1994, Construction Today, p.10.

Israeli falsework fall brings call for tighter checks

Third party verification of falsework design has been recommended in Israel after a bridge widening collapse in mid-March. Design and construction errors caused the collapse which brought a 100t precast bridge widening beam crashing on to a motorway, killing three people.

In a report, published a week after the incident, the public inquiry committee said: "The collapse of the temporary supports for the bridge was due to a combination of faults in the design and execution of the construction of the support towers on which the precast beams were resting."

The committee recommended falsework designed to support such heavy loads be checked by an independent expert and for falsework where supports cannot be spread across the load to be built of concrete or large diameter steel tubing.

Committee member Professor Ben Tur, who is head of the Israeli National Building Research Institute, said the design had wrongly assumed that the load would be even across the falsework. "More accurate calculations showed that the load was not evenly distributed," he said. "Some supports were more heavily loaded, taking them beyond their capacity, and this was the main cause of the collapse."

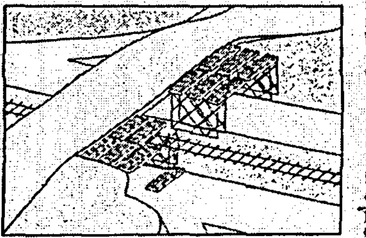
Tur said the problem had been exacerbated by the spacing of the support towers. "Usually, the legs of the support structure would be spread under the load," he said. "Here they were concentrated between the carriageways so as to leave the freeway open."

The collapse brought a 100t precast concrete beam down on the Jerusalem-bound carriageway of the motorway, 8km east of Tel Aviv. It killed two motorists and a construction worker.

The triple web beam was one of six resting on falsework across the carriageway as part of a bridge widening scheme on the Shapirim junction. A further six beams straddle the Tel Aviv carriageway and a railway running along the central reservation.

Tur said the support between the carriageways was probably the first to fail. "The tower in the middle had the greatest load," he said. "It collapsed under a combination of buckling and diagonal pulls."

The inquiry committee decided that the conditions leading to the collapse had been peculiar to the project. It recommended that work on Shapirim junction be stopped until the remaining falsework was strengthened and the speed limit reduced on the motorway under the bridge.



The report is now in the hands of Israeli Housing Minister Benjamin Ben Lezer. He is waiting for the conclusions of separate investigations by client Ma'atz (the public works department) and contractor Sollel Boneh before deciding where to lay blame.

Ma'atz ordered strengthening of the falsework after the accident.

No one from Ma'atz or Sollel was available to comment after the report as *CT* went to press, although shortly after the accident Ma'atz director general Ben Zion Salmon did say that his department had designed the bridge and supervised work. "We have overall responsibility," he said, "but the contruction process is the repsonsibility of the contractor."

Salmon also said the method used, with the beams resting on falsework before tensioning and connection to permanent supports, was quite common. "We have constructed temporary scaffolding for many bridges without a problem," he said. "We checked the design of this scaffolding and it had a safety factor of three for the beams. The pressure on the scaffold was only 55% of the design load."

None of the organisations involved would comment further, but neither the contractor nor the public works department has accepted the findings of the official report.

Matthew Pettipher

BOOKS

Santiago Calatrava. Second edition monograph on his work. Edited Dennis Sharp. Publisher Chapman & Hall. Price £14.99 ($22).

Global change on planet earth. From Megascience OECD Forum series. Published by OECD Paris. Price FFr130; outside France FFr170 ($29) ($42.50).

Asphalt paver safety manual. Twelth in a series. Published Construction Industry Manufacturers' Association, Wisconsin, USA.

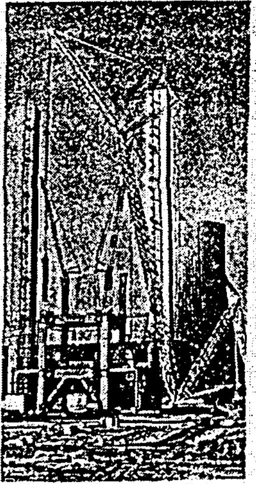
Yearbooks. Concrete £62 ($90); **Ground Engineering** £62 ($90); **Waste-recyling and environmental directory** £45 ($63); **Water directory** £25 ($36.60). Published Thomas Telford Publications.

Construction of fills – second edition. Part of practical construction series. Edward J Monahan. Published John Wiley and Sons. Price £49.50 ($72.50).

Concrete on site. Boxed set of 11 subject booklets. Published British Cement Association.

Arbitration practice in construction contracts. Third edition. Douglas A Stephenson. Published E & FN Spon (Chapman & Hall) Price £16.50 ($24) softback.

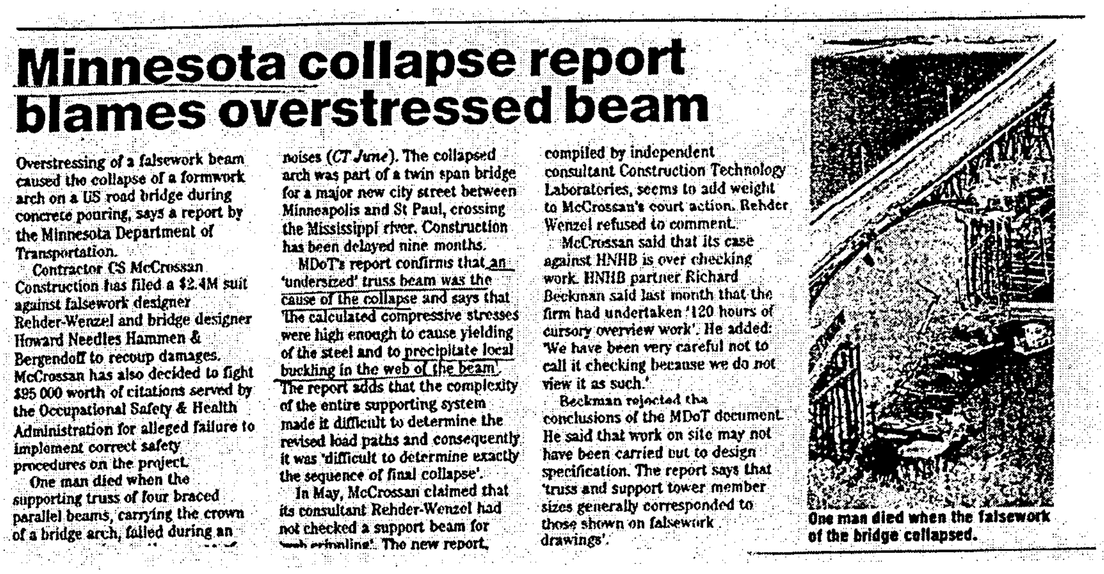
The complete manual of housebuilding. Robert Mathews. Published J M Dent and Sons. Price £14.99 ($22) softback.



ON STATION: One of Europe's biggest mobile cranes, this Mannesmann Demag PC 9600 is currently working on construction of a new lignite or brown coal power station in former eastern Germany. The machine, with a 112m main boom and 70m jib has to lift in up to 105t steel sections for the boiler house on the Schkopau station sited halfway between Halle and Leipzig. Maximum lift height is 150m. The huge power station, part of a mass of infrastructure being created in the so called Funf Neue Lande is designed and built by Ruhr based firm Weber Kraftwerke Ruhr AG which will also operate the 900MW station when it comes on stream in 1995. The project is financed 60% by KWR and 40% by Zahler Energie, a joint venture owned by Britain's Powergen and the US NAG Energy. The crane is on hire from UK lift specialist Grayston White & Sparrow.

Case Ref. No. 14 Maryland, USA

Source: November 1990, Construction Today



Minnesota collapse report blames overstressed beam

Overstressing of a falsework beam caused the collapse of a formwork arch on a US road bridge during concrete pouring, says a report by the Minnesota Department of Transportation.

Contractor CS McCrossan Construction has filed a $2.4M suit against falsework designer Rehder-Wenzel and bridge designer Howard Needles Hammen & Bergendoff to recoup damages. McCrossan has also decided to fight $95 000 worth of citations served by the Occupational Safety & Health Administration for alleged failure to implement correct safety procedures on the project.

One man died when the supporting truss of four braced parallel beams, carrying the crown of a bridge arch, failed during an

noises (*CT June*). The collapsed arch was part of a twin span bridge for a major new city street between Minneapolis and St Paul, crossing the Mississippi river. Construction has been delayed nine months.

MDoT's report confirms that an 'undersized' truss beam was the cause of the collapse and says that 'the calculated compressive stresses were high enough to cause yielding of the steel and to precipitate local buckling in the web of the beam'. The report adds that the complexity of the entire supporting system made it difficult to determine the revised load paths and consequently it was 'difficult to determine exactly the sequence of final collapse'.

In May, McCrossan claimed that its consultant Rehder-Wenzel had not checked a support beam for 'web crippling'. The new report, compiled by independent consultant Construction Technology Laboratories, seems to add weight to McCrossan's court action. Rehder Wenzel refused to comment.

McCrossan said that its case against HNHB is over checking work. HNHB partner Richard Beckman said last month that the firm had undertaken '120 hours of cursory overview work'. He added: 'We have been very careful not to call it checking because we do not view it as such.'

Beckman rejected the conclusions of the MDoT document. He said that work on site may not have been carried out to design specification. The report says that 'truss and support tower member sizes generally corresponded to those shown on falsework drawings'.

One man died when the falsework of the bridge collapsed.

Case Ref. No. 15 USA

Source: August 1989, Engineering News Record

Contractor fined on bridge collapse

'Gross deviations' from contractual plans caused the collapse last year of falsework during construction of a US highway bridge, according to Maryland safety investigators.

Worst of these was the use of jacks of insufficient capacity at the top of the scaffold towers. Contractor JP Smith Co has been fined $910 220, a state record, by the Occupational Safety & Health Administration.

The 18m span bridge at Laurel, Maryland, was one of four similar structures which will carry the two carriageways of Maryland Route 198 over the Baltimore Washington parkway, Interstate 295. The steel formwork collapsed midway through pouring the deck slab last August, injuring 14 people (*CT* October 1989).

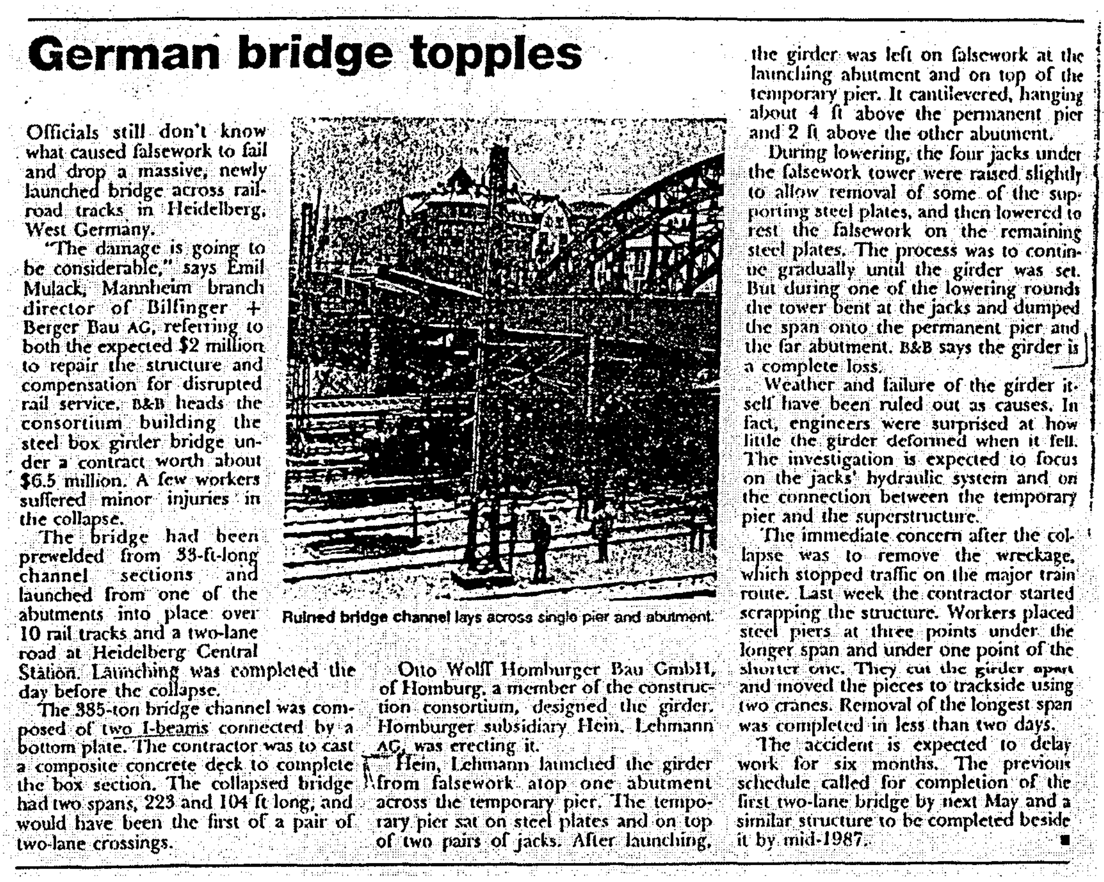
Craig Lowry Maryland OSHA chief of enforcement said there were a number of 'very severe' deviations from the agreed plans, of which the most significant concerned 112 screw jacks at the top of the scaffold towers. The contractor used jacks of only 44kN capacity instead of 107kN called for by the approved drawings. A fine of $7100 was levied for each jack.

Planning and coordination engineer Roy Crawford of the Federal Highway Administration's eastern federal lands division was surprised that the contractor had deviated so far from the agreed plans. Although the division, which designed the bridge, had 'limited experience' of JP Smith Co, many of its employees were well known in the industry.

JP Smith Co president John Smith declined to comment.

Case Ref. No. 21 Heidelberg, W. Germany

Source: December 1985, Engineering News Record, p.14.



German bridge topples

Officials still don't know what caused falsework to fail and drop a massive, newly launched bridge across railroad tracks in Heidelberg, West Germany.

"The damage is going to be considerable," says Emil Mulack, Mannheim branch director of Bilfinger + Berger Bau AG, referring to both the expected $2 million to repair the structure and compensation for disrupted rail service. B&B heads the consortium building the steel box girder bridge under a contract worth about $6.5 million. A few workers suffered minor injuries in the collapse.

The bridge had been prewelded from 33-ft-long channel sections and launched from one of the abutments into place over 10 rail tracks and a two-lane road at Heidelberg Central Station. Launching was completed the day before the collapse.

The 385-ton bridge channel was composed of two I-beams connected by a bottom plate. The contractor was to cast a composite concrete deck to complete the box section. The collapsed bridge had two spans, 223 and 104 ft long, and would have been the first of a pair of two-lane crossings.

Ruined bridge channel lays across single pier and abutment.

Otto Wolff Homburger Bau GmbH, of Homburg, a member of the construction consortium, designed the girder. Homburger subsidiary Hein. Lehmann AG, was erecting it.

Hein, Lehmann launched the girder from falsework atop one abutment across the temporary pier. The temporary pier sat on steel plates and on top of two pairs of jacks. After launching, the girder was left on falsework at the launching abutment and on top of the temporary pier. It cantilevered, hanging about 4 ft above the permanent pier and 2 ft above the other abutment.

During lowering, the four jacks under the falsework tower were raised slightly to allow removal of some of the supporting steel plates, and then lowered to rest the falsework on the remaining steel plates. The process was to continue gradually until the girder was set. But during one of the lowering rounds the tower bent at the jacks and dumped the span onto the permanent pier and the far abutment. B&B says the girder is a complete loss.

Weather and failure of the girder itself have been ruled out as causes. In fact, engineers were surprised at how little the girder deformed when it fell. The investigation is expected to focus on the jacks' hydraulic system and on the connection between the temporary pier and the superstructure.

The immediate concern after the collapse was to remove the wreckage, which stopped traffic on the major train route. Last week the contractor started scrapping the structure. Workers placed steel piers at three points under the longer span and under one point of the shorter one. They cut the girder apart and moved the pieces to trackside using two cranes. Removal of the longest span was completed in less than two days.

The accident is expected to delay work for six months. The previous schedule called for completion of the first two-lane bridge by next May and a similar structure to be completed beside it by mid-1987. ■

Case Ref. No. 22 Colorado, USA

Source: 28th November 1985, Engineering News Record, p.12.

State supervision 'lacking' in Denver viaduct collapse

A consultant's report to the Colorado Department of Highways says contractor misunderstandings about a construction sequence and lack of professional supervision by DOH engineers were the reasons for collapse of a Denver viaduct. Failure of a concrete pier table dropped eight concrete girders across Interstate 25 early last month, killing one worker and seriously injuring four.

The report, prepared by consultant KKBNA, Inc., Wheat Ridge, Colo., was released under court order by the state's attorney general after the wife of an injured worker demanded its release in a suit seeking damages.

The collapse occurred during placement of the last of eight 55-ton girders onto a partially completed pier table (ENR 10/17 p. 16). The investigation centered on whether a construction sequence calling for a second, heavily reinforced lift—to complete the pier cap before the girders were placed—was adequately spelled out in design plans. The report determined it was not, although the design itself was adequate.

The contractor, Martin K. Eby Construction Co., Wichita, "misunderstood the construction sequence intended by the designer," the report said. The plans submitted by the designer, the Lakewood, Colo., office of Howard Needles Tammen & Bergendoff (HNTB) "did not contain a specific pier 6J construction sequence, nor a specific concrete girder erection sequence." This led construction personnel to develop a sequence "based on their interpretation of certain notes in the contract plans."

The notes "were not sufficiently clear and unambiguous as to properly describe the construction sequence by the designer." The report said neither Colorado DOH personnel nor the contractor's field personnel "could reasonably be expected to understand structural consequences of their planned construction sequence." The only reference in the 120-page report to the highway department's supervisory role said: "At no time during the construction of Pier 6J did any [DOH] engineer with the training and experience necessary to recognize the implications of the planned construction sequence visit the site for the specific purpose of reviewing the progress of construction." The state DOH has declined to comment on the substance of the report.

A spokesman for Eby Construction says the contractor believes it "acted properly under the supervision, review, inspection and direction of the Colorado DOH." The report notes the contractor's field personnel "disregarded" state regulations on the removal of falsework supporting the pier cap.

A lawyer representing HNTB said "The plans prepared by HNTB depicted pier 6J as a single structural member and there was no provision for stopping construction at any point prior to placing the girders. The decision to halt construction after the first pour was a decision we were not involved in."

KKBNA Vice President John K. Bright says, "The design was just unusual enough that there should have been some sequencing. If they'd done that, the accident wouldn't have happened."

Girders collapsed onto Denver's Interstate 25.

12 ENR/November 28, 1985

Case Ref. No. 24 Sunshine Skyway, Tampa Bay, U.S.A.

Source: 1st November 1984, New Civil Engineer, p.10.

Three failures possible cause of Skyway fall

Strong winds and a possible crane impact probably contributed to the collapse of Florida's Sunshine Skyway launch gantry says a report published recently by the accident investigators.

The 100m long steel spaceframe gantry slumped in August injuring four men. Since then work has stopped on deck segment launching and an investigation has been underway.

The exact combination of static and dynamic forces which caused the failure has yet to be determined says Zetlin Argo Structural Investigations of New York. But failure of one of three structural elements within the gantry support is thought to have started the complex collapse mechanism.

A prestressed anchoring strand securing a temporary vertical truss over pier five snapped and this has been singled out as the element most likely to have started the collapse.

The gantry failed during the crucial placement of a 220t bridge segment for the new $230M (£188M) Tampa Bay crossing. The original structure was wrecked in 1980 when a freighter collided with it during fog.

Three piers supported the gantry at the time of the accident, and it is the vertical truss connection between the piers and the gantry which has attracted closest scrutiny during the investigation.

The first concrete segment to be placed was within minutes of being seated on top of pier five north when the accident occurred. Support at the top of pier five north comprised a vertical truss secured by prestressed cables to the pier side (*NCE* 23/30 August).

'The main culprit in the gantry failure was this eccentric connection to the bottom of the vertical truss on pier five' says the report. 'A higher than expected vertical load made the truss "spring" outwards and the anchoring strand snapped due to excessive tension.'

A second mode of failure considered in the report is possible local crushing of a clevis joint between the top of the vertical truss and the jacks which actually supported the gantry. 'This source and mode of failure was possible but unlikely on the basis of presently available evidence' the report states. The evidence Zetlin Argo has includes the mangled remains of the 150t lifting jacks which were wrecked during the collapse and were later found on the Tampa Bay seabed.

At the time of the incident investigating engineer Jim Hinckley of Zetlin Argo told *NCE*: 'It is easy to see that the jacks have failed in axial and bending forces simultaneously.'

The third failure mode considered by Zetlin Argo looks at the local failure of a concrete pier wall. If the concrete corner support of pier five crumbled before the collapse, not as a result of it, the truss would have failed instantly.

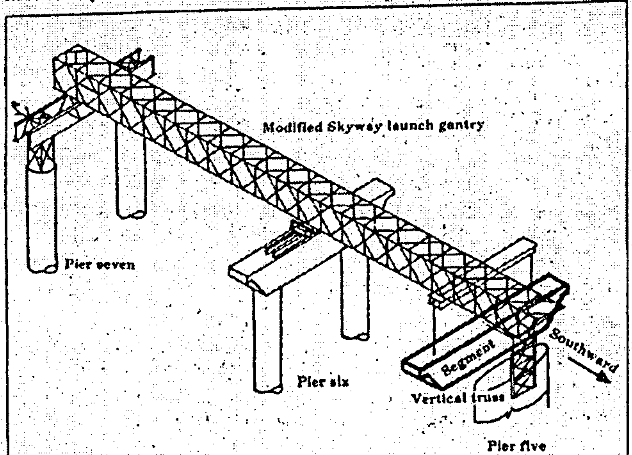
By computerised comparison of the gantry as designed, built and failed, Zetlin Argo has established the most likely mode of collapse. 'Buckling of pier five support by one of the three described failure modes triggered three simultaneous actions' reads the report.

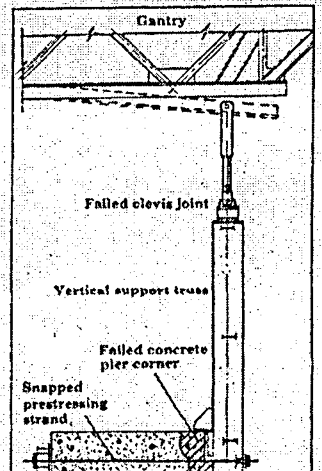
The front of the gantry lost its vertical support and slumped downwards. The fixings on top of pier seven failed and then moved southward. Lastly this southward movement of the support girders shot the whole gantry southward, damaging pier five.

Hinckley stressed that his investigation has not included recommendations on how the collapse could have been avoided. 'But it is evident that if the southward and northward movement of the gantry had been locked the collapse might not have happened' he says.

The gantry was designed in the late 1970s for launching deck segments at Seven Mile bridge in southern Florida. For the new Skyway job panel members were beefed up and member connections redesigned for greater loads. 'But we have not been asked to compare the structural responses of the two designs' says Hinckley. 'That is another investigation altogether. So far our work has only involved analysing and categorising the forces in excess of purely static forces.'

As to whether heads are likely to roll following recent publication of the report on August's accident in which four men were injured Hinckley replied: 'That remains to be seen. Client Florida Department of Transportation, contractor Paschen and designer Howard Needles Tammen & Bergendoff could all be at fault but it's not our job to attribute blame.'





ABOVE: The first segment was being placed as the failure occurred.
RIGHT: Section through pier five gantry support.

Case Ref. No. 26 Ramp C, East Chicago, USA

Source: December 1982, New Civil Engineer, p.6.

NEWS

One killed in another US falsework failure

America has suffered another collapse of falsework to a bridge under construction just a few months after a disastrous failure in East Chicago.

Timber falsework to the main span of an overbridge on US Route 36 in Kansas collapsed on 17 November killing one and injuring eight workers. An inspection team has been on site and is due to meet again on 14 December following which a report may be issued if investigations are complete.

The bridge was the first of a pair planned to carry a two lane westbound carriageway over an interchange access road being built by contractor A M Cohron & Son of Atlantic, Iowa, for client the Kansas Department of Transportation. Cohron's contract for two adjacent bridges is worth about £250 000 and is part of a £12.5M scheme to cross the Missouri river between Elwood, Kansas, and St Joseph, Missouri. Design of the bridge was conventional reinforced concrete slab construction and engineering consultant Wilson of Salina, Kansas, says it has executed some 100 similar designs. The firm is only responsible, it says, for design of the structure and has no brief for construction supervision which is the responsibility of Kansas DoT, or falsework design which is said to be the contractor's.

The three span bridge has two 11.9m side spans and a 15.6m main span which was under construction when the collapse occurred. Concrete pouring was in progress around mid span although none was being discharged when the timber falsework collapsed. A concrete finishing machine is reported to have been approaching mid span at the instant of collapse.

There was one fatality, a Kansas DoT inspector described as 'a young girl', who was monitoring discharge from a ready mixed concrete truck. This delivered the mix via a concrete pump to one side of the 15.2m wide, slightly ramped deck and by craned skip to the other side. She had to repeatedly cross the deck width at ground level and was crushed. The eight injured men were among operatives working at deck level who all 'rode down' the 7.3m to the ground as the deck lost its support. At least one is still in hospital.

The investigating team's task has been aggravated by the immediate bulldozing of the debris to recover the inspector's body thereby destroying potential evidence.

Falsework structure was founded on timber piles capped with 355m square section timber. Thrust from screw jacks was transmitted through 250mm steel girders to 375mm steel stringers running parallel with the bridge's centreline. These stringers supported curved timber infills following the contour of the bridge soffit and plywood formwork was positioned on transverse timber studding.

The American Portland Cement Association is also making an independent investigation into the collapse as well as the Kansas DoT.

(See feature page 16). ■

Case Ref. No. 27 Chicago, USA

Source: 29th April 1982, New Civil Engineer, p.6.

Guyrope use probed in Chicago check

US safety officials confirmed this week that investigation of April's disastrous sliproad failure in East Chicago is centring on guyropes used to stabilise the ill-fated structure's falsework and foundation of the falsework towers.

At the same time engineers from the Indiana Department of Highways said they were examining a new scheme to remove hanging concrete debris from site.

Collapse of the elevated roadway occurred five weeks ago and killed 12 men (NCE 22 April). 'It is early days yet but we have conducted 95% of our interviews and are continually inspecting debris as it is cleared' said Indiana Commissioner of Labour Howard Williams on Monday.

Williams has overall control of the Indiana Occupational Safety & Health Administration. IOSHA has ten inspectors on site, four of them are under contract from the US Bureau of Standards.

'We are particularly concerned about configuration of guyropes meant to laterally restrain each pair of falsework towers and bearing capacity. IOSHA was also looking carefully at the manner in which contractor Superior Construction had founded the towers, and bearing capacity of the soil beneath.

'We were taking soil samples last week' said Williams. 'Much of the rubble has been cleared and we are now being held up by delay in removing the deck trough still hanging by its tendons.'

Specialist engineering firm Raths & Johnson of Chicago has been commissioned by Superior to take down the hanging concrete. Original proposal put to the highways department for approval involved installing timber cribbing under the trough, splitting the concrete longitudinally, then lowering each half after cutting the tendons.

This was turned down due to possible difficulties of erecting the cribbing. Now a second proposal is being considered. This is based on lifting the trough with two cranes, severing the tendons with a lance point torch and dropping the debris onto a specially constructed sand embankment 'cushion'.

'If our engineers give this method the OK we could have the concrete down by Thursday' said a highways department spokesman earlier this week. Once on the ground the trough will be jack hammered and saw cut into manageable pieces.

Superior currently has a reduced workforce on site following the accident. It is working in areas remote from the elevated sections.

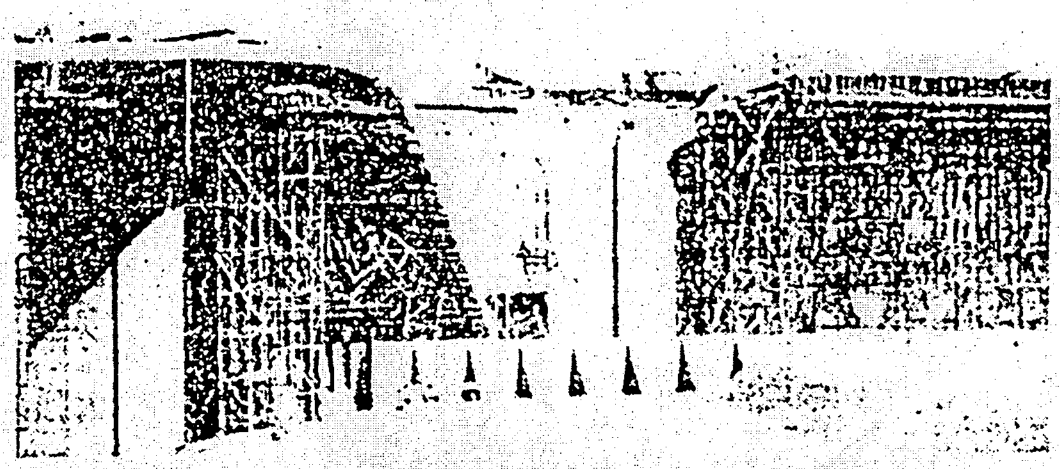
The contractor and its consultant, Figg & Muller Engineers are reportedly in the process of evaluating alternative methods of construction for the elevated sliproads. The highway department will be approached for consent to continue construction once a method has been chosen.

Consent is likely to be given even if the agencies investigating the collapse have not reported their conclusions. ■

TOP: High-Capacity shoring towers should have been based on sand jacks, timber blocks and precast concrete pads. ABOVE: Engineers are still struggling for a safe and effective method of lowering hanging debris.

Case Ref. No. 29 Saudi Arabia

Source: 20 May 1982, New Civil Engineer, p.5.



ON THE DECK: Demolition of debris from this collapse in Saudi Arabia is due to start soon. The collapse abruptly halted the construction programme for the Riyadh outer ring road. The 43m span fell eight days after concrete pouring in January. It is believed post tensioning was in progress when the deck buckled and that large cut outs in the deck for anchors and jacks may have created critical compression forces in the deck slab section. Contractor on the three level Mecca interchange is local firm Al-Muraibidh working to designs by Renardet-Sauti spa. Two or three other spans are thought to have been similarly constructed. Demolition by blasting is expected.

Case Ref. No. 30 Bombay, India

Source: 25th June1981, New Civil Engineer, pp.10-11.

Bombay inquiry points to falsework failure

Judicial inquiry into a flyover construction collapse is drawing to a close in Bombay, India. Already the evidence points to a failure of temporary support.

Collapse occurred in the Byculla neighbourhood of Bombay one night last September during the final stages of construction.

Approach spans had been finished and two of the structure's four longitudinal centrespan T-beams had been cast.

First of these had been prestressed and was self supporting. Its falsework of adjustable steel props had been removed but the beam was still supported at either end by a trestling arrangement 2.6m above final level.

This was to allow easy access for prestressing and was to have been a common feature of all four beams' construction.

Beam number two, meanwhile, had been cast but not prestressed. It was supported by a traditional falsework of ballis (wooden logs) with bamboo bracing. Shuttering for the third beam was just being started on props taken from beam one.

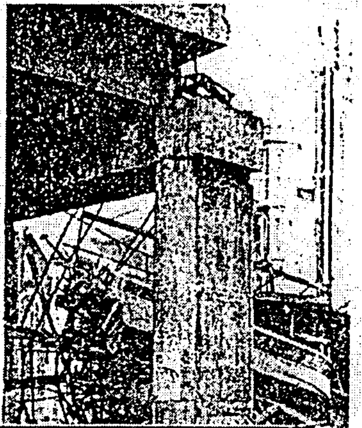
From evidence given at the inquiry, it appears that beam one's trestle support was inadequate. Made up of steel cribs and timber sleepers, the trestles had shown signs of distress some four days before collapse.

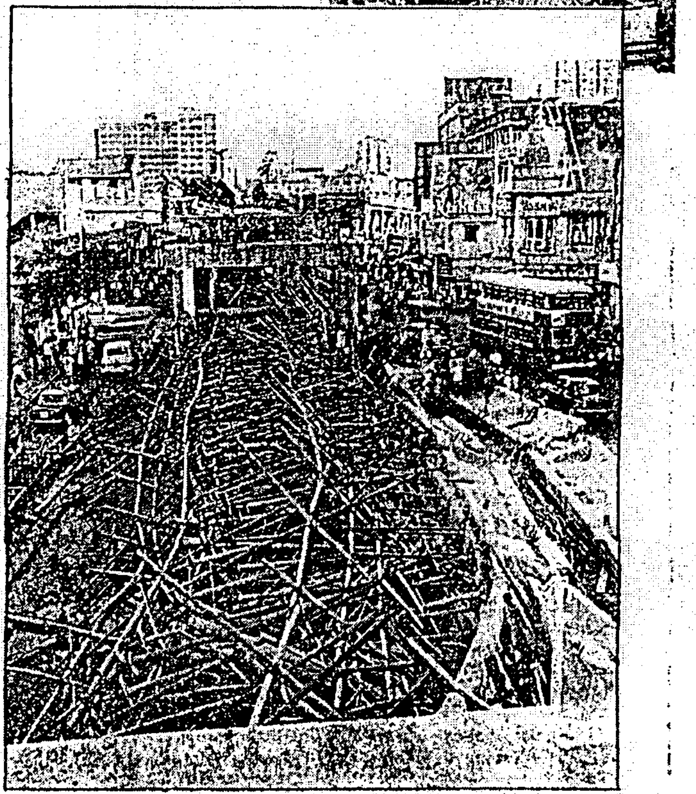
Main theory is that they failed first, causing beam one to fall and to push over the second beam and temporary support for the third' local consulting engineer Tony Remedios told *NCE*.

Other witnesses at the inquiry suggest it was failure of the traditional falsework under beam two which precipitated collapse.

The flyover was let to local contractor Model Construction Company for Rupees 4M (about £220 000), and Bombay based consultant V S Dewan was commissioned to undertake design and supervision.

Debris was cleared last month following examination by government appointed technical experts. No-one was hurt in the collapse.





New Civil Engineer, 25 June 1981

Case Ref. No. 31 Jalans Euros Flyover, Singapore

Source: 12th July 1979, New Civil Engineer, p.26.

Box outs probable cause of Singapore flyover failure

Collapse last February of the 65m long central section of a six lane flyover under construction in Singapore may have been caused by larger than planned temporary box outs in the deck of the concrete box superstructure.

The findings of an internal inquiry by client, the Government's Public Works Department, have yet to be announced, but they are expected to point to the box outs as the prime cause of failure and the investigation may well single out a lack of on site co-ordination as a contributory factor in the collapse.

Official secrecy still surrounding the collapse — neither the client nor the locally based contractor is willing to discuss the incident — gave rise to considerable speculation on the island over why the isolated span dramatically failed soon after its supporting falsework was removed.

But suggestions of low strength in situ concrete or inadequate prestressing have now been firmly ruled out. And the only questions left unanswered are should the design still have been adequate to accommodate the large box outs, or alternatively why were they not partially filled in prior to the falsework being stripped?

The failed structure, to be known as the Jalan Eunos flyover, is one of 11 new bridges needed for the Pan Island Expressway, a 25km long bypass to the north of Singapore city.

Some of the 11 bridges are being tendered by PWD as a design/construct package, some are out to consultants and others are designed wholly by the client. The flyover, which will sweep the expressway over (and provide an interchange with) a two lane north south running highway, was designed in house by PWD.

One of the island's largest contractors, Lim Kah Ngam, started the £2M contract early last year. The flyover, symmetrical about its central point, was to be constructed in five sections and, by this February, the central span over the Eunos Road was virtually complete.

The structure's two carriageways are separated longitudinally by a 25mm wide expansion joint running the length of the flyover. Each carriageway comprises a twin concrete box, carried by V shaped concrete piers.

The all in *situ* construction programme was dictated by the stressing sequence. The central 47m long span plus a one fifth length of the spans on either side were to be built first. This 65m long section was then to be stressed before the two remaining sections on either side of the central span were started.

Stressing cables, up to six in each box web, were to overlap between the construction sections, with the cables from stages two and three running a short distance into each end of the central span. Thus while the central section was being built access had to be left through the deck for installing the anchorage and stressing jacks for the sections on either side.

The original plan was to leave a rectangular shaped box out above the stressing points in each of the six webs across the deck. The boxes were to be about 1.5m long, 1m wide and 450mm deep.

However LKN and stressing subcontractor VSL Systems suggested that to simplify construction, provide better access for stressing and ease the fixing of transverse deck steel a single box out the full width of both carriageways would be more suitable. Longitudinal

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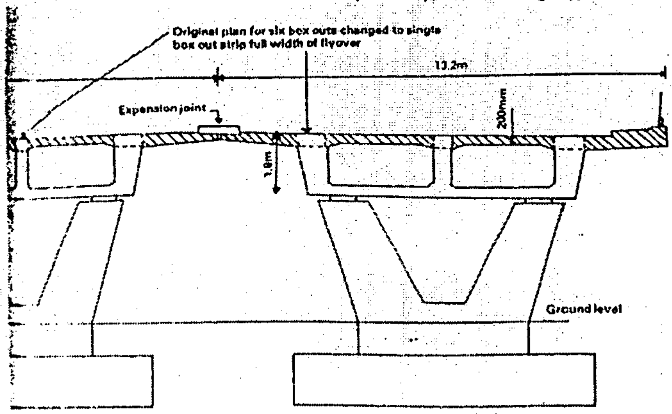
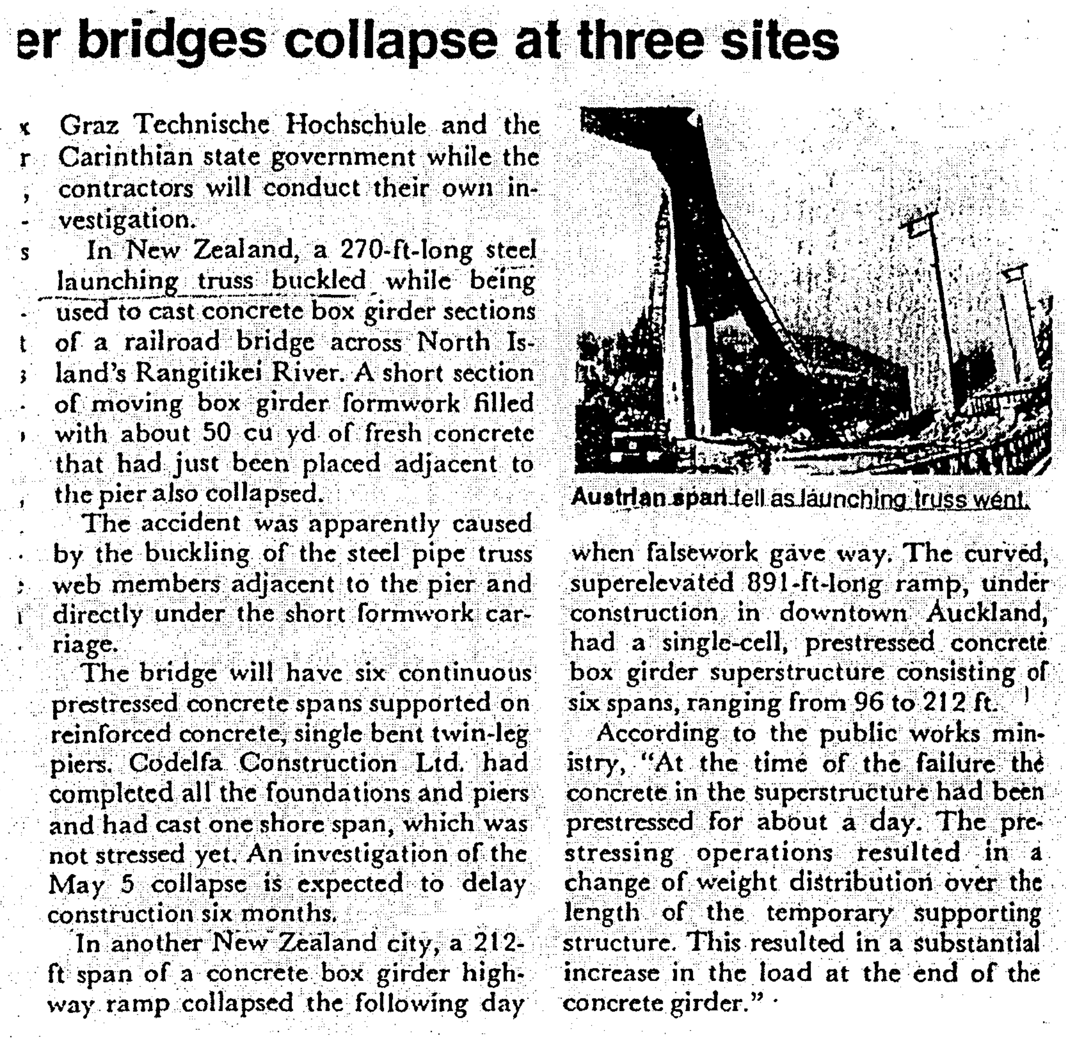


lew Civil Engineer, 12 July, 1979

Case Ref. No. 32 New Zealand

Source: 29th May 1975, Engineering News Record, p.12.



er bridges collapse at three sites

Graz Technische Hochschule and the Carinthian state government while the contractors will conduct their own investigation.

In New Zealand, a 270-ft-long steel launching truss buckled while being used to cast concrete box girder sections of a railroad bridge across North Island's Rangitikei River. A short section of moving box girder formwork filled with about 50 cu yd of fresh concrete that had just been placed adjacent to the pier also collapsed.

The accident was apparently caused by the buckling of the steel pipe truss web members adjacent to the pier and directly under the short formwork carriage.

The bridge will have six continuous prestressed concrete spans supported on reinforced concrete, single bent twin-leg piers. Codelfa Construction Ltd. had completed all the foundations and piers and had cast one shore span, which was not stressed yet. An investigation of the May 5 collapse is expected to delay construction six months.

Austrian span fell as launching truss went.

In another New Zealand city, a 212-ft span of a concrete box girder highway ramp collapsed the following day when falsework gave way. The curved, superelevated 891-ft-long ramp, under construction in downtown Auckland, had a single-cell, prestressed concrete box girder superstructure consisting of six spans, ranging from 96 to 212 ft.

According to the public works ministry, "At the time of the failure the concrete in the superstructure had been prestressed for about a day. The prestressing operations resulted in a change of weight distribution over the length of the temporary supporting structure. This resulted in a substantial increase in the load at the end of the concrete girder."

Case Ref. No. 33 Belgium

Source: 20th June 1974, Engineering News Record, p.42.

Cantilever arm of box girder span collapses, taking footbridge with it.

Falsework failure blamed for bridge collapse

Belgian public works officials blame the failure of steel falsework supporting a 42-ft-long cantilever arm of a concrete box girder bridge, under construction over the Meuse River in Belgium, for the collapse of the 500-ton section earlier this month.

The 60-ft-wide post-tensioned concrete bridge at Wepion, designed and being built by Societé Belge des Betons (SBB), Brussels, will have two 192-ft-long main spans, each consisting of cantilever arms from a shore pier and a mid-river pier, and a drop-in girder between the arms. The main spans are flanked by 144-ft side spans, extending from shore piers to the abutments.

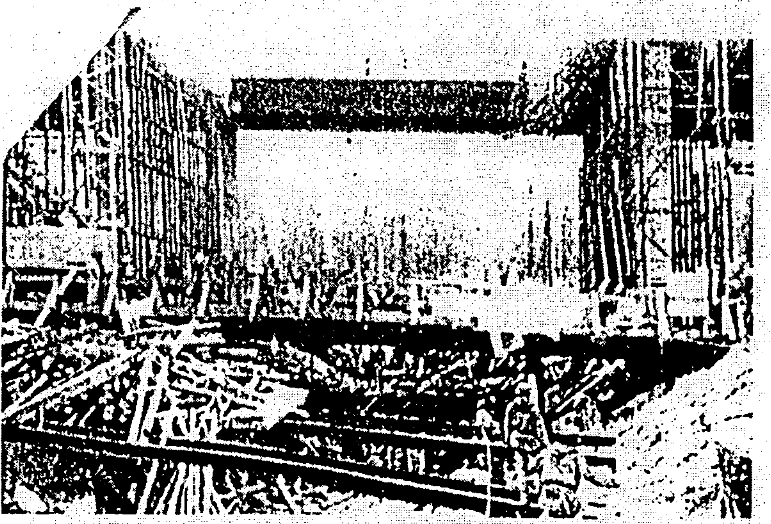
The collapse also took down a footbridge that extends the length of one main span. SBB had poured the concrete for the cantilever arm, which was curing at the time of the collapse, but had not post-tensioned it. The arm was supported on tubular steel falsework, designed by the Brussels-based firm, Échafaudages Demontables en Acier.

Insurance representatives for the contractor are currently investigating the collapse, according to the government agency supervising construction.

42 ENR June 20, 1974

Case Ref. No. 34 Kempton, West Germany

Source: 9th May 1974, Engineering News Record, p.10.



Failure in center span support frames during concreting may be cause.

Bridge falsework collapse kills nine

The 72-ft-long center span of a two-lane West German Autobahn bridge under construction in Kempten, 70 miles southwest of Munich, collapsed last week, killing nine workmen and seriously injuring 13. Preliminary and unofficial reports point to faulty steel falsework as the cause.

The collapse occurred after workmen placed about half of the concrete for the middle section of the reinforced concrete bridge, which was to be post-tensioned later. The contractor's plan was to pour the entire three-span deck of about 1,000 cu yd of concrete in a single operation starting at the center and working toward either side span. Part of the 16.5-ft-wide deck slab was blocked out with tubular casings about 3 ft in diameter to save weight.

According to initial reports, the most critical area of the falsework was beneath the center span, where steel A-frames spanned the 72-ft-length to take the entire load. Tubular scaffolding towers resting on the bridge's foundation slabs supported the A-frames. A structural failure reportedly occurred in one or more of the cross-members helping to support the frames.

Rudolf Grimme, a Munich engineer hired by the contractor, Schmitt and Junk, Munich, says he had examined the falsework on the day before the collapse and had "uncovered a number of defects," which Grimme reported to the contractor. It has been compulsory in Germany for contractors to hire private consulting engineers to check falsework since the Koblenz bridge collapses in 1971 and 1972 (ENR 11/18/71 p. 1 and 9/28/72 p. 22).

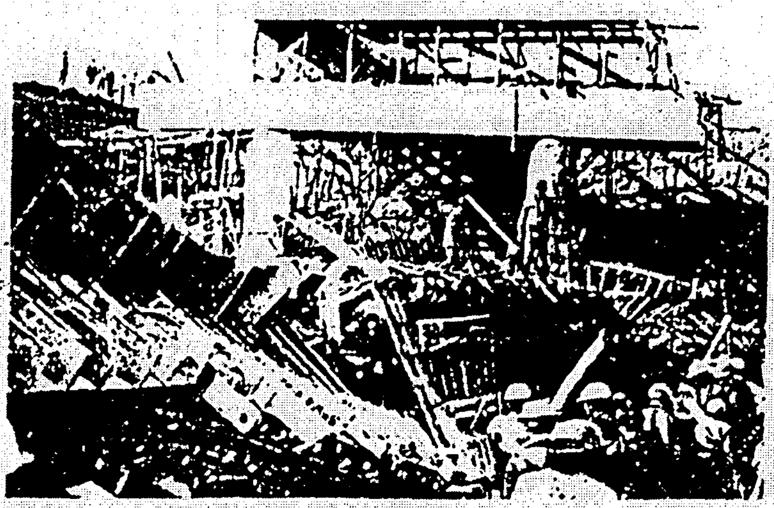
A spokesman for the contractor says that only minor defects had been established and that they had "nothing to do with the safety of the falsework." The spokesman says all the instructions in Grimme's report had been carried out. Grimme says he does not know if his recommendations had been followed.

An official panel probing the cause of the collapse has not yet reported its findings.

The Kempten Highway Construction Agency, a regional office of the Federal Transport Ministry, designed the 195-ft-long bridge which crosses the Leubas River in Bavaria. Roehro, a Dusseldorf-based subsidiary of Thyssen was responsible for falsework design and erection.

Case Ref. No. 35 Sao Paulo, Brazil

Source: 31st May 1973, Engineering News Record, p.12.



Center span collapse is blamed on shifting falsework.

Concrete span collapses during pour

Wooden falsework supporting forms for the 131-ft center span of a reinforced concrete overpass near Sao Paulo, Brazil, collapsed last week while workmen were casting concrete for the last of three longitudinal girders. At least six men were hurt when the 19.5-ft-high span came down.

Initial indications are that several days of rain had loosened the sandy soil under the falsework, causing it to shift. Both 98.5-ft side spans of the viaduct had been completed, and wooden forms for the other two center span girders were still in place while the third was being poured.

The viaduct is one of three designed and being built by Escritorio de Construcoes e Engenharis Ecel S.A. for a total of $410,000.

[redacted] part of a prestressed concrete viaduct under construction collapsed on May 18, killin[redacted]man and injuring two others. Entreprise Coignet, a well known French contractor in the industrialized housing field, was erecting the 15-span structure using the balanced cantilever method. A crane had erected five precast box girder elements projecting from one pier and was lining up the sixth when the collapse occurred.

Until the city magistrate hears testimony, officials won't know the cause of the collapse. However, the timing of the accident has led engineers to believe that either the crane buckled or it released the element before it was prestressed to the previously erected section, causing an imbalance.

Construction of the 60-ft-high structure, with spans up to 512 ft, began last September and was scheduled for completion by the end of this year.

Case Ref. No. 36 London, Berkshire, England

Source: 2 November 1972, Engineering News Record, p.14.

Bridge falls during concrete pour

A partially completed section of a 110-ft concrete bridge span collapsed 40 ft into the River Loddon during construction last week, 40 miles west of London, killing three workmen and injuring 10 others.

The accident occurred after about 500 tons of concrete, about half the day's pour, had been placed. The wooden formwork was supported by tubular steel scaffolding braced by steel cross girders, the same scaffolding used to construct a parallel, 30-ft-wide twin span completed last August.

Marples Ridgway Contractors, Bath, held the $12.5-million contract to construct the 32-span, post-tensioned viaduct for the Berkshire County Council, which designed the bridge. The 1,000-ft viaduct will link two major highways outside of Reading.

About 40 to 50 men were working on the bridge when it collapsed. The other half of the crew was on a lunch break. Eyewitnesses said the bridge vibrated all over for about 30 seconds, then there was a loud crack and the front of the span dipped 3 in. before it collapsed. Workmen were trapped under piles of piping and wet concrete, making rescue work difficult.

Scaffolding and wet concrete trapped crew.

So far there is no clue as to what caused the collapse, according to John Clarke, managing director of the construction company.

The British Science Research Council and the Construction Industry Research Information Association will conduct a $72,000 research project on the design and loading of scaffolding. The decision to do the study was prompted by the California bridge collapse that killed four last week (ENR 10/19 p. 11).

Case Ref. No. 37 Arroyo Seco Bridge, California, USA

Source: 26th October 1972, Engineering News Record, p.11.

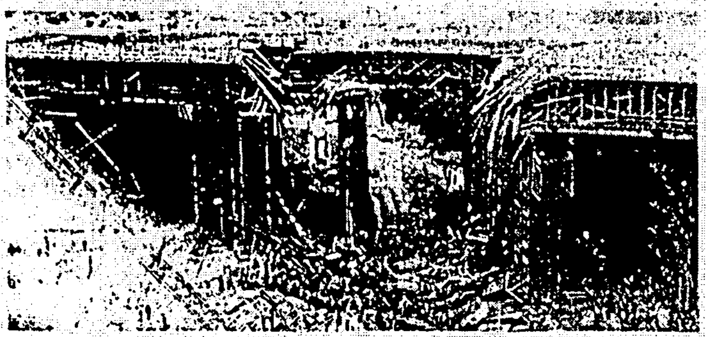
Bridge collapse during concrete pour kills six men

A 150-ft section of an expressway bridge collapsed last week at Pasadena, Calif., and plummeted 90 ft into a ravine as workers were placing concrete, [illegible]ing six and injuring six others.

Contractor Polich-Benedict Construction Co., Inc., Rosemead, Calif., had completed one of the twin, 580-ft four-lane structures. At the time of collapse of the second box girder structure, crews were placing concrete with a con[illegible]eyor for the main span. They had poured about 450 cu yd of concrete, making up 135 ft of the span. There were about 25 persons but no heavy equipment on the 70-ft-wide span when it went down.

The Arroyo Seco Bridge is part of a $9-million, 1.2-mile contract on the state's Foothill Freeway and was scheduled for completion next April. Damage is estimated at $300,000 to $400,000 and the project is expected to be delayed several months.

The causes of the failure may never be determined, according to assistant highway district engineer Keith McKean, because rescue workers moved much of the 2,000 tons of debris in an all-night attempt to reach workers trapped under hardening concrete. Ted Polich, secretary of the construction company, says, "We have no idea as to the cause. There is no evidence thus far that the collapse was caused by any act or omission of this company."



Four-lane span was supported on pipe tower bents topped by steel girders.

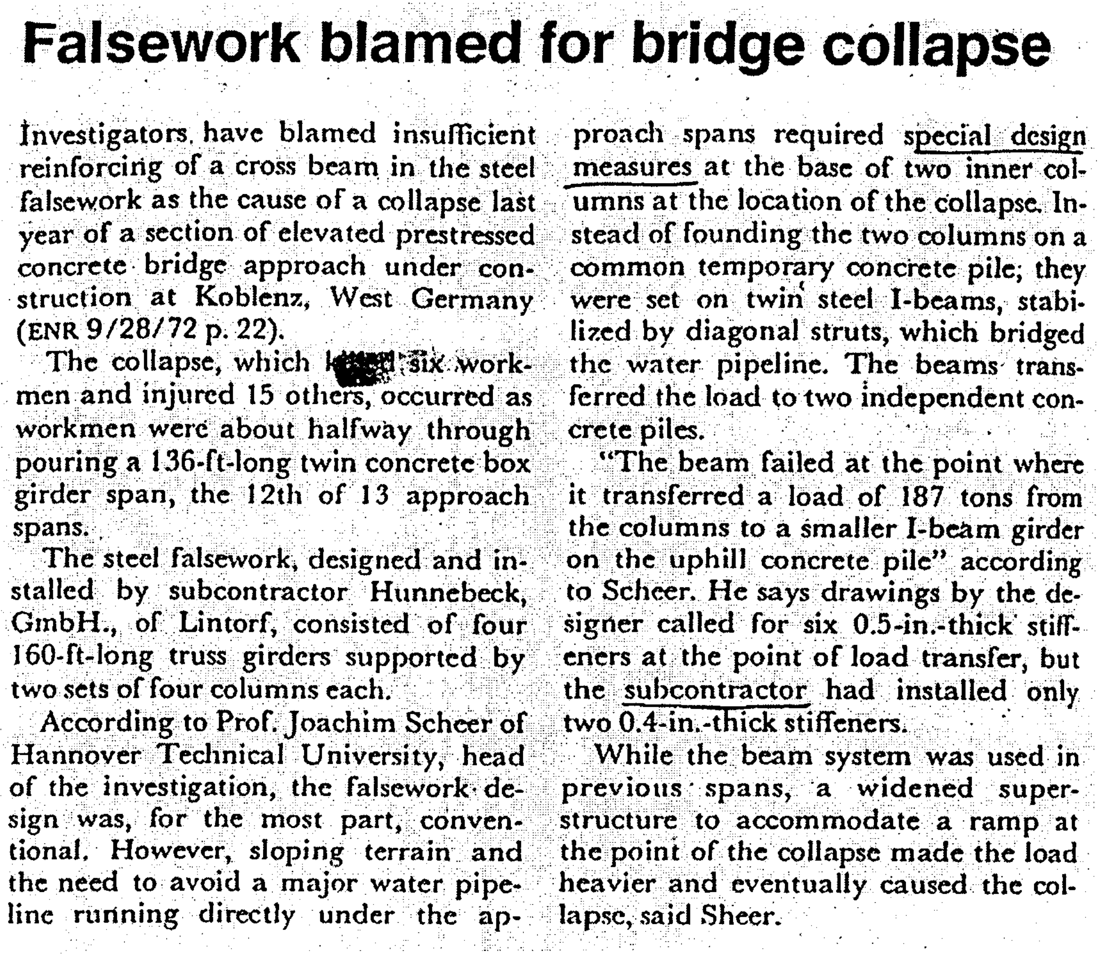
But the accident will probably spur legislative probes in addition to investigations launched by federal and state highway and safety agencies. Failure of falsework has caused seven bridge collapses in California in the past three years. Polich-Benedict was contractor on a 125-ft overpass that collapsed during construction east of Los Angeles in May, 1970, killing a motorist. State investigators said falsework may have been overloaded (ENR 8/20/70 p. 22).

According to Carl Vernor, state bridge resident engineer at Arroyo Seco, there is nothing unusual about the falsework there. There are four bents, each with seven 4-legged towers topped by wide-flange beam caps. Spanning a maximum of 70 ft between bents are 48-in.-deep plate girders. On top of them is a plank platform topped by timber pony bents and finally timber stringers and joists that carry the plywood forms.

The state assembly's select committee on industrial safety will convene hearings Nov. 1 on the collapse, plus the performance of the state's highway and safety divisions. Says Speaker Robert Moretti, (D-Van Nuys), "Many of us in the state legislature have been convinced that California workers are dying needlessly." U.S. Rep. Glenn Anderson (D-Calif.) called for an investigation by the House roads subcommittee, of which he is a member. He says federal inspectors have not visited the job site since August.

Case Ref. No. 38 Koblenz, West Germany

Source: 20th December 1973, Engineering News Record, p.24



Falsework blamed for bridge collapse

Investigators have blamed insufficient reinforcing of a cross beam in the steel falsework as the cause of a collapse last year of a section of elevated prestressed concrete bridge approach under construction at Koblenz, West Germany (ENR 9/28/72 p. 22).

The collapse, which k[illegible] six workmen and injured 15 others, occurred as workmen were about halfway through pouring a 136-ft-long twin concrete box girder span, the 12th of 13 approach spans.

The steel falsework, designed and installed by subcontractor Hunnebeck, GmbH., of Lintorf, consisted of four 160-ft-long truss girders supported by two sets of four columns each.

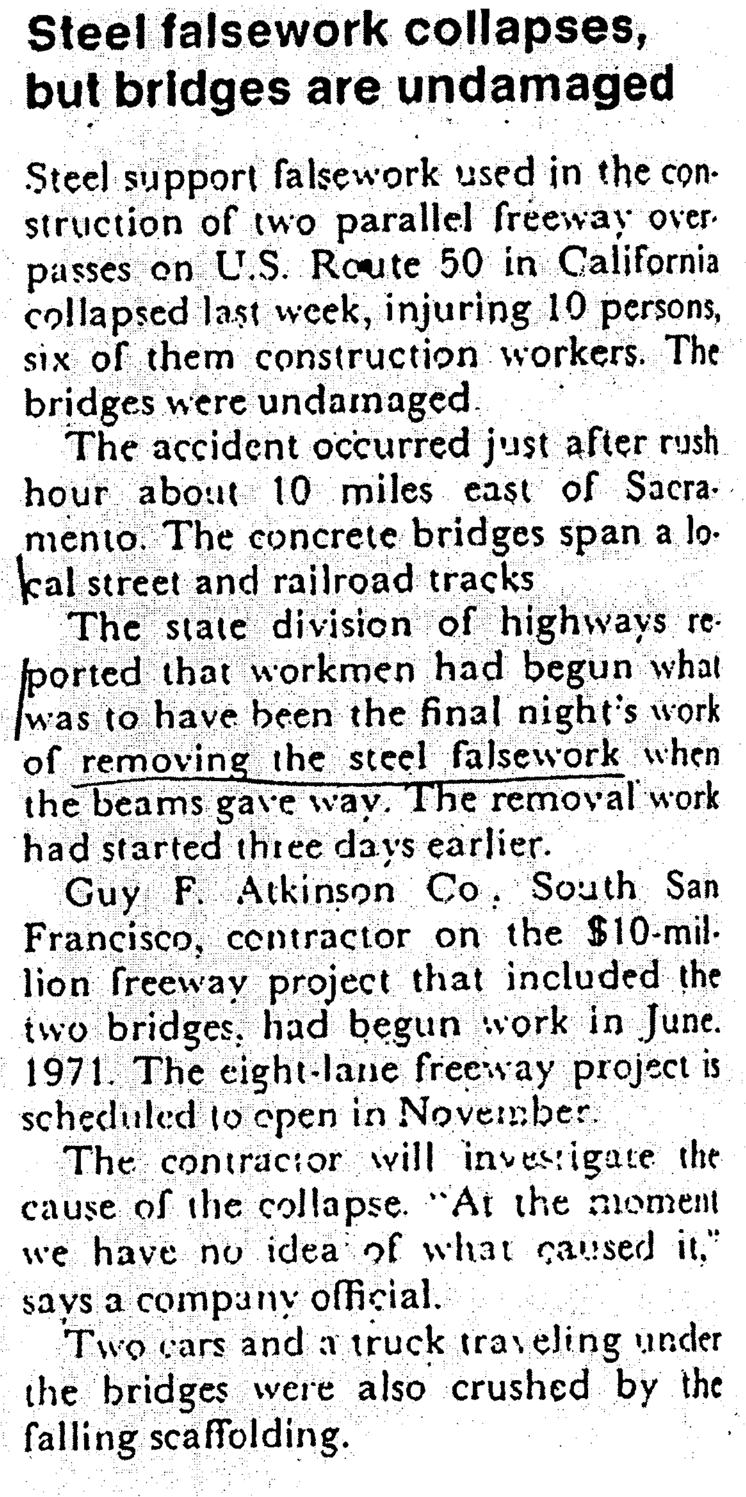
According to Prof. Joachim Scheer of Hannover Technical University, head of the investigation, the falsework design was, for the most part, conventional. However, sloping terrain and the need to avoid a major water pipeline running directly under the approach spans required special design measures at the base of two inner columns at the location of the collapse. Instead of founding the two columns on a common temporary concrete pile, they were set on twin steel I-beams, stabilized by diagonal struts, which bridged the water pipeline. The beams transferred the load to two independent concrete piles.

"The beam failed at the point where it transferred a load of 187 tons from the columns to a smaller I-beam girder on the uphill concrete pile" according to Scheer. He says drawings by the designer called for six 0.5-in.-thick stiffeners at the point of load transfer, but the subcontractor had installed only two 0.4-in.-thick stiffeners.

While the beam system was used in previous spans, a widened superstructure to accommodate a ramp at the point of the collapse made the load heavier and eventually caused the collapse, said Sheer.

Case Ref. No. 39 Route 50, Sacramento, California, USA

Source: 31st August 1972, Engineering News Record



Steel falsework collapses, but bridges are undamaged

Steel support falsework used in the construction of two parallel freeway overpasses on U.S. Route 50 in California collapsed last week, injuring 10 persons, six of them construction workers. The bridges were undamaged.

The accident occurred just after rush hour about 10 miles east of Sacramento. The concrete bridges span a local street and railroad tracks.

The state division of highways reported that workmen had begun what was to have been the final night's work of removing the steel falsework when the beams gave way. The removal work had started three days earlier.

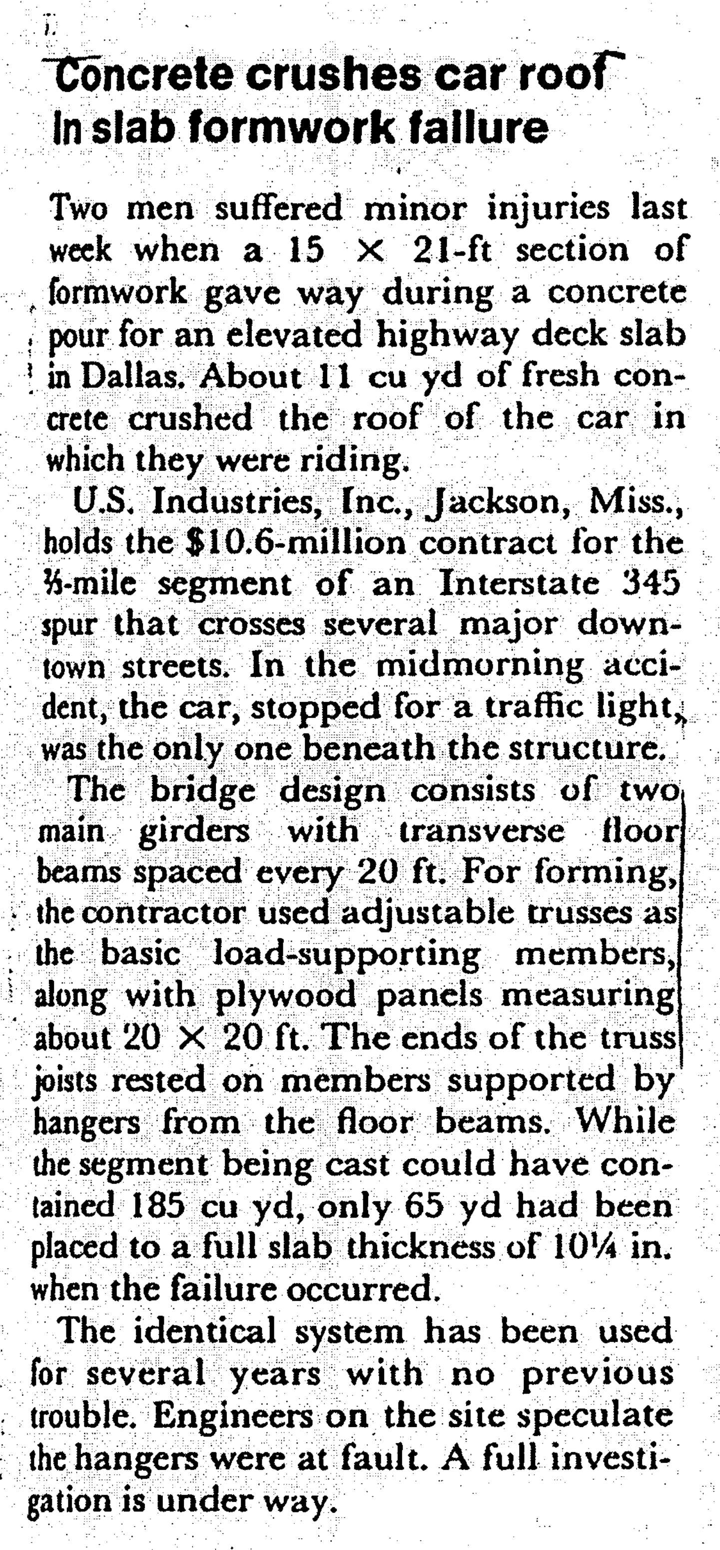
Guy F. Atkinson Co., South San Francisco, contractor on the $10-million freeway project that included the two bridges, had begun work in June, 1971. The eight-lane freeway project is scheduled to open in November.

The contractor will investigate the cause of the collapse. "At the moment we have no idea of what caused it," says a company official.

Two cars and a truck traveling under the bridges were also crushed by the falling scaffolding.

Case Ref. No. 40 Dallas, USA

Source: 13 July 1972, Engineering News Record, p.13.



Concrete crushes car roof in slab formwork failure

Two men suffered minor injuries last week when a 15 × 21-ft section of formwork gave way during a concrete pour for an elevated highway deck slab in Dallas. About 11 cu yd of fresh concrete crushed the roof of the car in which they were riding.

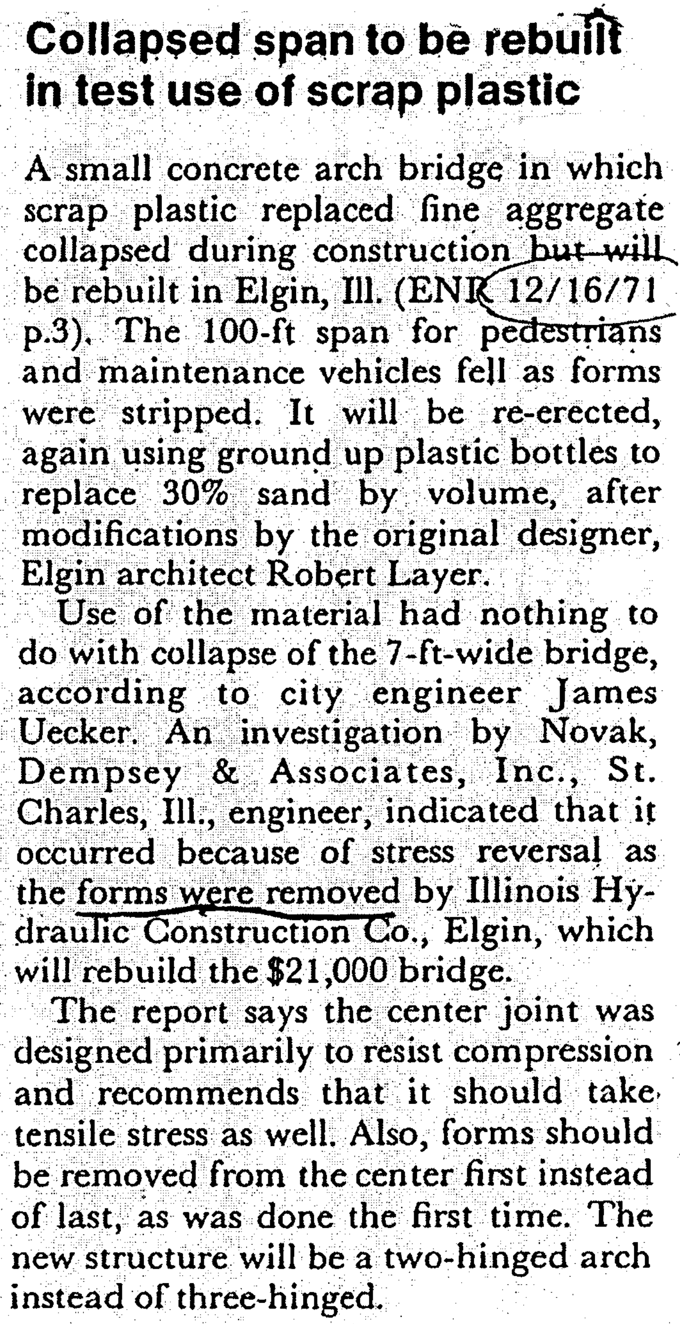
U.S. Industries, Inc., Jackson, Miss., holds the $10.6-million contract for the ⅓-mile segment of an Interstate 345 spur that crosses several major downtown streets. In the midmorning accident, the car, stopped for a traffic light, was the only one beneath the structure.

The bridge design consists of two main girders with transverse floor beams spaced every 20 ft. For forming, the contractor used adjustable trusses as the basic load-supporting members, along with plywood panels measuring about 20 × 20 ft. The ends of the truss joists rested on members supported by hangers from the floor beams. While the segment being cast could have contained 185 cu yd, only 65 yd had been placed to a full slab thickness of 10¼ in. when the failure occurred.

The identical system has been used for several years with no previous trouble. Engineers on the site speculate the hangers were at fault. A full investigation is under way.

Case Ref. No. 41 Elgin, Ill, USA

Source: December 1971, Engineering News Record



Collapsed span to be rebuilt in test use of scrap plastic

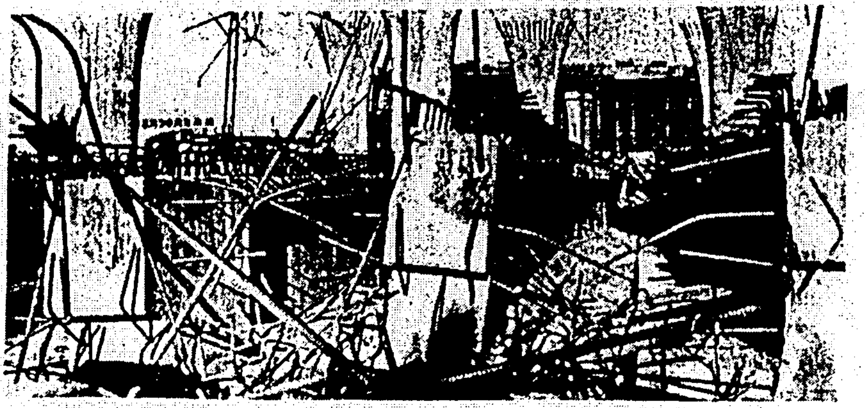
A small concrete arch bridge in which scrap plastic replaced fine aggregate collapsed during construction ~~but will~~ be rebuilt in Elgin, Ill. (ENR 12/16/71 p.3). The 100-ft span for pedestrians and maintenance vehicles fell as forms were stripped. It will be re-erected, again using ground up plastic bottles to replace 30% sand by volume, after modifications by the original designer, Elgin architect Robert Layer.

Use of the material had nothing to do with collapse of the 7-ft-wide bridge, according to city engineer James Uecker. An investigation by Novak, Dempsey & Associates, Inc., St. Charles, Ill., engineer, indicated that it occurred because of stress reversal as the forms were removed by Illinois Hydraulic Construction Co., Elgin, which will rebuild the $21,000 bridge.

The report says the center joint was designed primarily to resist compression and recommends that it should take tensile stress as well. Also, forms should be removed from the center first instead of last, as was done the first time. The new structure will be a two-hinged arch instead of three-hinged.

Case Ref. No. 42 San Bruno, California, USA

Source: 29th April 1971, Engineering News Record, p.11.



Precast tees slipped from falsework, injuring two as they dropped 25 ft.

Concrete overpass stringers fall on railroad

Fifteen precast overpass girders, weighing up to 90 tons and supported on falsework, fell on railroad tracks last week in San Bruno, Calif. Two workers were slightly injured when the Interstate span fell 25 ft.

The prestressed, inverted T-beams are 95 ft long, mostly weighing 40 tons. ? Three with decorative fascias are heavier. Falsework consisted of steel scaffolding bearing on wood planks and topped by timber. The concrete girders rested on wide-flange steel beams paralleling the line of three columns at each end of the span. The collapse occurred with all the girders in place for one span as two truck cranes set the first girder for a parallel twin span.

The mid-afternoon collapse reportedly occurred slowly. Workers heard a crack, then felt the girders sag slightly. One of the three men atop the structure leapt to a column while the others rode the falling girders to the ground.

The California Division of Highways is investigating the accident. Officials at the site speculate that the steel scaffolding may have buckled or been displaced laterally by girder placement. Representatives of Peter Kiewit Sons' Co., Omaha, contractor on the $4-million project, declined to comment.

The two spans with prestressed stringers are part of a pair of four-lane overpasses 1,000 ft long that will carry I-380 between San Francisco International Airport and I-280. Most of the concrete superstructure will be cast in place. The spans over the two railroad tracks were built with precast girders, however, to avoid extensive falsework that would have blocked trains.

Kiewit dragged the fallen girders off the tracks with crawler tractors and service was restored the following morning on the commuter railroad.

The highway division estimates cost of the damage at $100,000 to $150,000. Completion of the job, set for this October, is not expected to be delayed.

Case Ref. No. 45, 48 and 49

Source: D.W. Smith, B Eng, MA, FICE, Proc. Instn Civ. Engrs, Part 1, 1976, 60, Aug., pp.367-382

Proc. Instn Civ. Engrs, Part 1, 1976, 60, Aug., 367–382

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Bridge failures

D. W. SMITH, B Eng, MA, FICE*

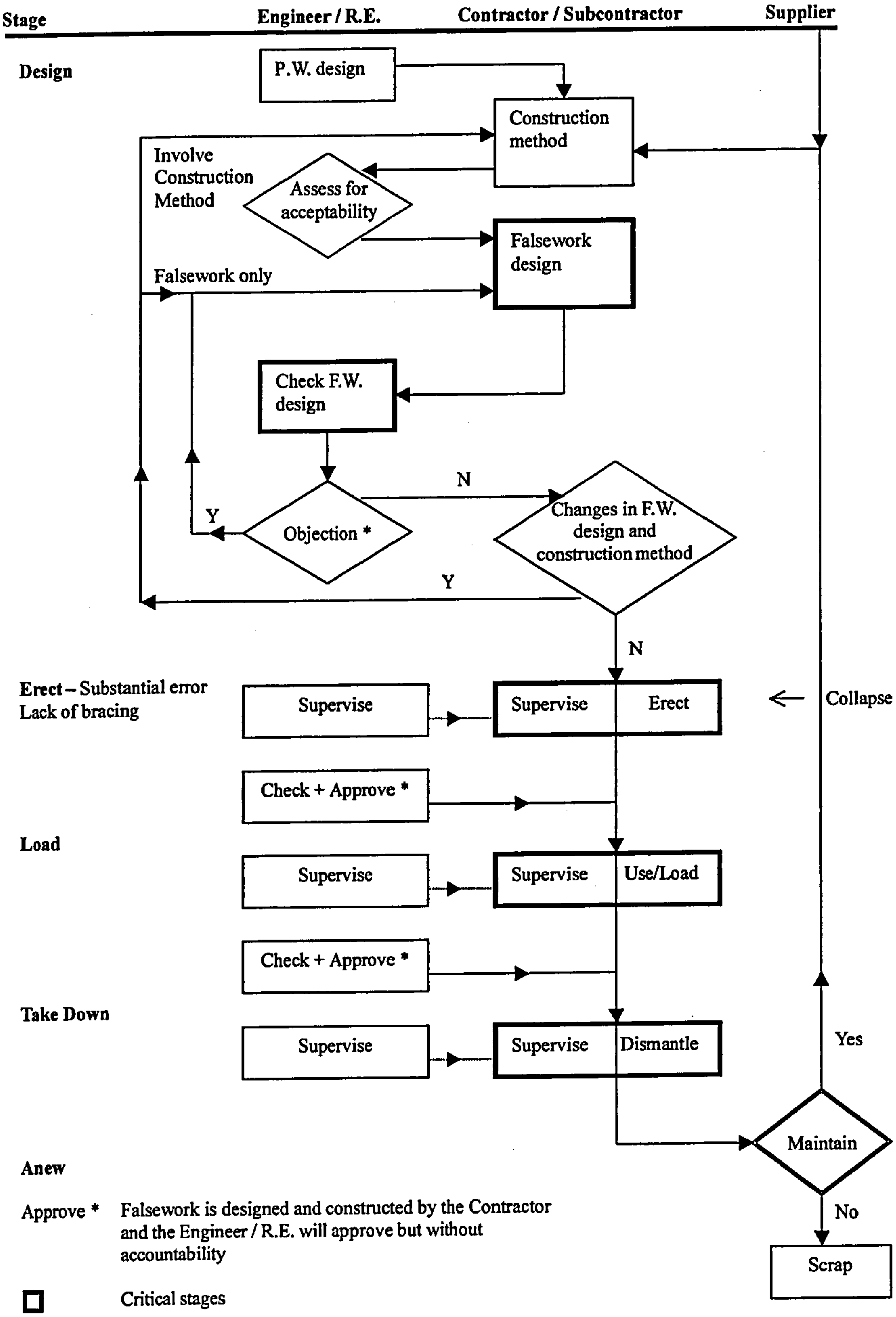
Table 1. Failures during construction

Bridge	Type of failure	Date	Remarks
Tay[1]	Spans 12 and 13 fell during high wind	2 Feb., 1877	1 workman lost
Quebec[2]	Cantilever collapsed by buckling of main compression chord	29 Aug., 1907	74 killed
Quebec[3]	Suspended span collapsed due to failure of supporting casting	11 Sep., 1916	13 killed
Oder, Gartz[4]	Two spans collapsed when river pier failed due to faulty workmanship in concrete placed under water	1925–6	
Sando[5]	Temporary timber 244 m span tied arch centering collapsed when supporting part weight of concrete bridge, possibly due to weakening of timber by prolonged damp	Aug. 1939	
Second Narrows, Vancouver[6]	Steel truss spans collapsed due to inadequate base of temporary column	June 1958	18 killed
Barton, Lancs[7]	Steel girders fell due to buckling of temporary supports	Feb. 1959 ✓	4 killed ← 49
Barton, Lancs[8]	Four steel plate girders overturned before being adjusted for level or braced together	Dec. 1959 ✓	2 killed
Fife[9]	Superstructure of road overbridge collapsed due to buckling of temporary supports after concrete they were supporting had set	22 June, 1962 ✓	3 killed ← 48
Calder, Yorks[10]	76 m concrete span collapsed due to low strength and inadequate bracing of steel beams in temporary supports	23 Aug., 1967 ✓	4 killed ← 45
Willemstad, Curaçao[11]	Steel bridge collapsed due to brittle fracture of anchor bars at unauthorized(?) welds	Nov. 1967 ✓	20 killed
Fourth Danube, Vienna[12]	210 m centre span of steel box girder bridge buckled without collapse due to temperature contraction of top flange	6 Nov., 1969 ✓	
Seebrucke, Brennerautobahn[13]	Concrete superstructure severely deformed by 1·7 m differential movement of foundations near lake side	Nov. 1969	
Milford Haven[14]	Steel box girder collapsed during cantilever erection due to buckling of support diaphragm	2 June, 1970	4 killed
Soboth, Austria[15]	192 m length of concrete box girder collapsed, possibly due to fracture of temporary stay by crane	July 1970	3 killed
West Gate, Melbourne[16]	112 m steel box girder collapsed by compression buckling of top flange	15 Oct., 1970	34 killed
Koblenz[17]	Steel box girder collapsed during cantilever erection by bottom flange buckling at site joint	10 Nov., 1971	13 killed
Rio[18]	Viaduct collapsed on city street before post-tensioned ducts had been grouted	Nov. 1971	24 killed
Koblenz[19]	Concrete approach span collapsed due to failure of temporary supports	Sep. 1972	5 killed
Pasadena, California[20]	Centre of three spans in 177 m long structure collapsed during placing of concrete due to failure of falsework	Oct. 1972	6 killed
Loddon, Berks[21]	24 m span collapsed during placing of concrete due to failure of falsework	Oct. 1972	3 killed
Leubas, Kempten, W. Germany[22]	Centre section collapsed during placing of concrete when centering became dislodged from scaffold tower	30 Apr., 1974	9 killed
Gmünd, Austria[23]	Concrete box girder collapsed due to compression failure of bottom flange, 3 h after most severe cantilever condition had been passed; width/thickness ratio apparently over 24	16 May, 1975	10 killed

Case Ref. No.

APPENDIX C

Flow Chart of Fifty Failure Cases

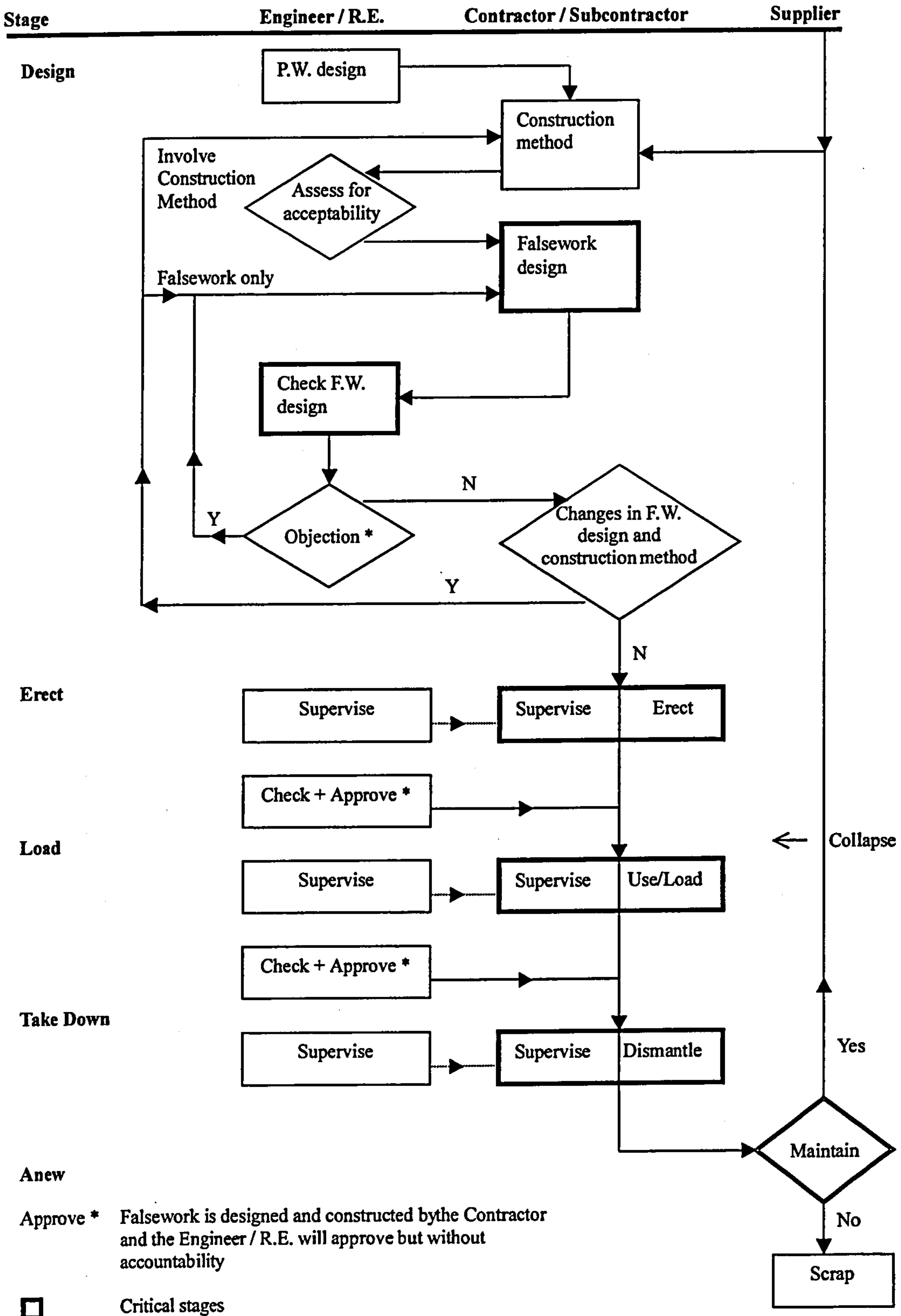


Anew

Approve * Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

Figure C.1: Case Ref. No. 1 Shenzhen, China [D]

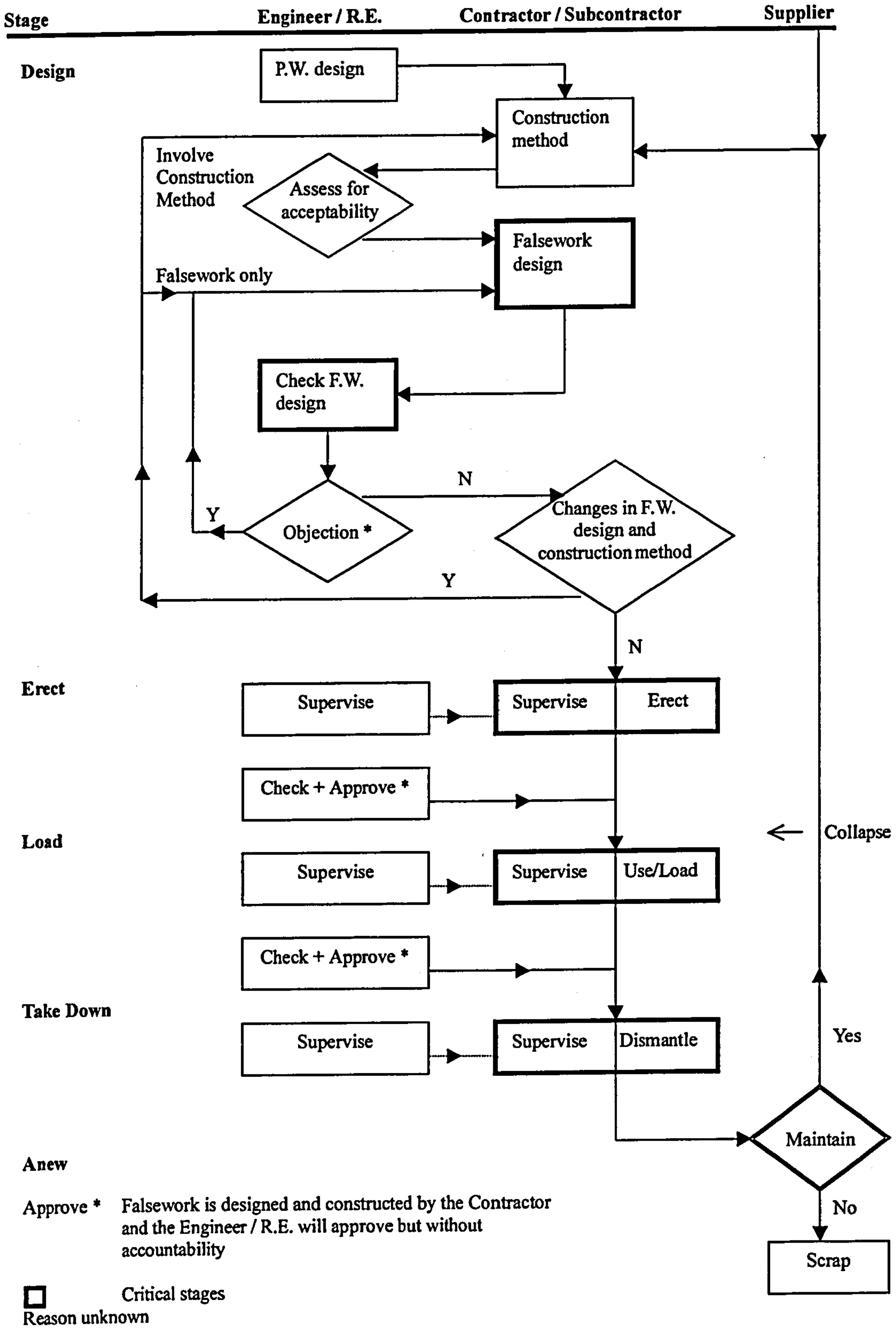


Approve * Falsework is designed and constructed bythe Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Reason unknown

Figure C.2: Case Ref. No. 2 Castle Peak, Hong Kong [D]

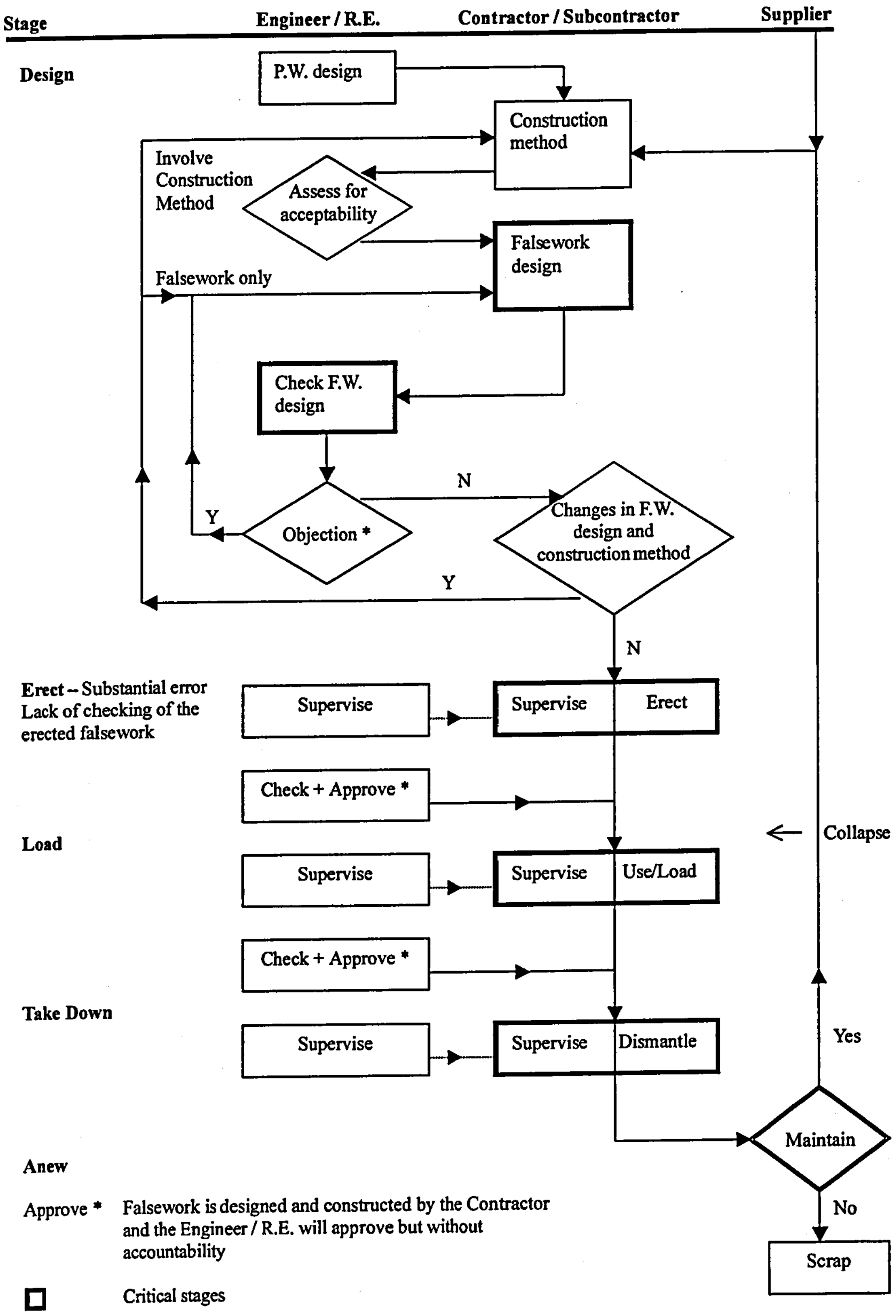


Approve * Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

Reason unknown

Figure C.3: Case Ref. No. 3 Siu Sai Wan, Hong Kong [D]



Approve * Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Figure C.4: Case Ref. No.4 Sai Wan Ho, Hong Kong [D]

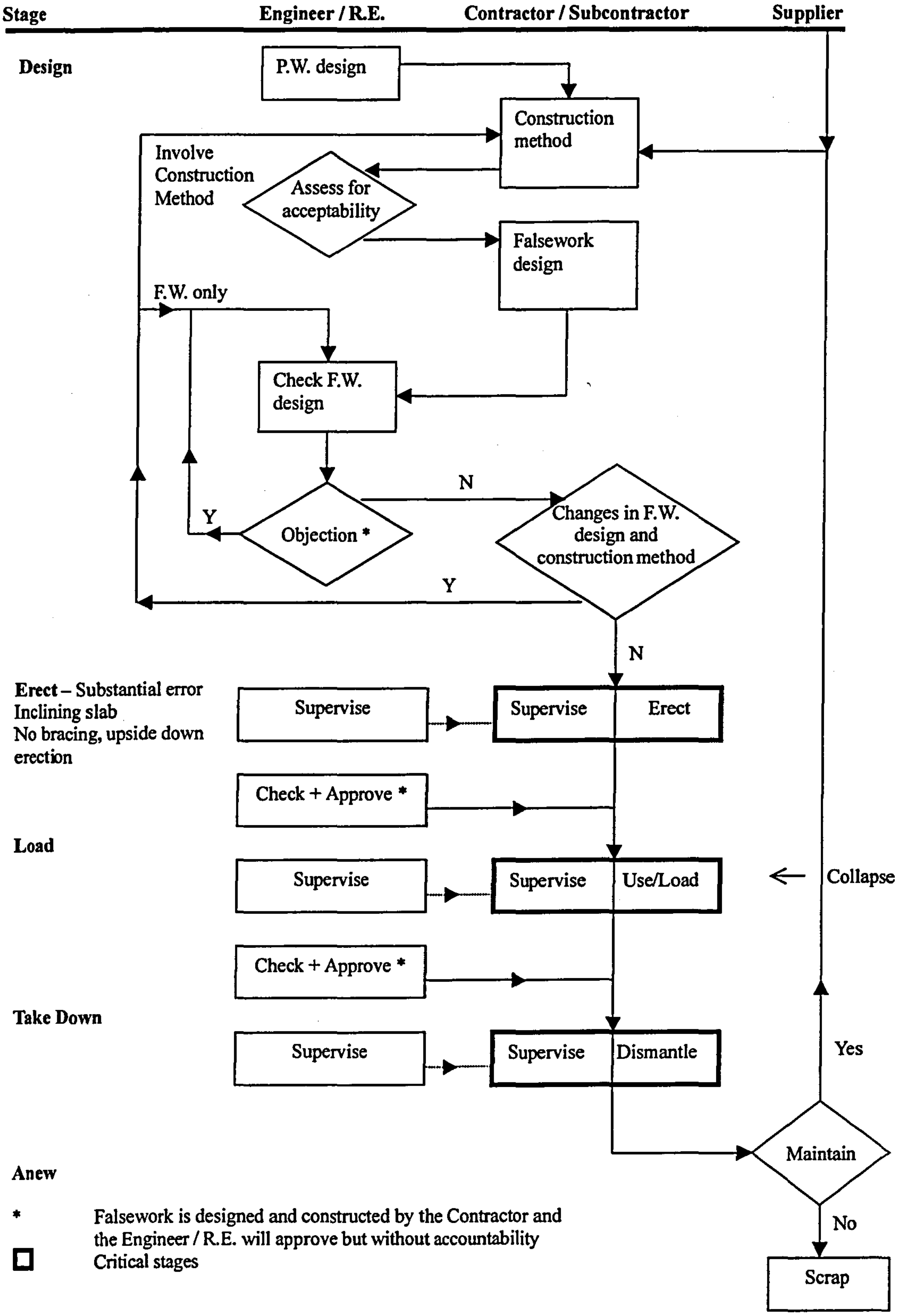
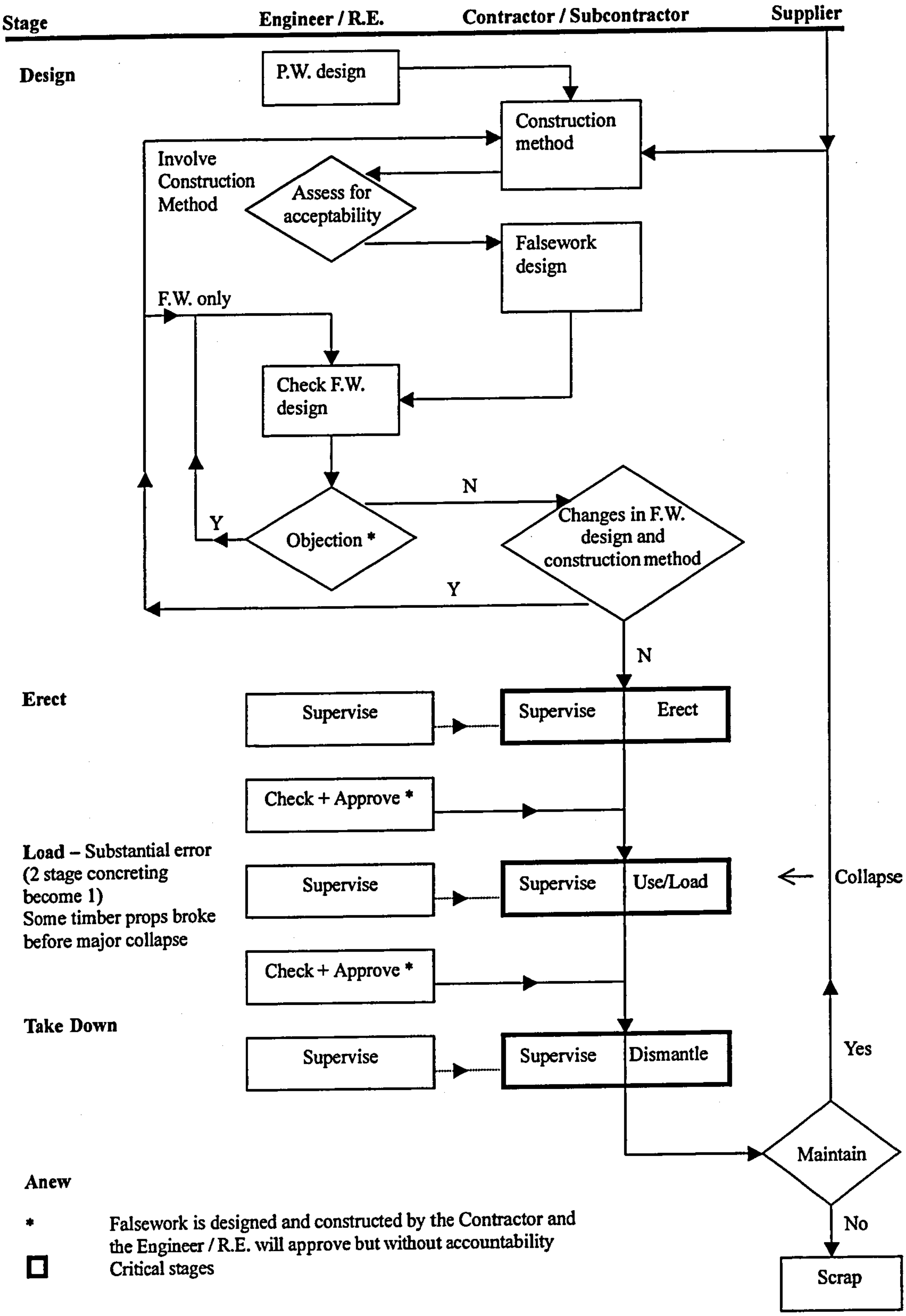


Figure C.5: Case Ref. No. 5 Tsing Yi, Hong Kong [D]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Figure C.6: Case Ref. No. 6 Guangzhou, China [D]

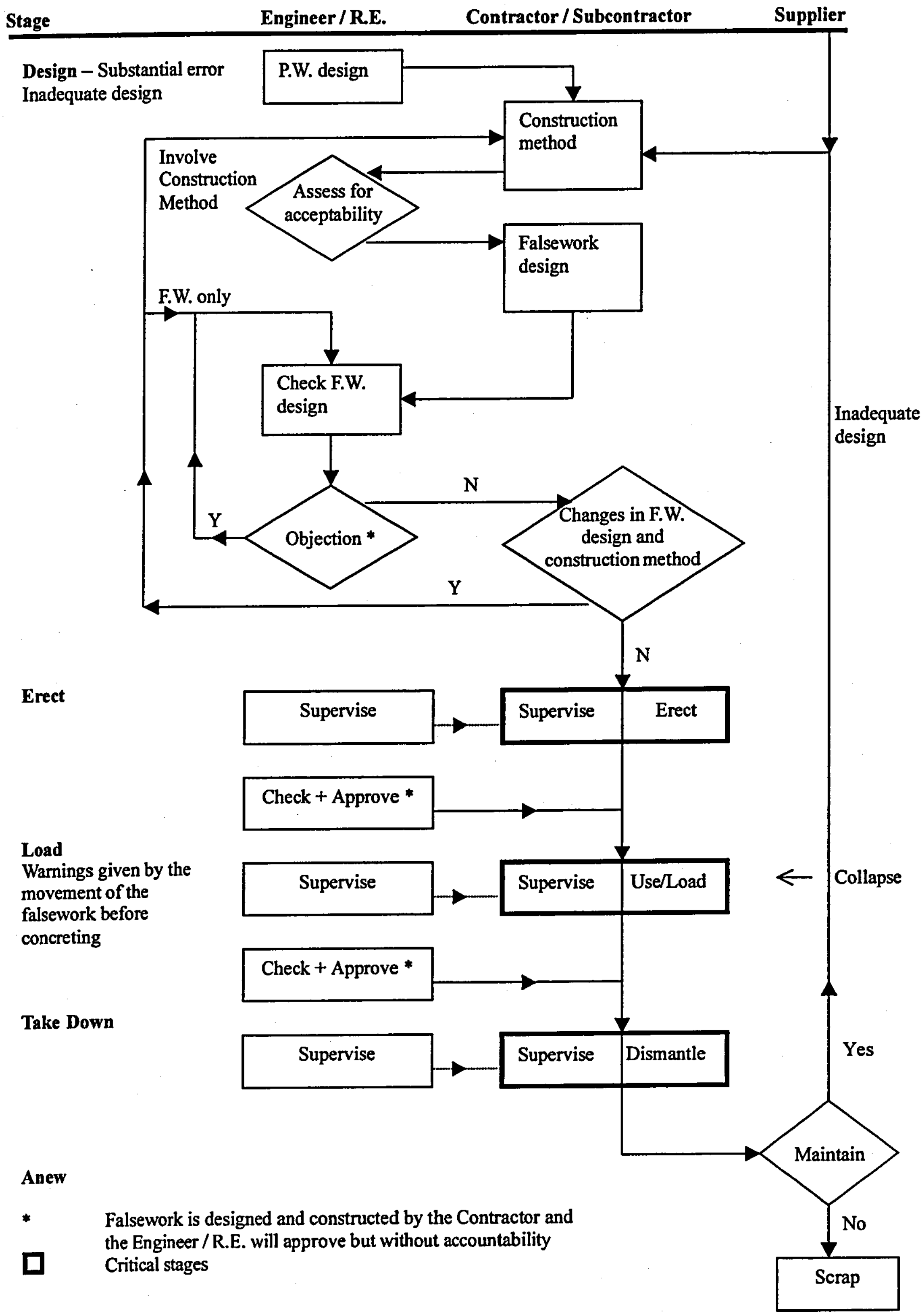
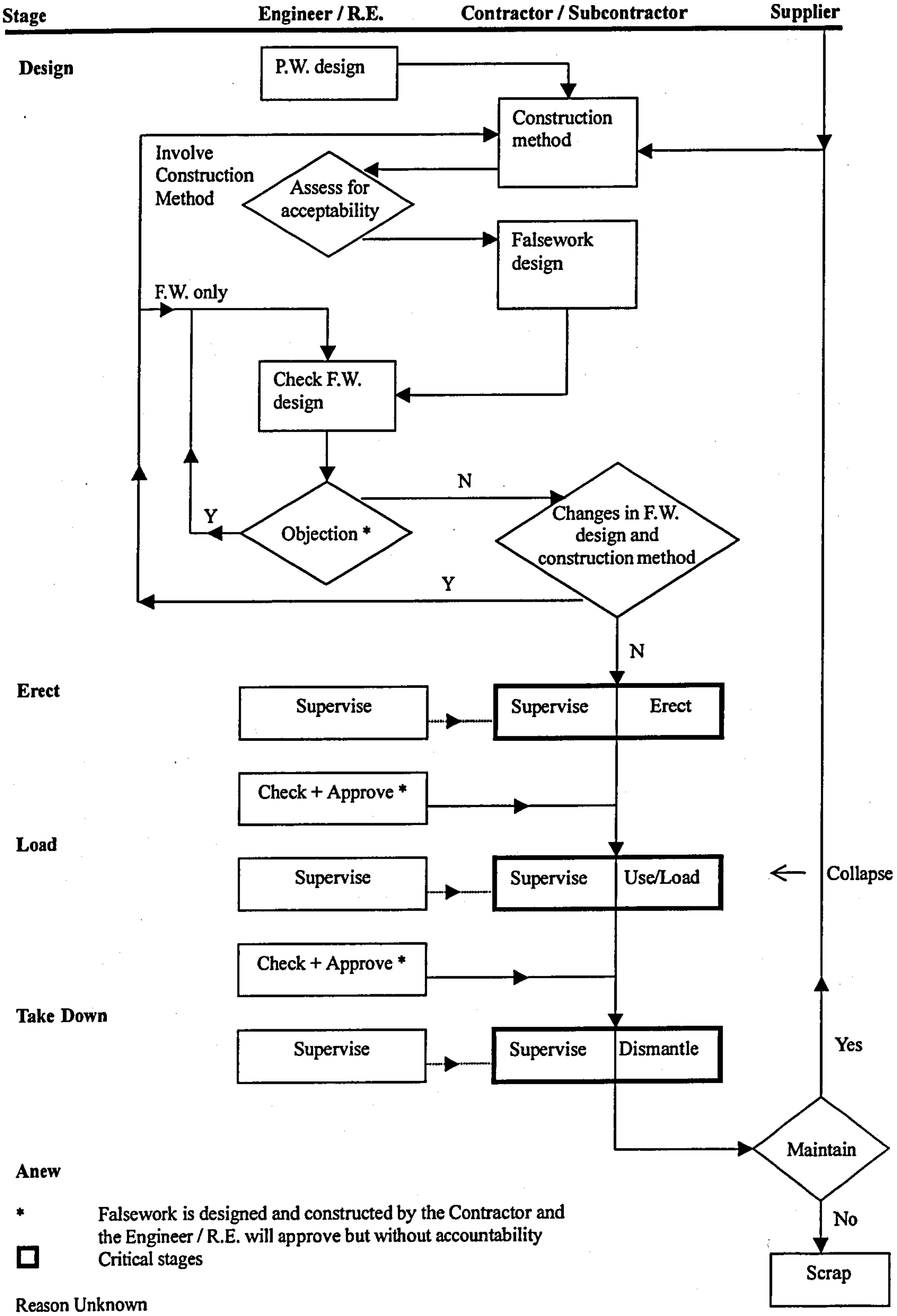


Figure C.7: Case Ref. No. 7 Ru Yuan, Guangdong, China [D]

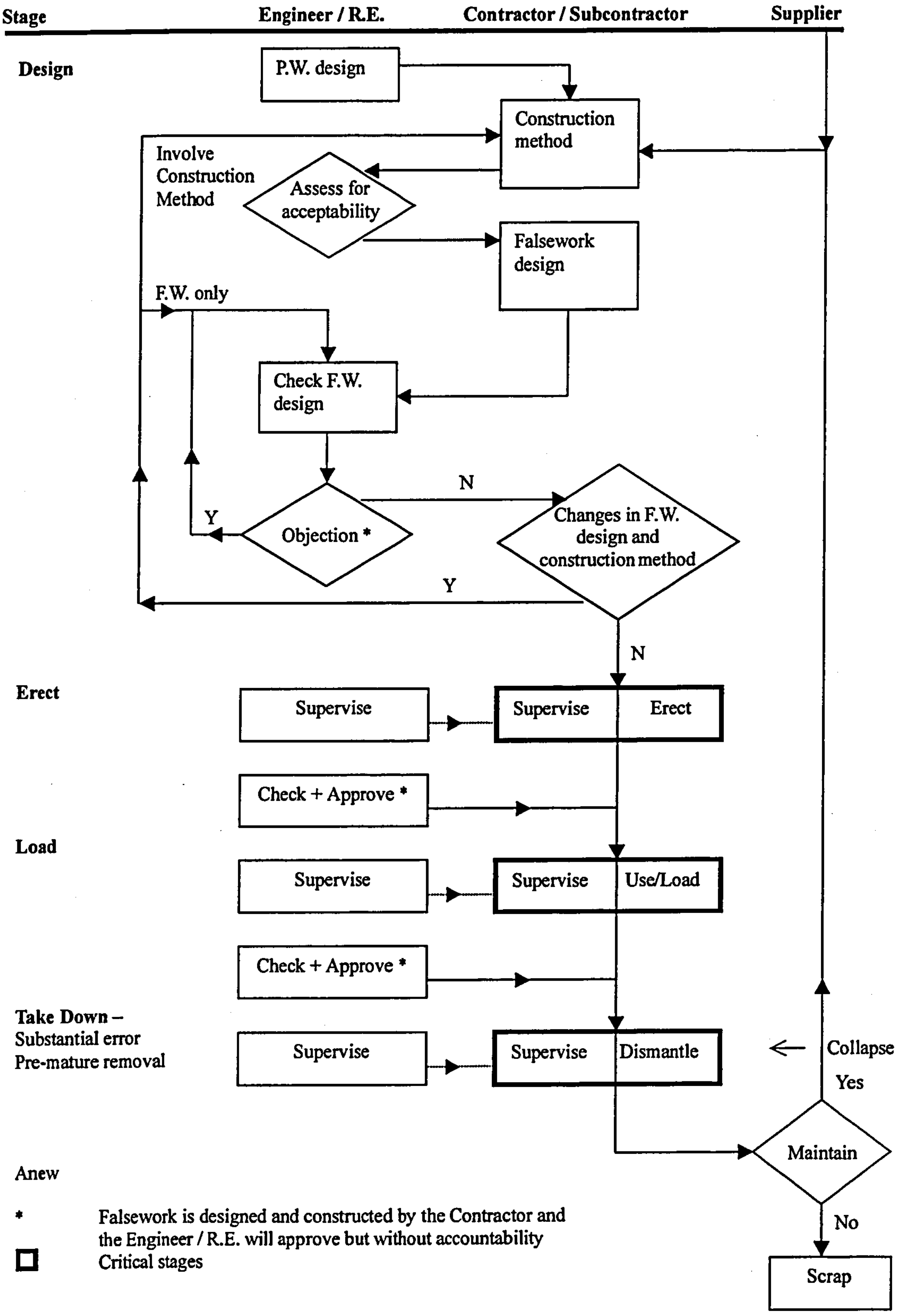


* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Reason Unknown

Figure C.8: Case Ref. No. 8 Kwai Chung, Hong Kong [D]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

Figure C.9: Case Ref. No. 9 Jakarta, Indonesia [D]

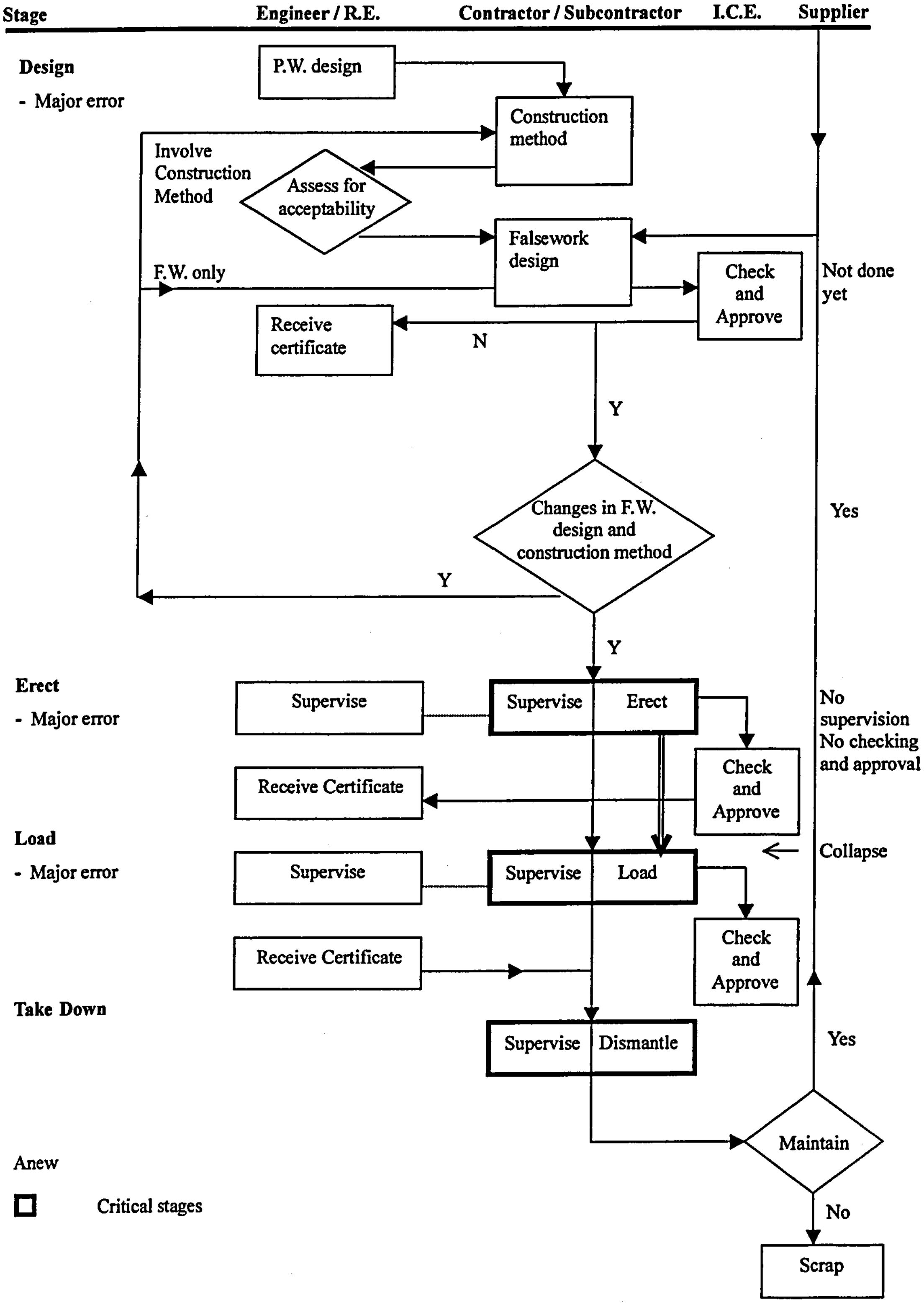


Figure C.10: Case Ref. No. 10 Tseung Kwan O, Hong Kong [B, D]

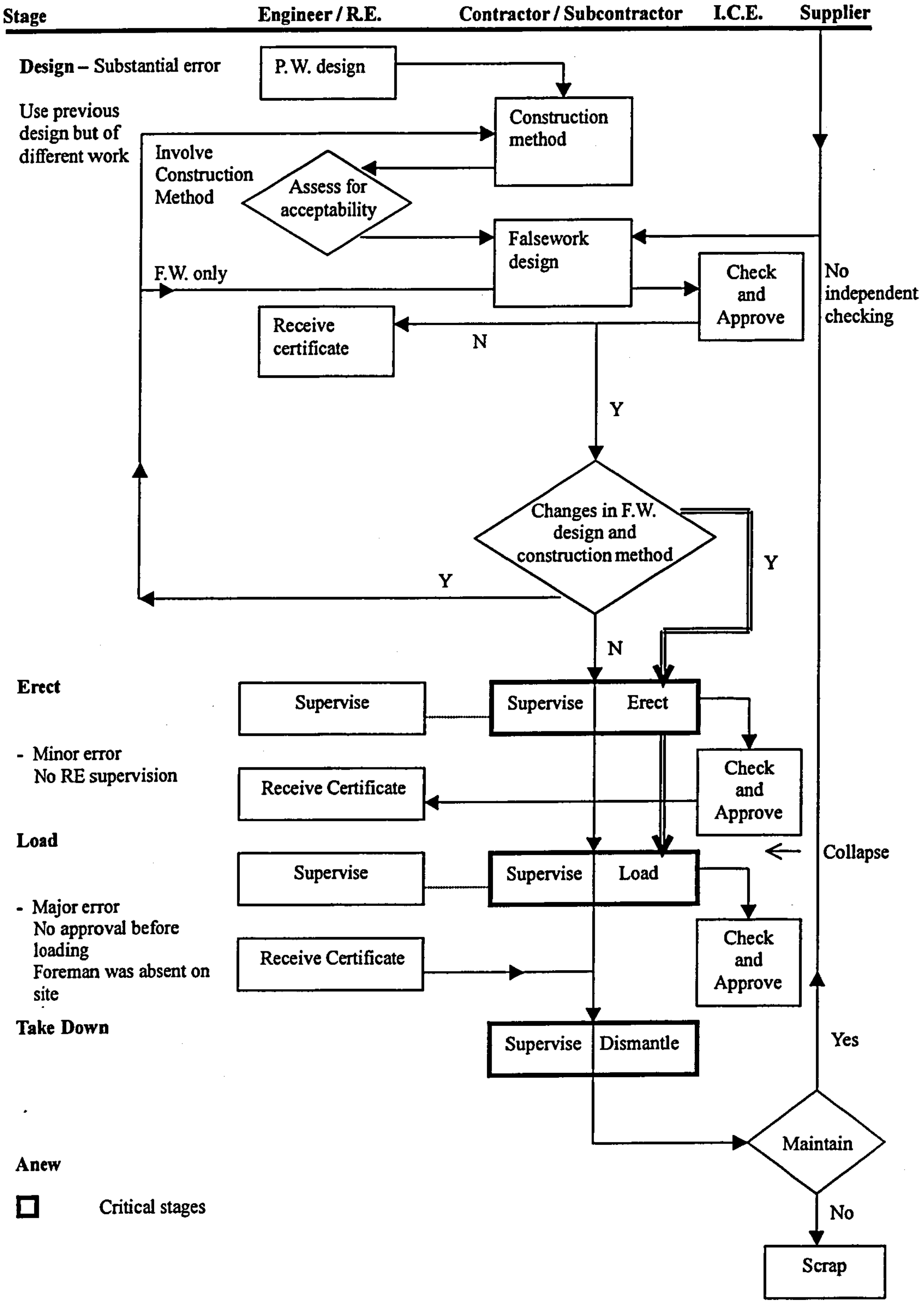
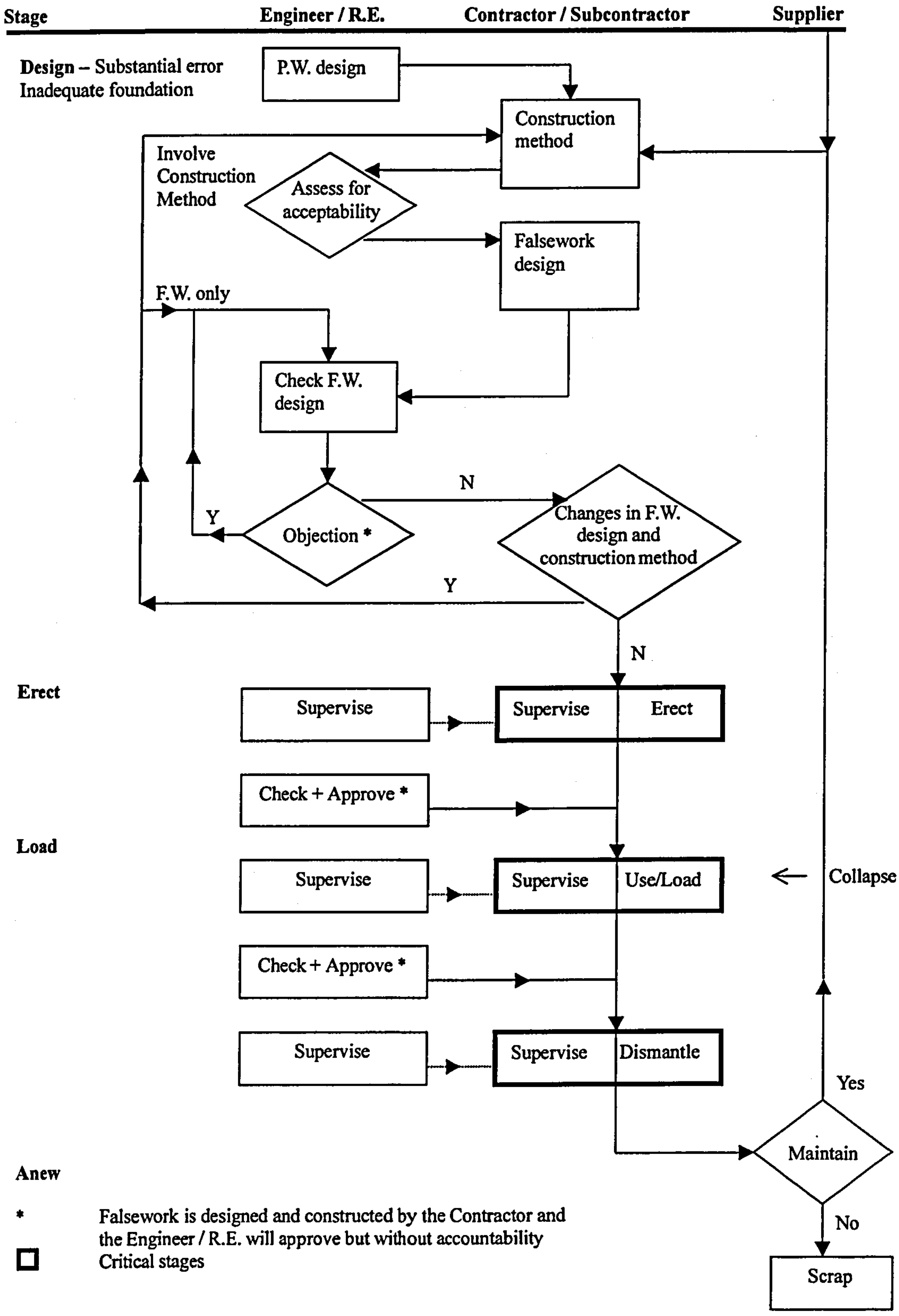
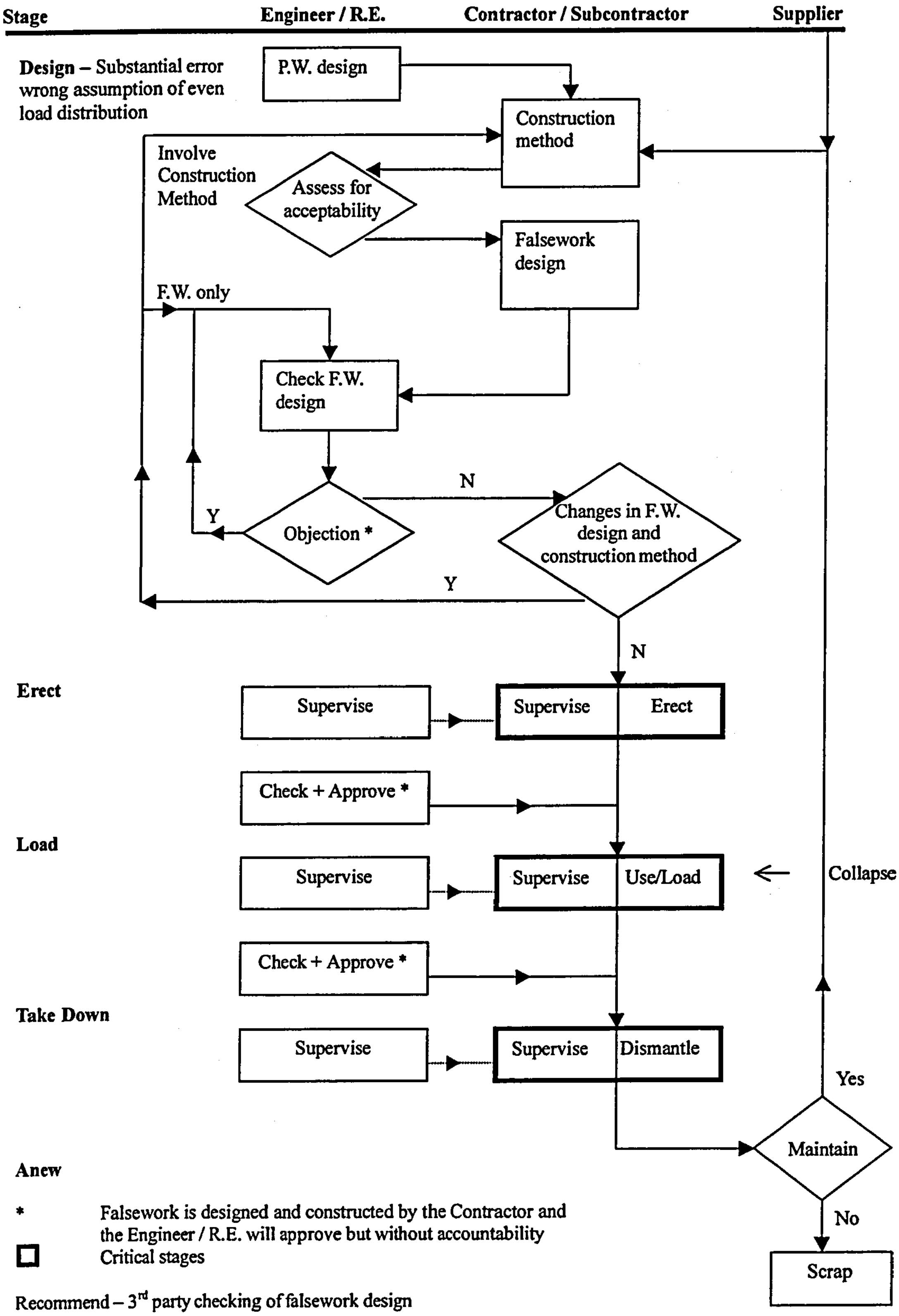


Figure C.11: Case Ref. No. 11 Route 3, Hong Kong [B, D]



*	Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability
☐	Critical stages

Figure C.12: Case Ref. No. 12 Macao [D]

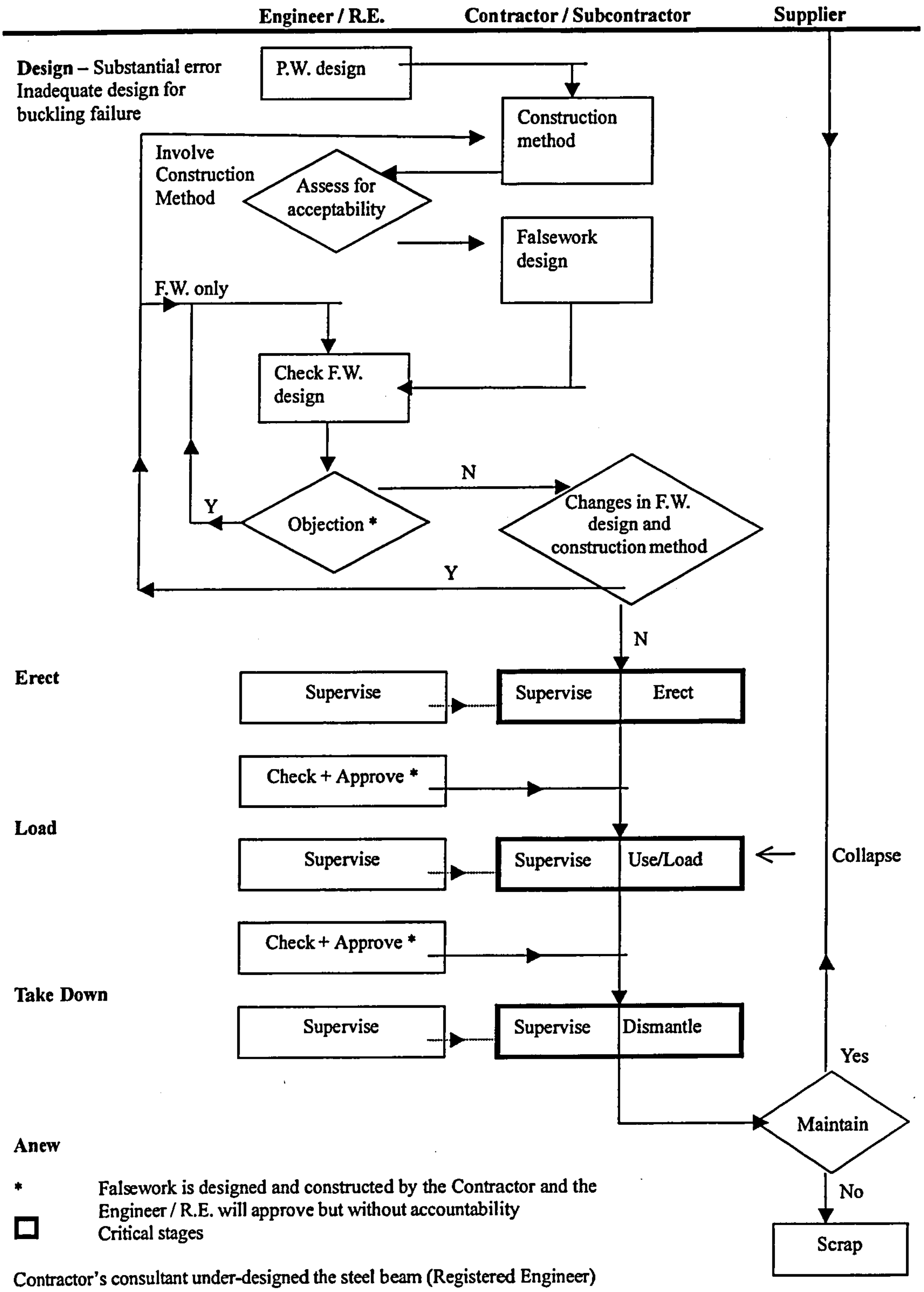


* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

Recommend – 3rd party checking of falsework design

Figure C.13: Case Ref. No. 13 Israel [C, A]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Contractor's consultant under-designed the steel beam (Registered Engineer)

Figure C.14: Case Ref. No. 14 USA [C, B]

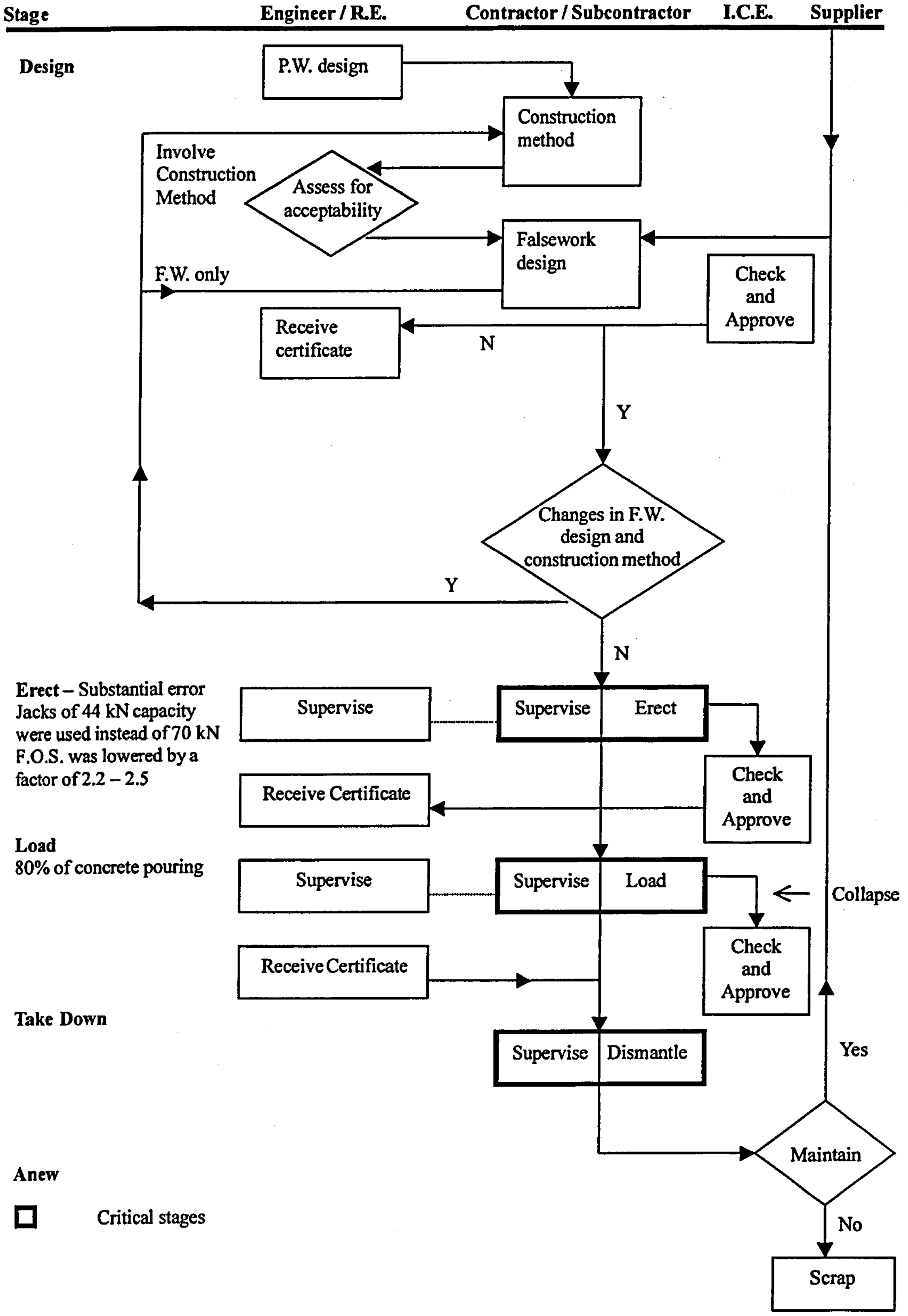
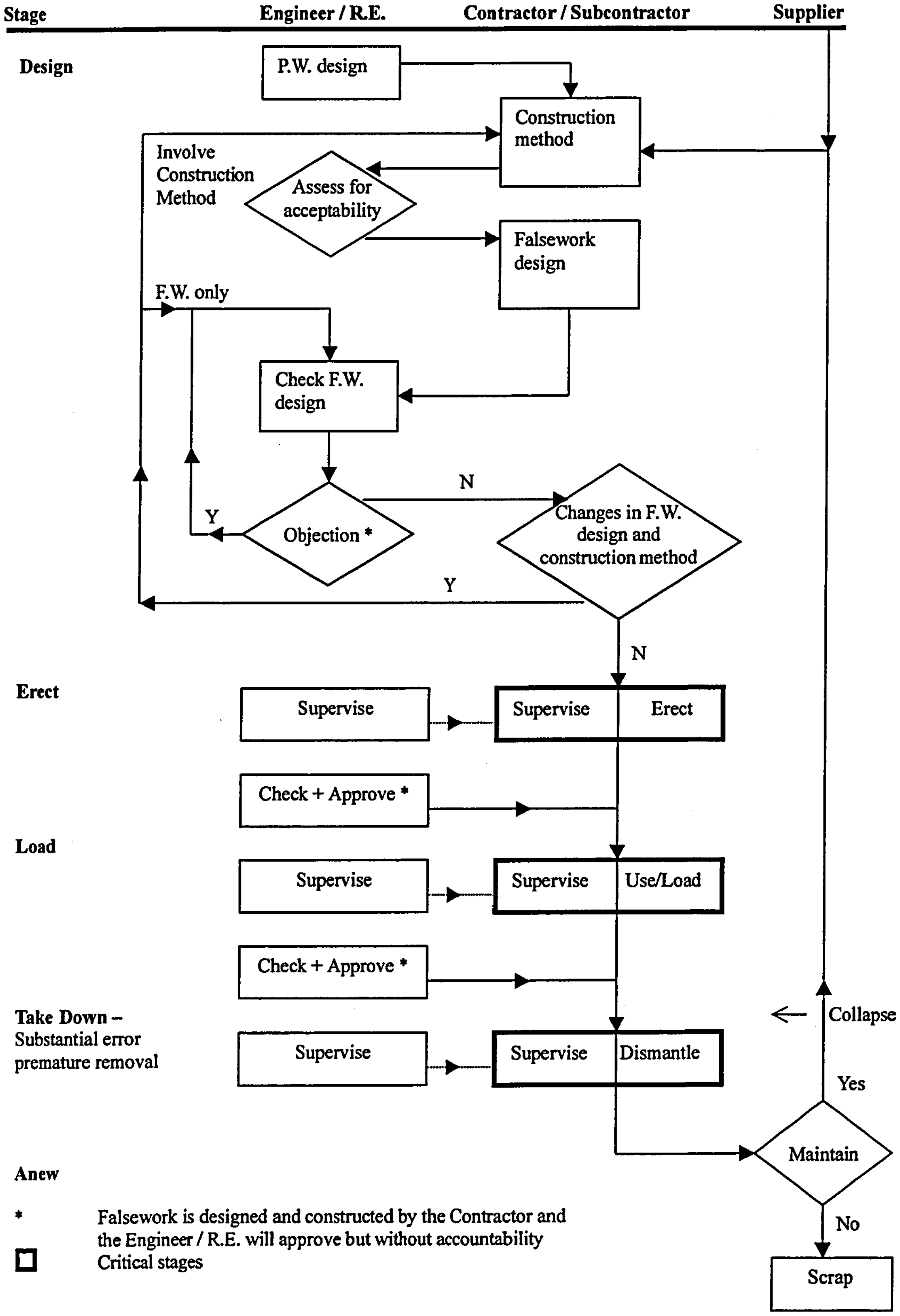


Figure C.15: Case Ref. No. 15 Maryland, USA [C, B]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Figure C.16: Case Ref. No. 16 Chongqing, China[D, B]

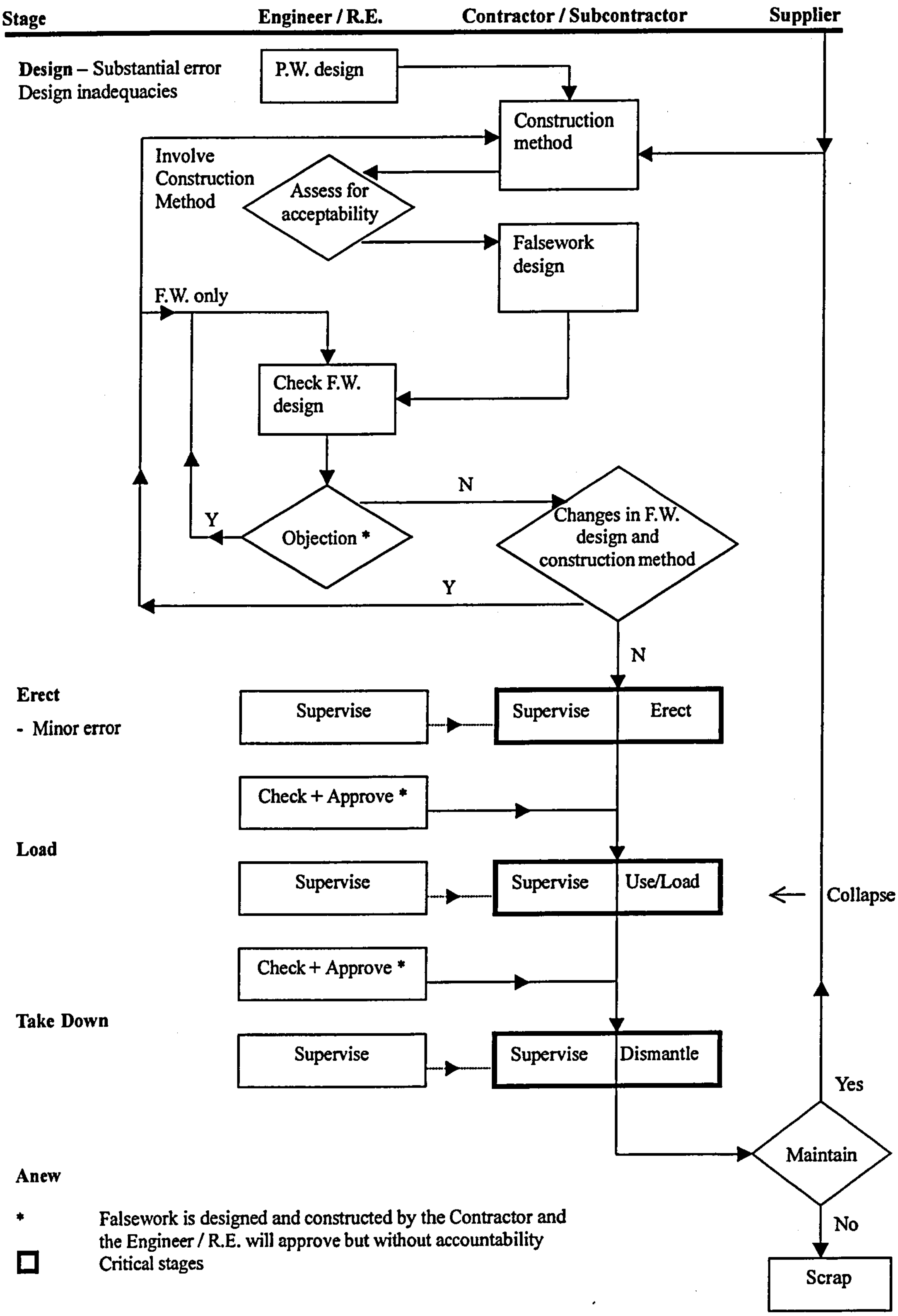
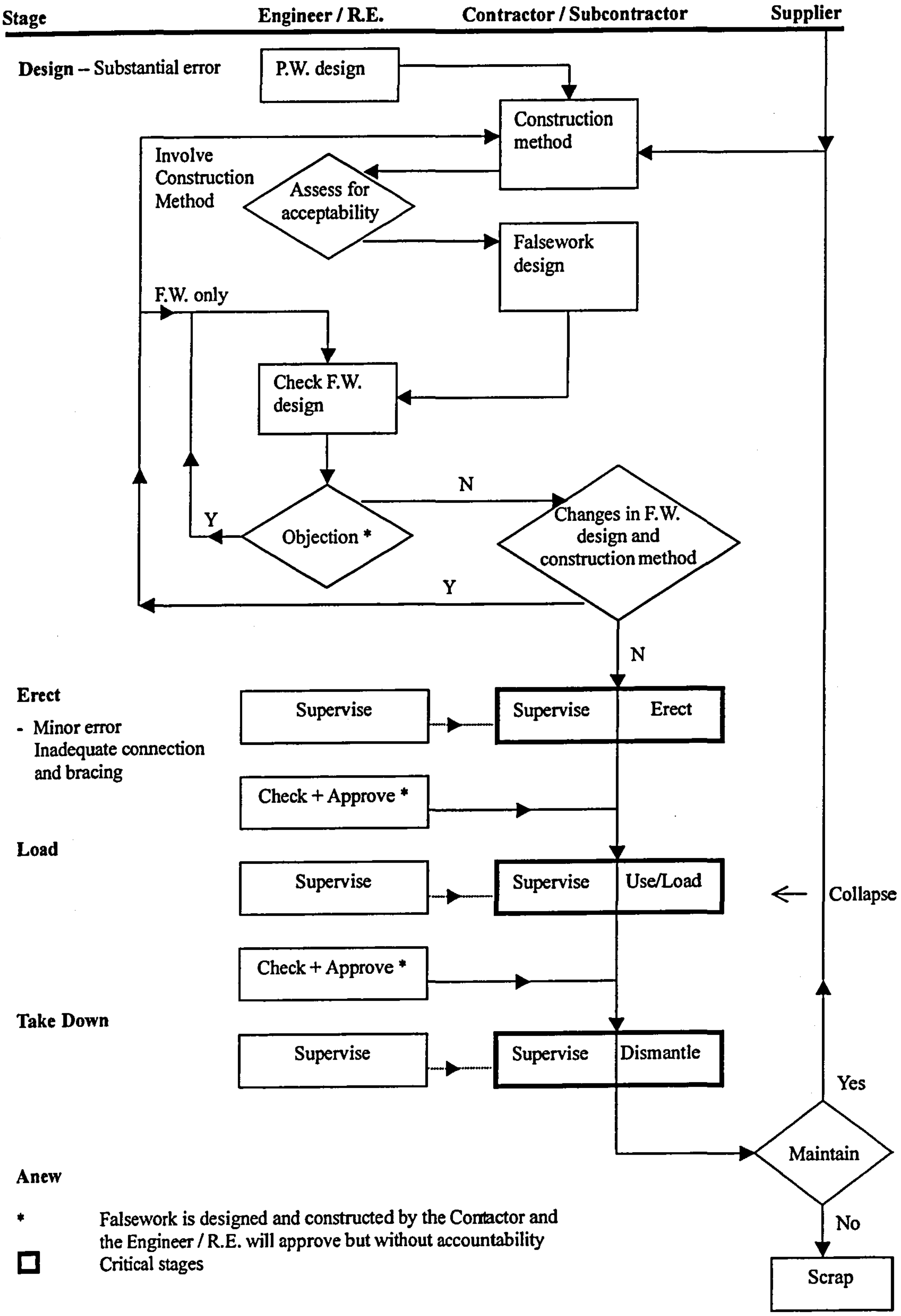


Figure C.17: Case Ref. No. 17 Taipei, Taiwan [D, B]



* Falsework is designed and constructed by the Contactor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

Figure C.18: Case Ref. No. 18 Taipei, Taiwan [D, B]

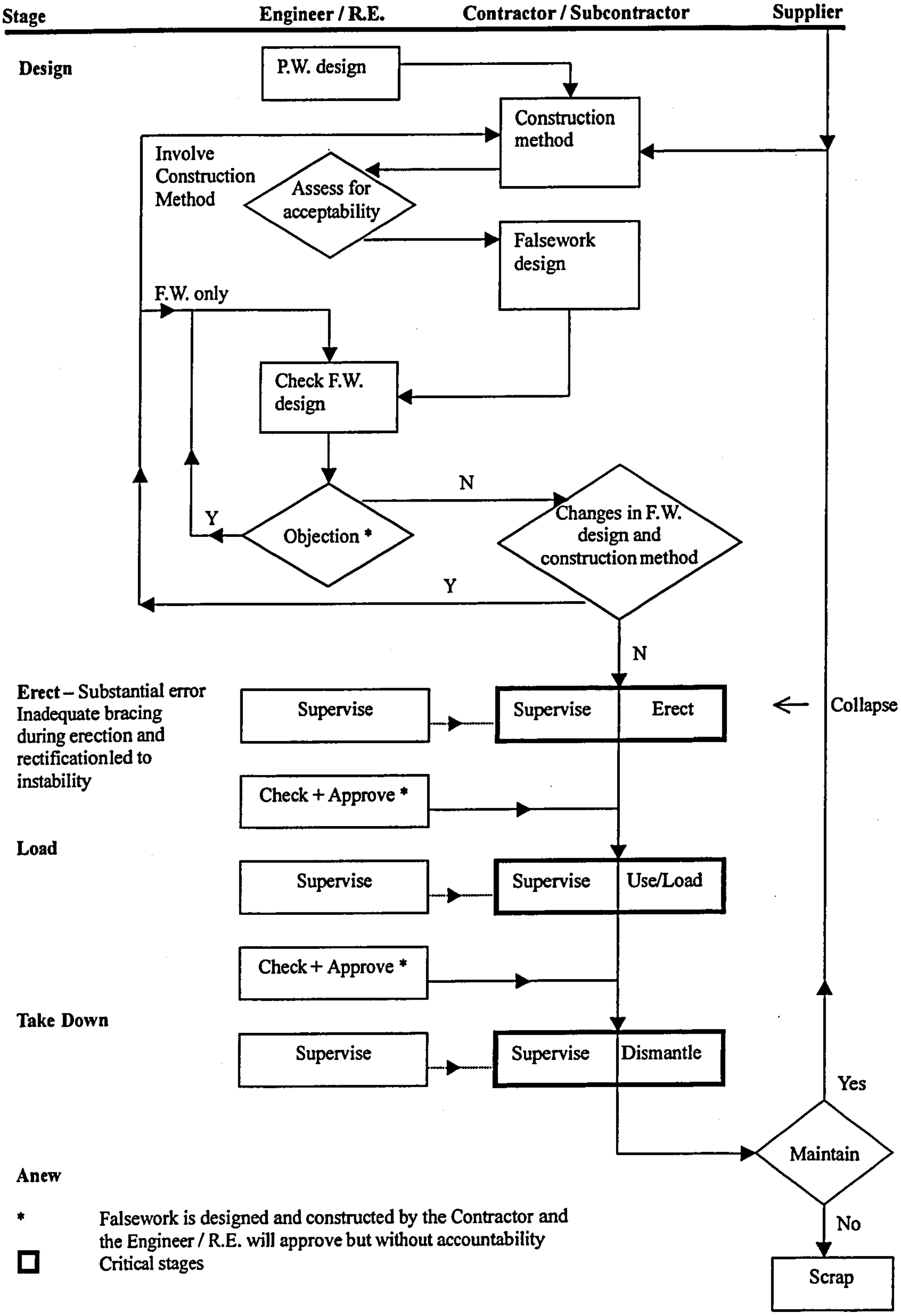
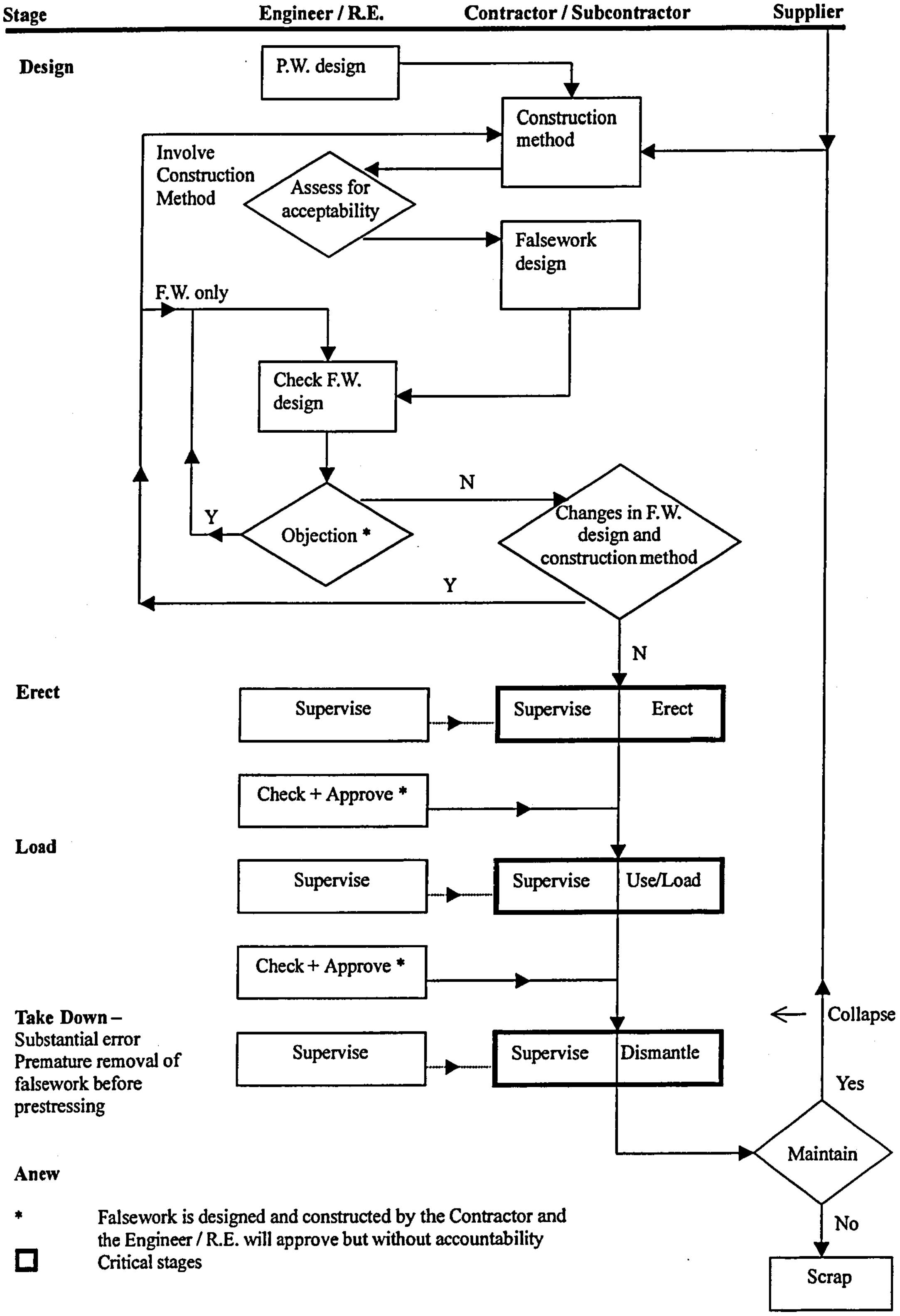


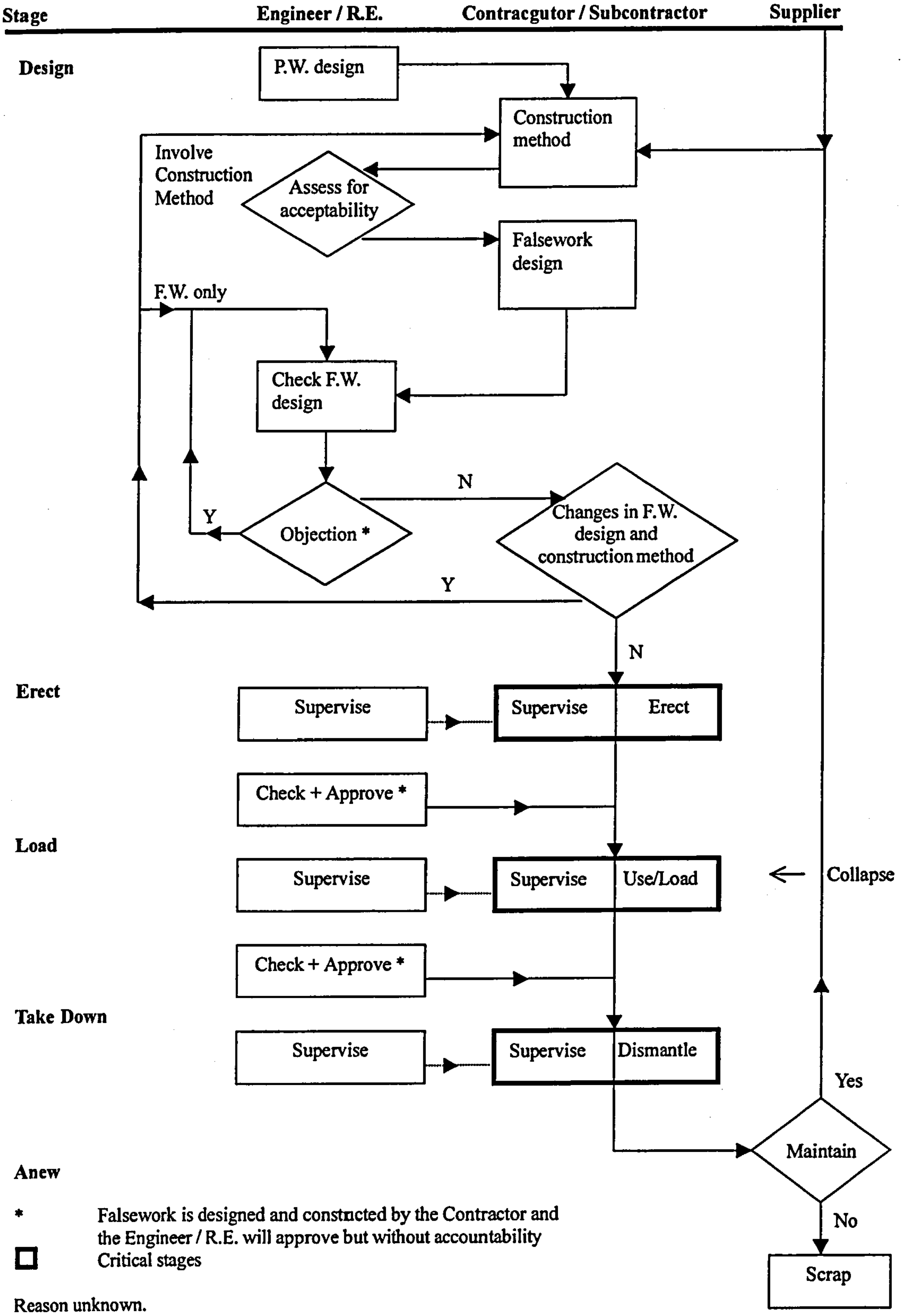
Figure C.19: Case Ref. No. 19 Tsing Yi, Hong Kong [D, B]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

Figure C.20: Case Ref. No. 20 Taiwan [C]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

Reason unknown.
Failure occurred during lowering of the steel beam by jacking

Figure C.21: Case Ref. No. 21 Heidelberg, W. Germany [C]

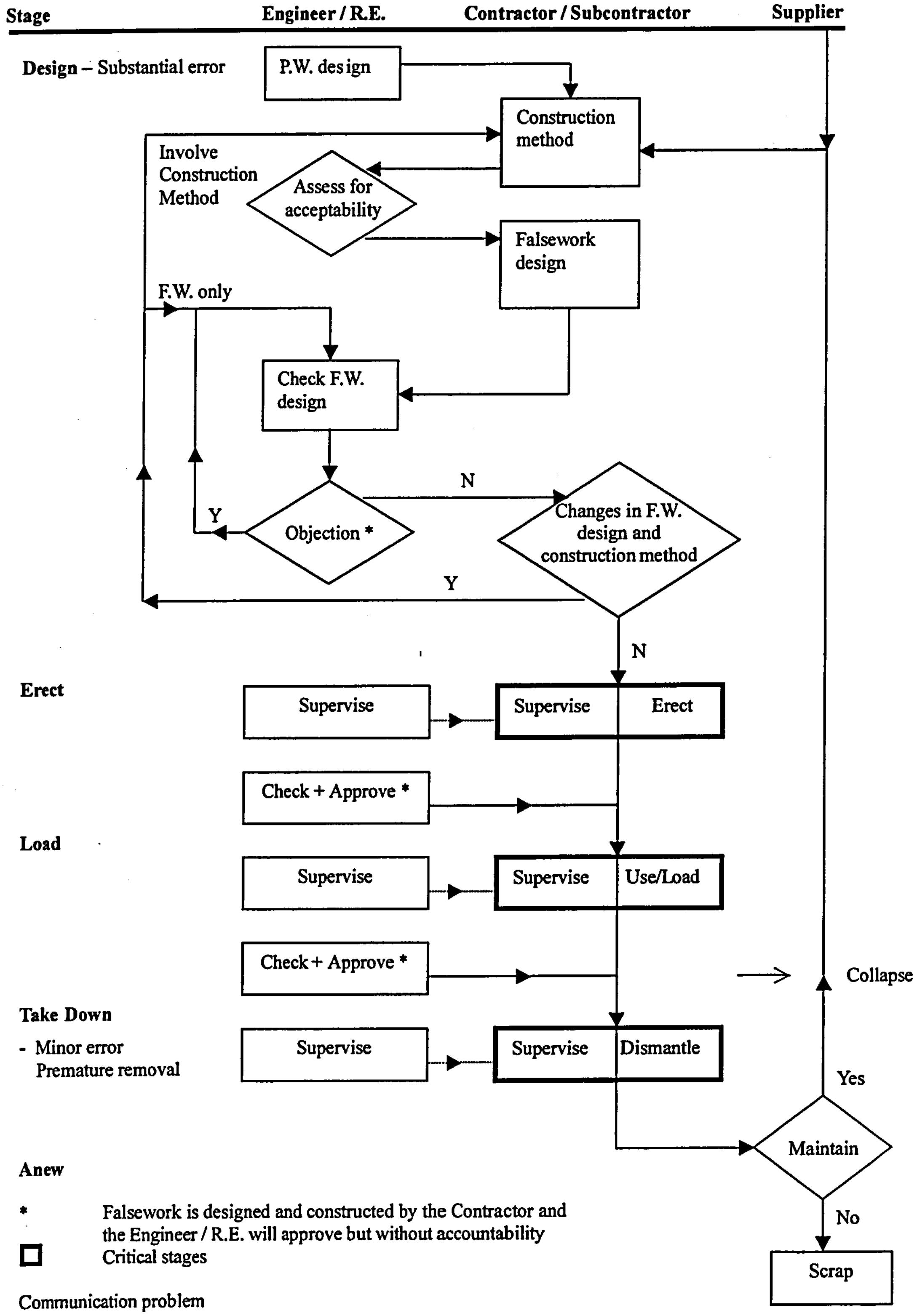


Figure C.22: Case Ref. No. 22 Colorado, USA [D, B]

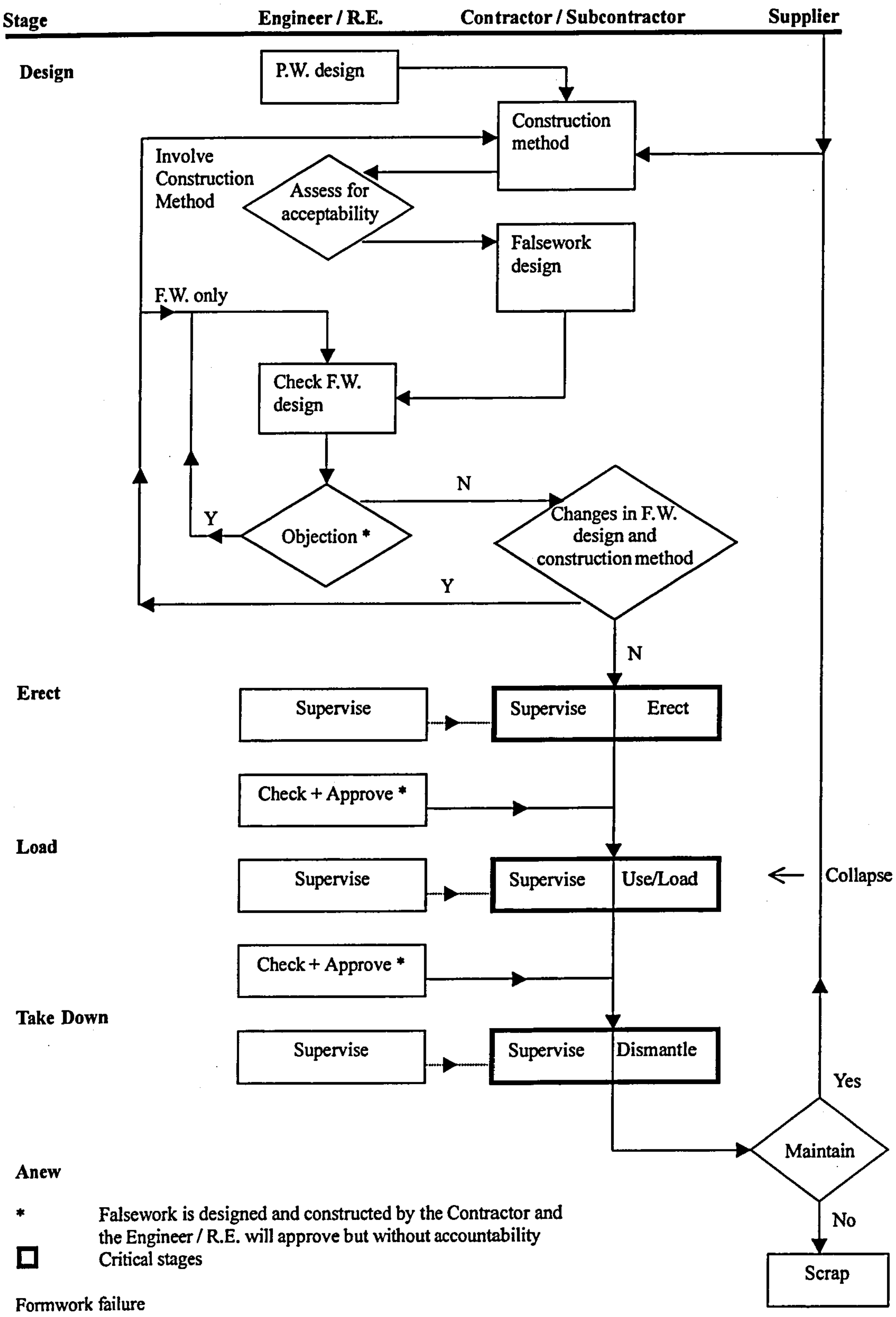


Figure C.23: Case Ref. No. 23 Taiwan [C]

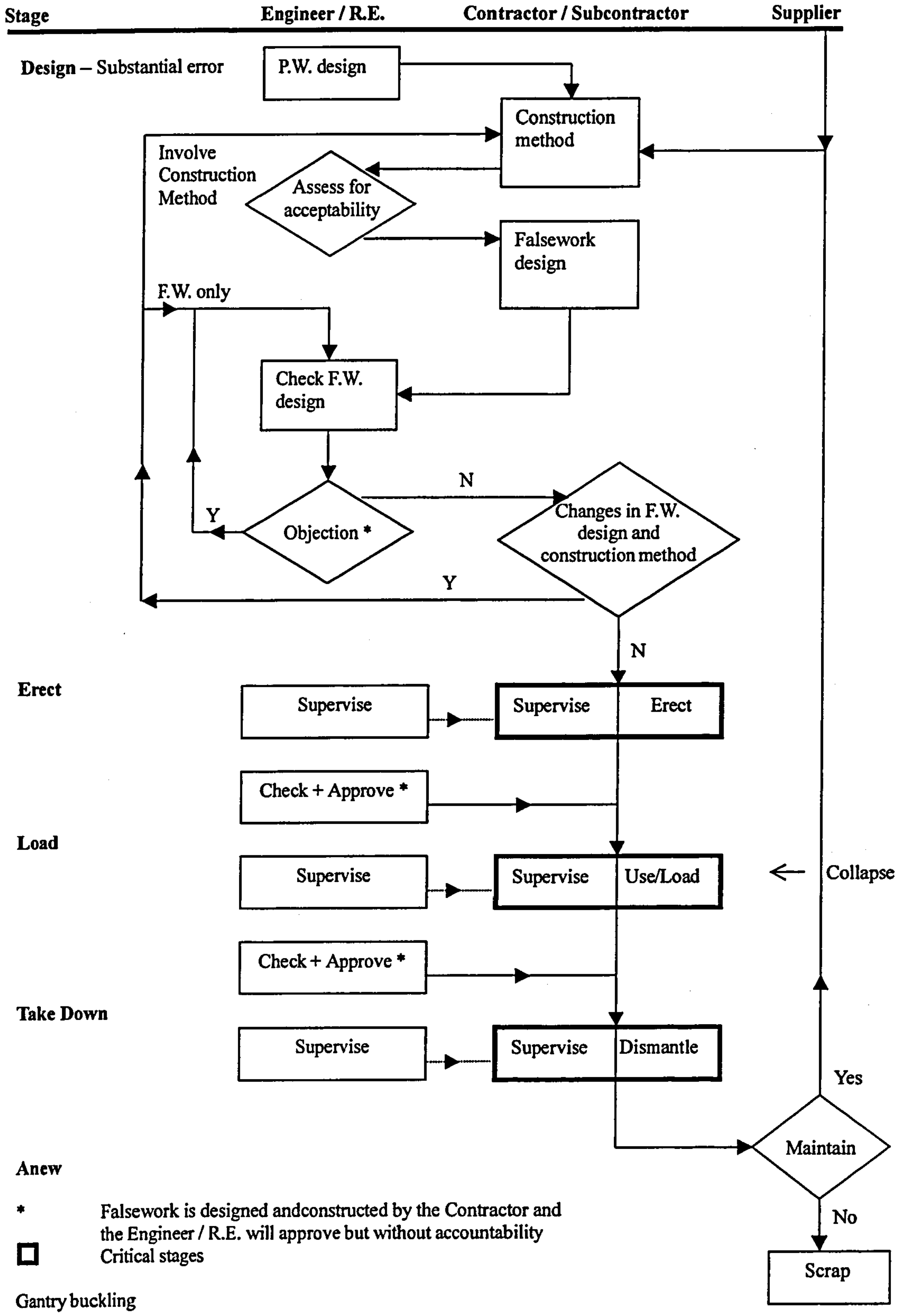
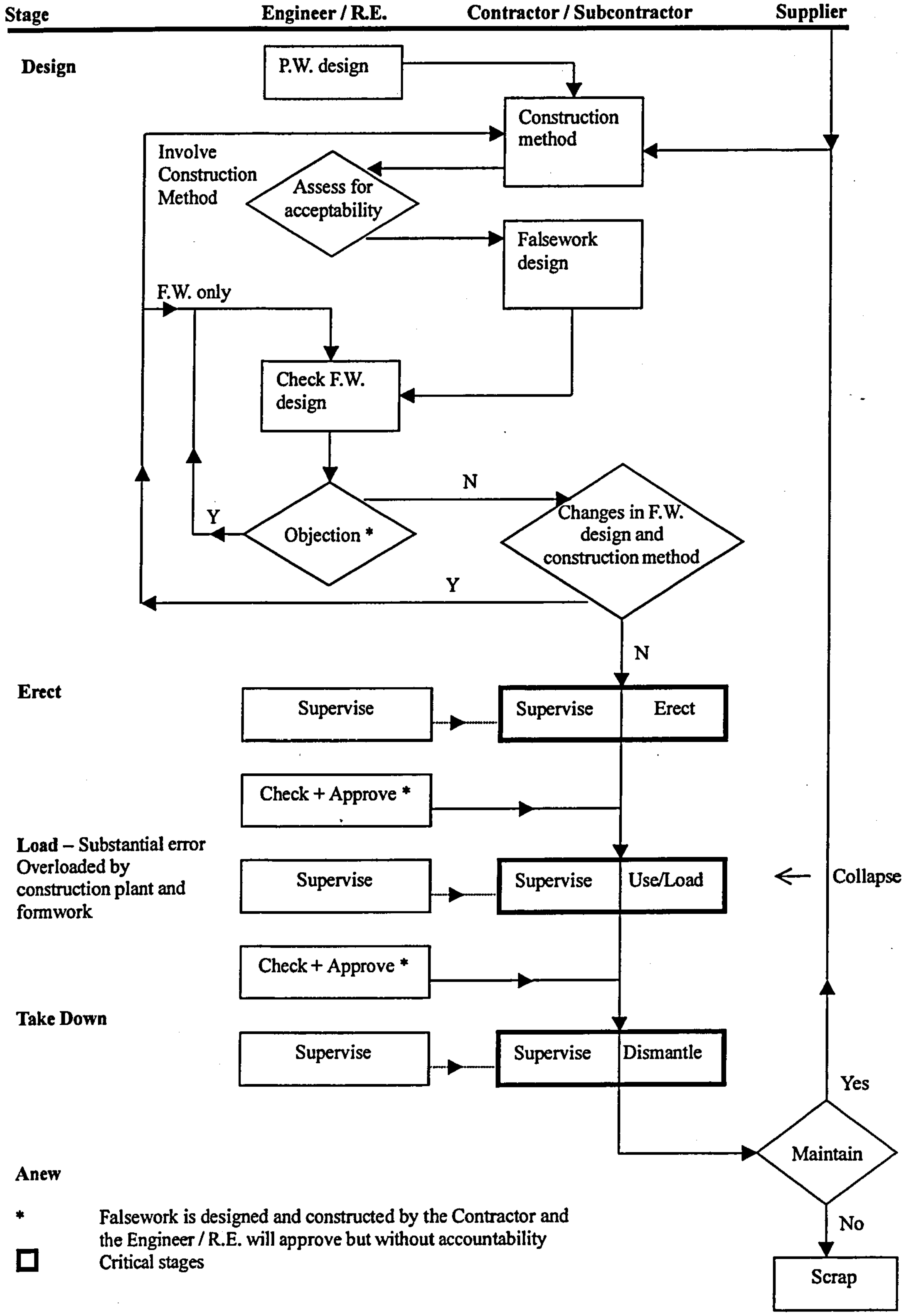


Figure C.24: Case Ref. No. 24 Sunshine Skyway, Tampa Bay, U.S.A. [C, B]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Figure C.25: Case Ref. No. 25 Taiwan [C]

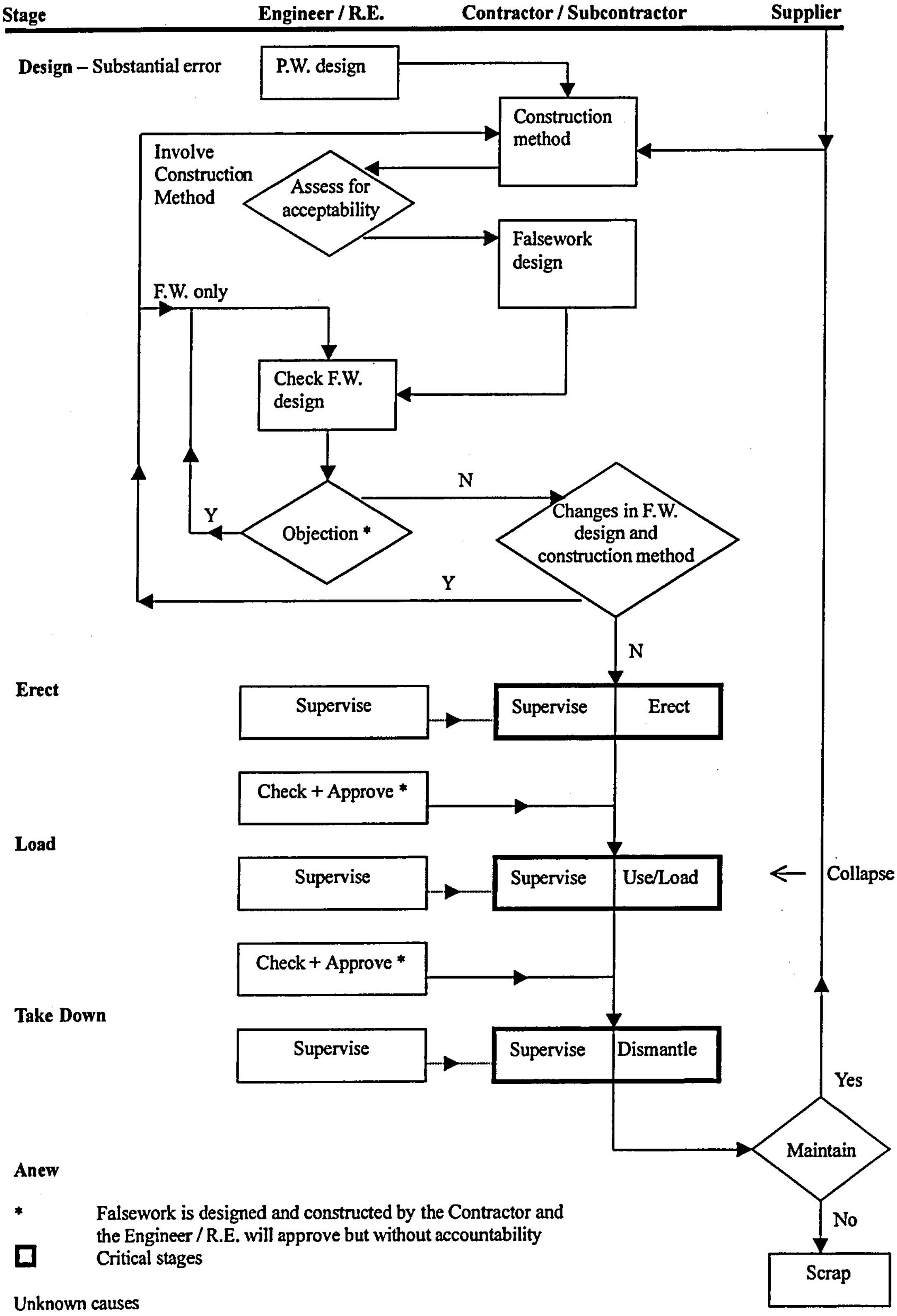


Figure C.26: Case Ref. No. 26 Route 36, Kansas, USA [C]

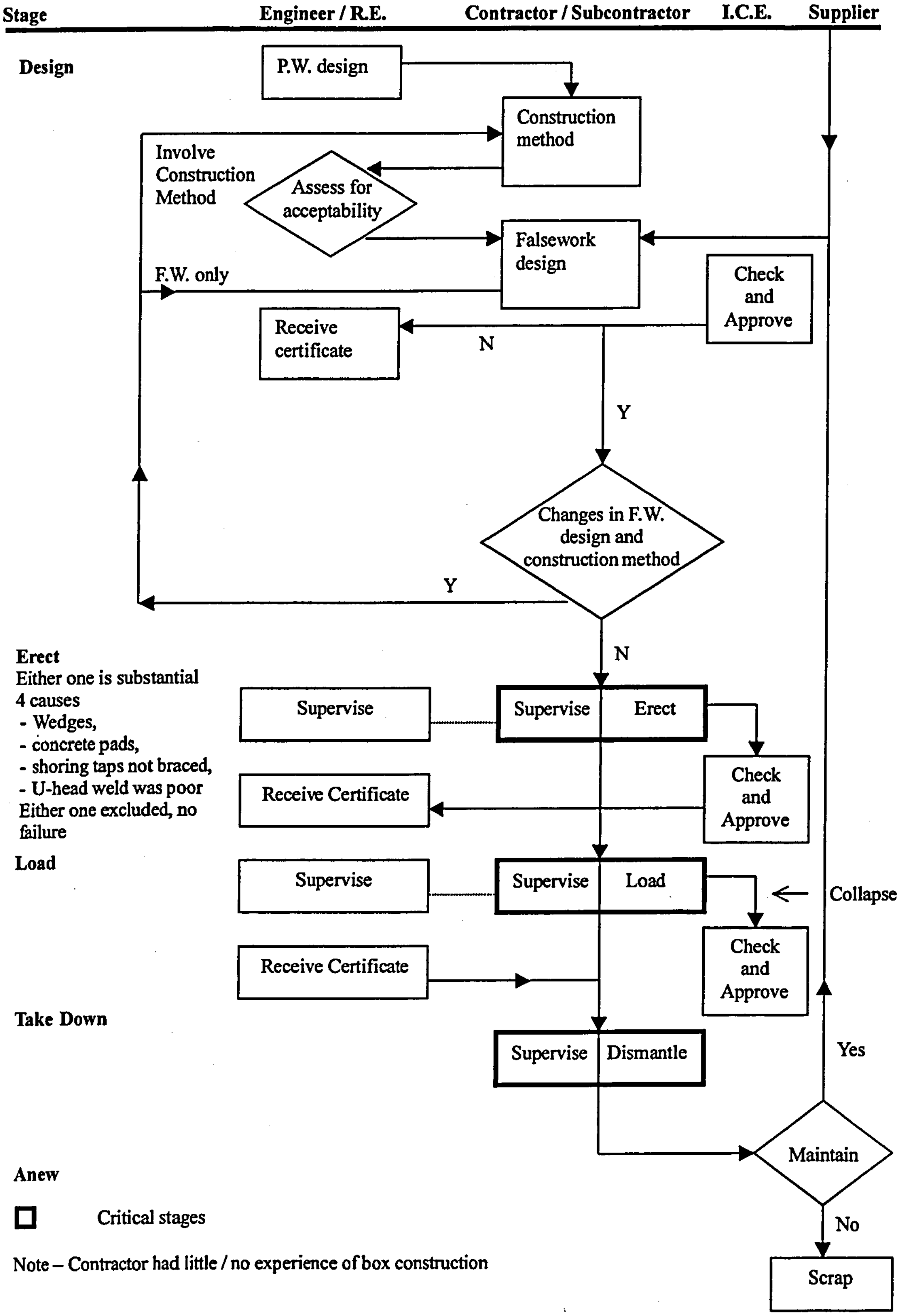
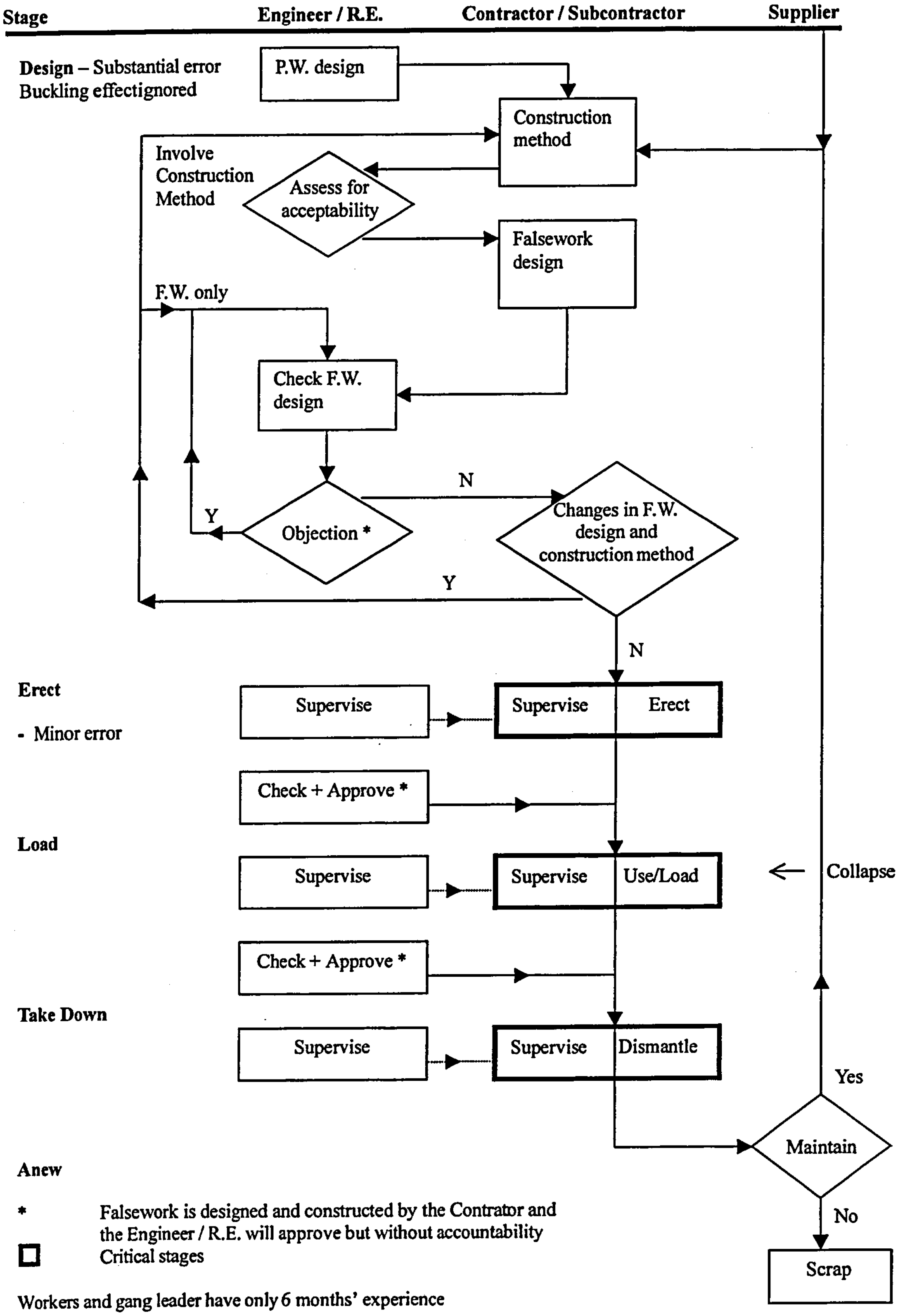


Figure C.27: Case Ref. No. 27 Ramp C, East Chicago, USA [C, B]

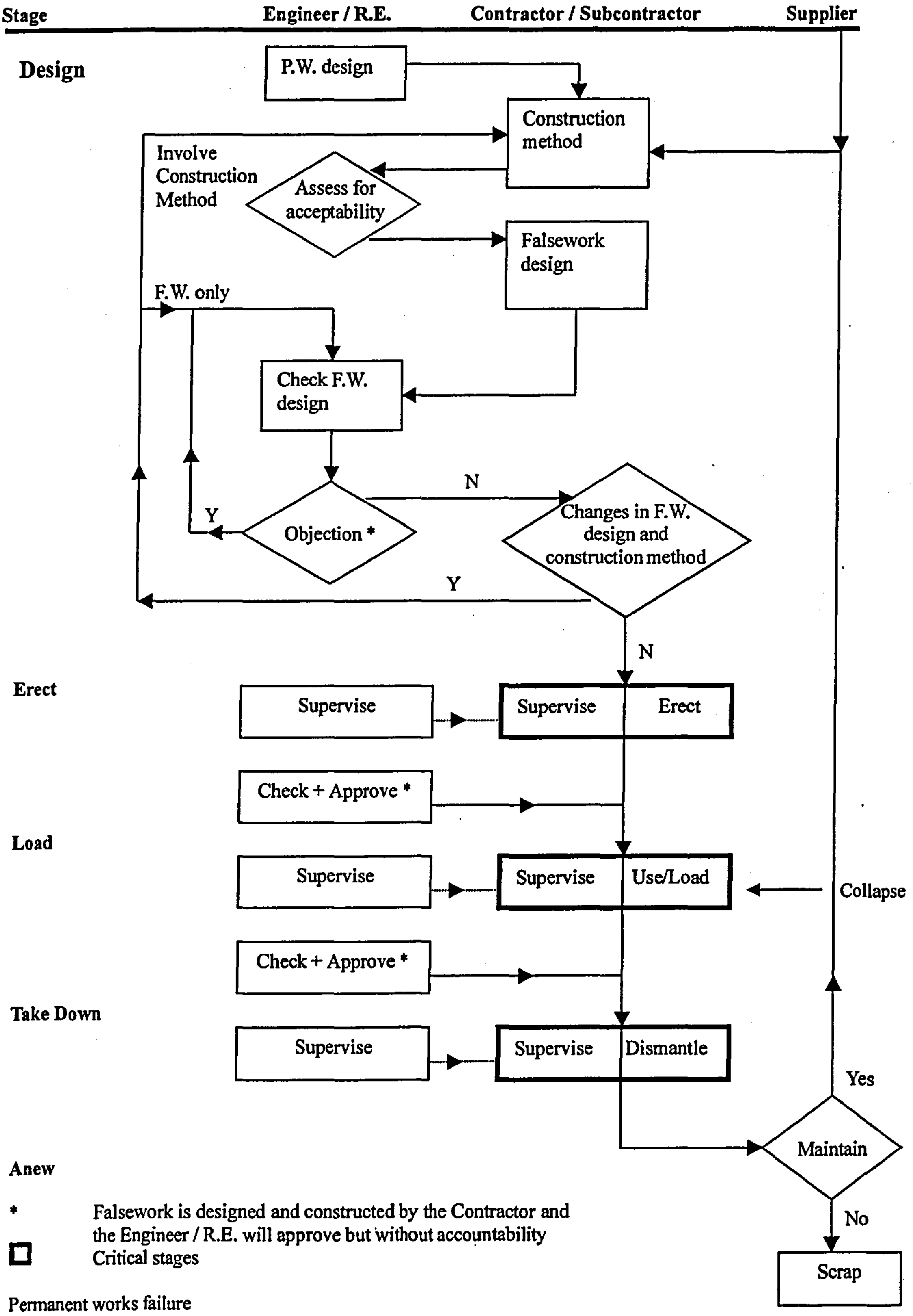


* Falsework is designed and constructed by the Contratωr and the Engineer / R.E. will approve but without accountability

□ Critical stages

Workers and gang leader have only 6 months' experience

Figure C.28: Case Ref. No. 28 Tuen Mun, Hong Kong [B, C]

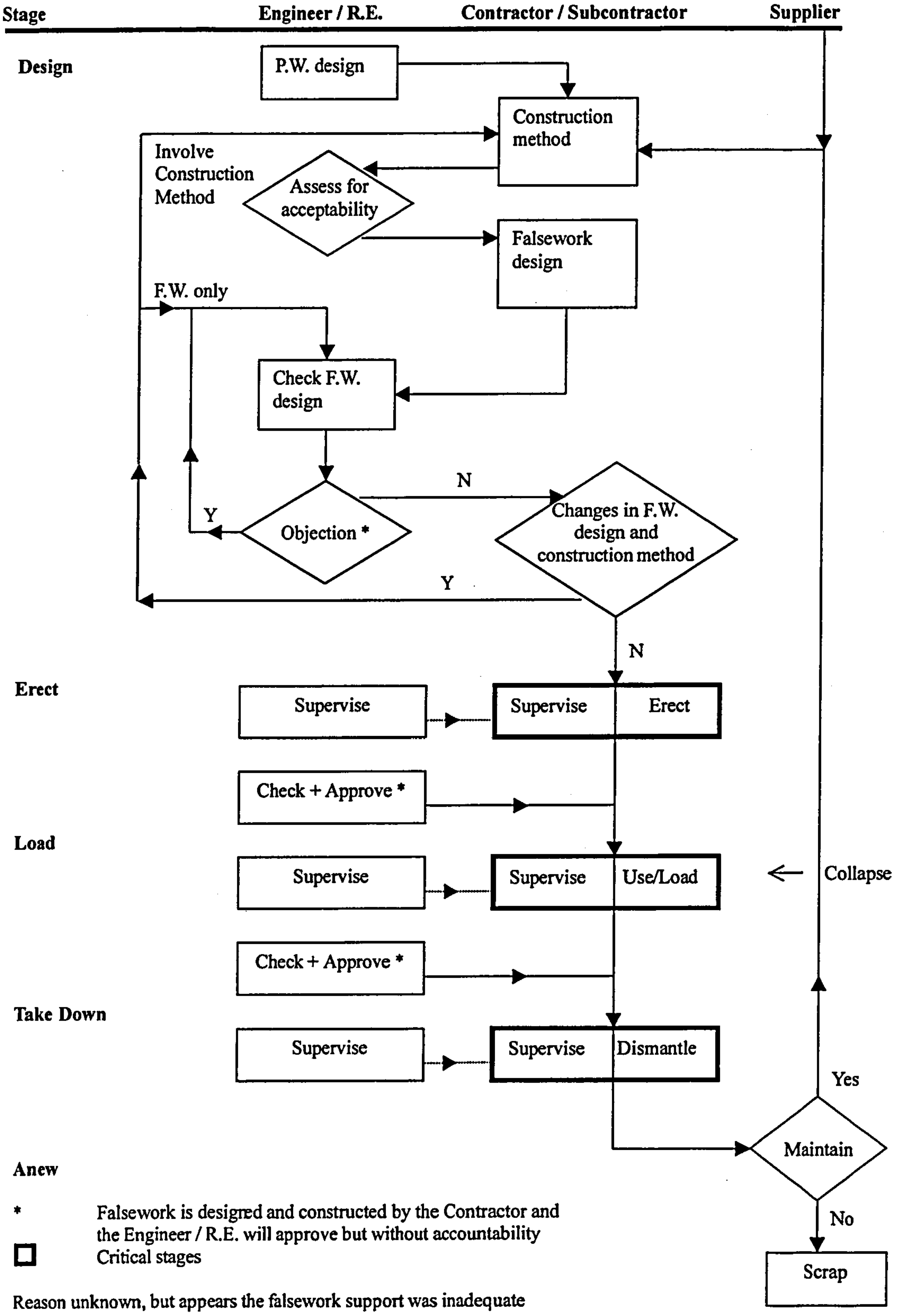


* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Permanent works failure

Figure C.29: Case Ref. No. 29 Saudi Arabia [C]

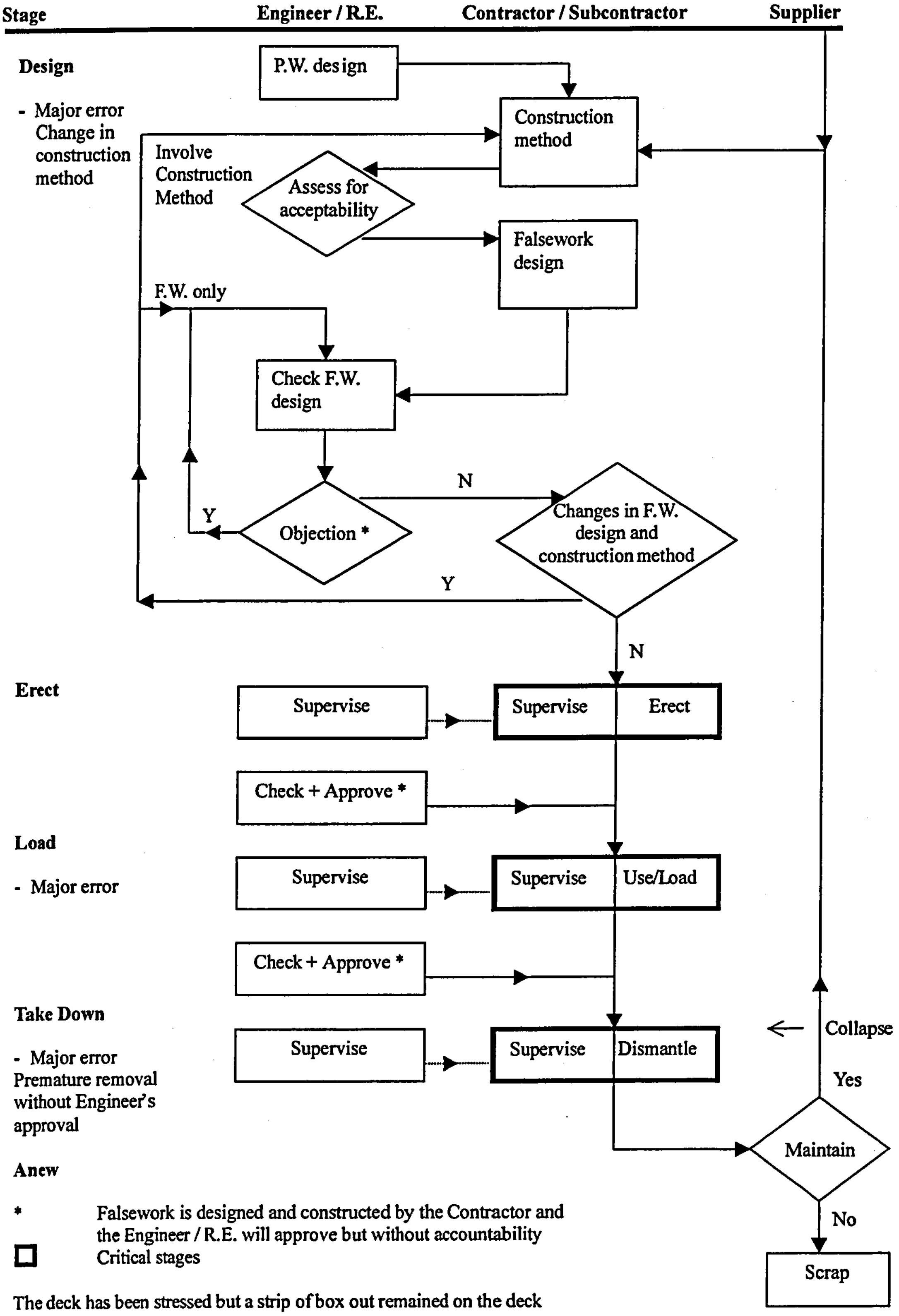


* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

Reason unknown, but appears the falsework support was inadequate

Figure C.30: Case Ref. No. 30 Bombay, India [C, B]

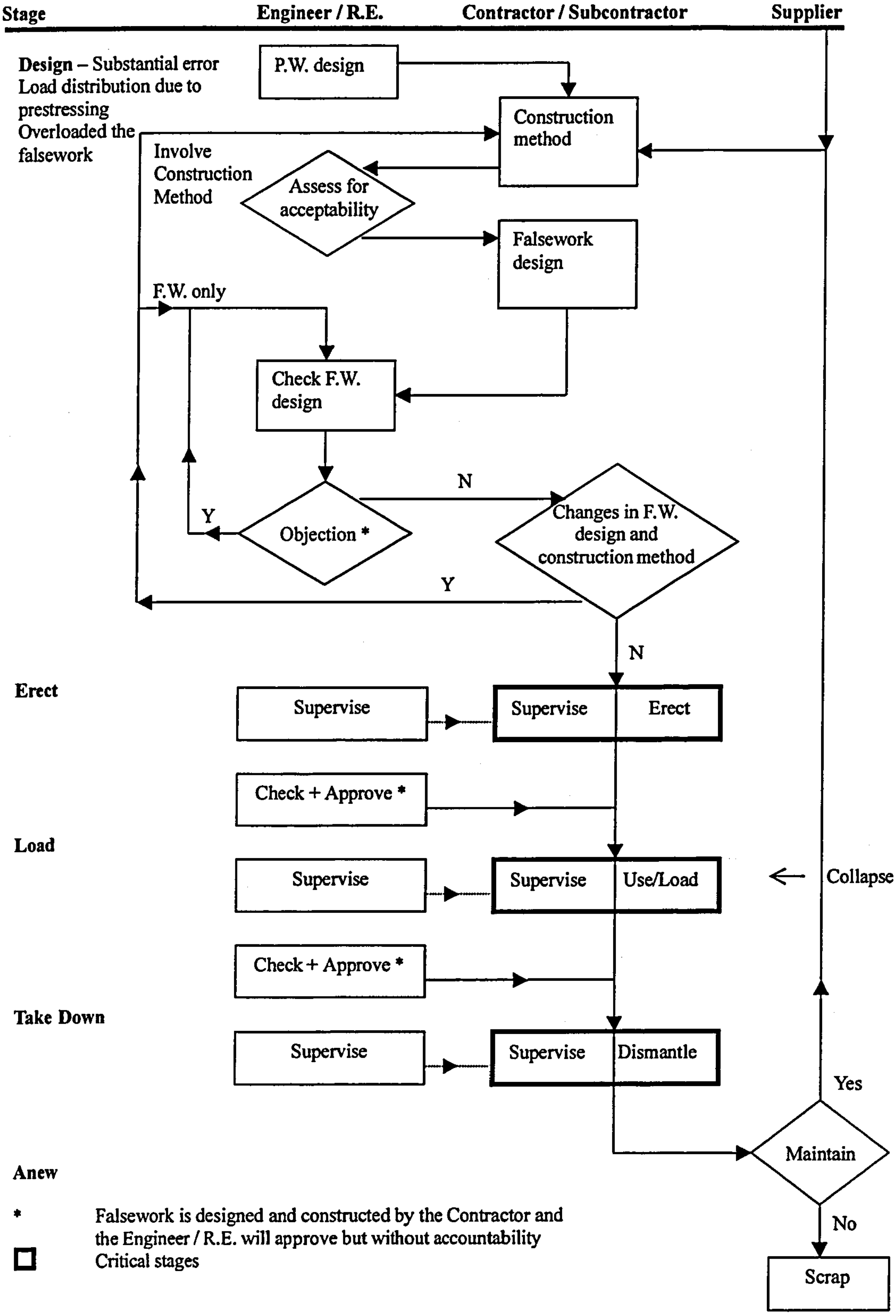


* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

The deck has been stressed but a strip of box out remained on the deck

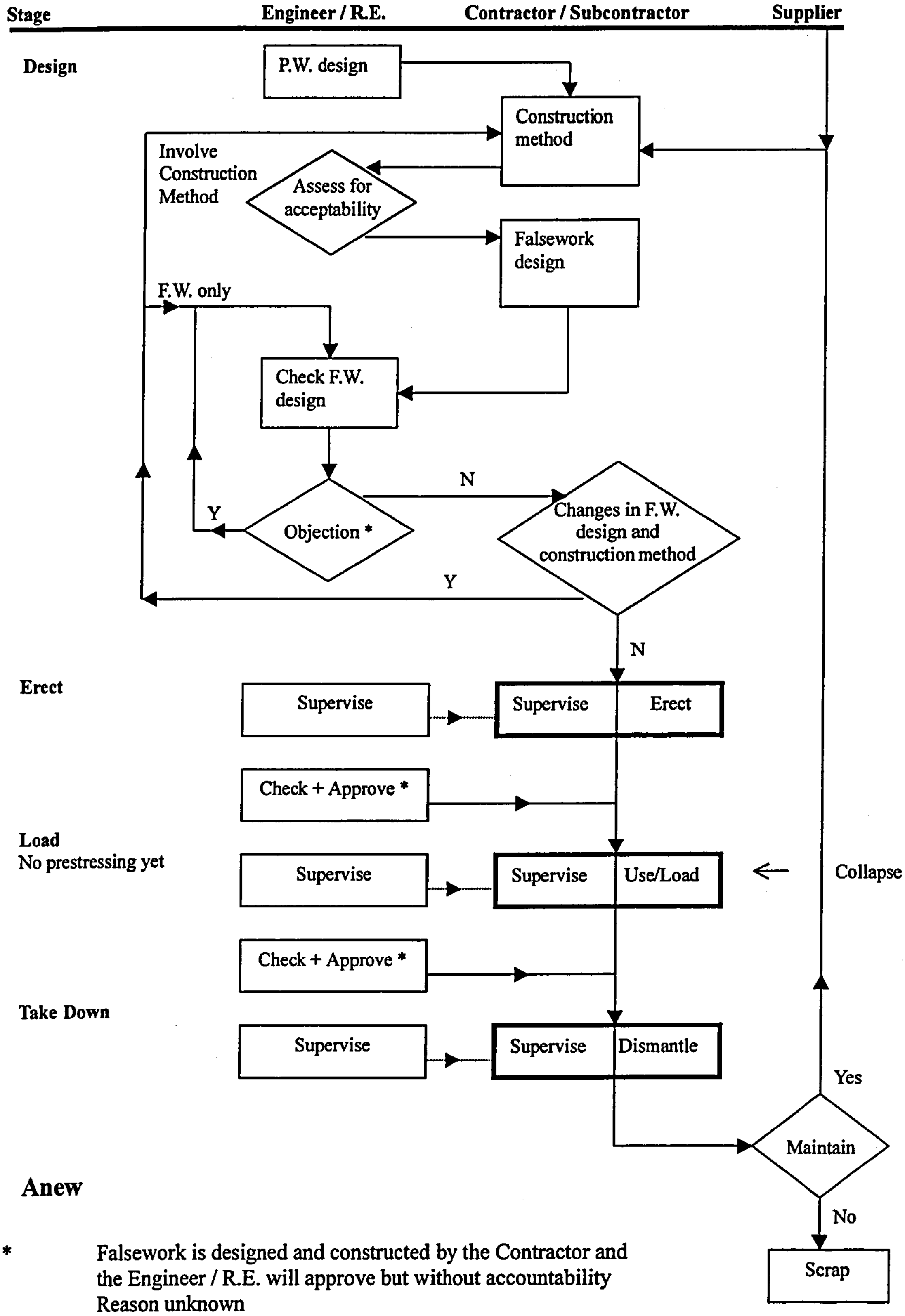
Figure C.31: Case Ref. No. 31 Jalans Euros Flyover, Singapore [C]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Figure C.32: Case Ref. No. 32 New Zealand [C]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability
Reason unknown

Figure C.33: Case Ref. No. 33 Belgium [C]

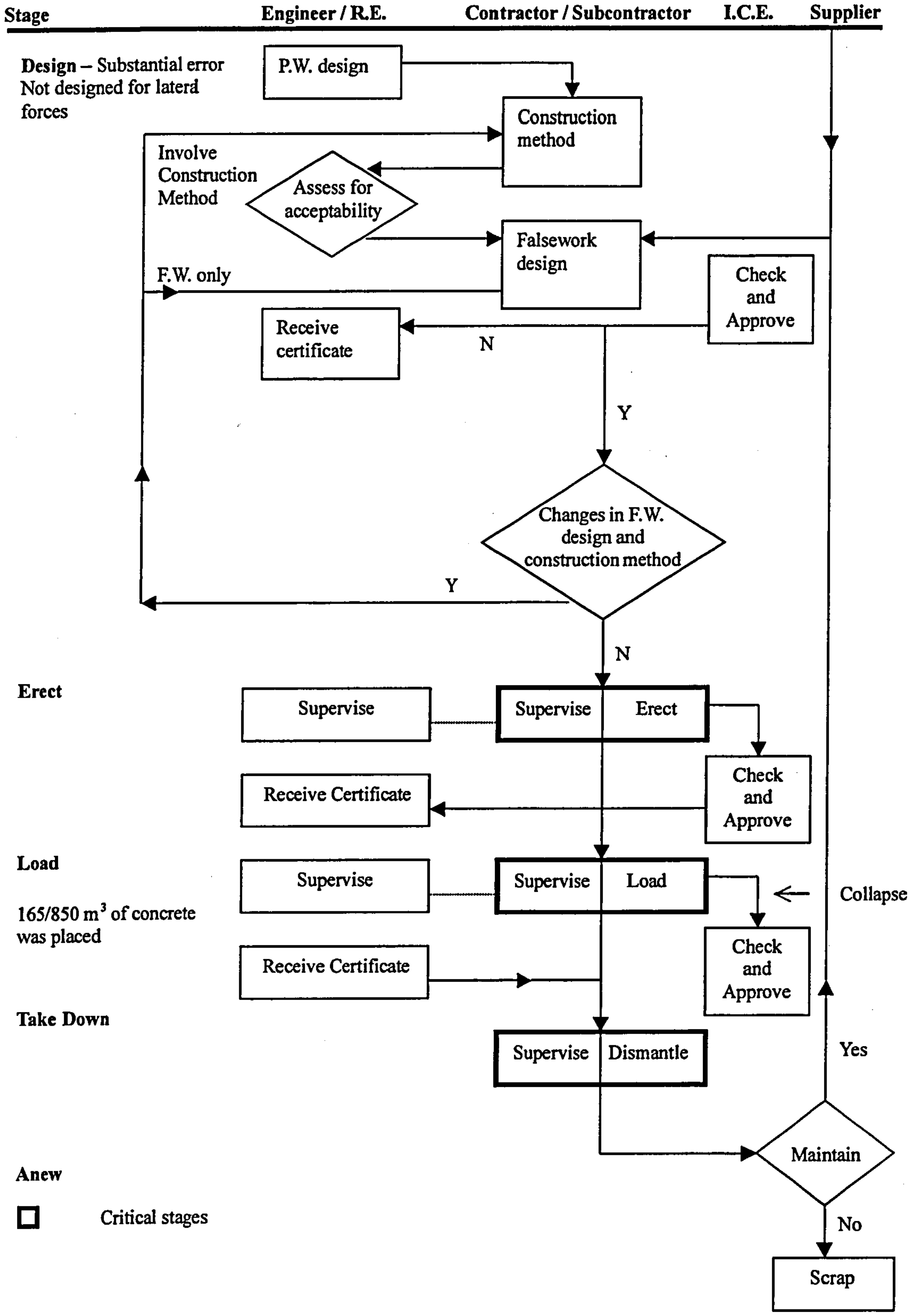
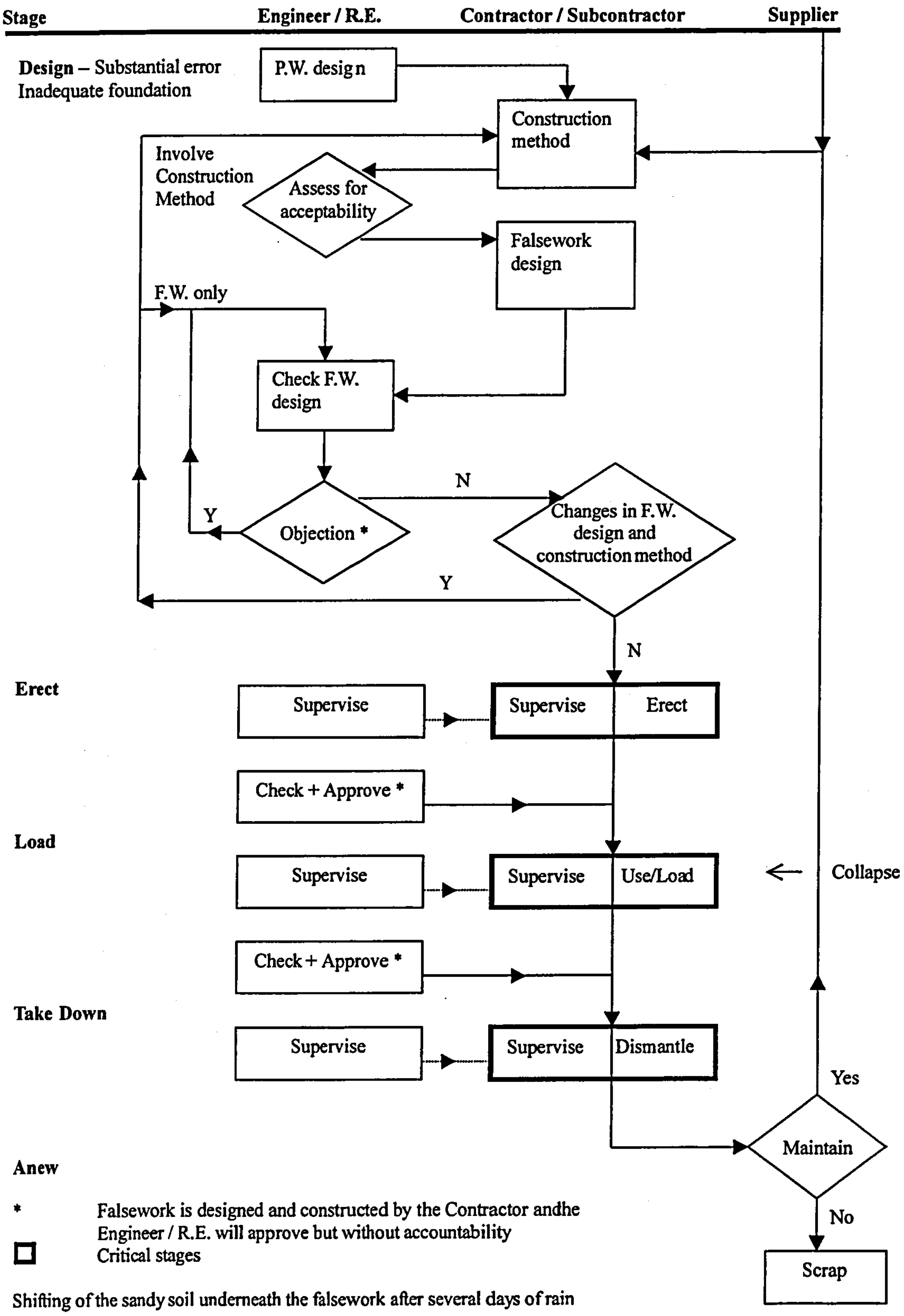


Figure C.34: Case Ref. No. 34 Kempton, West Germany [C, B]

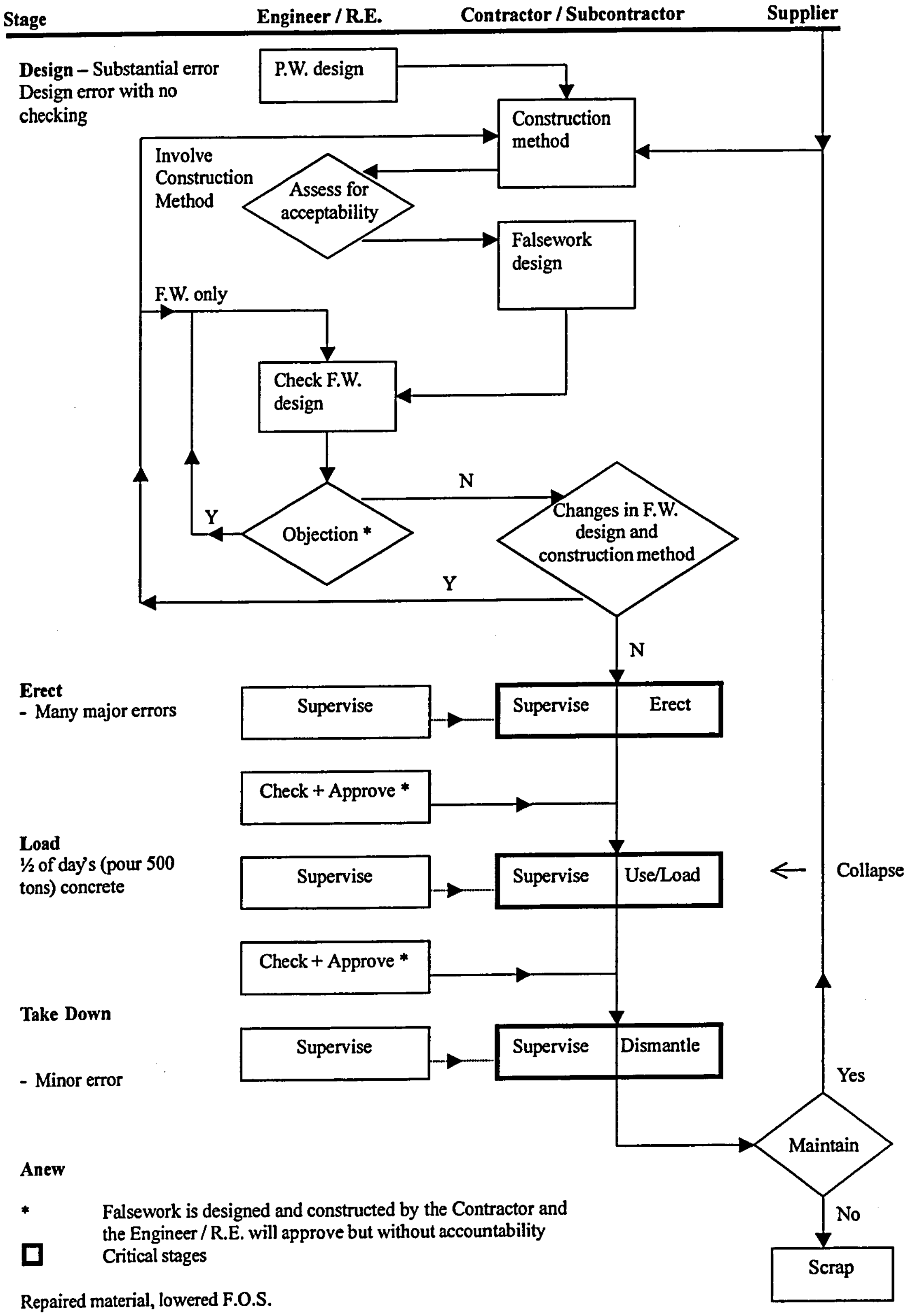


* Falsework is designed and constructed by the Contractor andhe Engineer / R.E. will approve but without accountability

☐ Critical stages

Shifting of the sandy soil underneath the falsework after several days of rain

Figure C.35: Case Ref. No. 35 Sao Paulo, Brazil [C]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

Repaired material, lowered F.O.S.

Figure C.36: Case Ref. No. 36 London, Berkshire, England [C, B]

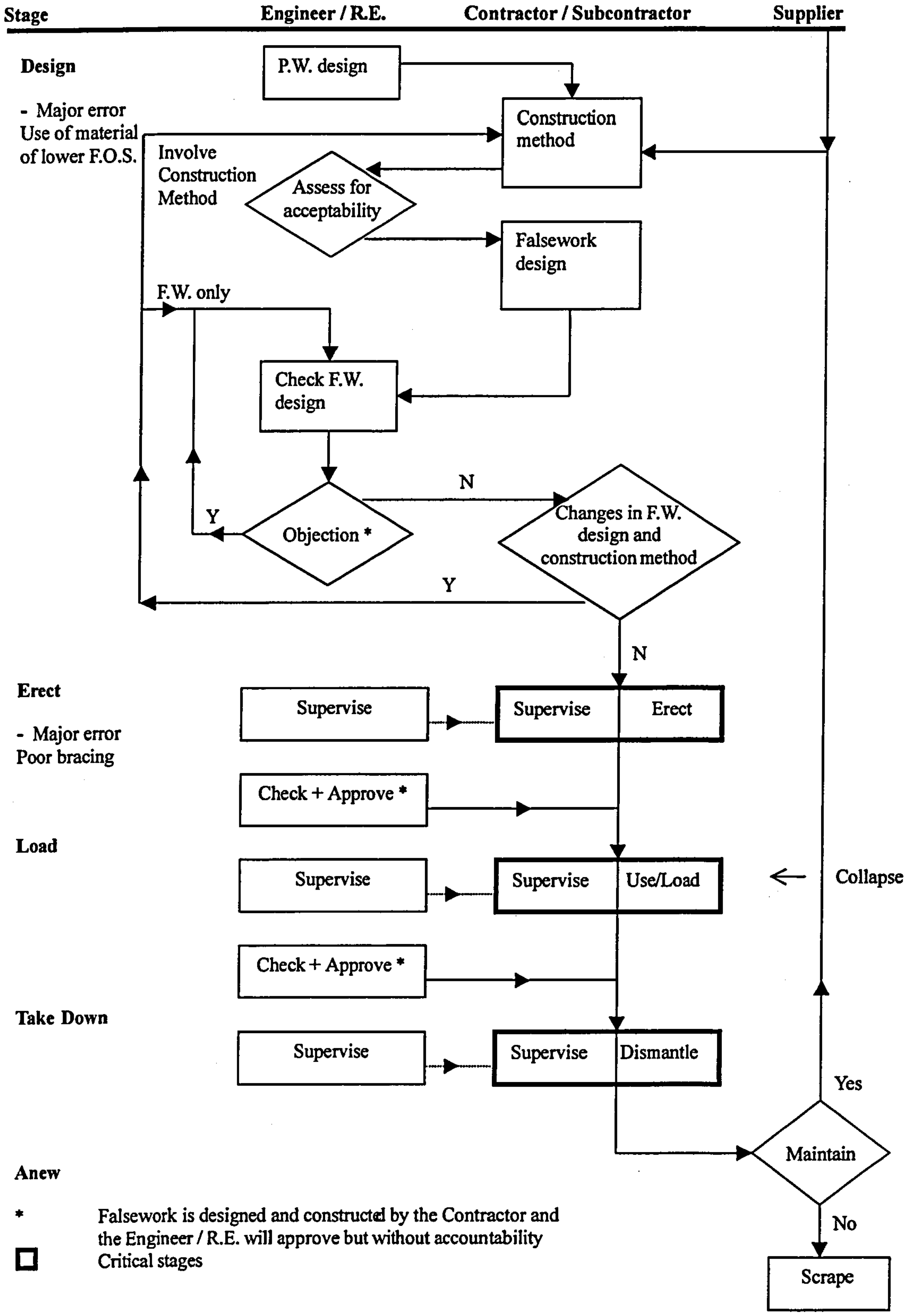


Figure C.37: Case Ref. No. 37 Anoyo Seao Bridge California,USA(Pasadena) [C]

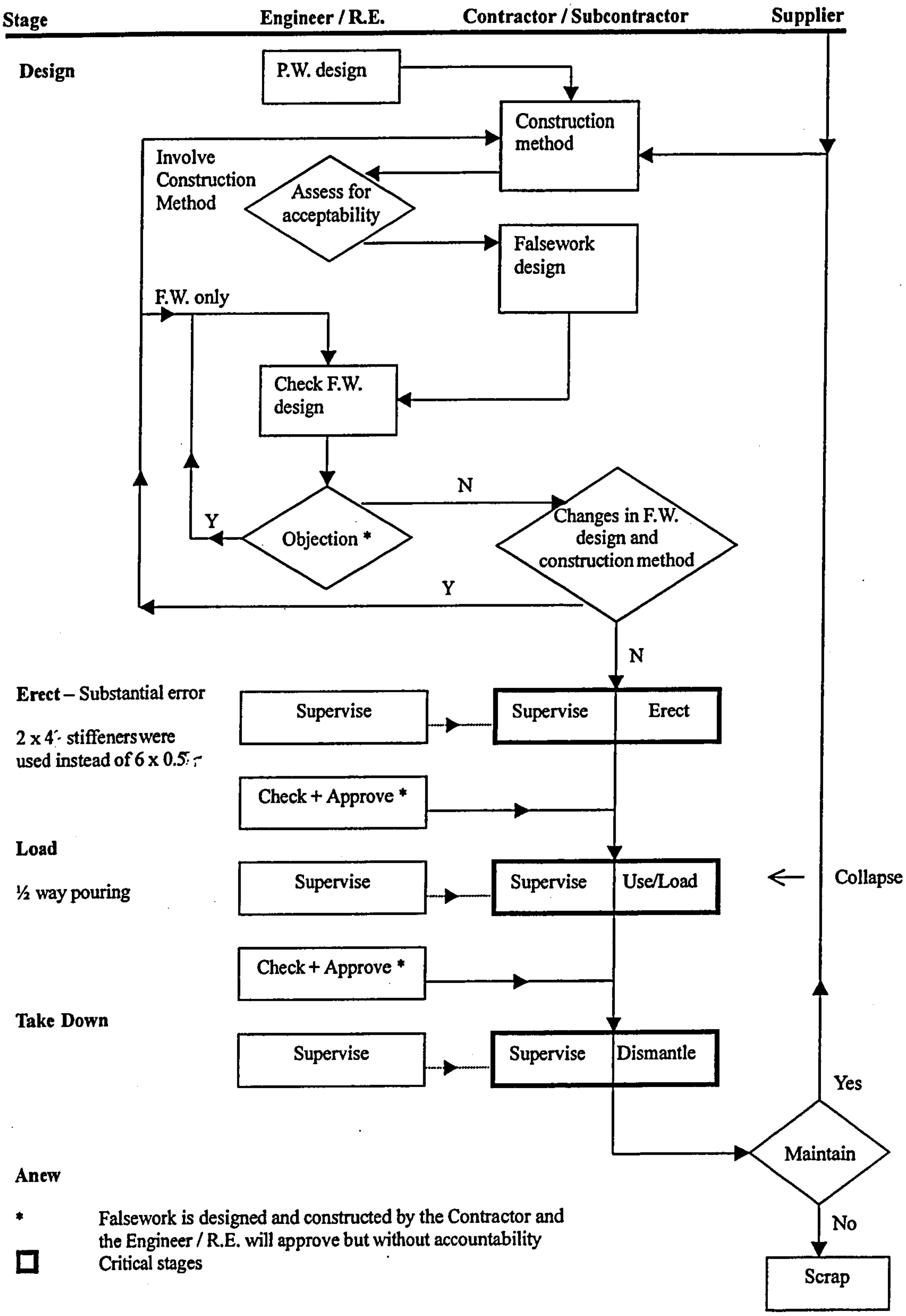
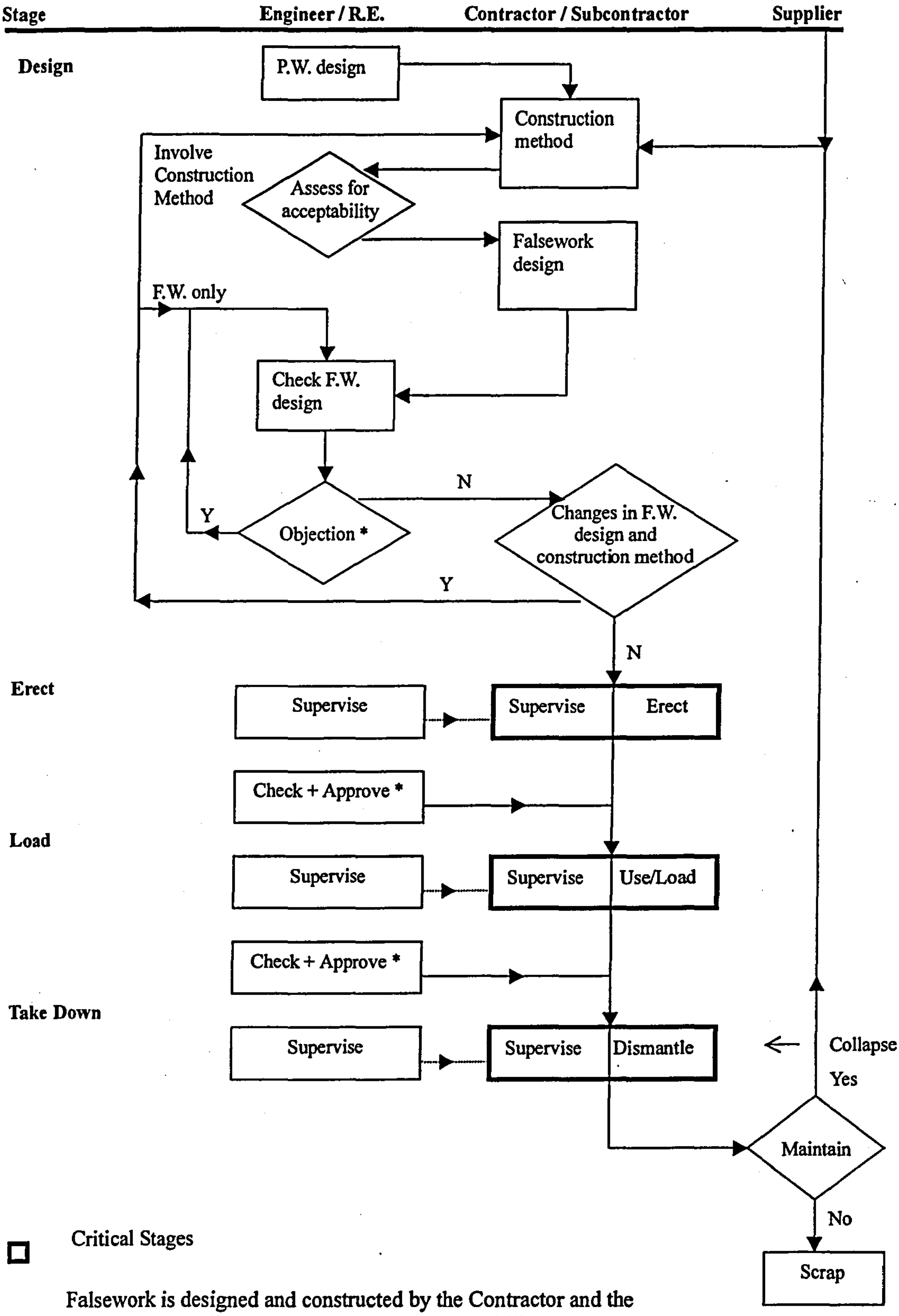


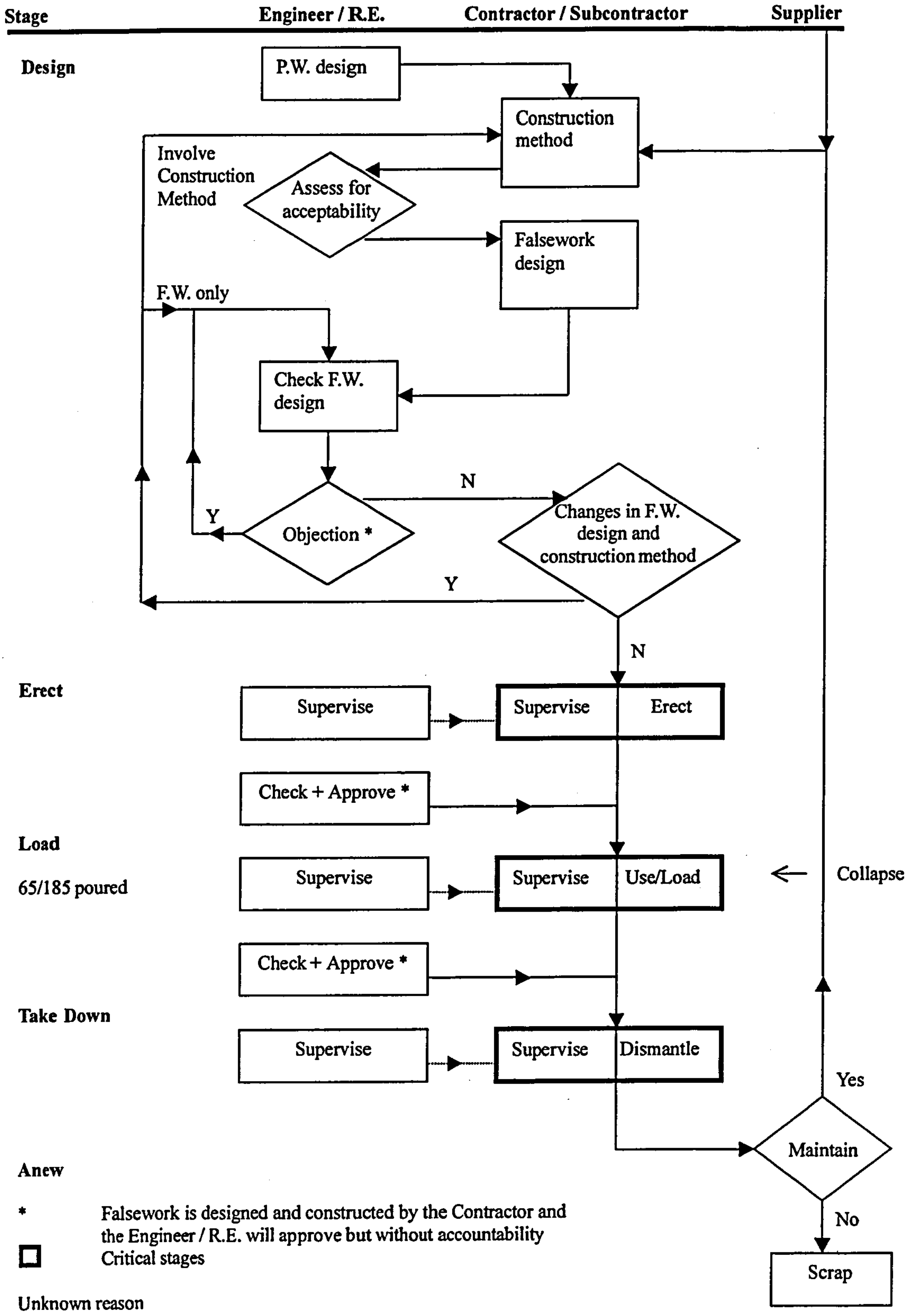
Figure C.38: Case Ref. No. 38 Koblenz, West Germany [C, B]



□ Critical Stages

* Falsework is designed and constructed by the Contractor and the Engineer/R.E. will approve but without accountability
Reasons unknown

Figure C.39: Case Ref. No. 39 Route 50, Sacramento, California, USA [C]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

Unknown reason

Figure C.40: Case Ref. No. 40 Dallas, USA [C]

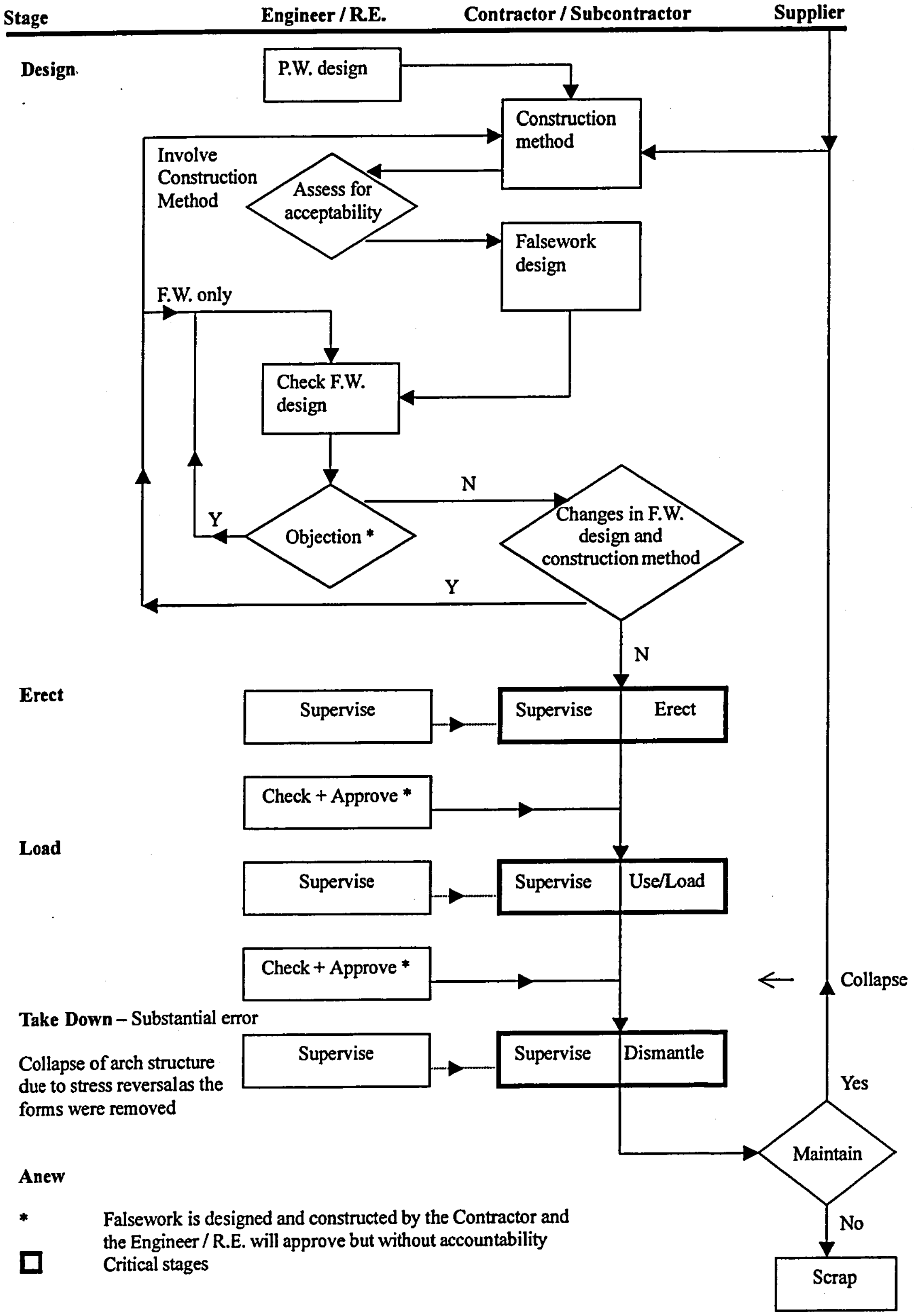
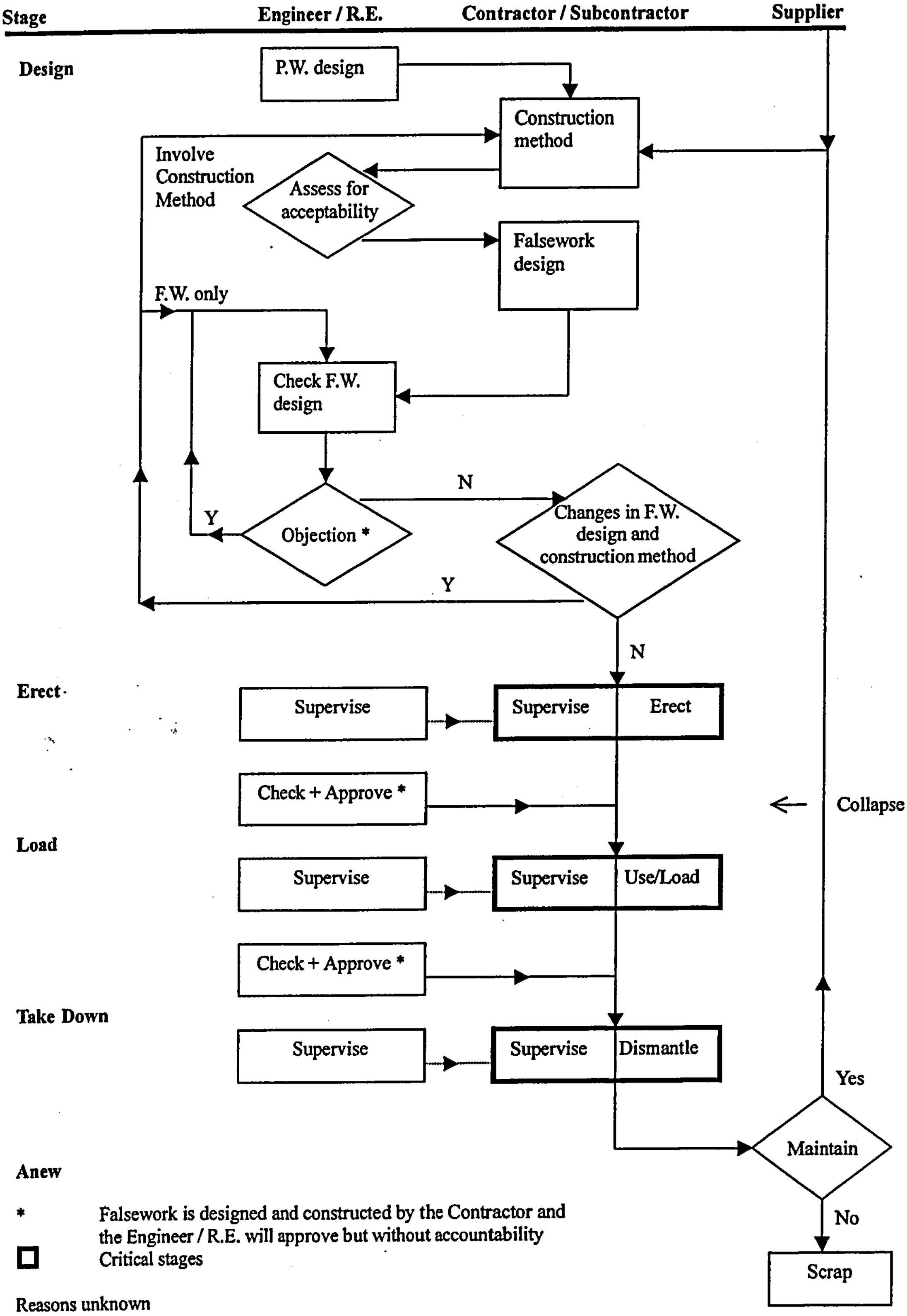


Figure C.41: Case Ref. No. 41 Elgin, Ill, USA [C]

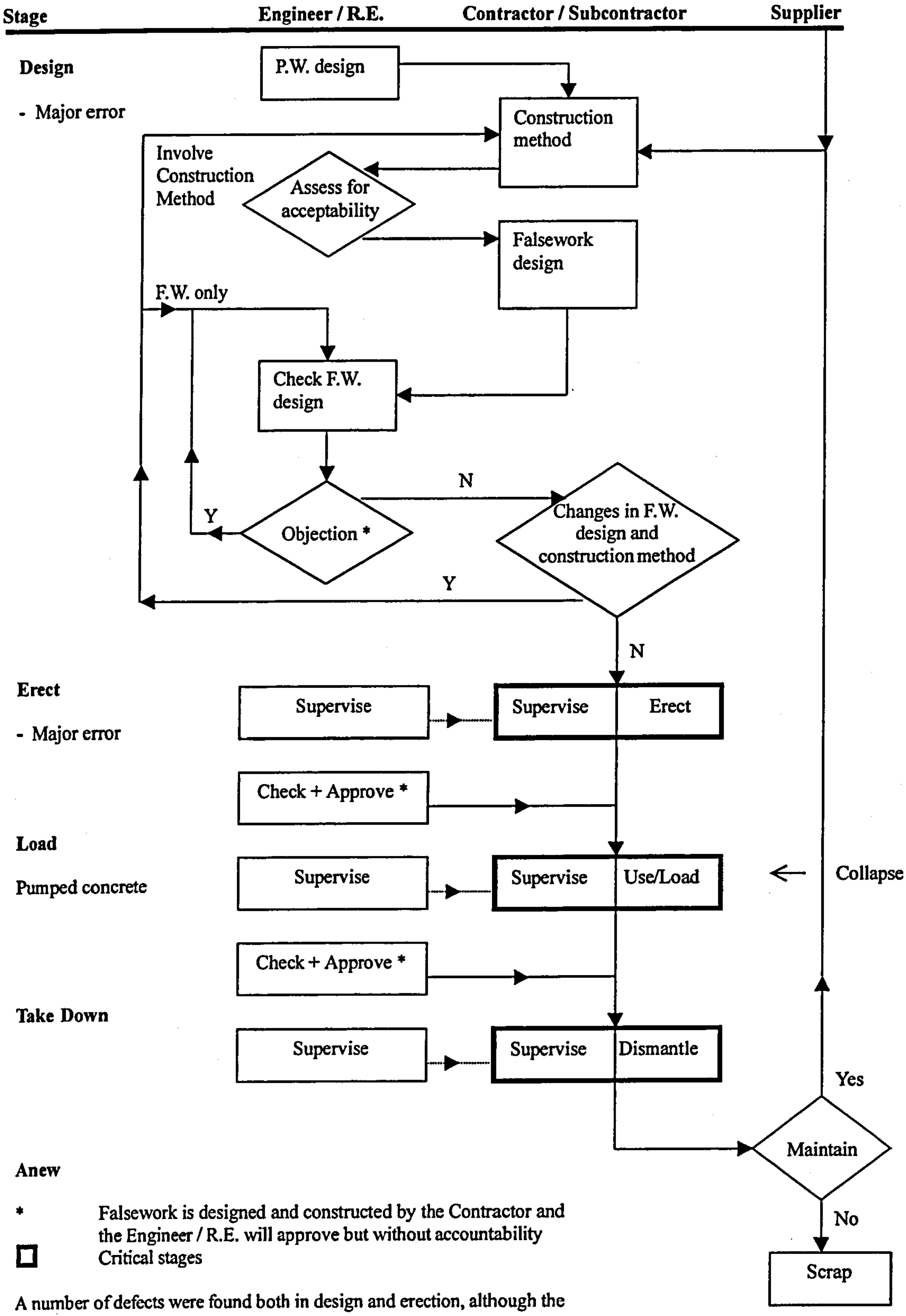


* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Reasons unknown

Figure C.42: Case Ref. No. 42 San Bruno, California, USA [C]



Anew

* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

A number of defects were found both in design and erection, although the real single cause was unknown.

Figure C.43: Case Ref. No. 43 Birling Road Overbridge, Kent, UK [C]

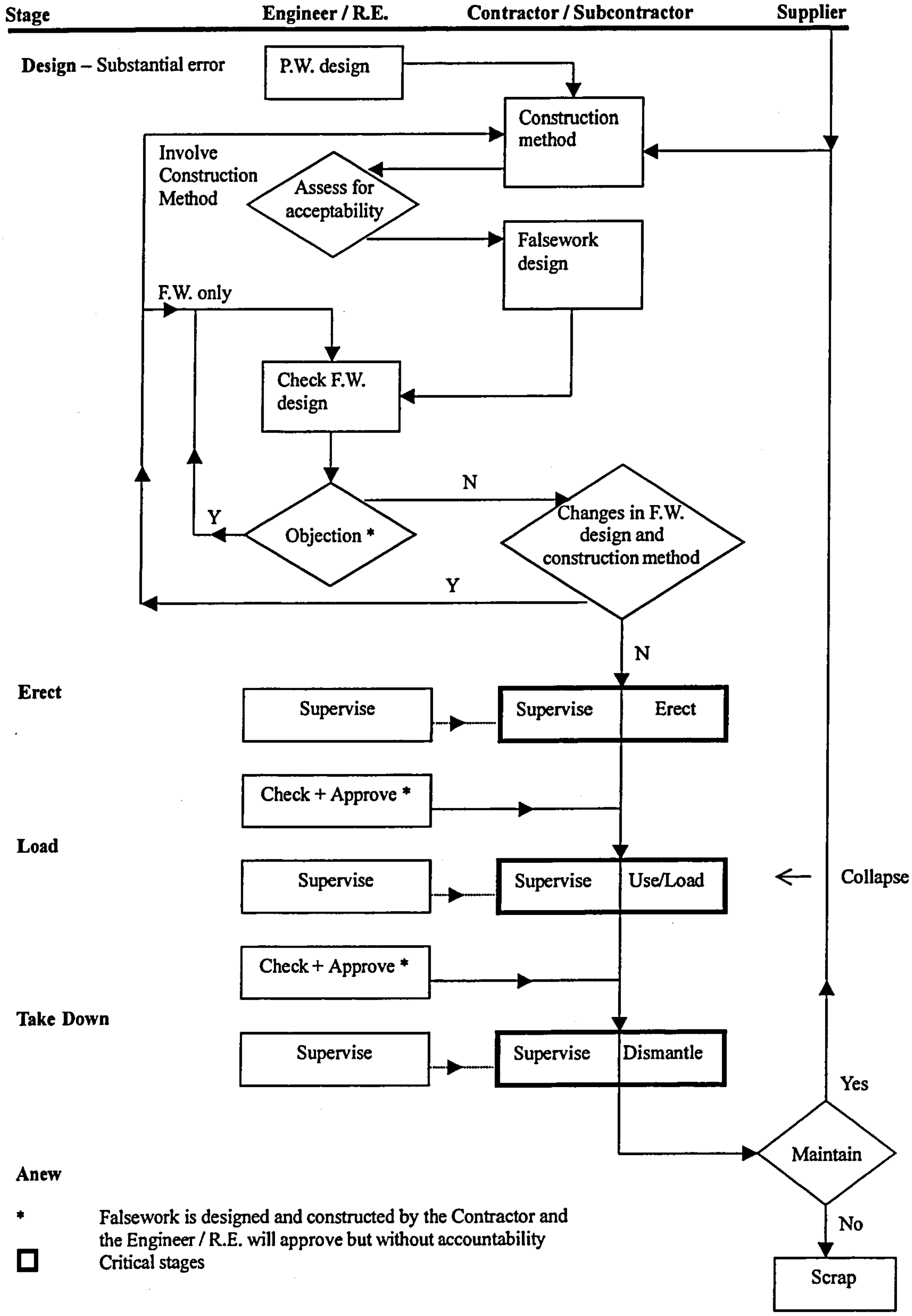
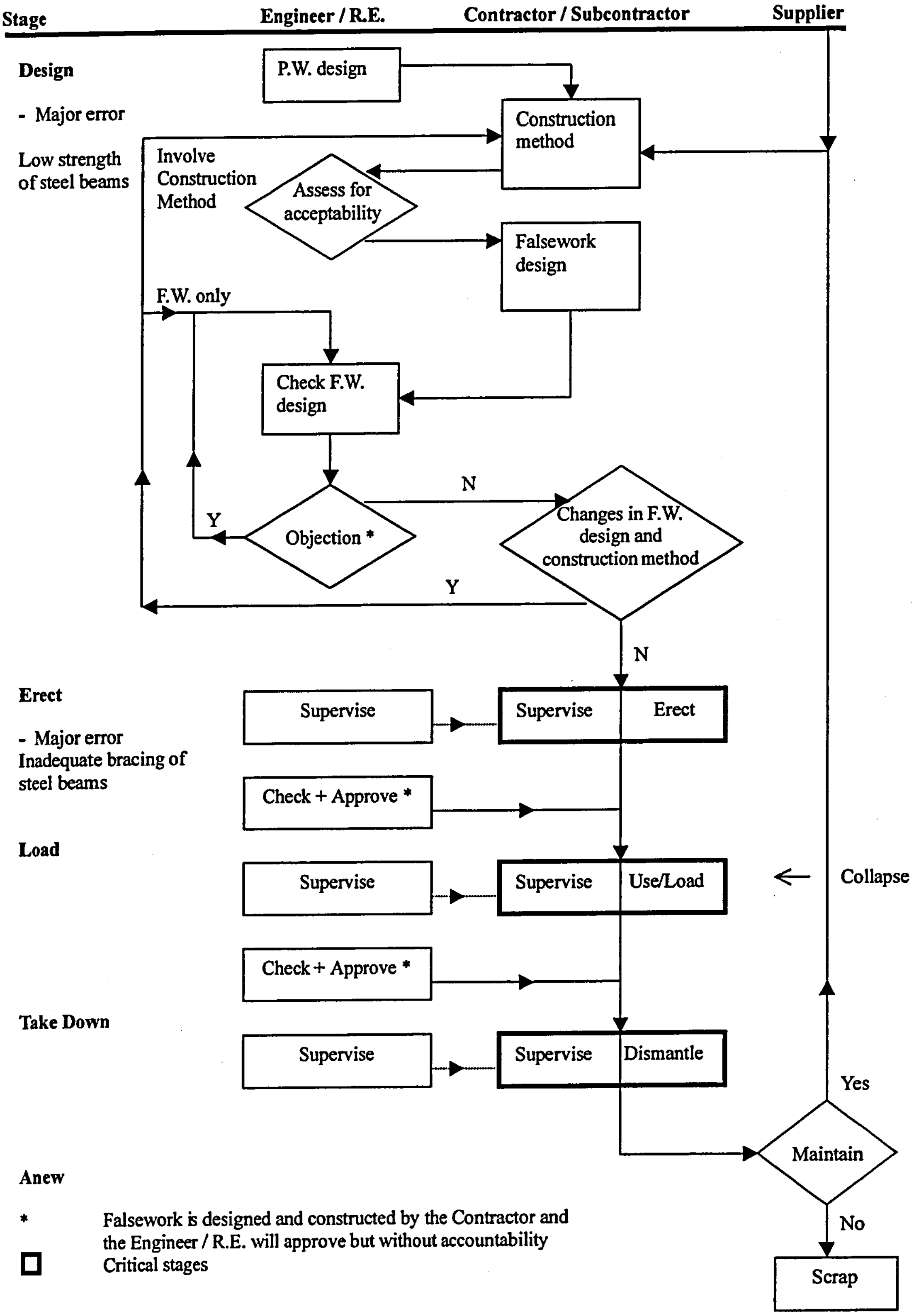


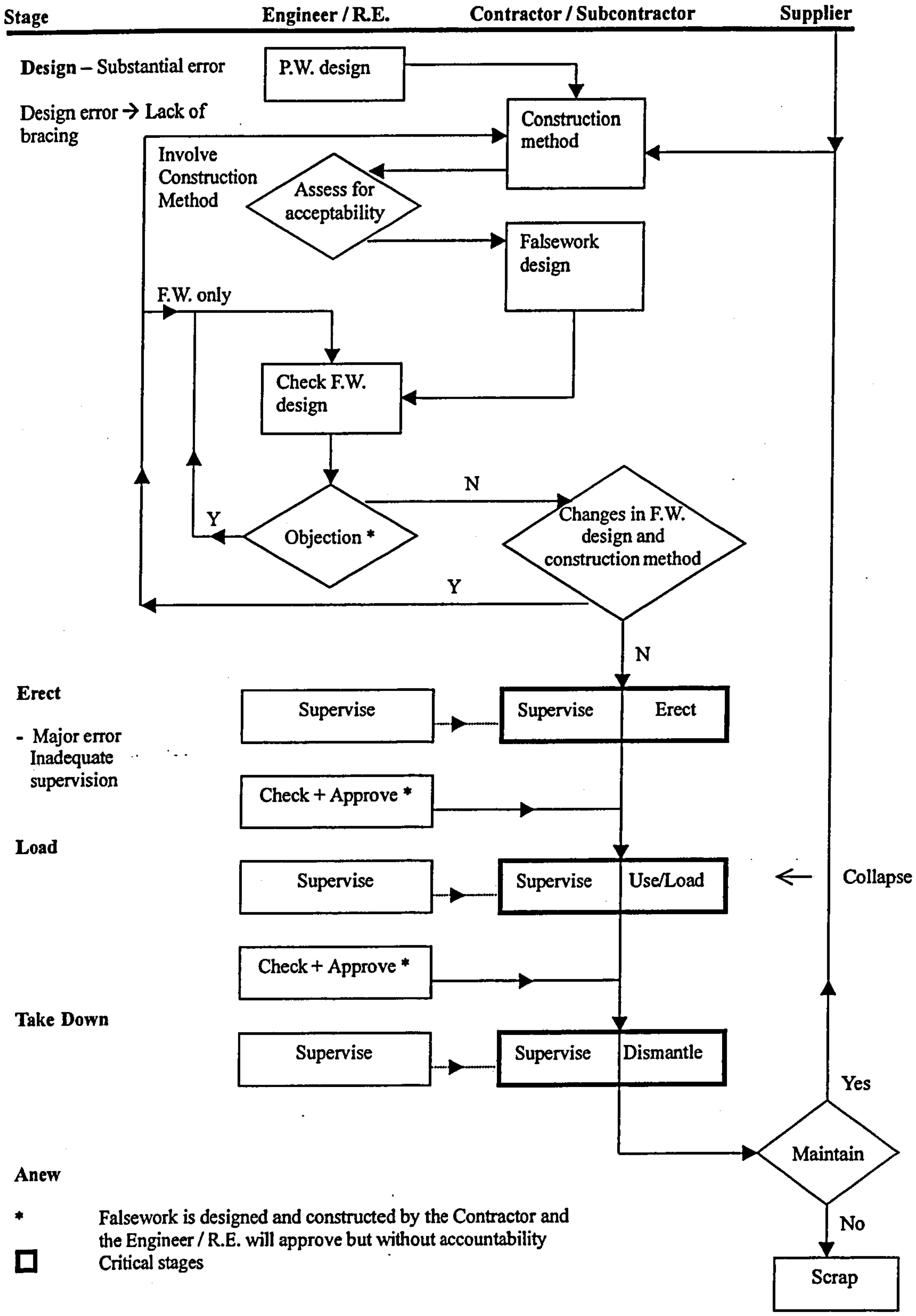
Figure C.44: Case Ref. No. 44 Johannesburg, South Africa [B]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Figure C.45: Case Ref. No. 45 Calder, Yorks, UK [C]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Figure C.46: Case Ref. No. 46 Heron Road Bridge, Ontario, Canada

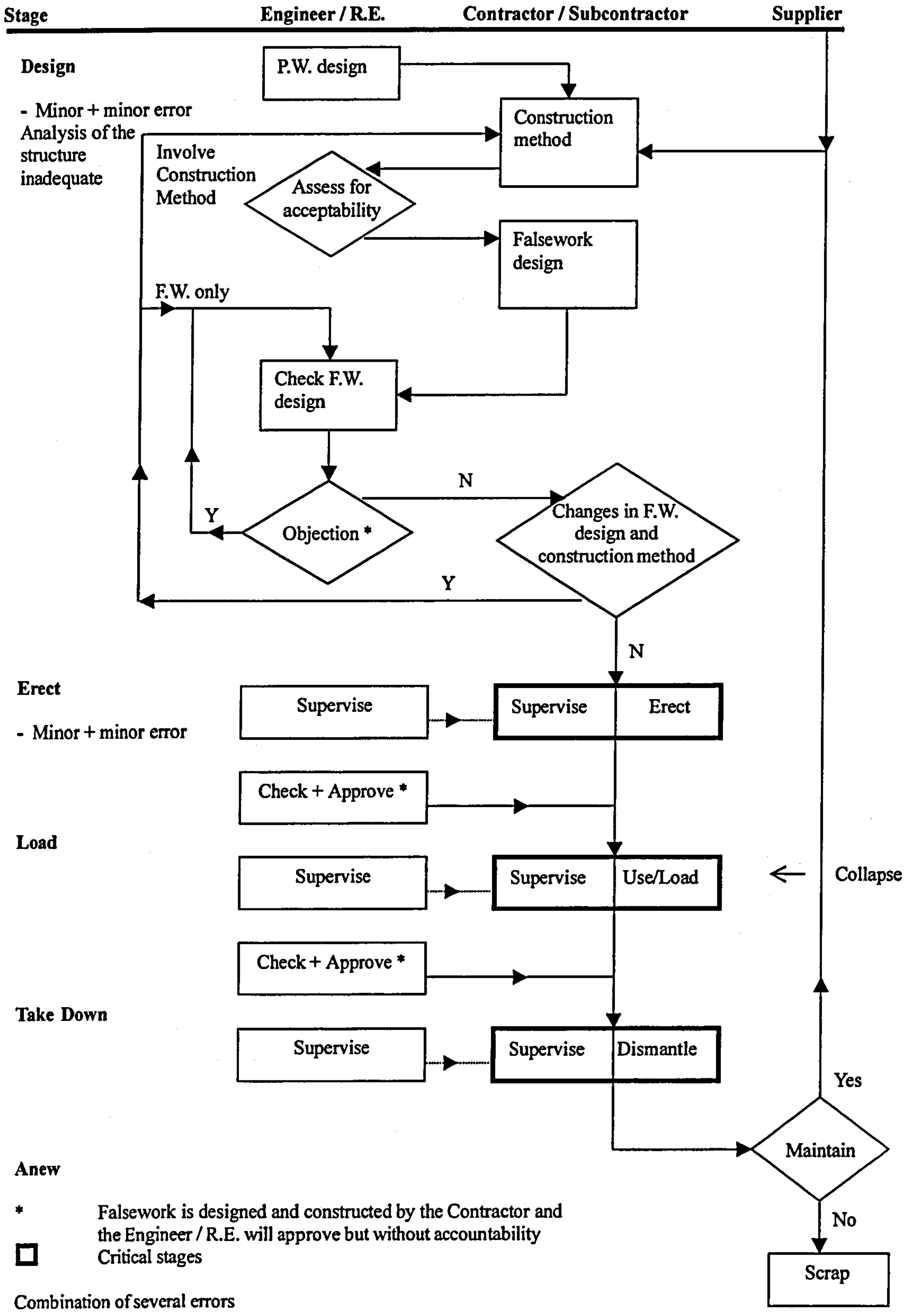
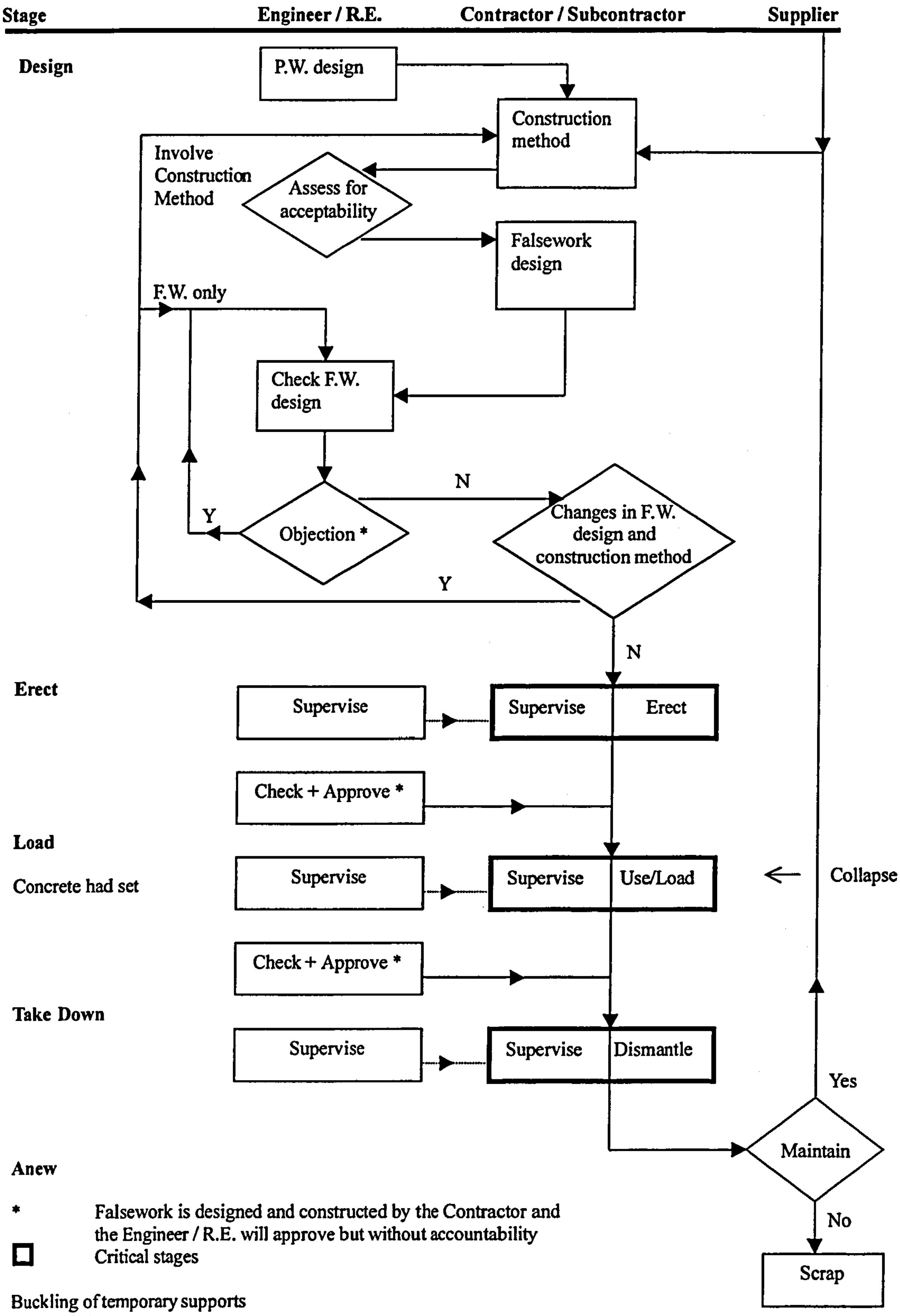


Figure C.47: Case Ref. No. 47 Welshpool Road Overpass, W. Australia [C,B]

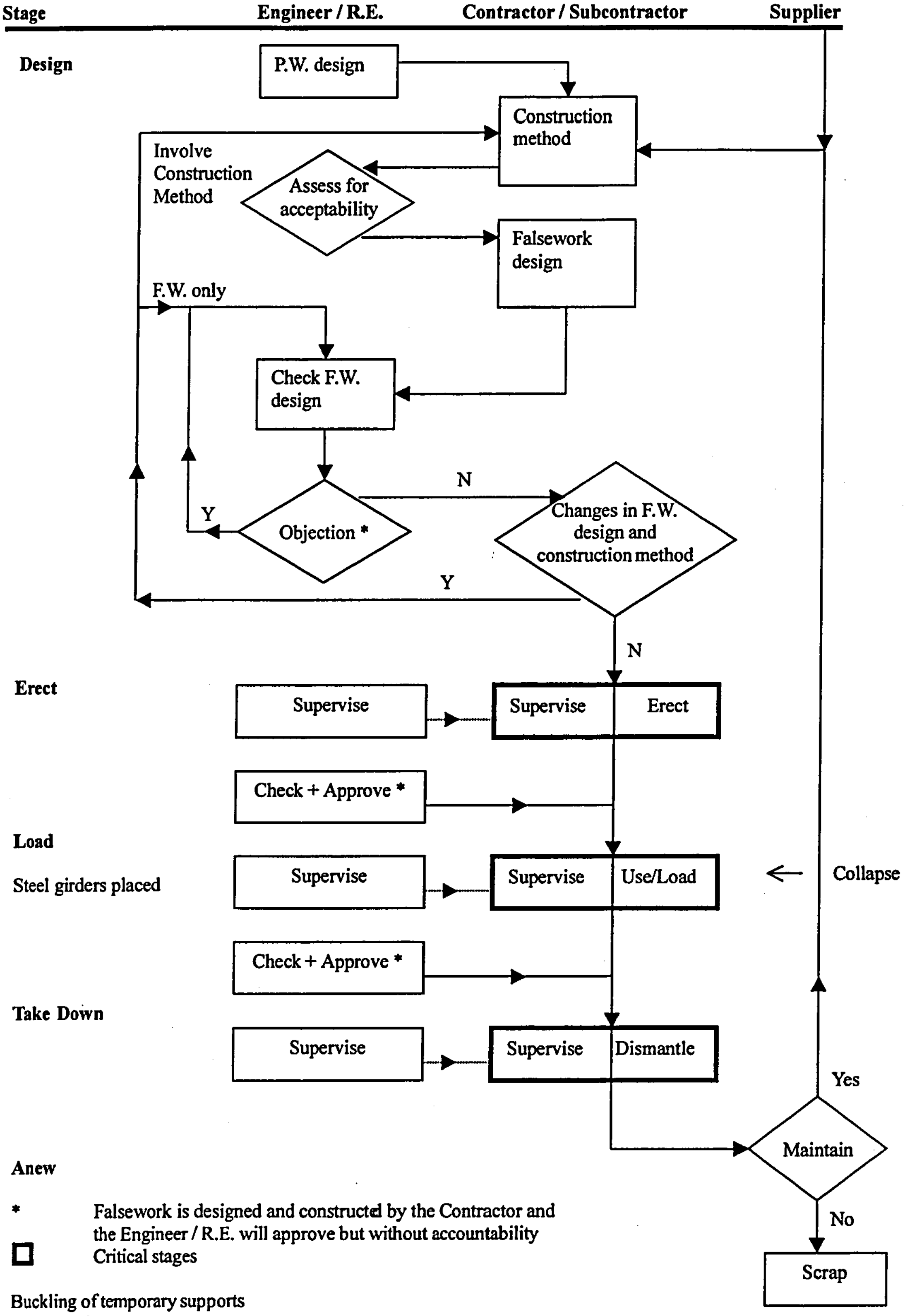


* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

☐ Critical stages

Buckling of temporary supports
Reason unknown

Figure C.48: Case Ref. No. 48 Fife, UK [C]



* Falsework is designed and constructed by the Contractor and the Engineer / R.E. will approve but without accountability

□ Critical stages

Buckling of temporary supports
Reason unknown

Figure C.49: Case Ref. No. 49 Barton, Lanes, UK [C]

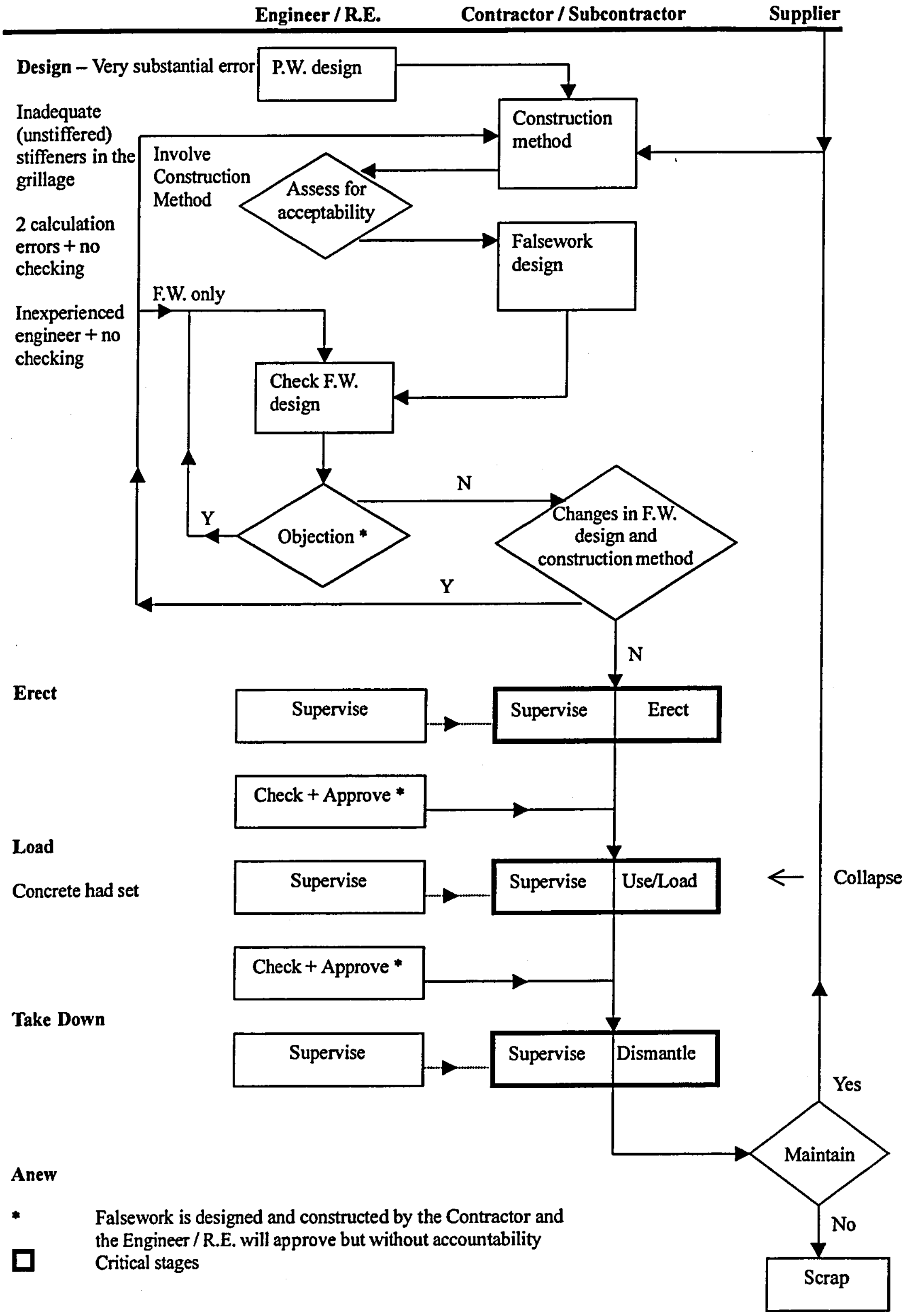


Figure C.50: Case Ref. No. 50 Second Narrows Bridge, Vancouver, Canada [C, B]

APPENDIX D

Certified findings of the procedural framework

To: Mr. S.W. Poon
From: Mr. Hua Zhao Lu

I am director and general manager of a building construction firm.

I have over 17 years experience in falsework construction and I have witnessed several falsework failures and undertaken remedial measures. The falsework collapsed normally during concrete casting or near completion of the concreting operation.

The design of falsework is very important but is often not properly checked. I would suggest the factor of safety of falsework to be reduced by 20% after erection.

Your model of analysing and predicting falsework failure would be very useful for controlling falsework construction on site.

Mr. Hua Zhao Lu
Director and General Manager
China Construction Builders Pte. Ltd.

10 June 2002

To:	Mr. S.W. Poon

From:	Ms Xu Yuqing

Comments on the Model of Analysing and Predicting Falsework Failure

Currently I am a procurement manager of a large contracting firm and have twenty years experience in construction in China, Hong Kong and Singapore.

During the last six years I have involved in falsework construction. The design and stability of falsework are very important but regrettably they are frequently ignored. From my experience, no design, no checking particularly no independent checking are common errors.

I would estimate the factor of safety of falsework would have been lowered by twenty precent after erection. Your model developed can be very useful in assessing the safety of falsework and predicting possible failure.

Ms Xu Yuqing
B.Eng., MSc

To: Mr. S. W. Poon

From: Dr. George Zhou

Comment on the Model for Analysing and Predicting Falsework

I am a professional engineer with extensive experience in temporary works design and construction. Since 1992, I have been employed as independent checking engineer for over one hundred jobs of falsework construction. I have also investigated falsework collapses and undertaken remedial works.

From my experience, many contractors attempted to lower the factor of safety of falsework in the design, thus control of falsework is very important and essential. In many instances, only if the resident Engineer insists, otherwise no independent checking of the design and no approval certificate would be required. Without the third party checking, I would predict twenty to thirty percent of falsework construction would have failed. I agreed fully with the flowchart, illustrating the activities and duties, developed for the three control systems.

With my knowledge and experience, I can judge the factor of safety of falsework would drop from 1.6 to 1.7 in the design stage to about 1.2 in the loading stage. Proper control and prediction of falsework at various stages would be essential.

Dr. George Zhou
B. Eng. PhD (Japan), AIStructE, MIES
Chartered Eng (UK), P. Eng. (S'pore)

10 June 2002

List of Interviewees in Validating the Procedural Framework.

1. Dr. George Zhou
2. Mr. Maurice Lee
3. Mr. William K.Y. Tang
4. Mr. Chong Kwok Lai
5. Mr. Eddy W.M. Yip
6. Dr. Benson H.M. Chan
7. Mr. C.M. Leung
8. Mr. H.K. Lee
9. Mr. Ken K.K. Tsang
10. Mr. Kong Peng Sum
11. Mr. Li Yong Sheng
12. Mr. Yuan Kai
13. Ms. Xu Yu Qing
14. Mr. Hua Zhao Lu
15. Mr. Ji De Xing