FAULT TREE ANALYSIS AS A MODERN TECHNIQUE FOR INVESTIGATING CAUSES OF SOME CONSTRUCTION PROJECT PROBLEMS

Assistant Lecturer Abbas M. Burhan,
Baghdad University, College of Engineering

ABSTRACT:

Construction projects contain many problems that can occur during the execution. Each problem results from many causes. Fault tree analysis (FTA) technique is a graphical model for analyzing causes of a problem (or undesired event) using logic gates to describe combinations of individual faults that can create an undesired event. Each level of the tree lists the lower level events that are necessary to cause the event shown in the level above it. The assessment process of a problem with FTA technique can be divided into two types: qualitative and quantitative assessment. As a case study to apply FTA technique in construction field, the researcher studied a building in Baghdad that had *punching shear* problem to analyze the causes lead to this problem.

This research aims to introduce the main principles of FTA technique and how to use in identifying and analyzing the causes of problems that can occur in the construction projects. Also, it aims to compute the probability of occurrence of any problem or undesired event.

الخلاصة:

أن المشاريع الأنشائية تحتوي على الكثير من المشاكل أثناء التنفيذ وكل مشكلة تنتج من عدة أسباب. تقنية تحليل شجرة العيب (FTA) هي نموذج تصويري لتحليل أسباب مشكلة معينة (أو حدث غير مرغوب) بأستخدام رموز منطقية (Logic Gates) لوصف مجموعة من العيوب أو الأسباب التي تولد الحدث الغير مرغوب فيه. كل مستوى من شجرة العيب يضم الأحداث الأقل مستوى التي حدوثها يكون ضروري لتسبب الحدث الذي في أعلى المستوى من الشجرة.

أن عملية تقييم أي مشكلة ضمن تقنية تحليل شجرة العيب يمكن تقسيمها الى نوعين: تقييم نوعي وتقييم كمي. كدراسة حالة لتطبيق تقنية (FTA) في حقل الأنشاء، أخذ الباحث بناية في بغداد تعاني مشكلة قص الأنثقاب لتحليل الأسباب التي أدت الى هذه المشكلة.

يهدف هذا البحث الى تقديم المباديء الأساسية لتقنية FTA وكيفية أستخدامها في تحليل أسباب المشاكل التي قد تحصل في المشاريع الأنشائية وكيفية أحتساب أحتمالية حدوث أي مشكلة.

KEYWORDS:
Fault Tree Analysis, FTA, Project Problems, punching shear

MAIN PRINCIPLE:

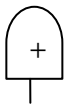
A fault tree analysis technique can be simply described as an analytical technique, whereby an undesired state of the project is specified. Fault tree itself is a graphical model of the various combinations of faults that will result in the occurrence of predefined undesired event. The faults can be events that are associated with errors and omissions or any risks which can lead to the undesired event. A fault tree thus depicts the logical interrelationships of basic events that lead to the undesired event which is the top event of the fault tree.

HISTORY OF FTA TECHNIQUE:

FTA was first used by Bell Telephone Laboratories in connection with safety analysis of the minuteman missile launch control system in USA in 1962, and improved by Boeing Company. FTA is now widely used in the electronics, nuclear, and aerospace industries (Burke and Weiss 1980)(Haasl 1965). Because the construction industry is one of most important industries, the researcher developed this technique to be used in the construction industry to analysis causes of any problem can be occurred.

WHAT IS FTA:

FTA technique evaluates hypothesized undesired event in a project to expose their causes. FTA is a top-down approach to failure analysis, starting with a potential undesired event (problem) called a top event, and then determining all the ways it can happen. The analysis proceeds by determining the causes of occurrence the top event which will be connected through logic gates(Rausand 2004). In this research, two types of gates are used(Clemens 1993):

* AND Gate: 

An event is connected to its causal events through AND gate if all the causal events must happen in order for the resulting event to take place as shown in Fig.1.

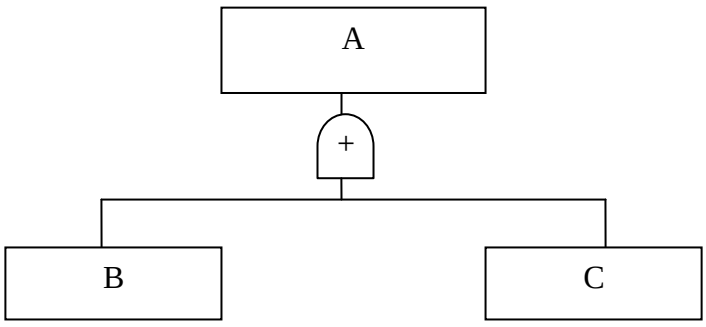


Fig.1, Three Events Connected through AND Gate

* OR Gate: 

An event is connected to its causal events through OR gate if the resulting event can be produced by any of the causal events as shown in Fig.2.

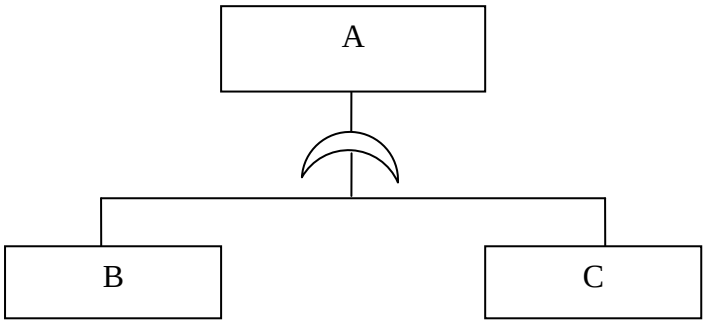
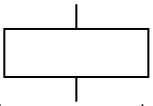


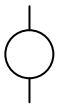
Fig.2, Three Events Connected through OR Gate

BUILDING BLOCK OF FAULT TREE:

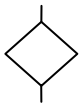
A typical fault tree is composed of a number of symbols which are described in detail below(Ericson2000)(Andrews 1998):

* Rectangle: 

This symbol is used to represent events are considered to be the results of other events within the project.

* Circle: 

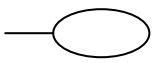
This symbol is used for a basic event, which is independent of all other events; hence no further investigation is necessary.

* Rhombus: 

This symbol is for events that are not basic but are considered to be so for the purpose of the FTA. The rhombus may be used for some lower-level events for the expediency of not exploring events of little consequence, or for events that are analyzed on a separate fault tree.

* Triangle: 

This symbol is used for transferring a branch of the FTA onto another page. It is consist of a triangle containing the page number of continuation.

* Ellipse: 

This ellipse is used to record any conditions or restrictions that apply to any logic gate.

STEPS OF BUILDING FAULT TREE:

There are many steps that be adopted when building fault tree as follows:

- Define the problem (or undesired event) for analysis.
- Draw a box at the top of the tree diagram and list the topic of problem inside it.
- Identify all faults related to the problem.
- Identify causes for each fault. List all applicable causes for faults in ovals below the fault. Connect the ovals to the appropriate fault box.

- Work towards a root cause. Continue identifying causes for each fault until you reach a root or controllable cause.
- Give probability of occurrence for roots of fault tree depending on historical collected data or the experience.

THE CONCEPT OF UNDESIRED EVENT:

Fault tree analysis is a deductive failure analysis which focuses on one particular undesired event and which provides a method for determining causes of this event. The undesired event constitutes the top event in a fault tree diagram constructed. Careful selection of the top event is important to the success of the analysis. If it is too general, the analysis become unmanageable; if it is too specific, the analysis does not provide a sufficient broad view of the problem. Fault tree analysis can be an expensive and time consuming exercise and its cost must be measured against the cost associated with the occurrence of the relevant undesired event. Some examples of top events that might be suitable for beginning a fault tree analysis such as:

a. Time delay problem which occur in most of construction projects. Since many causes may lead to this problem such as drawing and design delay, poor planning, poor incorporating between subcontractors, labour accidents, etc.
b. Catastrophic failures which occur in the structures of a building because of causes related to design or execution phases.
c. Contractor's failure to complete the project within the budget because of poor planning, errors in calculations of estimation, etc. Since, according to UK Department of Trade and Industry Key Performance Indicator (DTI 2002):
   - 50% of all construction projects finish over budget.
   - 54% of all construction projects finish behind budget.
   - 24% of construction projects are completed unsatisfactory, 48%of those having a significant negative impact on business operations.
d. Labours accidence problem related to the manners of safety adopted in the site.

THE ASSESSMENT OF PROBLEM:

In this research, the assessment process is divided into two types: qualitative assessment and quantitative assessment; as detailed below.

Qualitative Assessment:

It is the type of assessment that deals with a problem that has already taken place in a project, in order to diagnose the causes behind this problem.

Case Study:

In this study, the researcher has investigated a problem of *punching shear* which occurred during the construction of a certain building in Baghdad, as an example to illustrate the process of qualitative assessment. The punching shear was encountered in the flat plate slab of this building, as some of the columns had gone through (punched) the concrete slab as shown in Fig.3.

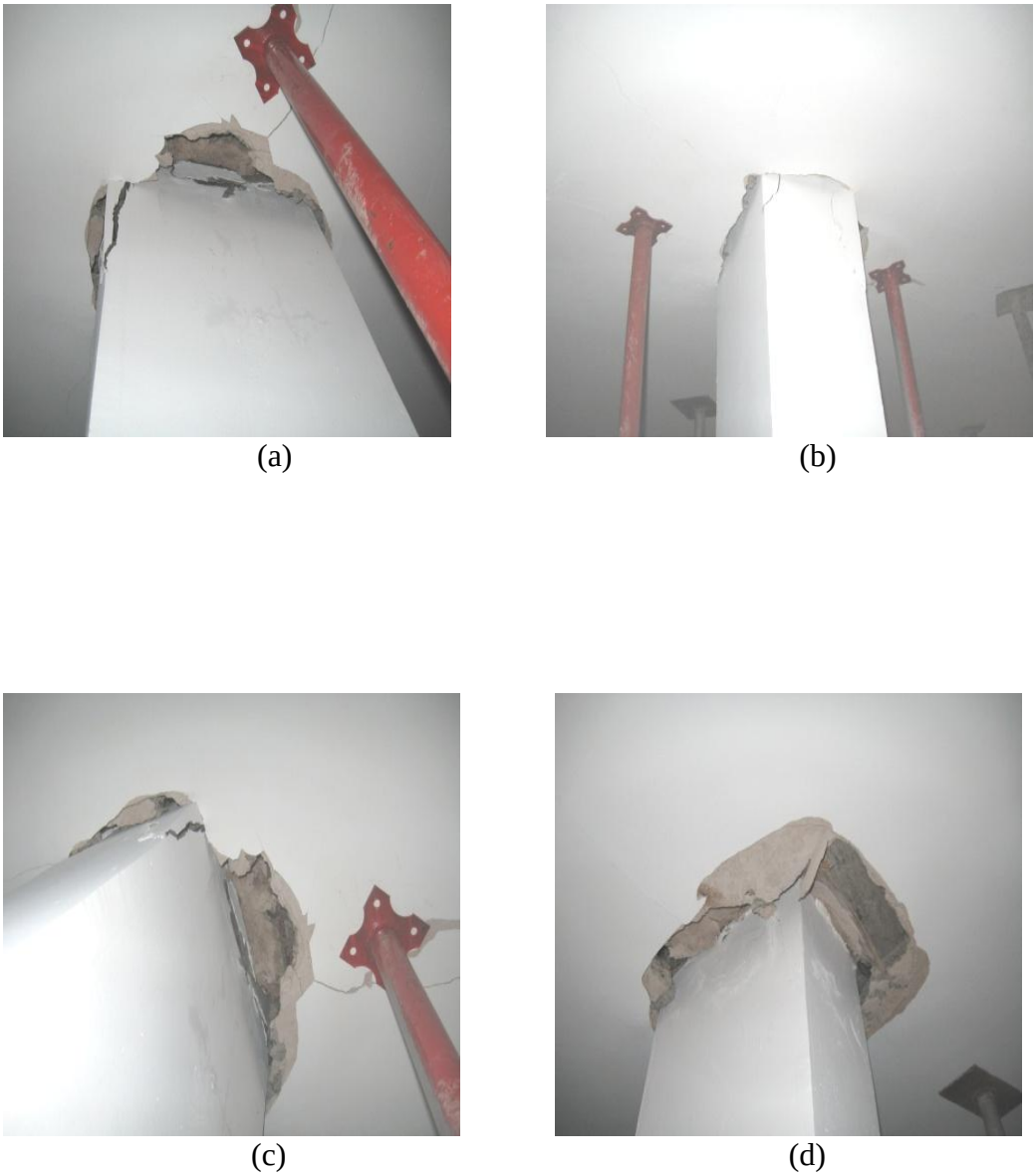
The investigation started with a field study including visiting and inspecting the site, taking photos to the case features, and collecting data through interviewing some of the specialists in the fields of design and implementation. This field study procedure aims at diagnosing the possible reasons and factors that had led to this punching shear occurrence; then a fault tree is to be drawn to analyze the situation more accurately. There are two points must be considered before drawing fault tree:

1. Defining the top event (the problem) in clear and unambiguous way, e.g.:
   - What is the problem: "punching shear"
   - Where: "building in Baghdad"

- When: "after the execution"

2. Determining the necessary events and conditions causing the top event.

Here, FTA can be prepared to explain and show the causes that led to the main problem (punching shear) as shown in Fig.4.



(a) (b) (c) (d)

Fig.3, Punching Shear was Encountered in the Flat Plate Slab of a Building in Baghdad.

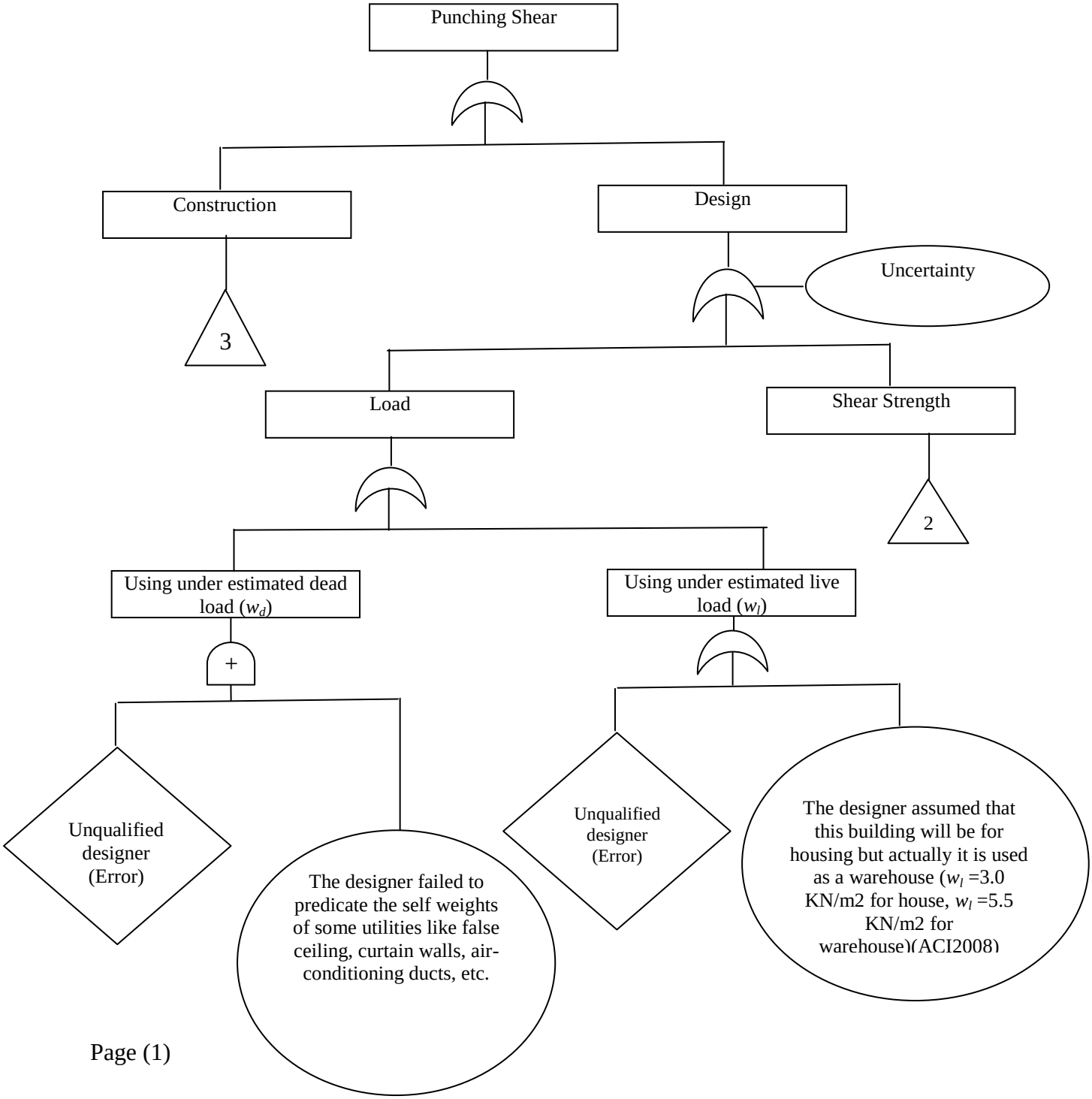
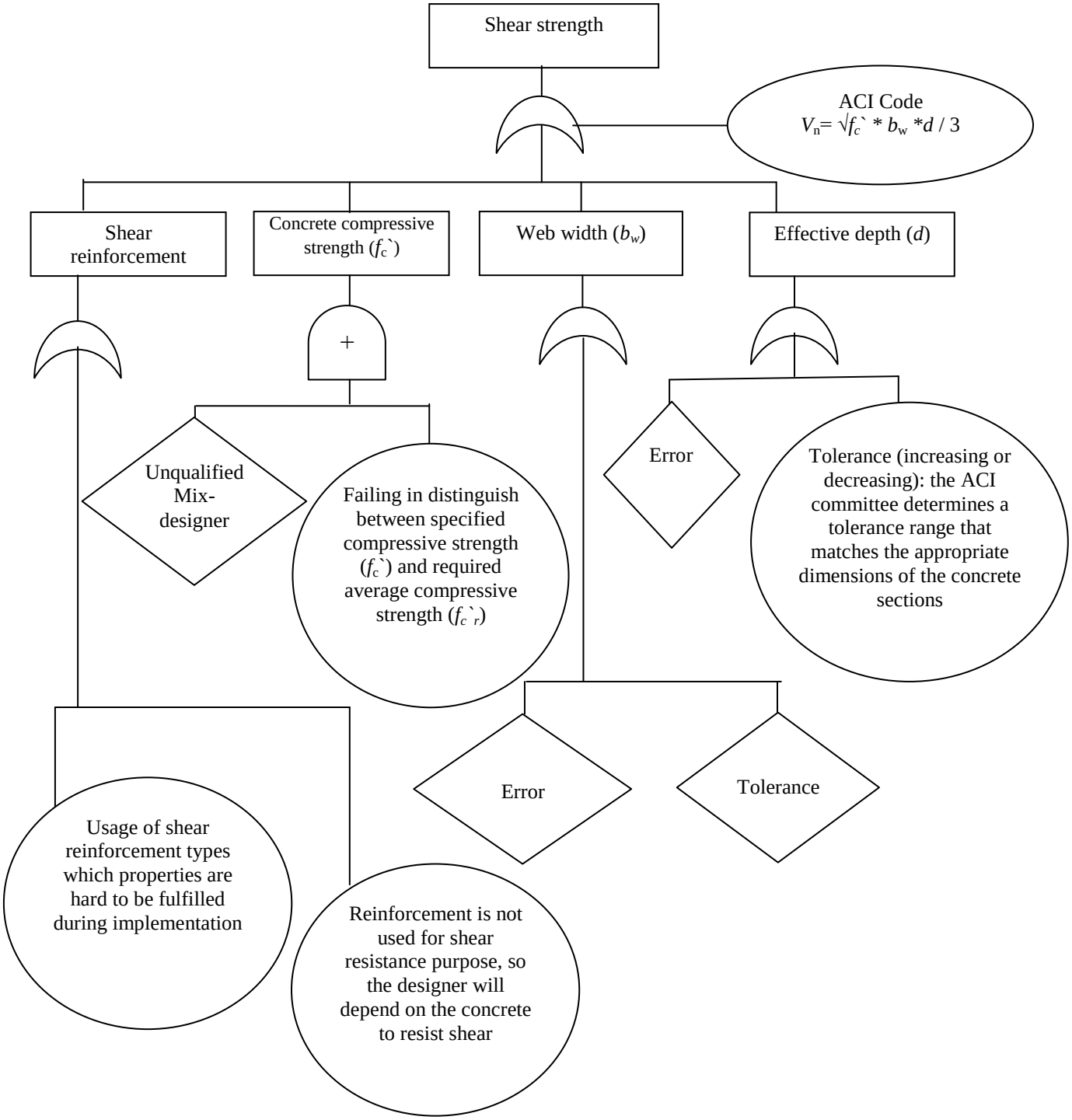
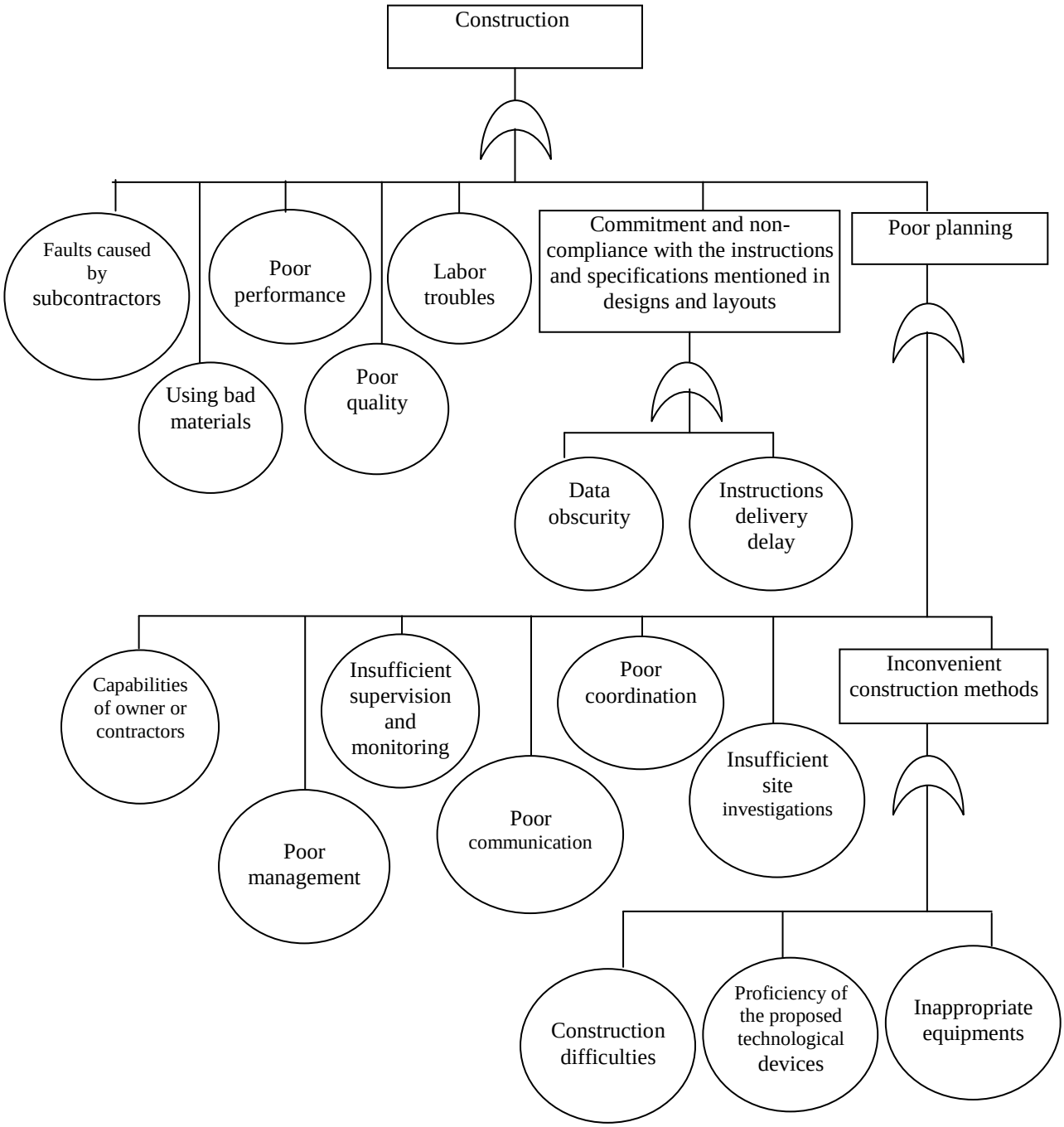


Fig.4, Fault Tree Diagram for Punching Shear Failure



Page (2)

Fig.4-continued, Fault Tree Diagram for Punching Shear Failure



Page (3)

Fig.4-continued, Fault Tree Diagram for Punching Shear Failure

QUANTITATIVE ASSESSMENT:

This type can be used for the sort of assessment that deals with a proposed problem (hasn't occurred yet); but it is predicted so that this assessment process can diagnose the causes and factors that had led to the main problem. The analysis provides failure probabilities at the system level that are needed for assessing the problems involved in a construction project; e.g. safety, subcontractors ability to deliver on time, equipment productivity, and costs and schedules associated with construction activities.

In the quantitative assessment, it is possible to assess the probability of a top event from estimates of probabilities of the basic events in the fault tree. When events are connected to a higher order event through OR-gate, we add the probabilities. When events are connected to a higher order event through AND-gate, we multiply their probabilities(Kales 1998). The estimation of probabilities of occurrence any basic event depend on the experience and records or information about previous projects. For example, if all the probabilities of basic events and events assumed to be basic in the fault tree of Fig.5 are estimated to be the follow:

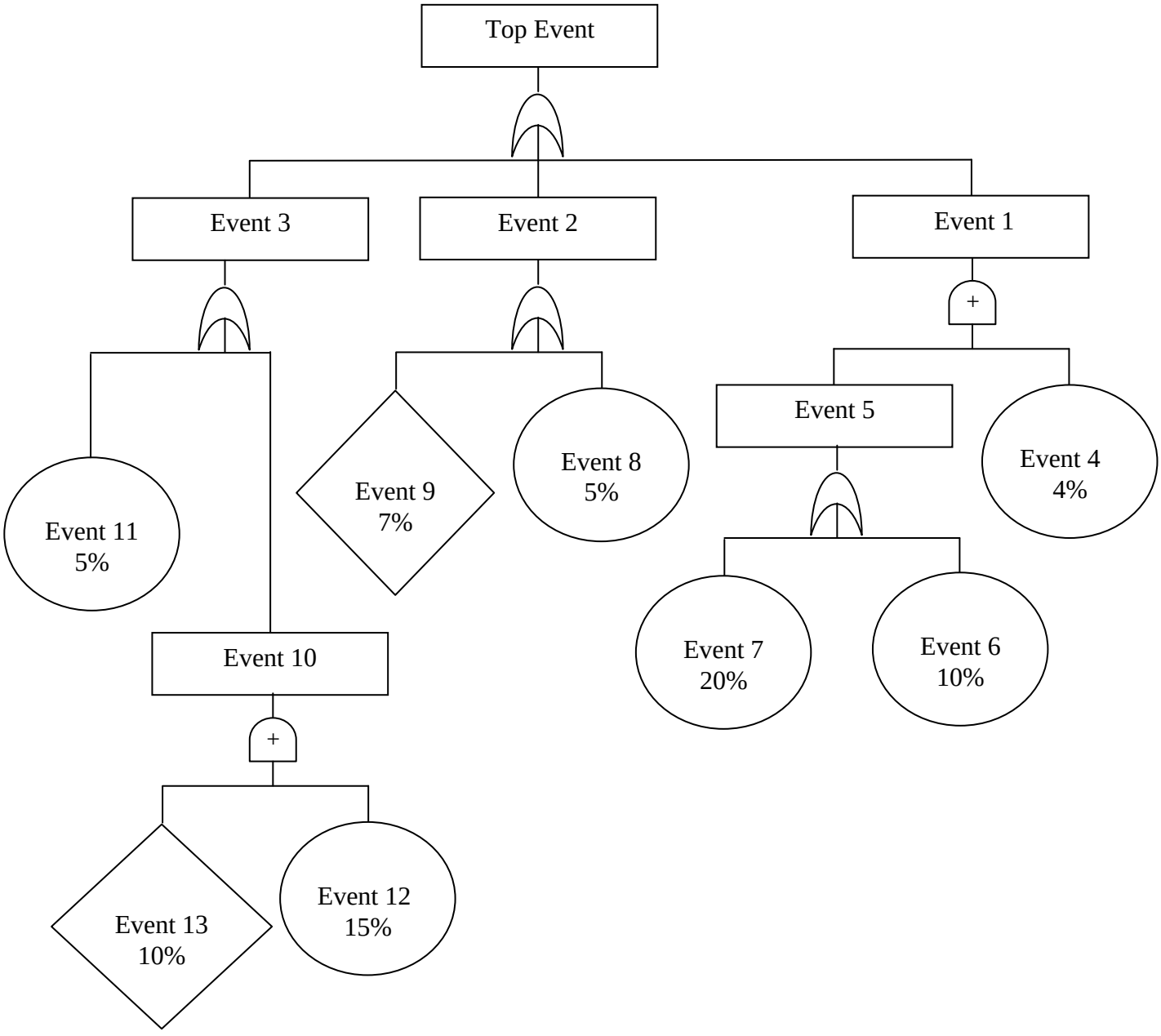


Fig.5, Fault Tree Diagram which Example

P(Event 4) = 4%
P(Event 6) = 10%
P(Event 7) = 20%
P(Event 8) = 5%
P(Event 9) = 7%
P(Event 11) = 5%
P(Event 12) = 15%
P(Event 13) = 10%

Then the probability of the top event can be determined as shown:

P(Event 5) = P(Event 6) + P(Event 7) = 0.10 + 0.20 = 0.30
P(Event 1) = P(Event 4) * P(Event 5) = 0.04 * 0.30 = 0.012
P(Event 2) = P(Event 8) + P(Event 9) = 0.05 + 0.07 = 0.12
P(Event 10) = P(Event 12) * P(Event13) = 0.15 * 0.10 = 0.015
P(Event 3) = P(Event 10) + P(Event 11) = 0.015 + 0.05 = 0.065

So, P (Top Event) = P (Event 1) + P (Event 2) + P (Event 3)
= 0.012 + 0.12 + 0.065 = 0.197 = 19.7%

This value (19.7%) represents the probability of occurrence the problem (Top Event). Based on this value, the management can decide the level of problem and put good plan to avoid this problem or decrease its effects on the project or parties.

CONCLUSION:

- Fault tree analysis technique is used in all industries, but it can be used effectively for investigating the problems which occur in the construction projects. It is effective tool to show the events or causes which lead to the main problem or top event (undesired event).

- Fault tree analysis (FTA) technique is a graphical model of the pathways within a system that lead to a foreseeable undesired event. The pathways interconnect contributory events and conditions using standard logic symbols called AND-gate and OR-gate. Numerical probabilities of event occurrence can be entered and propagated through the model.

- The user of FTA technique must carefully select the top event (undesired event) in order to success the analysis of problem.

- The assessment process of any problem can be divided into two types: qualitative and quantitative assessment. The first type deals with problems which have already been taken place in a project, while the second type deals with a proposed problem (hasn't occurred yet; but it is predicted).

- In quantitative assessment, the user of FTA technique depends on his experience and records or information about previous projects to estimate the probabilities of occurrence any basic event.

REFERENCES:

- ACI Code, (2008) "Building Code Requirement for structural concrete" ACI 318RM.
- Clifton A. Ericson, (2000) "fault tree analysis" www.fault-tree.net/papers/ericson-fta-tutorial.pdf.
- Department of Trade and Industry UK (2002) *Construction Industry KPI's Industry*
- *Progress Report 2002.*
- David F. Haasl, (1965) "advanced concepts in fault tree analysis" presented at system safety symposium sponsored by University of Washington and the Boeing Company, www.fault-tree.net/papers/ haasl-advanced-concept.pdf.
- John J. Burke, and Volker Weiss, (1980) "Risk and failure analysis for improved performance and reliability" P 34.
- John Andrews, (1998) "fault tree analysis" proceedings of the 16th International System Safety Conference, www.fault-tree.net/papers/andrews-fta-tutr.pdf.
- Marvin Rausand, (2004) "system reliability theory" Wiley 2nd ed., P36, www.ntnu.no/ross/str/slides/fta/.pdf.
- Paul Kales, (1998) "reliability for technology, engineering and management), Printice-Hall, Inc., U.S., 1st Ed., P(288-303).