Safety in Deep Excavation

and

Numerical Simulation of Room Corner Test for Polycarbonate

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Safety in Deep Excavation

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Numerical Simulation of Room Corner Test for Polycarbonate

Thesis submitted in partial fulfilment

of the requirements of the degree of

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in

Safety Engineering

by

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under the supervision of

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May, 2016

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This is to certify that the works presented in this thesis entitled "*Safety in Deep Excavation and* "*Numerical Simulation of Room Corner Test for Polycarbonate* " by "*Sanil Kuriakose*", Roll Number 214CH2524, is a record of original work carried out by him under my supervision and guidance in partial fulfilment of the requirements of the degree of *Master of Technology* in *Safety Engineering*. Neither this thesis nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

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Declaration of Originality

I, *Sanil Kuriakose* Roll Number *214CH2524* hereby declare that this thesis entitled "*Safety in Deep Excavation*" and "*Numerical Simulation of Room Corner Test for Polycarbonate*" presents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, it contains no material previously published or written by another person, nor any material presented for the award of any other degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the section "Reference". I have also submitted my original work records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

May 21, 2015

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Safety in Deep Excavation

Abstract

Excavation work is recognized as one of the most hazardous activity in the construction industry . The fatality rate in this activity is larger than this rate for general construction meanwhile the fatality rate in construction is three time more than this rate in overall industry. Current statistics on the fatal accidents which caused by excavation projects necessitates preliminary studies and precautionary actions to resolve the problem. Therefore, the investigation and revision of safety management strategies have been brought up in order to ensure the health of the project before beginning any excavation work. This study will present the important safety factors which should consider in excavation site and find out common hazards during the excavation activities. This report extends a risk assessment for excavation and providing means to offset the impacts of them on sites.

Keywords: *Excavation; Hazard; Construction; Cave-in, Accident*

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Chapter 1

Introduction

1.1 Overview

The Construction industry is a hazardous at the same time one of the major economic sector in most of the countries. It has the capability to influence the total GDP of every country. Construction industry consists of several types of activities containing construction, alteration and/or repair, and demolition. Examples of construction work include building construction, roadway paving, excavations, bridge erection, large scale painting jobs, and demolitions etc. Every project has its unique aspects and risk, even though excavation work is one of the most dangerous practices. Excavation is one of the most important activities in construction industry. In the past several decades, with the urbanization and development of construction industry, depth of excavations grow deeper and deeper and in case of nuclear power project requirement of deep excavation are unavoidable.

What's more, these excavations are usually located in populated area and more and more problems of personal injury and property damage are come across and due to this it is carried out in complicated safety consideration. In addition, the nature of excavation work is different from other type of construction. Besides the obvious issue associated with soil and water, holes in the ground create confinement and access problems. The unknown aspect of the thing which is already existing in the work location prior to digging, the size and handling requirements of what is being constructed inside the hole, and the ground surface staging and activity within the confines of public activity are different from other construction activities. All these conditions require using advance safety method and techniques construction technology.

India's energy requirements are increasing, and it is much higher than all nations including other developing countries. Indian energy sector currently depending on fossil fuels as a major energy source and making a high level of contribution to global warming. In the starting of 21st century, India has expressed interest in other energy sources, mainly nuclear power to overcome this issue. In consideration with this Indira Gandhi centre for atomic research (IGCAR), a unit of department of atomic energy (DAE) is piloting the work of India's first fuel reprocessing plants project, Fast Reactor Fuel Cycle Facility (FRFCF) in

Kalpakkam, Tamilnadu. Larsen & Toubro Heavy Civil Infrastructure got the tender and doing the Excavation Dewatering & Sub soil investigation for various plant buildings of fast reactor fuel cycle facility (FRFCF) at Kalpakkam.

The term excavate is means to removal of the rock massif from its original place. This operation involves two task, first digging the ground and second its disposal. This operation in the earth surface can create excavations or openings in different shapes, sizes and configurations in the required location. The location for excavation can be plain ground, hilly terrain, desert, forests, cropland, or any other landscape. The purpose excavation work is diverse therefore, in this modern world the requirement of excavation with different shapes and size are inevitable. Based on location condition, the excavation can be classified into Surface excavations (Fig 1.1) and underground excavation. This project is discussing surface excavation specifically for storage and buildings.

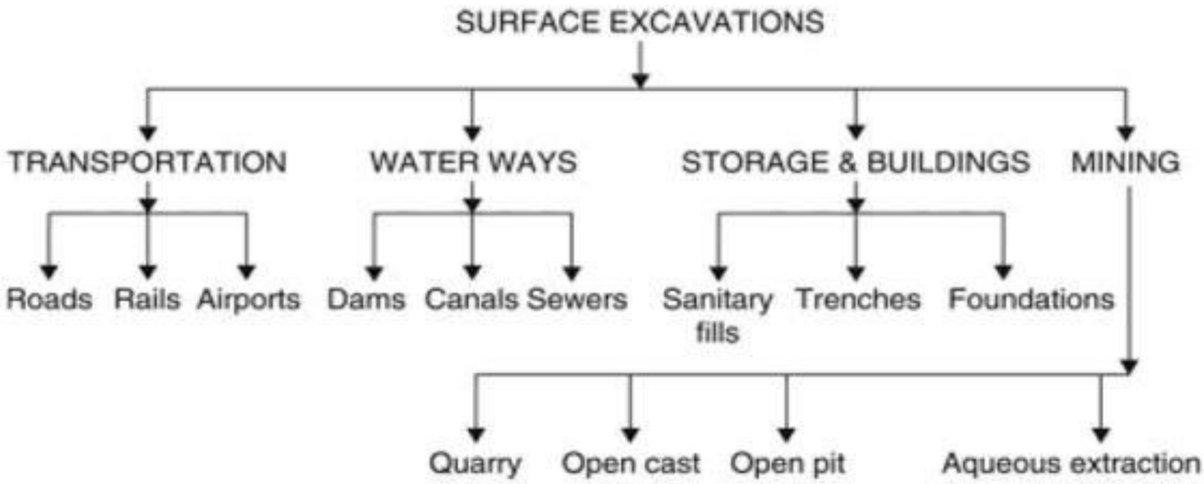


Figure 1.1: Classification of types of surface excavations

An adequate factor of safety should be ensured from the design stage itself to support the soil in deep excavations, and also the adequate factor of safety for the nearby permanent structures. Deep excavations below river or sea beds require specific design consideration. For the most part deformation or subsidence will be less important than excavation on land unless existing works are nearby. The risk of scour effect to sea or river bed, which are possible as a result of new work themselves, may prove to be additional hazards which could cause structural collapse, and must be guarded. The risk to construction personnel and users of the permanent structure must be defined separately to the risks of damage to the property and services.

Design and construction of works for the deep excavations require investigations of the site topology, the subsoil and groundwater conditions, the states of sea and river water and stability of sea river beds, the risk of seismic loading, the extent of superimposed loads, the state of existing structures and services, and availability and quality of available structural materials. Excavations have an obvious potential for injury particularly if deep. If not properly fenced and “sign board” posted and the area properly illuminated during night, it could lead to persons falling into the excavated area. The appropriate angle of repose should be considered in the sides of an excavation and properly shored wherever required. The excavated soil should be dumped at least 1.5 mtr from the edge of the trench. Undercutting and Undermining should be avoided and ground water if present should be dewatered. Excavation work must be planned and checked so that arrangements are made to locate underground services, establish ground conditions and design adequate support systems. Check whether the excavation will destabilize any existing structures. Construct ramps and gangways as required, and issue appropriate protective clothing and equipment.

1.2 Background Of Study

Excavation safety aspects are studied and discussed by the Occupational Safety and Health Administration (OSHA) in their ‘Trenching and Excavation Safety’ guidelines. In 1971, the first standard was issued by OSHA on excavations and trenching to reduce injuries and fatalities. This standard gives the idea of benching and sloping requirements, examples of shielding devices with a pictorial view, selection charts, and shoring tables.

This project work emphases on excavation safety problems in the surface excavation. OSHA subpart P discuss scope and application of below surface excavation work. All open excavations made in the earth’s surface applies to this sub part P. Trenches also defined under the excavation. OSHA 1926.652 section and all the remaining appendices apply to worker protection from cave-in. The entire 29 CFR Part 1926 Safety and Health Regulations for Construction apply to all construction operations; however, OSHA Subpart P is specifically for excavation work. Apart from this the main reference for excavation is from Indian Standard Excavation Work - Code of Safety (First Revision); IS 3764: 1992(Reaffirmed 2002).

Nevertheless there are a lot of articles which have studied about safety in excavation. Malcolm Puller, Joe Turner P.E, and Chang- Yu Ou discusses the existing OSHA’s excavation and trenching standards, specifically describing the requirements and safety aspects for excavation and the roles of a competent person, and other issues in OSHA Standard 1926.

1.3 L&T Heavy Civil Infrastructure Independent Company

Larsen & Toubro is a major construction, engineering, manufacturing, technology, and financial services conglomerate, with world wide operations. The key sectors of L&T include - Infrastructure, Hydrocarbon, Power, Defence and Process Industries - for the clients of different countries all over world. L&T is engaged in core, high impact sectors of the economy and our integrated capabilities span the entire spectrum of 'design to deliver'. With over 7 decades of a strong, customer focused approach and a continuous quest for world-class quality, we have unmatched expertise across Construction, Engineering, Technology, Manufacturing and Infrastructure Projects, and keeping a leadership in all of its business lines.

L&T believes in its every business by high values in corporate governance and professionalism. Sustainability is considered as the key factor for long term growth. L&T Heavy Civil Infrastructure has significance role in India’s infrastructure development, and comprehensive range of design and construction services are offered for: Metros, Hydro Power, Nuclear Power, Special Bridges, Ports, Tunnels and Defence.

L&T has a major involvement in Indian heavy water projects and nuclear power plants with their brand excellence.
Areas of expertise of L&T HC IC cover:

- Construction and erection work for nuclear structures like reactor buildings, auxiliary buildings, control buildings, and other related structures.
- Design, consultancy including seismic qualification, procurement and construction services for pump houses, cooling towers, head end facilities.
- Mechanical works and piping systems, associated detailed engineering, procurement and other related works.
- Engineering, construction, and procurement for instrumentation and electrical

- Construction and commissioning of back end projects such as storage buildings and fuel reprocessing.

1.4 Fast Reactor Fuel Cycle Facility (FRFCF)

Fast Reactor Fuel Cycle Facility (FRFCF) is the India's first fuel reprocessing plants project, in Kalpakkam, Tamilnadu. L&T Heavy Civil Infrastructure got the tender and doing the Excavation dewatering & sub soil investigation for various plant buildings of Fast Reactor Fuel Cycle Facility (FRFCF) at Kalpakkam. The fast reactor fuel cycle facility group is entrusted with work of planning, designing and constructing the Fast Reactor Fuel Cycle Facility, to close the fuel cycle of Prototype Fast Breeder Reactor (PFBR). FRFCF is a multi-unit project involving Bhabha Atomic Research Centre (BARC), Indira Gandhi centre for atomic research (IGCAR), and Nuclear Fuel Complex (NFC). IGCAR is piloting work on this project.

Closure of fuel cycle implies that after the discharge of fuel from the PFBR begins, the spent fuel is processed to recover the unburnt fissile isotopes and those that have been bred in the reactor and these are fabricated into fresh fuel subassemblies for reloading into the reactor, thus establishing a sequence that would continue to the end of life of the reactor. The Figure 1.1 shows the excavation plan for FRFCF excavation project.

Fast Reactor Fuel Cycle Facility consist of the following plants.

- Fuel Reprocessing Plant (FRP)
- Waste Management Plant (WMP)
- Reprocessed Uranium Oxide Plant (RUP)
- Core Sustainability Plant(CSP)

1.5 Project Highlights

Name of the work	:	Excavation dewatering & sub soil investigation for various plant buildings of fast reactor fuel cycle facility (FRFCF) at Kalpakkam.
Client	:	Indira Gandhi centre for atomic research (IGCAR)
Location	:	Kalpakkam, Tamilnadu.

Scope of work	:	Excavation dewatering & sub soil investigation for various plant buildings.
Budgeted manpower required	:	350 Approx.

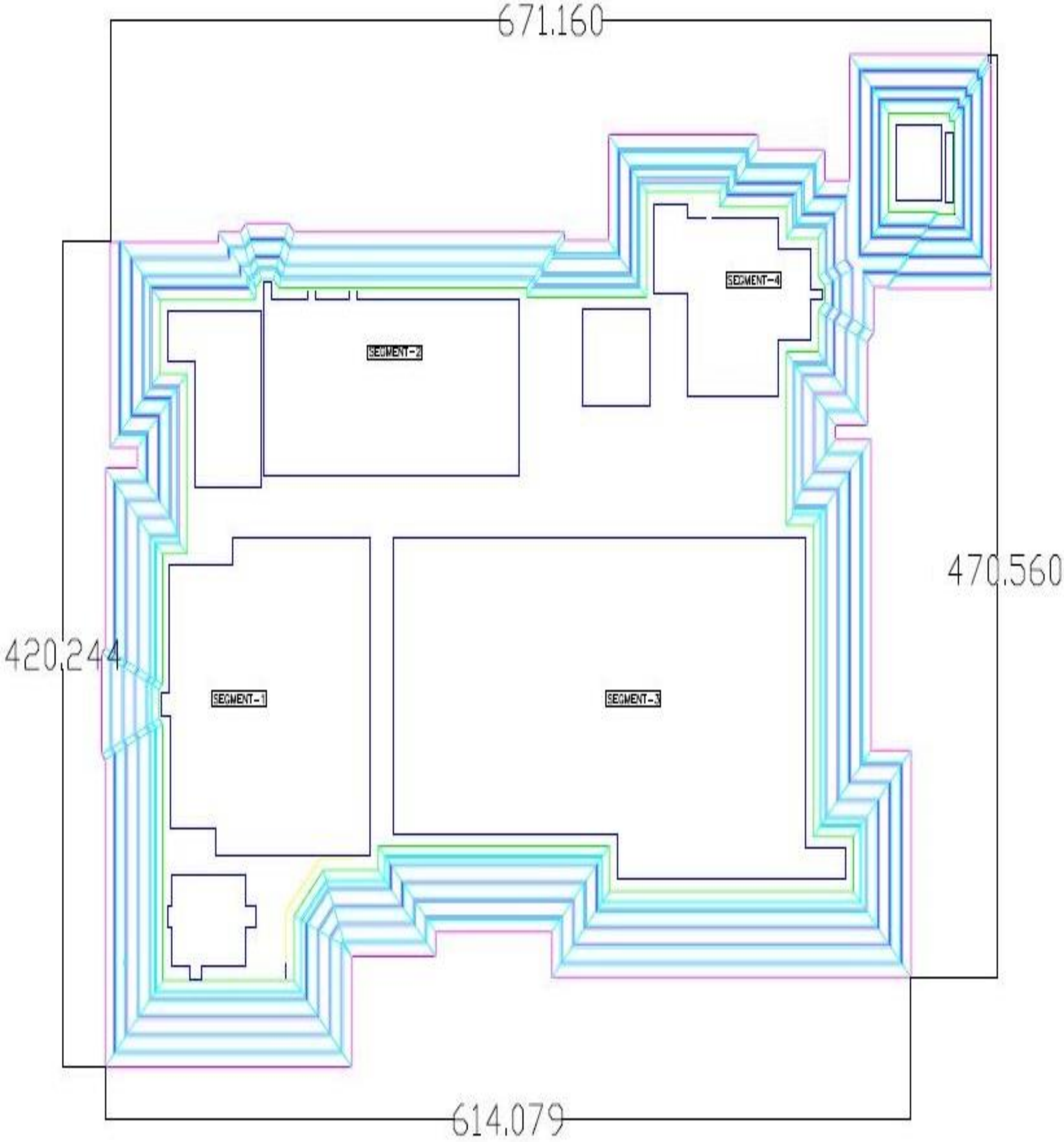


Figure 1.2: Excavation Plan

1.6 Aim and Objectives of project

The aim of this project is to investigate aspects of safety in excavation to propose ways to reduce the accidents during excavation work and improve the level of safety performance in excavation activities. To prevent accident, a company should know how to identify and be aware of all potential accidents that can happen during normal business operations.
The objectives of this project are followed as:

1. To study the different aspect of deep excavation and related works and review of literature on safety in deep excavation.
2. To identify common hazard during excavation work;
3. Review of accidents in excavation.
4. To study the control measures implemented in site to mitigate safety related deficiencies.
5. To identify high hazardous operations in the excavation work and specify control measures to mitigate.
6. To propose appropriate control methods to manage safety in the worksite.
7. To find out the unsafe conditions and unsafe acts existing in the work site which may led to the accident.

Chapter 2

Literature Review

2.1 Basic Excavation Terminology

A few basic terms used throughout this project report can use some up-front clarification because they are used so often and sometimes interchangeably.

Excavation OSHA defines excavation as meaning any human made cut cavity, trench, or depression in the earth's surface, formed by earth removal. This is a good definition until it becomes necessary to talk about an excavation that is not a trench such as excavation of a large rectangular hole. Sometimes this excavation is referred to as a structure excavation or open cut. Within the excavation industry, the word excavation generally means a cut that is not a trench.

Trench OSHA defines a trench or trench excavation as an excavation in which the depth of excavation is larger than width, but the bottom measured width of trench not larger than 4.6m. One of the reasons that OSHA has defined a trench in this way is so that a distinction about access and egress of the excavation can be made. In a trench, there must be access to a ladder within 25 ft. of travel. In an excavation there needs to be a way to get into and out of it; otherwise, an excavation the size of a city block would need a lot of ladders.

Open excavation means the width is larger than that of the depth of excavation measured at the bottom.

Shoring is a method to prevent the soil or material from falling using structural members to avoid collapse.

Support structure is a permanent or temporary structure or device used to safeguard the workers during an excavation, or protect from collapse, cave-ins, sliding or rolling materials.

2.2 General Recommendations

Ground Conditions

Before starting the excavation work, ground water level and type of soil shall be identified. Water level can be due to surface water and ground water. Surface Water from streams, ditches, etc. shall be diverted before beginning the excavation work. If there any presence of ground water dewatering should be done either by the well pointing system or shallow well pumping in order to reduce the water level below the range at which excavation required. The dewatering technique can be as shown in figure 2.1.

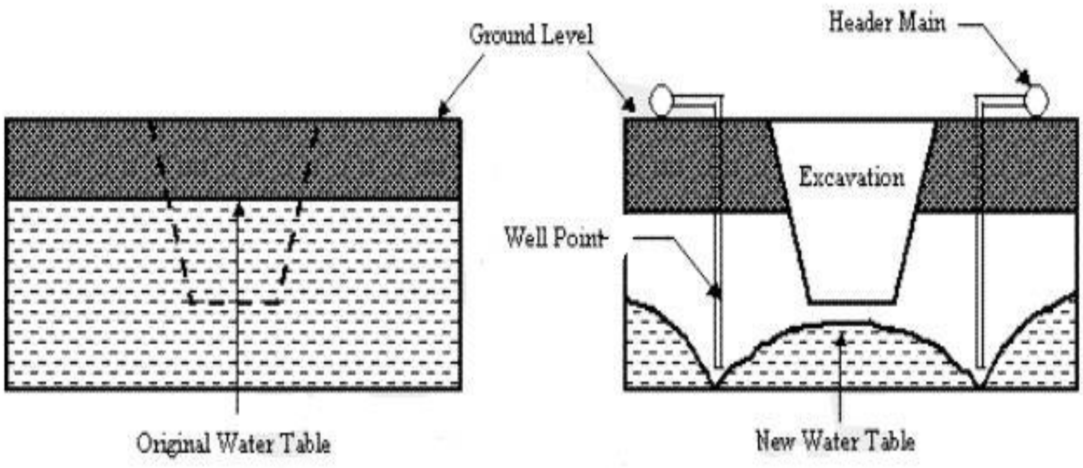


Figure. 2.1: Water table for ground water

Underground Utilities

Complete details of underground services such as gas lines, water pipes, electrical utilities, sewers, and other services should be identified before starting of excavation work. Excavation permits shall be obtained if underground facilities exist or the excavation is done in the proximity of structure. Adequate precautions shall be ensured to prevent the accident due to this underground utilities.

Existing Structure

Excavation below the foundation level of any existing structures or building shall not be started unless proper measures are taken to prevent the hazardous condition to workers, from the collapse of the structure. The adjacent foundations shall be properly supported by shoring technique if the excavation is below the foundation level of existing structure.s

Under cutting/Cave-in

Borrowing or mining shall not be allowed in any trench where such methods have been followed, the cavities left shall be eliminated by cutting back the bank slope before removing any further materials from the section of trench or movement of any heavy vehicle or crane operation.

2.3 Sloping (Angle of Repose) and Benching

Sloping and benching for various classification of soil shall be follows:

Table 2.1: Soil Classification

Soil or Rock Type	**Maximum Slope (H:V)**	**Angle of repose**
Stable Rock	vertical	90^0
Soil Type-A: Cohesive soil compressive strength - 144kPa or more. Examples: clay, sandy clay loam and silty clay loam.	0.75:1	53^0
Soil Type-B: Cohesive soil Compressive strength - more than 48kPabut less than 144kPa. (or) Granular cohesionsless soils including: silt, silt loam, angular gravel, sandy clay loam.	1:1	45^0
Soil Type-C: Cohesive soil compressive strength - 48 kPa or less; (or) Granular soils including sand, gravel, and loamy sand; or Submerged soil or soil from which water is freely seeping; or submerged rock that is not stable.	1.5:1	34^0

2.3.1 Excavation made in Type A soil

Simple slope excavations with a depth of 20 feet or less will have a maximum permissible slope of ¾:1.

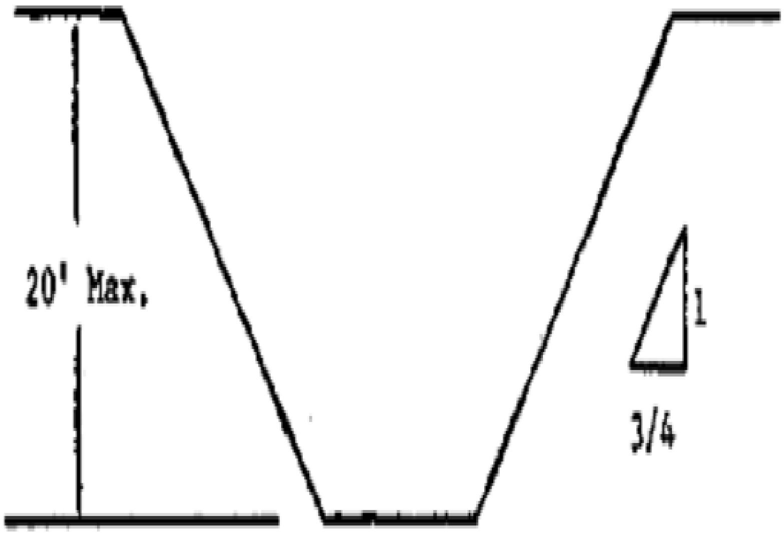


Figure 2.2: Simple Slope - Type A soil

Benched excavations with a depth of 20 feet or less will have a maximum permissible slope of ¾:1 and the maximum bench dimensions are shown in figure 2.3 and 2.4.

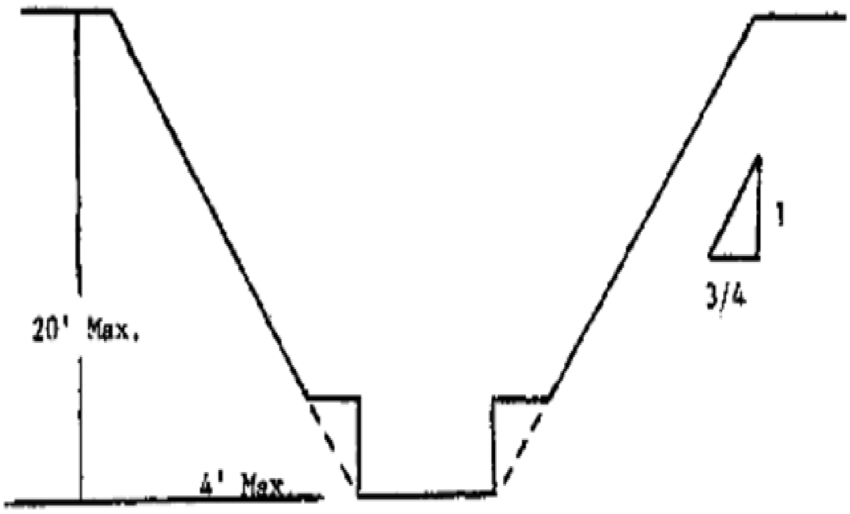


Figure 2.3: Simple Bench -Type A Soil

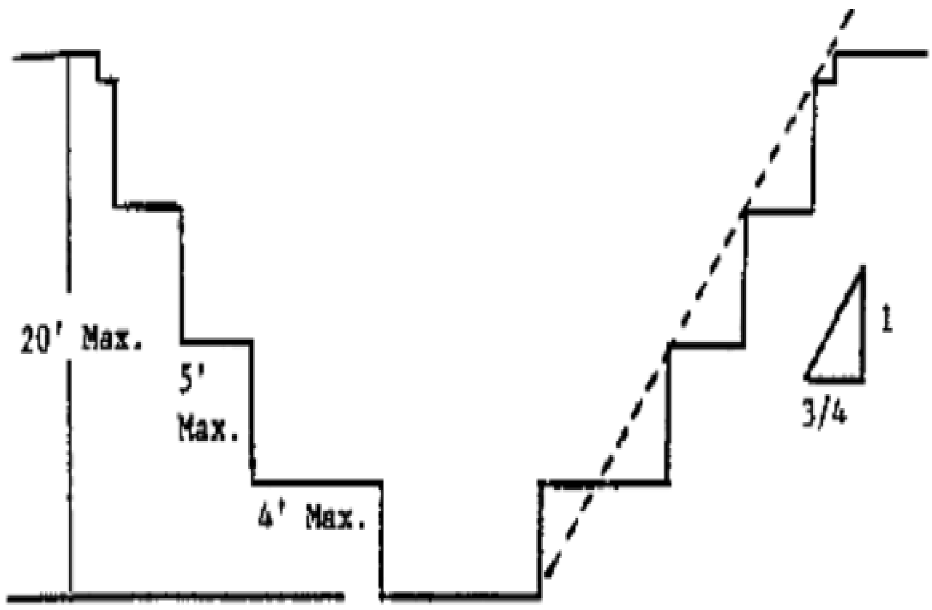


Figure 2.4: Multiple Bench - Type A Soil

Excavations with a depth of 8 feet or less, which having an unsupported vertical lower portions side allow a maximum vertical depth of 3½ feet.

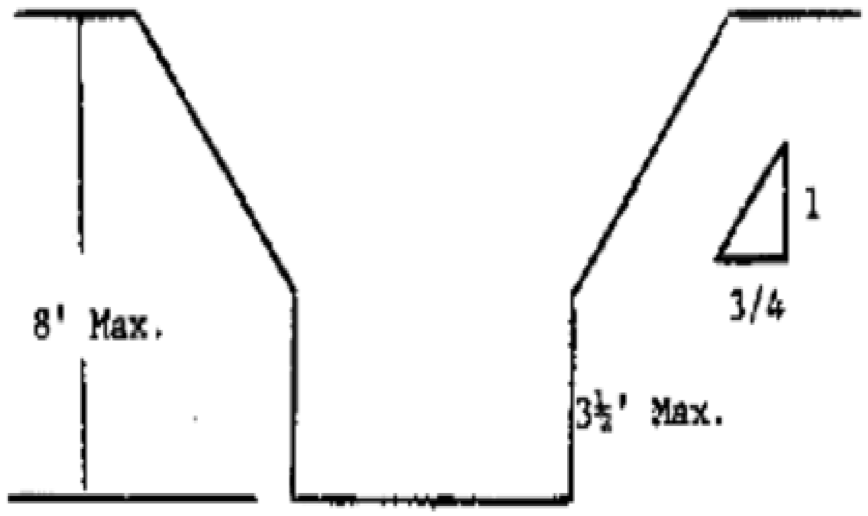


Figure 2.5: Vertical sided unsupported lower portion-- 8 feet maximum depth

Excavations with a depth 8 feet but not above 12 feet depth, which having an unsupported vertical lower portions side allows a maximum slope of 1:1 and a maximum vertically sided lower portion of 3½ feet.

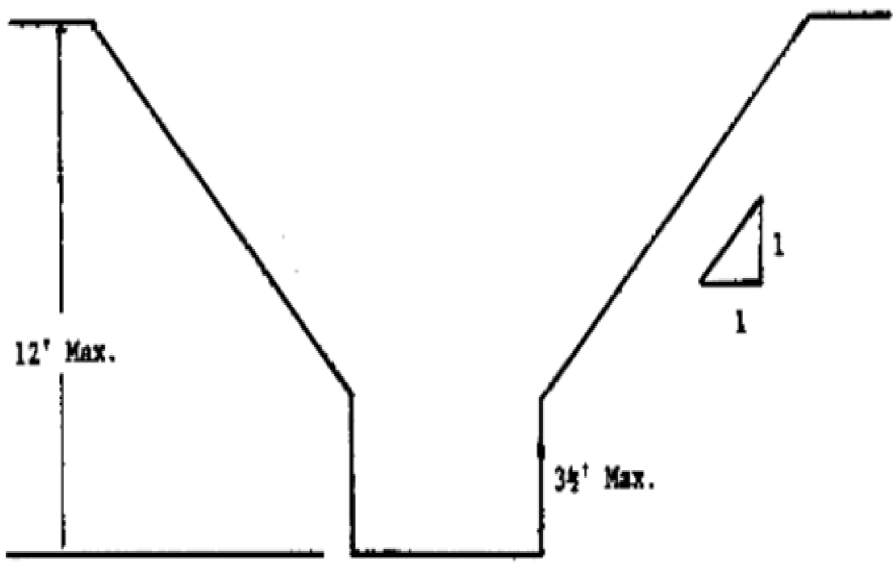


Figure 2.6: Vertical sided unsupported lower portion - 12 feet maximum depth

2.3.2 Excavations made in Type B Soil

Simple slope excavations with a depth of 20 feet or less will have a maximum permissible slope of 1:1.

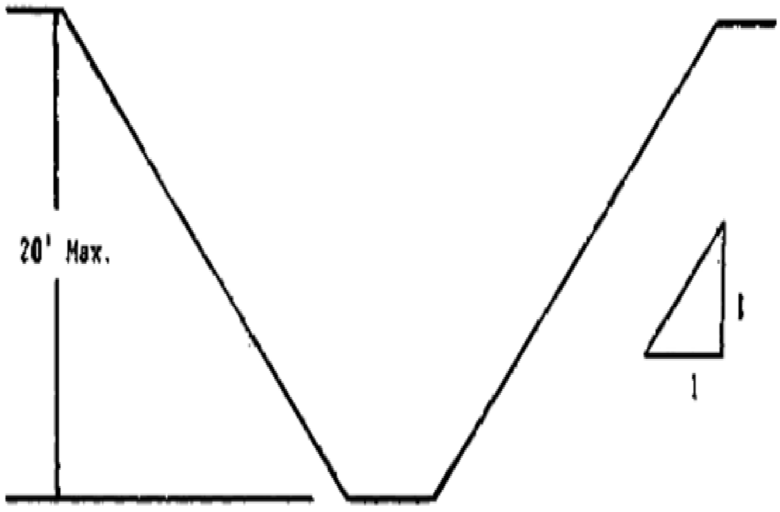
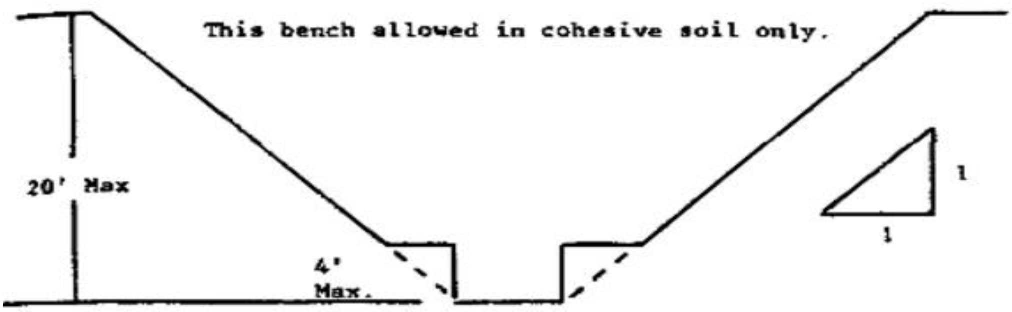
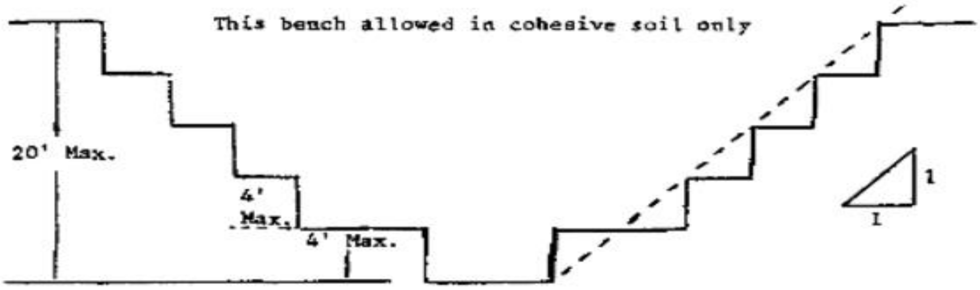


Figure 2.7: Simple Slope – Type B Soil

Benched excavations with a depth of 20 feet or less will have a maximum permissible slope of 1:1 and the maximum bench dimensions are shown in figure 2.8.



SINGLE BENCH



MULTIPLE BENCH

Figure: 2.8 Simple Bench & Multiple Bench - Type B Soil

2.3.3 Excavations Made in Type C Soil

Simple slope excavations with a depth of 20 feet or less will have a maximum permissible slope of 1½ :1.

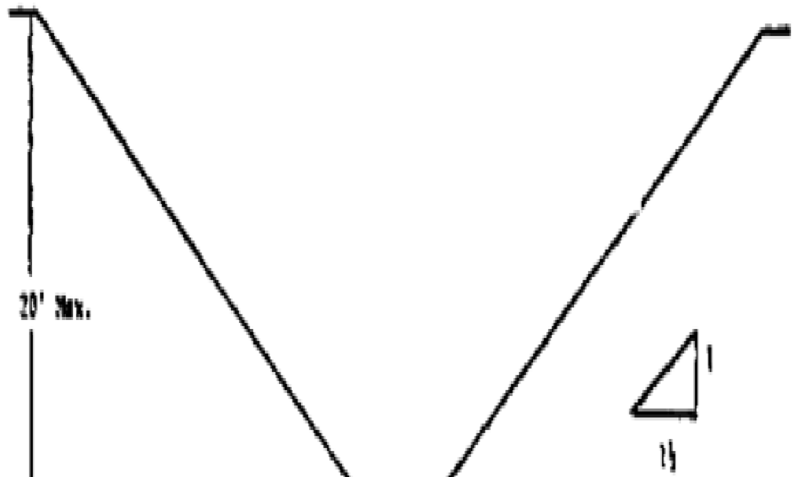


Figure: 2.9 Simple slope (Type C Soil)

Chapter 3

Safety Management - Excavation

3.1 Concept of Excavation Safety

The goal of L&T FRFCF project is to construct an excavation project without injury to workers, with a motto of work incident free to Live Injury Free Each day (LIFE) to achieve a zero harm vision throughout the project. The solution is to take steps along the way that will "make it happen." The term safety is used as a focal point for all efforts directed toward producing a safe project. To focus clearly, it is important to be clear on the concept. Figure 3.1 is one model of a minimum set of components that should go for attaining the safety goals.

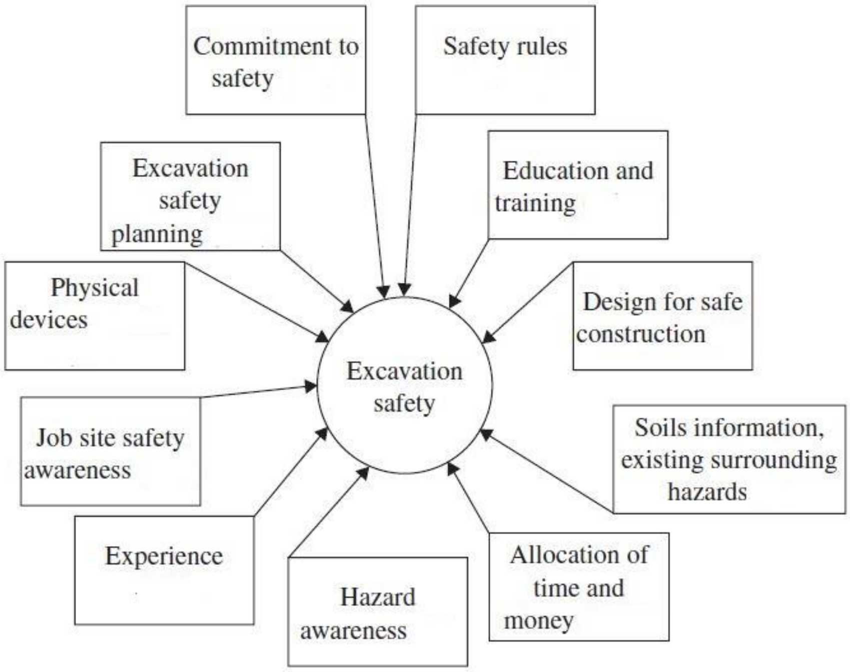


Fig. 3.1 Components of Excavation Safety

The nature of excavation work is different from other types of construction. Besides the obvious issues associated with soil and water, holes in the ground create access and confinement problems. The size of equipment required to break up and move the earth in conjunction with the proximity to associated workers on the ground creates unique problems. The unknown aspect of what is already buried prior to digging, the size and handling requirements of what is being constructed inside the hole, and the ground surface staging and activity within the confines of public activity are different from other construction activities.

All types of construction have their own unique aspects and risks; however, excavation work is one of the most dangerous. For these reasons OSHA created Subpart P excavations separate from general safety orders. It is important to keep in mind that all the other rules are pertinent and apply.

3.2 Safety Aspect of Excavation

Excavation, Trenching and Earth Removal

All trenches having a depth 1.2 m or more shall be supplied with a ladder for every 30 m gaps in length of trench. The top portion of ladder shall be extended at least 1 m above the ground. The trench depth is more than 1.2m depth shall be stepped by providing proper sloping or bracing using timber to avoid the collapsing. A 1.5 m distance or half the depth of the trench, whichever is higher shall be maintained while disposing excavated material from the edges of the trench. Under cutting shall not be allowed at any circumstances and always make sure that cutting from top to bottom pattern. The stability and safety of adjacent structures, works and structures shall be esured. Proper fencing shall be provided with railing and warning signs shall be displyed to prevent falling or slipping of workmen into the excavations.

Traffic System

A proper traffic control program should implemented in the excavation area, mainly for open excavation. Warning signs of standard colour, shape, size and symbols are the most common way to make drivers aware of work zones.

To ensure safe traffic control following point shall be considered;

- Vehicles are being operated on the described access ramp/roads inside the excavation area.
- Convex mirrors are placed all the junction turnings and deployed traffic marshal at critical junctions.

- Separate access provided on the slope with steps and hand rails for workmen entry to excavation area to segregate peoples and vehicle.
- Movement of vehicle shall be restricted in the congested / narrow approach, work areas.
- Safety sign have been displayed prominent location of the work area.
- Suitable vehicle (size, capacity, vision etc.) are being used for transporting the materials.
- Reverse horn made available for all dumpers.
- Standard wheel chockers provided all vehicles.
- Fit for use certified for all plant & machinery and a valid green card provided all plant & machinery.
- All drivers and operators are being tested to check the influence of alcohol, drugs or other controlled substances by using breath analyser on daily basis.
- All the drivers are instructed to drive the vehicles on 20 kmph inside the site premises.
- All the drivers are instructed to avoid the usage of mobile phones while driving.
- Authorised operator only deployed for operate the machinery.

Safe Means of Access

Excavations at any level shall be ensured with safe access and exit for all work place. Working stage, paths and stairways should be constructed to the point that they might not sag unduly or unequally and if the stature of the stage or passage or stairway is more than 3.5m over the ground level or floor level. Workmen and materials easy movements shall be ensured by proving proper width for access. Adequate safety measures shall be taken up to prevent risk from electrical power lines and equipment.

Construction Machinery

The maintenance and operation of construction equipments or machineries shall be done as per checklists, guidelines and by authorized personnel. The stability of all equipments shall ensure before starting of any work. Roll over protection, reverse alarms, seatbelts, warming horns, emergency stop etc. shall be checked before deployment into the work site and properly maintained. All heavy machineries should be operated by authorized operator accompanied by a helper.

Personal Protective Equipment

All the required personal protective equipments shall be determined before staring of excavation work and the maintained its quality for immediate use. The proper use of PPEs shall be ensured by concerned authorities.

a) All workmen employed at the excavation site shall use minimum PPE’s like safety helmets, safety shoe, Safety Jacket.
b) Workmen engaged on mixing asphaltic materials, cement and lime mortars shall use shoes, hand gloves, respirators and protective goggles, .
c) Protective goggles and ear plug shall be worn chipping, grinding and stone breakers.
d) Rotary drilling operators and helper shall use protective goggle, nose mask ear muffs and sufficient rest shall provide them.

Barricading and Sign Boards

It shall be necessary to display adequate numbers of signboards at workplaces, nearby mechanical equipment, first aid center, diesel store etc. in order to inform the workmen and other employees about the hazards involved in the work site. The local language or the majority workmen language should be used in the sign boards. Some of the important topics for signboards are given below;

a) Personal Protective Equipment (PPE) and its use.
b) No Smoking signs near stores, diesel room, and combustible materials.
c) Rotating parts viz. pumps, fly wheels etc.
d) Hot works viz. gas cutting, welding and grinding, etc.
e) Open Excavation (especially near excavated pit, trenches, etc.)
f) Electrical installation and high voltage equipment
g) High noise level area especially rock drilling area, rock ribbing area, etc.
h) Fire extinguisher
i) Assembly points.
j) Emergency access ways and exit.

Noise

For a noise level of 85dBA and above, suitable ear protection equipments shall be provided to all workmen. The exposure rate shall be limited to the defined period of time as per AERB rules. In main areas which require ear protection in excavation are rotary drilling, air compressor, rock drilling, grinding etc. The short time exposure of noise shall be managed by ear plug but for a high noise level ear plugs are not applicable.

Area Illumination

Sufficient lighting facilities, for example, floodlights, halogen lights, and hand lights shall be given at the work site, stack yard, access roads, etc. The work site illumination shall be such it promotes work and safety for all workmen at the site and creates a pleasant work environment at the site. The intensity of light shall rely on the work nature supported the recommendations of Hand Book on Functional Requirements of Industrial Buildings (Lighting & Ventilation: SP32-1986). However, a minimum illumination as per the task performed shall be maintained at the site; which might be increased supported nature of job from time to time.

Dust and fumes

Adequate control measures like dust extractor or arresters should be accessible for use to anticipate spread of dust to close-by ranges for open operations. Sufficient rest shall be provided to workmen to reduce the exposure time for a specific job. The same workman might not be engaged in for rock drilling work for a long period of time continuously and they should be deployed with job rotation. All fundamental PPEs like dust respirators, hand gloves, ear plugs/muffs, safety goggles, protective garments like apron etc. should be given. Any sickness because of nonstop work in dust or smoke might be answered to the First Aid Center.

Chapter 4

Risk Assessment - Excavation

Risk assessment is a systematic analysis of any job, activity or process that perform for the determination of;

- Identifying the hazards that exist (hazard is situation, source or act that has a potential to cause illness, property damage and even death).
- Deciding whether any control measures are already taken or not for reduce the risk to an acceptable level.
- Deciding what further control measures take to reduce the risk to an acceptable level.

Risk Assessments should also be done to satisfy the requirements of law but more than that to make sure the Safety & Health of workmen.

Hazard is situation, source or act that has a potential to cause injury, illness, property damage and even death.

Risk is the probability of an occurrence of a hazard or severity and the exposures of any harmful event.

4.1 Procedure for Risk Assessment

Activities to be considered

Risk Assessment shall be done for

- Routine & non routine activities.
- Activities of all peoples in the workplace (including visitors and subcontractors).
- All facilities in the workplace.

Input for Risk Assessment

The input for conducting the EHS Risk Assessment shall include

- All Work activities
- Machineries and tools using for work
- Records of past incidents

- Relevant legislations, codes, rules and specifications
- Full details of present control measures
- Feedback from clients, staff, suppliers, interested parties
- Other information such as MSDS, Instruction manual
- Previous risk assessments reports

The following points shall be considered while identifying Health & Safety Hazards, Environmental Aspects:

- Hazards initiating outside the workplace.
- Environmental aspects created in the surrounding area of the workplace
- Human behaviour, competencies and other human factors.
- Infrastructure, materials and equipment at the work site.
- Amendments to the Environment health and safety system, including temporary changes.
- All design aspect of work site.

Evaluation of Health, Safety, and Environment Risk Impact level

The evaluation shall be done by

- Identifying the existing risk control measures;
- Determining the likelihood of occurrence (probability);
- Assessing the potential severity of the health & safety hazards, environmental aspects;

Ascertain the risk / impact level based on the likelihood and severity. The Table 4.1 shall help to define the level of probability and severity of a risk.

Probability & Severity

Likelihood of happening of an incident is classified as per the table given below.

Severity is the extent or degree of harm that can be caused by the hazardous event or the environment aspect as a result of an incident.

Table 4.1 Probability and severity

Severity	Value	Probability	
Fatality	4	Very Likely	The event is almost certain to occur and has occurred repeatedly in the construction industry
Reportable Injury or illness resulting in > 2 days off work / Permanent Total Disability / Major Pollution	3	Likely	The event will probably occur in most circumstances
Non-Reportable Lost Time Injury/ Illness resulting < 2 days off work	2	Unlikely	The event may occur only in exceptional circumstances
Injury or illness requiring First Aid treatment. Minor Pollution	1	Very Unlikely	Very unlikely but remotely possible

Table 4.2 shows the risk rating and recommended action for the specific risk.

Table 4.2 Risk rating

Risk Rating	Risk level	Recommended actions
1 to 3	Low Risk	No additional risk control measures may be needed.
4 to 8	Medium Risk	Work can be carried out with Risk controls in place
9 to 16	High Risk	Don’t start work. Risk level must be reduced to Medium / low before commencing work.

4.2 Matrix for Risk Assessment:

- If the likelihood/probability and severity have been recognised, the risk / impact level can be determined.

- The risk / impact level can be determined by selecting the identified value row of Severity and the value column for probability/Likelihood; the cell where they overlap shows the Risk / Impact Level.

Table 4.3 Risk score

		Severity (S)			
		1	2	3	4
Probability (P)	1	1	2	3	4
	2	2	4	6	8
	3	3	6	9	12
	4	4	8	12	16

Control of Risk / Impact

- Based on the level determined, control measures should be implemented to reduce the risk / impact level to a tolerable level. The risk reduction can be done by reducing the Likelihood/probability and/or Severity.
- From the risk matrix table, when the risk level score is "High" or "Medium", they are considered "SIGNIFICANT" and effective controls must be applied to reduce the High Risk level to ALARP Level "As low as reasonably practicable".
- Environment Impact with respect to environment aspects, they are considered as "SIGNIFICANT" when the impact level is medium or high. Control measures are evolved to bring them to lower than significant level.
- All legal requirements are considered to be significant only.
- The control measures or changes to the exiting control measures for risk assessment shall be done by the following hierarchy:
  - Elimination
  - Substitution
  - Engineering controls
  - Signage / warnings and / or administrative controls

- Personal protective equipment

Residual Risks / Impact

Residual risks / impacts are the remaining risks / impacts, for which the planned controls are not able to effectively remove or control. It shall be ensured that the residual risks / impacts are acceptable and manageable.

4.3 Risk Assessment for Mechanical Excavation

Table 4.4 Risk Assessment for mechanical Excavation.

Sl No	Activity	Hazard	Risk Involved	People at risk	Assessment			Control Measures	Re-assessment		
					P	S	Risk Level		P	S	Residual Risk
1	Deployment of Equipment	Defective Machine	Fatal/Serious injury due to non-functioning of safety related devices and mechanisms.	Site Workers Site Staff Client Staff	2	4	8	• As per standard checklist, check the working of machine and its condition without fail before start of the Job. • Green card system shall be implemented for vehicle fitness.	1	4	4
		Inadvertent operation of Machine	Fatal/Serious injury	Site Workers Site Staff Client Staff	2	4	8	• Park the machine at levelled ground. • Ensure the parking precaution like using chock block / parking break etc. • Keep the machine locked when not in use. • Only authorized persons should be allowed in the excavation area. • No one will be allowed to come near machine while machine is in use. • Minimum 20 lux of illumination shall be provided.	1	4	4

2	Excavation	Excavation / Trench collapse due to equipment failure	Fatal/serious injury due to soil collapse	Site Workers Site Staff Client Staff	2	4	8	• Only certificated of conformance and maintenance records for plant and machinery shall be reviewed at procurement stage. Risk Assessment shall be done for each plants / equipment incorporating installation & operational EHS risks. • Check all excavation equipment and issue green card before allowing onto site • Maintain excavation equipment / plant with approved spare parts and fittings not alternative non approved spare parts and fittings. • Equipment shall be operated by licensed and approved operators only.	1	4	4
		Excavation / Trench collapse due to inadequate / inappropria te excavation techniques or excavation support installation	Fatal/serious injury due to soil collapse	Site Workers Site Staff Client Staff	3	4	12	• All excavations shall be inspected by a competent person before start of day's work or after adverse weather conditions. • Excavations / tunnels shall be designed by a competent engineer. The competent excavation / tunneling supervisor / engineer shall prepare a method statement for excavation of underground services incorporating the requirements Excavations & Tunneling • Temporary makeshift shoring shall not be permitted, equipment used to shore excavations shall be fit for purpose and designed for the purpose employed • Angle of repose as per design & Bench cut shall be provided to the vertical faces of excavation when excavating in large volume spread in all directions. Vertical cuts shall be strictly avoided.	2	4	8

		Fall / topple of excavator or dumper into excavated pit or run over on people working or moving on site.	Fatal/serious injury due to soil collapse	Site Workers Site Staff Client Staff	3	4	12	• Ramp / approach road shall be constructed as per norms and designated for safe movement of vehicle. • Pedestrians and vehicles shall be segregated, intersections shall be signalled / warned / banks man provided for safe cross overs. • Excavated pit shall be hard barricaded. Warning lights and signs shall be installed. • A banks man shall be provide to help the drivers to make the maneuvers during loading or unload of materials.	2	4	8
		Excavation / Trench collapse due to void or cave in.	Fatal/serious injury due to soil collapse	Site Workers Site Staff Client Staff	2	4	8	• A 'Geotechnical' survey shall be carried out prior to commencement of works. • Precaution shall be taken to prevent cave in. If occurs then it should be sloped with 45^{o} Angle of repose. • Provide shoring. • Remove the excavated earth immediately. • Do not keep heavy objects on the edge of the pit.	1	4	4
		Contact with existing services causing a electrocution/Fire / explosion	Fatal to major injuries, or property damage	Site Workers Site Staff Client Staff	3	4	12	• Acquire current utility drawings and details. • Carry out survey to confirm depth and line of existing utilities (utilize suitable survey equipment relevant to the scope and scale of the work. Survey equipment may include ground radar, cable avoidance tools and accessories (CAT & Genny) • Dig sufficient trial pits to locate underground services and expose it for mechanical excavation where necessary.	2	4	8

								• Mark the line of underground services to ensure visibility to all persons working in the vicinity • Prepare method statement for excavation of underground services • Where possible, underground electrical services shall be de-energized prior to excavations. • Where services are to be re-routed, no work shall commence until services are confirmed as de-energized / inert • Permits shall be secured in advance from the relevant utility authority from client side prior to excavation in the vicinity of existing underground services			
		Excavation in the vicinity of or underneath existing structures	Collapse of existing structure Personal injury / fatality	Site Workers Site Staff Client Staff	2	4	8	• No excavation work or tunneling shall be carried out in the immediate vicinity of or underneath existing structure until the impact of the work on the existing structure is determined by a competent engineer • Underpinning requirements shall be determined by a competent structural engineer • Where possible, the structure shall be evacuated for the duration of the works as an additional safety measure. Closely monitor the behavior of structure during excavation & tunnel. • Excavation work under live tunnels (sewers etc.) shall also be held until the impact of the work on the existing tunnel is determined by a competent	1	4	4

		Water seepage / flooding into excavation	Fatal/serious injury due to soil collapse	Site Workers Site Staff Client Staff	2	4	8	• Plan for suitable de-watering system based on the ground water table level and soil strata. Where the water pressure is high, use total dewatering methods. • Make provision for continuous dewatering using pumps, have standby pumps and night shift operation.	1	4	4
		Toxic fumes / gases	Fatality Fire / explosion	Site Workers Site Staff Client Staff	2	4	8	• The air quality in deep excavations shall be periodically tested with a multi gas monitor. Acceptable entry conditions are: • Oxygen (O_2) – greater than 19.5% and less than 21% • Lower Flammable Limit LFL – less than 10% • Carbon Monoxide (CO) – less than 35ppm • Hydrogen Sulphide (H_2S) – less than 10ppm • Generators shall not be placed adjacent to deep excavations as exhaust fumes are likely to settle in the excavation. • Emergency rescue plan shall be available and briefed to workplace. Adequate no of escape sets shall be available near workplace	1	4	4
		Fall into pit due to lack of access & egress	Serious injury. Fatal due to delay in rescue	Site Workers Site Staff Client Staff	2	4	8	• There shall be 2 Safe means of access shall be provided to every working excavation pit.	1	4	4
		Fall of person into the pit.	Serious injury. Fatal due to delay in rescue	Site Workers Site Staff Client Staff	3	4	12	• Provide barricading with warning signals (warning light at night). • Use standard ladder to get into the pits.	1	4	4

								• Keep muck minimum 1.5 meter away from the edge of the excavation. • Provide barrier 1.5 meter (min) away from the edge of excavation. • Proper lighting of Excavation area.			
		Fall of heavy objects /stones, boulders etc. in the excavated bit.	Serious injury. Fatal due to delay in rescue	Site Workers Site Staff Client Staff	3	3	9	• Use only approved equipment. • No entry into the pit during excavation. • Keep the removed earth at least 1.5m away from the pit. • 20lux of illumination level to be maintained at excavation.	2	3	6
		Improper illuminatio n	Fatal / Serious injuries due to run over or fall of material Weakening of Eye sight	Site Workers Site Staff Client Staff	3	4	12	• Work permit has to be taken before starting of night shift. • Poor illumination area shall be barricaded. • Illumination level to be measured before work. Illumination should be min. 20 lux • All the workmen shall be worn reflective jackets.	1	4	4
3		Dust	Inhalation of Dust Contracting Pneumoconiosis	Site Workers Site Staff Client Staff	3	2	6	• Sprinkle water to moist the ground to settle the dust. • Use dust mask and goggles.	2	2	4

	Vehicle Movement	Working in congested areas	Medium or Minor Injuries	Site Workers Site Staff Client Staff	2	2	4	• Allow only minimum number of persons to work at a time • Train the workers for safe use of hand tools, and safe manual working procedures. • Provide alternate emergency access out of excavation area.	1	2	2
		Traffic manageme nt	Collision of vehicles	Site Workers Site Staff Client Staff	3	2	6	• Proper signal mans and traffic marshals to be provided as per the area requirement with proper blinker lights, whistles and reflective jackets. • Traffic signage to be provided around the working area to avoid the confusion. • Provide convex mirror to be provided at the turning of the junctions.	2	2	4
		Over exertion	Mistakes or Errors in operation	Site Workers Site Staff Client Staff	3	3	9	• No worker shall be allowed to work beyond 12 hrs. A shift registers to be checked to confirm the same. • Weekly off shall be given to worker after 6 days. Shifts register to be checked to confirm the same. • Availability of rest room, toilet, drinking water	2	3	6
		Workmen taking rest under/near to vehicle	Fatal / Serious injuries due to run over	Site Workers	3	4	12	• Vehicles to be parked on the parking area only. • Workmen rest shed shall be constructed for taking rest. • All workmen shall be instructed to use rest shed through induction training and tool box talk.	2	4	8

P: Probability, S: Severity

Chapter 4

Conclusion

This project report of safety in deep excavation dicuss the various safety aspects of deep excavation and the risk assessment for the mechanical excavation in the L&T Heavy Civil Infrastructure Kalapakam project site. The most specific finding from the risk assessment are as follows.

- The major risk in any excavation work is a soil collapse/cave-in.
- The other main risk in excavation works can be due to Falling excavated soil or objects in the edge an excavation, Earth moving equipment, Falls, trips, and Slips, Water accumulation hazards, Hazardous atmospheres, Underground utilities.
- A great extent of risk can be eliminated through proper benching, sloping, and shielding the excavation.
- An excavation permit shall be obtained before starting of an excavation work from concerned department .
- Excavation inspection shall be done on daily basis by a competent person.
- L&T Heavy Civil Infrastructure I C in Fast Reactor Fuel Cycle Facility (FRFCF) project has achieved more than two million man hours without any Fatalities and Reportable Lost Time Injury (RLTI) by implementing best risk control measures.
- This is a great achievement for L&T team as it considering the high risk involved in an excavation project.

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Numerical Simulation of Room Corner Test for Polycarbonate

Abstract

In the current study, a fire performance of polycarbonate panel of 74 mm thickness was simulated using BRANZFIRE. The model simulation was carried out in ISO 9705 Room-Corner test standard using the polycarbonate (Everbright 610) panel as a wall and ceiling material. This polycarbonate material was tested in Commonwealth Scientific and Industrial Research Organisation (CSIRO) Laboratory in Australia. The input parameters of the CSIRO room corner test was analysed in the current investigation using BRANZFIRE. The ISO 9705 fire test of polycarbonate for wall and ceiling exposed to propane burning at 100 kW for 10 minutes followed by 300 kW for a further 10 minutes. The flashover condition for the room corner test examined for both heat release rate of 1000 kW and temperature condition of 600 °C. BRANZFIRE simulation and real scale experiment results were compared for the flashover conditions. The observations from the both the data lead to the conclusion of the group number 2 classification according to ISO 9705 standard. The simulation results are compared with those obtained experimentally. The result were found as the flashover happened between 10 and 20 minutes, in real scale experiment flashover occur at 680s and in simulation time to flashover was 766s. The predicted simulation results of BRANZFIRE has shown good agreement with the experimental results.

Keywords: *Polycarbonate; ISO 9705; Room- Corner; Flashover; BRANZFIRE*

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Chapter 1

Introduction

1.1 Overview

The requirement of fire safety has diversified in every field, recently due to increased rate of construction of buildings as a result of urbanization always leading to a possibility of fire accidents in buildings. In recent years, the building fires are increasing which causes a threat to human life and also damage the environment and other resources. The rate of fire growth inside a building can be significantly influenced by the surface flammability of the wall lining and ceiling materials [1]. For example Colectiv nightclub fire [2] in Romania on 30 October 2015 was due to the ignition of the club's flammable polyurethane foam, and the fire spread rapidly. Most of the victims were poisoned by toxins released from the burning polyurethane.

The ISO 9705 Full-Scale Room Test for Surface Products [3] is a widely used room-corner fire test to evaluate combustible linings. This standard is intended for the evaluation of room surface lining material contribution to fire growth subjected to ignition source. In this test, the walls and the ceiling are lined with the test combustible material and fire is placed in a corner of the room containing the combustible lining. A standard ignition source is mentioned in the ISO standard; however other alternatives also permitted. The conditions like the heat output, type and position of ignition source will have a substantial effect on the fire growth of test material [1]. The room/corner test is performed in accordance with the standard detailed in ISO 9705, provides the information for the initial stages of fire from ignition source up to time to flashover.

The prediction of the environment in the building subject to fire is a complex phenomenon. BRANZFIRE was used to analyse the fire growth of ISO 9705 room corner test for polycarbonate. The BRANZFIRE is developed by Building Research Association of New Zealand for a multi-room zone model fully integrated with a flame spread and fire growth model applicable to room fire scenarios [4]. The software working is based on two-layer or zone model. The section 1.2 gives more details about the compartment modelling.

1.2 Test Material – Polycarbonate

Polycarbonate was used as the test material for this work. It is durable, mouldable, shatterproof, lightweight and flame resistant. It has good thermo-physical properties, one of the finest property is that the high-impact resistance, it can be 200 times greater than that of tempered glass. Polycarbonate panels for building applications include weather resistant, and UV protected, making them an efficient solution for non-residential buildings: they could be used as fenestration systems, continuous windows, shed, roofs, walls, and finally indoor partitions [5]. Figure 1.1 show the polycarbonate panels.

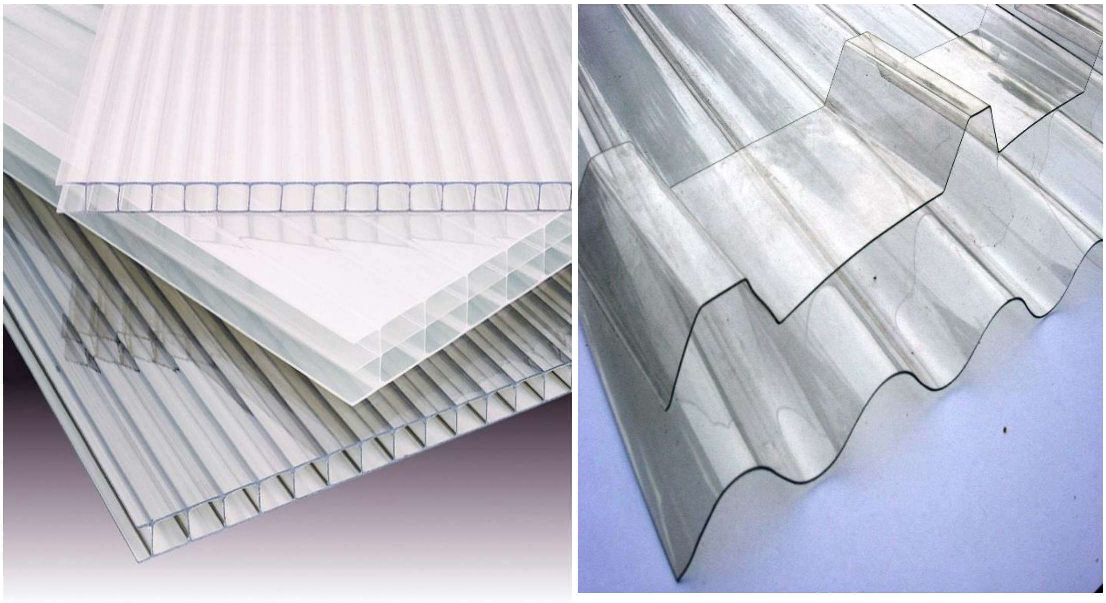

Figure 1.1: Polycarbonate Panels

Features of Polycarbonate [6]

- Impact strength is 200 times of glass.
- Light weight, aout half of glass.
- Transparency of Polycarbonate is 90% (clear), for different thicknesses.
- UV-protection.
- Resistance to weather and maintains good properties in a temperature range of -40 to 120°C.
- Good thermal isulation property compare to glass, thermal conductivity vallue of glass is 1.2 time higher than that of a PC.

- A polycarbonate sheet can be bent while cold or hot and can be utilized on curved roofs, windows and domes. The Minimum cold bend radius for PC is 100 times thickness and minimum hot bend radius is 175 times the thickness.

Polycarbonate panels can be completely opaque, translucent, or as clear as glass, subjected to the specific requirement or use. The sheet can be thick or thin, rigid or flexible, flat or corrugated. Moreover, different colours are available for vertical façade panels and custom colours or texts could be used in buildings. The material properties of polycarbonate are provided in Table 1.1.

Table 1.1. Material properties of polycarbonate

Property	**Value**
Thermal Conductivity	0.19–0.22 W/(m·K)
Specific Heat	1.2–1.3 kJ/(Kg·K)
Density	1.20–1.22 g/cm3
Emissivity	0.88
Pull Resistance	63N/mm²
Modulus of elasticity	2400N/mm²
Upper working temperature	115–130 °C
Lower working temperature	−40 °C
Compressive strength (σc)	>80 MPa
Impact strength	600–850 J/m

1.3 Compartment Fire Modelling

Zone modelling can be defined as the prediction of different aspect of fire phenomenon in a Compartment. Based on a theoretical representation for the compartment open fire process, it can be an approximation to the reality. Any fundamental departure by the fire system from the essential idea of the zone model can significantly affect the validity and correctness of the methodology. The zone model represents the system basically like two different compartment gas zones: a top volume zone and a lower volume zone caused by thermal stratification as a result of buoyancy. Conservation equation is applied to for each zone and provide to accept| the different transportation and combustion procedures that apply. Conservation equations are used for each zone and provide to adopt the different combustion and transportation processes that apply. The fire is characterised as a source of energy and mass expressed as a plume; it acts as a source for the mass from the lower zone to the top zone through a process called entrainment [7].

For predicting or calculating the temperatures| and other properties produced in a compartment fire, a model or information of the fire phenomena must be created. This model will be described in conditions of physical equations that may be solved to predict the temperature in the compartment. Such a model is, therefore, an idealization of the zone fire phenomena. Consider if a fire that starts somewhere below the ceiling. It produces heat energy and energy of combustion in the compartment that may vary with time. The heat of combustion from the fire form a plume that, due to buoyancy, rises toward the ceiling above the heat source. As the plume goes up, it draws the cool air from the compartment, and also decreasing the plume's temperature and increasing its volume level flow rate. Once the plume touches the ceiling, it spreads out the ceiling. When the expansion of this reaches the surfaces of the walls, the flow becomes downward and hot gas layer that descends as the plume's gases continue steadily to flow involved with it. Relatively good boundary between the hot upper layer in the compartment and the air in the lower layer. The only assumed interchange between the hot top layer and air in the lower layer of the room the made up of products of combustion is through the plume. When the hot layer reaches to the openings in the compartments walls (e.g., windows and doors), hot gas from the compartment will move out through the openings and the external air will flow into the compartment through the opening. This explanation of compartment fire phenomenon is known as a two-layer or zone model [10] [11] [12].

1.4 Objective of the Present Work

This study aims to simulate a fire that under well ventilated conditions starts in a corner of a small room with a single open doorway. The method is intended to evaluate the contribution to fire growth provided by a surface product using a specified ignition source

- Numerical simulation for ISO 9705 fire test in BRANZFIRE software.
- Evaluate the reaction of wall and ceiling products to fire when installed at the surface of a small room and exposed directly to a specified ignition source.

- Investigate fire behaviour of polycarbonate material.
- To conduct a quantitative, comparative analysis of the fire risk associated with polycarbonate lining materials using BRANZFIRE.
- Validate the simulation result with CSIRO Laboratory test results.

The present study provides a brief idea of the fire growth inside test room of ISO 9705, Full-scale room test for surface products: for polycarbonate material using BRANZFIRE software and compare with Commonwealth Scientific and Industrial Research Organisation (CSIRO) experimental test. The real scale experimental test of Everbright E610 (polycarbonate) had done in Commonwealth Scientific and Industrial Research Organisation CSIRO for Everbright Roofing Systems Pty Ltd. This test enables the assessment of group number classification of the material for use as wall or ceiling. All the input data for the simulation were added accordance with the CSIRO experimental test. The model was validated against the real scale ISO 9705 room/corner fire test conducted by CSIRO laboratory for polycarbonate material. The validation of test included comparing computer simulation results to the data on heat release rate (HRR), flashover time, heat flux and temperature rise in the test room.

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Chapter 2

Literature Review

Fire development in buildings/rooms are influenced by a wide range of factors;

- Type of wall, ceiling and flooring materials;
- Nature of the room contents ;
- Size and geometry of the room ;
- Available ventilation ;
- Presence of automatic suppression systems ;
- Characteristics of ignition sources.

The fire growth due to wall and ceiling lining materials is a complex phenomenon. The main factors that influence the fire growth spread on lining materials are due to lining configuration and environmental conditions. Lining configuration includes thermal and chemical properties, surface condition and thickness of lining material, direction of flame propagation from the surface. Surface temperature and air velocity near by the lining surface comes under environmental factors.

Drysdale [17] gives the details of attempts that have taken by different researchers to model the fire growth on compartment surfaces. Morgan J. Hurley [7] gives the physics of surface fire growth in detail. He differentiates between airstream supported fire spread and opposed-flow flame spread. He Points out that the correlations are for basic fire growth spread only. For example, the fire growth on surface lining material depends on additional features. The fire growth modelling on lining materials in rooms are explained more detailed in the following.

The time to flashover and total heat release rate inside a room or compartment due to lining materials is determined in ISO 9705 room corner test by the help of experimental calorimeter tests. Quintiere's [18] room corner test is the one of these models. This models helps to predict the total heat release rate from the room lining materials in ISO 9705 fire test and found that it has a reasonable accuracy for range of test materials. He also mentioned that the applicability of his model has been not proved for other surface materials and other compartment/room sizes. Wade [4] point out that the accuracy of fire growth predictions comes to less accurate when the room dimensions become larger. Fire design engineers and researchers should consider this point when Quintiere’s model applying for lining materials in room corner model.

BRANZFIRE compartment two zone modelling software is an adaption of Quintiere’s room-corner model. CFAST software by National Institute of Standards and Technology (NIST) is also a zone modelling software which follows the Quintiere’s model. Eventhough there are different computer models are available, only BRANZFIRE and CFAST are reported for the modelling of lining material fire growth. There are

M.J Tsai, Hung-Chi Su, P. Hsiao, C.Y Lin, M. Chih Ho [14] carry out four room fire test experiments with different fuel load and lining materials to determine the ignition source location on fire growth. A 6 m × 5 m × 3.3 m test room was partly lined with wood in the walls of the room. The test result shows that the total heat release rate inside the test room is varies with different test conditions.

C. Xiaojun, Y. Lizhong, D. Zhihua, and F. Weicheng [11] describe a multi-layer zone fire spread model created to predict the fire performance in a room. The room volume is divided into an arbitrary number of horizontal layers, in which the temperature and other physical properties are assumed to be uniform. The principal equations for each laminated horizontal layer are derived from the conservation equations of mass and energy. The implemented fire sub-models are introduced, including combustion, fluid flow and heat transfer models.

A.S Hansen, and P.J Hovde [12] point out that the ISO room corner test is used for classification of surface materials in a number of countries, and as the reference scenario test for the new European single burning item test, its importance increases even more. Time to flashover may be regarded the most important result from the room corner test. In this paper we describe three different calculation models for predicting in which period of testing time flashover in the room corner test will occur. The predictions are all based on test results from the cone calorimeter.

Scott Edward Dillon [16] developed a simulation model in order to predict the fire performance of materials in ISO 9705 room corner test. The materials were tested by L S Fire Laboratories of Italy, and the data they provided is analysed in his report. A method is established to define material properties including the heat of combustion, heat of gasification, thermal inertia, ignition temperature, and total heat release rate per unit area.

In conclusion, only few researches are done to find out the temperature conditions, total heat release rate and flashover condition inside a compartment/room due to room lining materials. All the test results are scenario based. A quantitative results on the fire growth for lining materials so far not published.

Chapter 3

Methodology

3.1 Experimental setup

There are several standards are available for room/corner test and are specified in the different codes, standards and regulations for the conformity of the interior lining materials. For example ISO 9705 Fire tests - Full-scale room test for surface products, ASTM E2257 - The American version of ISO 9705, NFPA 265 - Standard Methods of Fire Tests for Evaluating Room Fire Growth Contribution of Textile Coverings on Full Height Panels and Walls. The tests arrangements and procedures are all similar, but have some differences that can significantly affect the performance of the sample material. These differences include the size, location and heat energy release rate from the ignition burner. The main objective of these tests is to determine that the flashover does occur or not, if occur time for flash over.

The ISO 9705 Room/Corner Test consists of a room with a size of 3.6 m × 2.4 m × 2.4 m length, width and height respectively, with an open doorway opening for ventilation measuring approximately 0.8 m x 2.0 m wide and high in the front wall. Ceiling and walls are lined with polycarbonate for tests as per ISO 9705 standard. The polycarbonate panels were exposed to an ignition source, propane burner. The location of the burner is in the rear corner opposite single doorway opening, on the floor. The propane burner made up of a steel sandbox measuring 0.17 m × 0.17 m 0.145 m. The top surface of burner is at a height of 0.30 m above the test room floor. Fig. 3.1 shows the schematic diagram of the ISO 9705 room with dimensions.

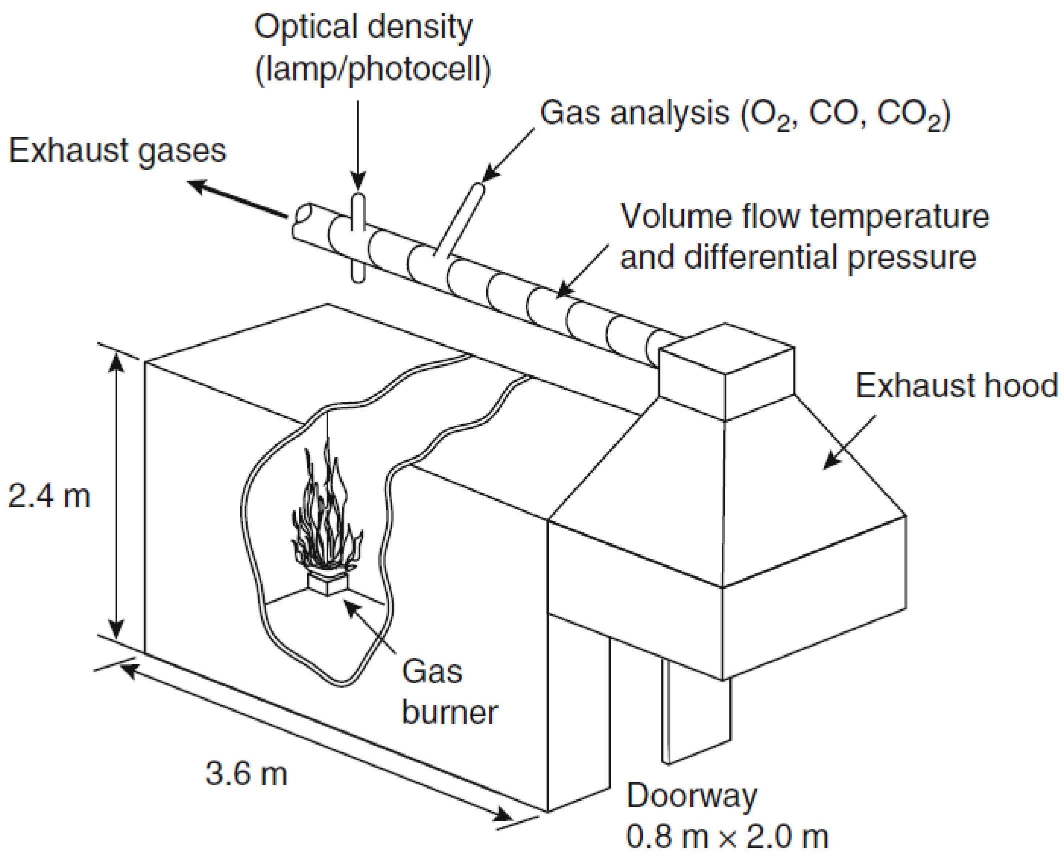

Figure 3.1: Schematic diagram of the ISO 9705 room with dimensions (m).

3.2 Experimental procedure

The procedure for the test is that the propane burner release a heat of 100 kW at a constant rate for the first 10 minutes of the test, after that a heat release rate of 300 Kw for the remaining 10 minutes. The test continue for the full test period, 20 minutes unless ended when the flashover criteria occurs. One useful ways of ranking materials and determining the fire growth potential for a particular material is by time to flashover under the conditions specified by the test standard. Flashover is an altogether complex process and is associated with different characteristics of fire compartment: heat flux to the floor of approximately 20 kW/m^2, an upper layer temperature of 600 °C, flames emerging from the doorway and a heat release rate of 1000 kW.

Heat release rate (HRR) is the rate at which heat is generated by fire. HRR is measured using calorimetry, and the unit is watts or Joules per second. Fig 3.2 Heat Release Rate from propane burner. Thermocouples were used to measure the temperature inside the test room.

Based on the flashover time the materials can be classified into four groups. Table 3.1 gives the idea of room lining material classification according time to flash over.

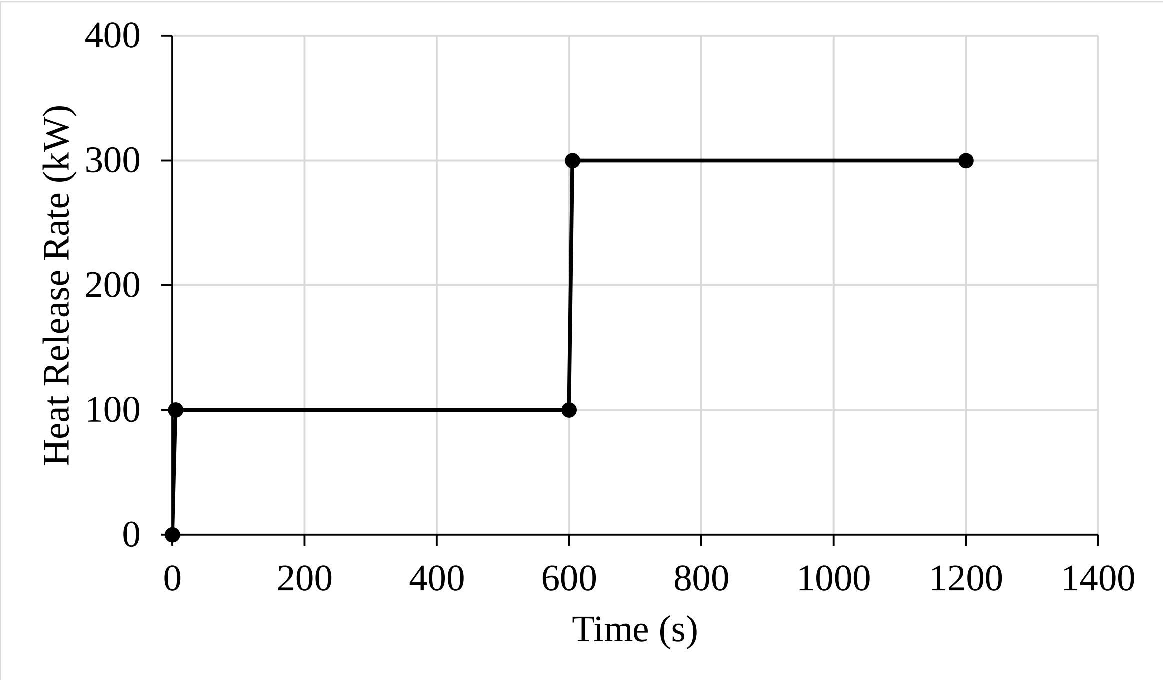

Figure 3.2: Heat Release Rate from propane burner

Table 3.1. Test material classification

Group Number	**Flashover Condition**
Group 1	No flashover within 20 minutes
Group 2	Flashover between 10 and 20 minutes
Group 3	Flashover between 2 and 10 minutes
Group 4	Flashover within 2 minutes

3.3 CSIRO ISO 9705 test for Polycarbonate

The ISO 9705 test for Everbright E610 polycarbonate was conducted on 7th May 2015 at CSIRO Highett Laboratory. The test was conducted for the Assessment of the group number classification of the material for use as a wall or ceiling lining in accordance with Building Code of Australia. The specimen description was 74 mm thick Polycarbonate building panel complete with aluminium internal locking band fixed with a density of 1.2 g/cm^3. The Fig. 3.3 shows the general room installation view prior to testing of Everbright E610 panel. Data recording equipment logging at 5 s intervals and a video recorder viewing the burner corner of the fire test. The burner output was set to 100kw for 10 minutes, after this period the burner output was increased to 300kw for further 10 minutes.

Figure 3.3: General Room installation view prior to testing of Everbright E610

The observations of room corner test were light smoke throughout the room after two minutes of the test. Melting panels on ceiling directly above burner observed with strands of molten plastic observed to be falling form ceiling. Significant flaming on all walls and ceiling observed before increasing the burner output to 300kW. Large flaming pool on room floor. Molten flaming plastic strands and drops were observed to fall heavily form ceiling. Panel inserts and flaming panel were observed to fall form ceiling and walls. Slight decrease in smoke density was observed. Visual observations of specimen behaviour were made through the doorway. Flames were observed to exit entrance approximately 300 mm below door. The test was formally ended at approximately 14 minutes 52 seconds at which point sprinklers were activated and the remaining fire extinguished. Observations indicate that flashover as indicated by flame passing through the door occurred at approximately 14 minutes 52 seconds. An initial heat release rate peak of 1040 kW at 680 seconds was measured with a secondary peak recorded to be 1704 kW at 910 seconds at the time of manual sprinkler suppression [13].

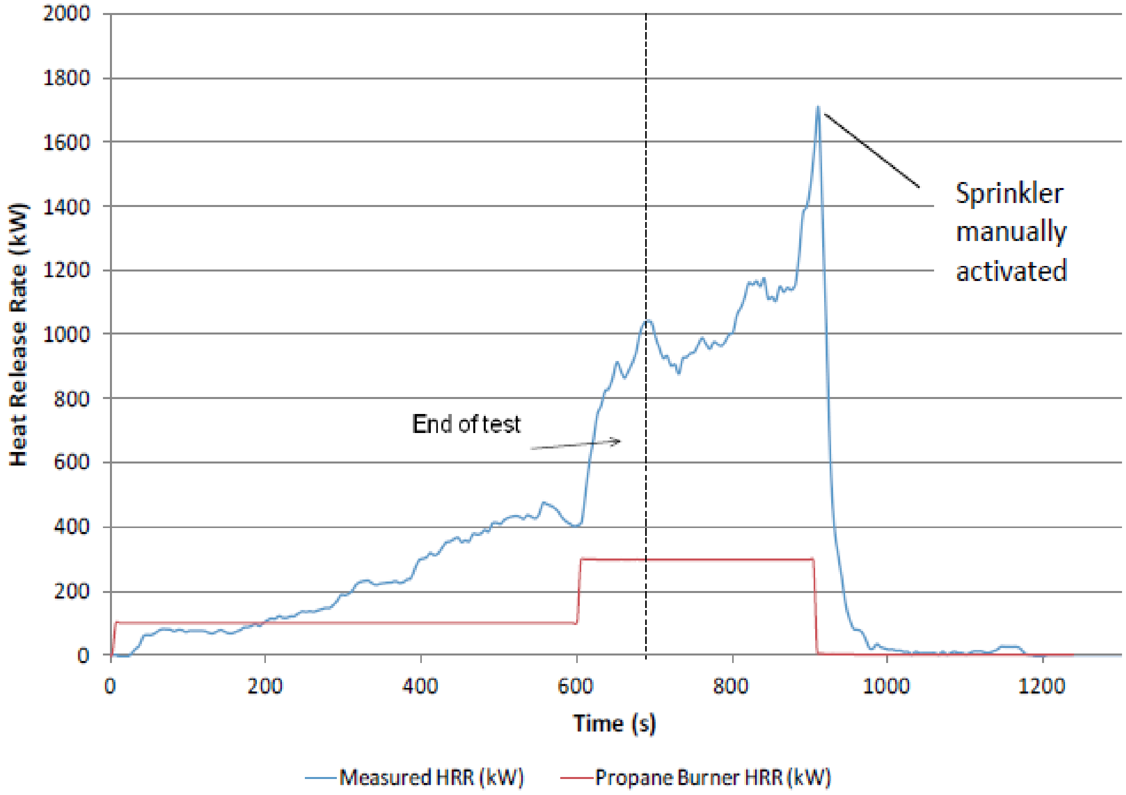

Figure 3.4: Rate of heat release including burner output

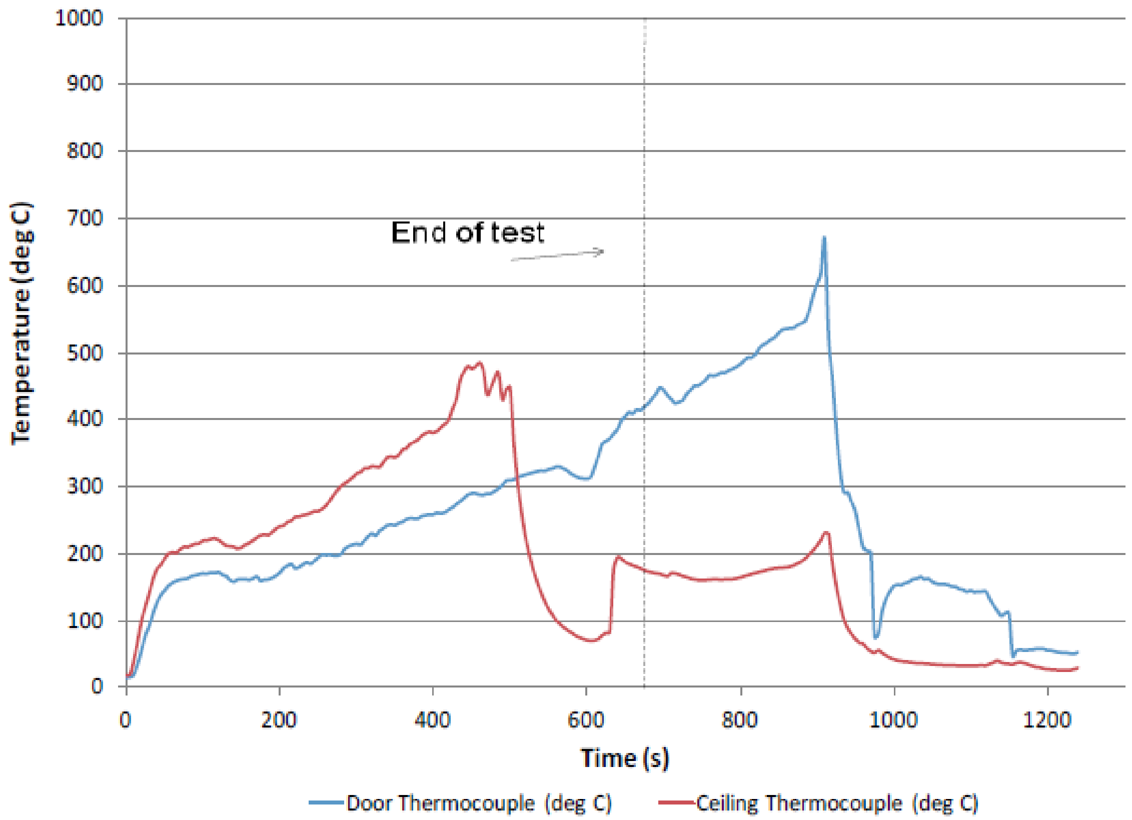

Figure 3.5: Temperature measurement during the experiment

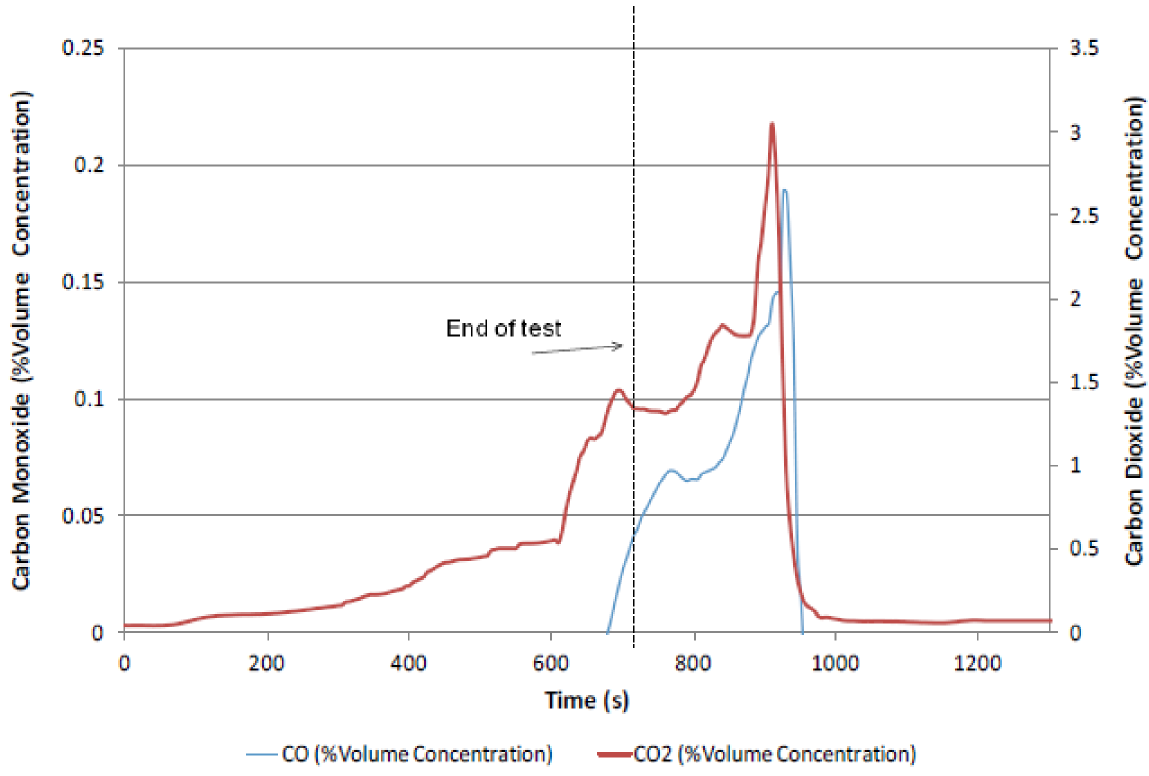

Figure 3.6: CO and CO_2 concentrations

3.4 Overview of BRANZFIRE

BRANZFIRE, 2012 is a zone modelling software which includes a fire growth and flame spread model for room lining materials. It can be used as multi-compartment room geometry limiting for the four-sided structures. The modelling enables multiple burning objects and multiple vents in ceiling or between rooms. BRANZFIRE is used to design the fire hazard involved with ignitable lining materials and other building substances, and calculate the lining material impact to the increase of smoke and fire growth in the compartment. The material burning can be started automatically by user defined ignition criteria [8]. The simulation model helps to predict different fire scenarios in the lower and upper layers including vent flows, temperature, layer and plume interface height, species concentrations, detector/sprinkler activation and fractional effective dose.

3.4.1 Input Data Required to Run the Model

All of the data required to run the BRANZFIRE model reside in a single input file that the user generates.

The file consists of the following information:

- Simulation time (seconds)
- Compartment dimensions (height, length, width)
- Test room environment (Inside and outside room temperature, Relative humidity)
- Test lining materials of the walls and ceiling.
- Test material properties (e.g. density, specific heat, heat of combustion, thermal conductivity, thickness, emissivity)
- Dimensions and positions openings such as windows, doors and vents.
- Mechanical ventilation conditions
- Fire properties (e.g., object location, heat release rate, CO_2 YIELD, Soot Yield)
- Sprinkler and detector specifications
- Sizes, positions and characteristics of materials at targets

The input data are provided for the validation exercises described in the study report. A complete explanation of the input data needed can be available in the BRANZFIRE User's Guide.

3.5 Simulation of ISO 9705 Test Room

The ISO 9705 test was modelled using BRANZFIRE, Version 2012. The computational works for the room corner test, as described in Fig. 3.1. BRANZFIRE predictions use the nominal steady heat release rate from the room corner experiment (100 kW for the first 10 minutes followed by 300 kW for a further 10 minutes) and propane fuel was chosen as the ignition source. The thickness of polycarbonate material in the walls and ceiling was taken as 74 mm. The heat of combustion OF fuel as 43.7 kJ/g, the radiant loss fraction was given as 0.3, the CO_2 yield as 2.34 g/g and the soot yield as 0.024 g/g. The burner positioned in such a way that at the corner of the room, in contact with two rear walls and burner elevated to height of 0.3 m above the floor. The modelling conditions used in BRANZFIRE were; simulation time – 1200 s, Interior and exterior temperature of test room as 23 °C and a relative humidity of 50 %. Compartment specification are as per the ISO 9705 standard. The thermal properties of polycarbonate inputted in model with a thermal Conductivity: 0.00020 kW/(m °C), Specific Heat - 1.2 kJ/(kg °C) and Density -1200 kg/m^3. Propane burner (C_3H_8) selected as ignition source with a heat of combustion of 43000 kJ/kg. Table 3.2 shows the polycarbonate material properties taken for the simulation.

Table 3.2 Lining material properties

Property	Value
Thermal Conductivity (W/mK)	0.20
Density (kg/m^3)	1200
Specific heat (J/kgK	1000
Emissivity	0.88
Minimum surface temperature for flame spread (°C)	0
Flame spread parameter (kW2/m3	0
Heat of combustion (KJ/kg)	20.6
Soot yield (g/g)	0.091
H_20 yield (g/g)	1.6
CO_2 yield (g/g)	1.65
Thickness (mm)	74

Chapter 4

Result and Discussion

A comparison of the heat release rate and temperature raise in the ISO 9705 test room were measured in the experiments with the BRANZFIRE. Table 4.1 shows the predicted values over the 20-minute period of the test. Fig.4.1 shows a comparison of the experimental heat release rate (HRR) and the BRANZFIRE simulations of polycarbonate material. The experimental and BRANZFIRE simulation, heat release rate shows an initial quick increase changing to a lower slope about 50s after ignition. Observations indicate that flashover as indicated by flame passing through the door occurred at approximately 14 minutes 52 seconds in real scale experiment in CSIRO Laboratory. An initial heat release rate peak of 1040 kW at 680 seconds was measured with a secondary peak recorded to be 1704 kW at 910 seconds at the time of manual sprinkler suppression for the experiment. In simulation the 1 MW for the flashover was attained at 766s. It was the initial peak in the simulation, after that HRR went for raise of 1478 kW at 1052 (17 minutes and 51 seconds). From this peak the HRR value reached at 1125 kW at the end of the simulation. From the comparison of both experiment and simulation data a difference of 86s found and it is acceptable.

Table 4.1 BRANZFIRE simulation outputs

Time (sec)	**Temperature (°C)**	**HRR (kW)**	**CO_2 (%)**	**CO (%)**
0	23	0	0.03	0.00
50	161.78	100	1.5	0.00
100	206.57	145.39	1.55	0.01
150	208.46	130.97	1.51	0.01
200	187.55	107.8	1.59	0.01

250	185.75	105.42	1.62	0.01
300	186.57	105.06	1.62	0.01
350	187.61	104.75	1.62	0.01
400	188.42	104.15	1.62	0.01
450	188.69	103.27	1.62	0.01
500	189.31	102.92	1.62	0.01
550	190.03	102.63	1.62	0.01
600	190.71	102.41	1.62	0.01
650	339.49	373.6	3.3	0.01
680	381.1	458.39	3.14	0.01
700	413.45	528.58	3.01	0.02
750	520.58	826.69	2.63	0.03
800	650.54	1234.51	1.35	0.16
850	679.09	1104.36	0.15	0.16
900	683.16	857.66	0.04	0.06
950	696.71	1042.47	0.07	0.03
1000	719.03	1396.01	0.5	0.02
1050	738.36	1445.62	0.89	0.02
1100	732.72	1359.81	0.98	0.02
1150	718.65	1260.59	1.04	0.01
1198	692.36	1130.6	1.13	0.01

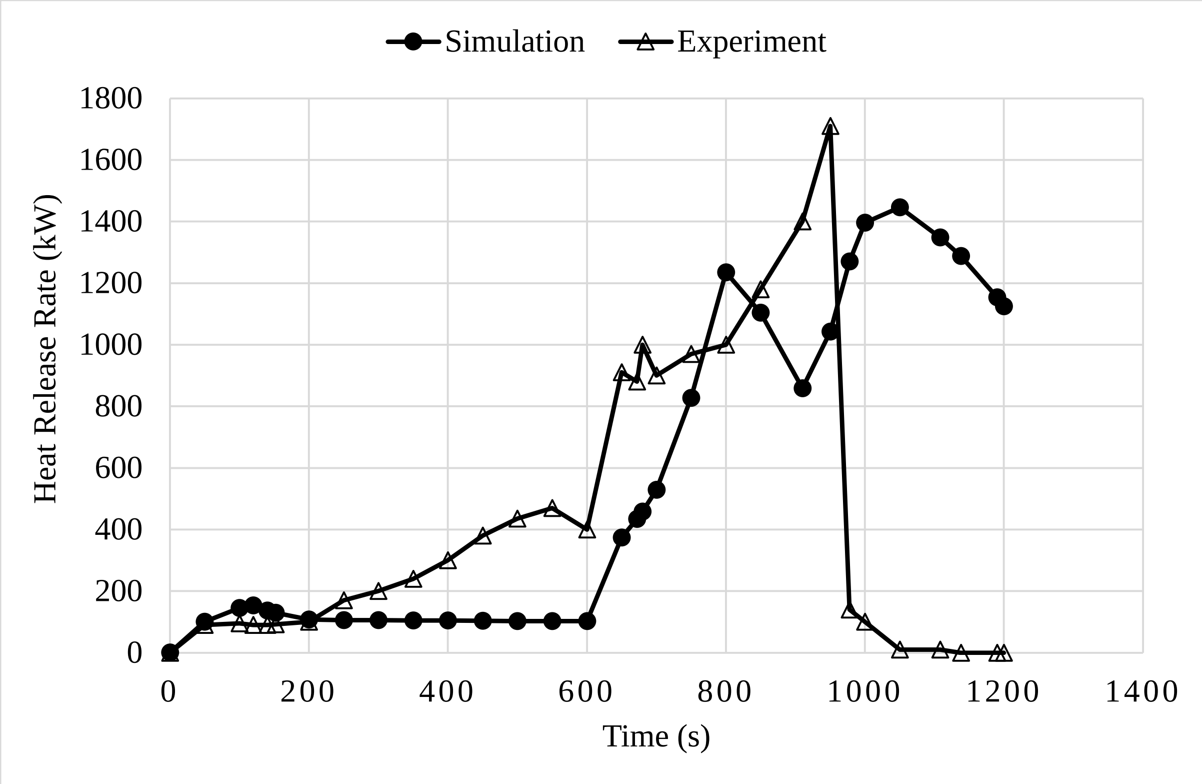

Figure: 4.1 Rate of heat release during test (Experiment & BRANZFIRE Simulation).

Fig. 4.2 shows the comparison the experimental temperature raise the ISO 9705 test room with simulation data. Both experimental and simulation data had a steady growth of temperature up to 150s. In CSIRO experiment the temperature raise found gradually up to 910s, after that the temperature came to low suddenly due to activation of sprinkler. In the simulation the temperature inside the test room found constant at the rate of approximately 200°C from 200s to 600s. When the heat release increased to 300kW the temperature also raised and reached to a peak of 744 °C at 1052s. The temperature condition of flashover 600°C attained at 774s in the simulation and in the real scale experiment this value reached approximately at 900s. So that the difference found 126s for the flashover condition for temperature in simulation and lab test.

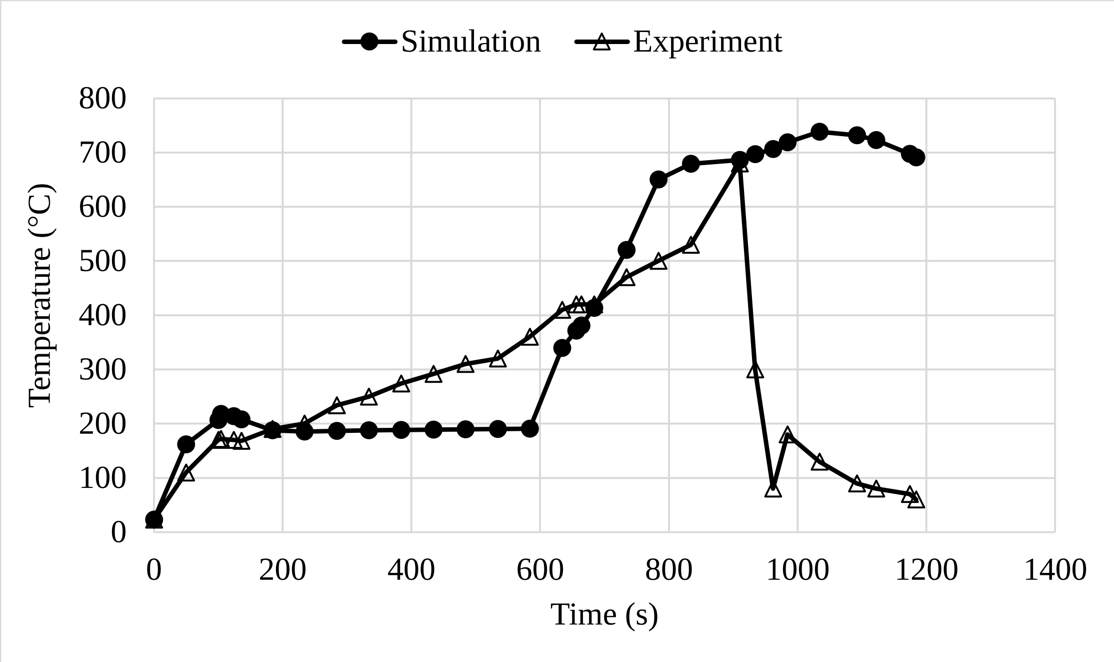

Figure: 4.2 Upper layer temperature (Experiment & BRANZFIRE Simulation).

Carbon monoxide (% volume concentration) is shown in Figure 4.3. The simulation result from BRANZFIRE software shows a good agreement with CSIRO result. In both cases the percentage of carbon monoxide concentration start increasing at a time of 650 s. It indicate that the raise was happened after the heat release rate of 300Kw. In simulation maximum CO concentration reaches at 850 second with a volume percentage of 1.6, and in the experiment the maximum value of 1.8 found at 910 s.

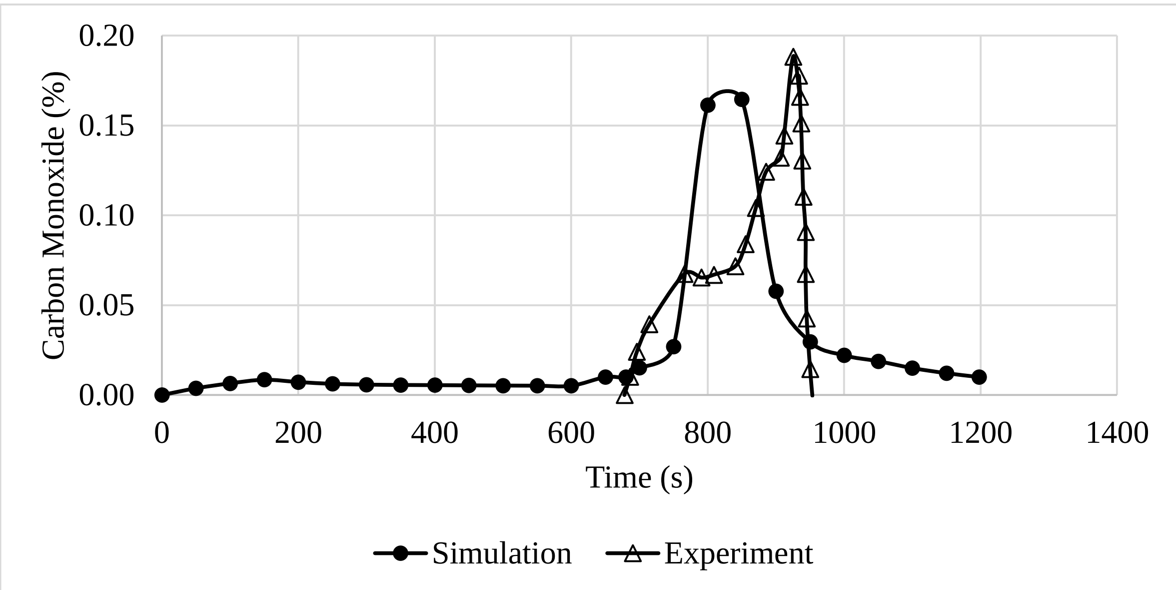

Figure: 4.3 CO concentration (Experiment & BRANZFIRE Simulation)

Figure 4.4 shows the comparison of experimental and BRANZFIRE Simulation results of percentage volume concentration of carbon dioxide production during the ISO 9705room corner test. The maximum values for CO_2 concentration reached at 650 s and 910 s in simulation and experiment respectively.

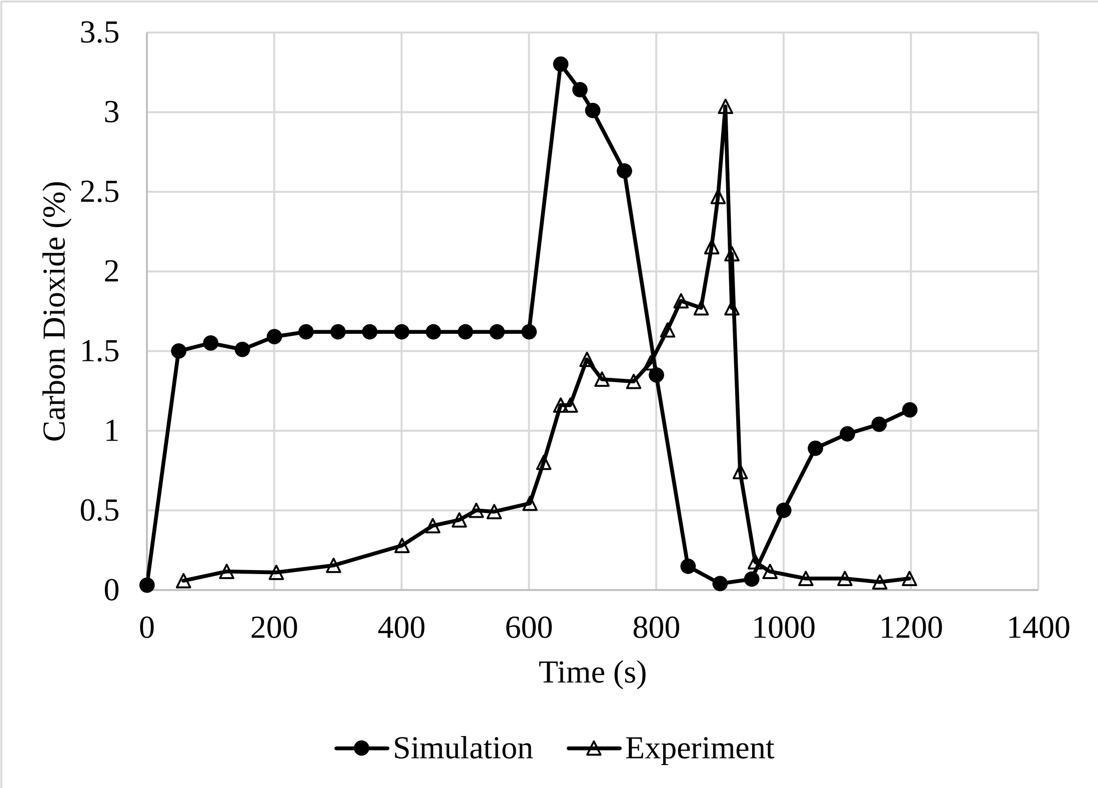

Figure: 4.4 CO2 concentration (Experiment & BRANZFIRE Simulation)

Chapter 5

Conclusion

The present work of Numerical Simulation of Room Corner Test for Polycarbonate deal with two aspect, first the numerical simulation of ISO 9705 room corner test using BRANZFIRE software and second, comparison of CSIRO real scale experiment results with simulation results. The most specific conclusions of the present work are as follows:

- Numerical simulation of ISO 9705 room corner test for forever bright E610 polycarbonate panel was performed in BRANZFIRE and compared with CSIRO Laboratory test results.
- A new test model has been developed and assessed using experimental data and simulations has done.
- The model enables fire propagation simulations in the standard ISO 9705 test room.
- The test result for Everbright E610 polycarbonate panel, in both real scale experiment and numerical simulation of ISO 9705 room fire test shows that the material can be classified in to Group 2.
- In the CSIRO Laboratory test shows that the flashover condition of 1MW attained in 680s, and in the simulation data shows the flashover time at 766s. So both the data lead to material classification in to Group 2.
- The predicted simulation results of BRANZFIRE has shown good agreement with the experimental results.
- From the information of experimental data and simulation data it can be concluded that fire growth on linings in CSIRO test is similar to the results obtained using BRANZFIRE if the walls or the walls and ceiling are lined with polycarbonate material.

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