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Zonal Analysis for LNG Terminal Containment Storage Tanks

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Abstract- A zonal risk analysis framework is developed in this work upon estimating the potential risks of liquefied natural gas (LNG) terminals using risk identification methods. Quantified results shows that LNG containment safety plays an important role in the overall safety of a typical LNG terminal. Zonal analysis is used to identify failures due containment in the same zone. Firstly, an overview of LNG safety is highlighted. Secondly, a detailed zonal analysis methodology is presented. Lastly, a sample finding in the application of zonal analysis is presented with additional reflections on the implementation of this qualitative method with regards to its advantages and limitations.

Keywords- *Risk Analysis, Safety, Containmen, Zonal Analysis*

I. Introduction

Switching to the use of low carbon energy such as LNG to combat climate change is of great importance to developing countries. The increase in demand of LNG in developing countries in Africa due to the need to meet the increase demand for power generation has led to the recent rapid construction of LNG terminal in the region [1]. Ghana a sub Saharan African country have over two decades produced power with LNG [2]. The primary means of gas supply to Ghana is currently via the West African gas pipeline, which makes landfall at Tema and Aboadzeb [3]. The increase demand to meet both domestic and industrial needs in Ghana has led to the present construction of the Tema LNG terminal which is a complex terminal with high risk to its working environment and surroundings. Zonal analysis (ZA) is an important safety risk analysis use in the design stage of critical components of LNG terminals. With the development of technology and the rapid demand of LNG around the world, it is increasingly complicated to rank the safety of large scale systems such as LNG production units. LNG terminals and operations are highly integrated design modes with induced stronger interactions that affects both the system and sub-system bringing hidden troubles to the safety of structural zones [4]. ZA is the systematic inspection of the geographical locations of components and interconnections of a system, evaluating of potential system – to system interactions with and without failures, and the assessment of severity of potential hazards inherent in the system installation [5]. ZA is important in identifying quantified risk with less time and efforts than other methods.

II. LITERATURUE REVEIW

A. *LNG Operation and Safety Regime*

Reference [6] carried out a research to estimate potential risks of LNG terminals using layer of protection analysis and Bayesian estimates to update information when available due to scarcity of data. The results of this analysis present the use of layer of protection analysis as a tool to represent result in less time and efforts. Reference [7] focused their research on nautical risk assessment for LNG using quantitative approach in line with collision and grounding risk assessment in the LNG area. Reference [2] presented a paper on integrated risk assessment framework for LNG terminals using basic risk assessment steps. Results from this assessment showed the need to improve design options for LNG terminals. Reference [8] summarized the public risks in LNG commerce using risk analysis process and a hypothetical LNG accident scenario for mapping. The authors studied the probability of LNG carrier rupturing taking into consideration the wind speed and appropriate fatalities in case of possible ignition. Reference [9] use a multiple attribute risk assessment approach to rank the risk of LNG carriers during loading and offloading at terminals. The developed method modelled decision maker's attitude towards risk by the use of semi - quantitative risk assessment approach using a software tool to for the ranking of alternative risk control measures. Reference [10] carried out a research on safety assessment of LNG terminal focusing on the consequence analysis of LNG spills, whilst reference [11] focused their risk analysis on LNG carrier operation with thorough review of historic LNG accidents and expert judgments for critical accident scenarios analysis. Reference [12] presented a paper on LNG decision making approaches identifying the hazards associated with LNG handling activities. The results of this analysis presented results from a maximum credible event approach comparing results from several models with larger scale experimental trial. Basic and advance risk analysis has been applied in other related industries ranging from marine technology to energy technologies, terminal station, siting standard, membrane type storage tanks, pipelines and regional electrical grids [13, 14, 15, 16, 17 & 18]. In the LNG industries in particular, accidents with fatalities have been registered around the world initiating public fears and controversy in LNG safety hence the need of the use of zonal analysis for systematic inspection of the interconnections of certain critical components in a typical LNG terminal as presented in Figure 1 showing the vaporizers, air compressors, storage LNG tanks, blower, primary & booster pumps, boil off compressors, and the unloading arms.

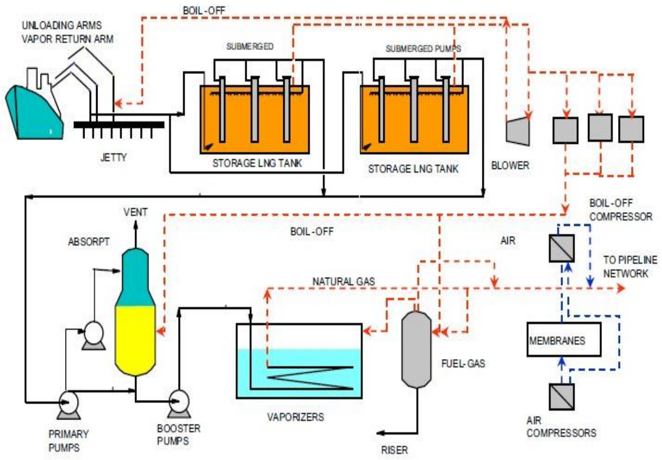

Figure 1. Typical onshore LNG terminal operation [2]

An onshore LNG terminal comprises of jetty, storage, boil-off recovery and vaporization [2]. The jetty is composed by the docking area for LNG ships and equipped with unloading arms. A pipeline goes along the jetty to the storage tanks and permits the LNG transfer [2]. The storage section is composed of two double containment tanks and three submerged pumps delivering LNG from the tanks. The boil-off recovery section is composed by cryogenic compressors and a blower. The role of the compressors is to recover boil-off gas generated during the normal operation and the unloading phase, and transfer it to the recondenser [2]. The vaporization section is composed by four vaporizers with primary and booster pumping systems. High pressure natural gas exiting the vaporizer is transmitted to the pipeline network [2]. The hazards identify in this system for the purpose of research include, loss of containment in storage tanks, LNG release, environmental pollution, and collision.

LNG storage tanks are usually very strong, as they in general consist of a cryogenic inner tank, insulation, load bearing outer tanks of carbon steel and/or concrete as seen in Figure 2 [19]. Once the inner tank has failed it is unlikely that the carbon steel outer tank will be able to withstand the thermal shock, hence the need for diked areas [19]. Tank designers have anticipated many of the stresses that can lead to tank failure, and the modern tank is vulnerable to perhaps only a direct aircraft strike, and a prolonged fire at close proximity [19]. Typical tank failures include catastrophic failure of inner tank leading to outer roof collapse, partial fracture of outer roof due to over pressurization, catastrophic rupture of primary and secondary containment and serious leakage form inner tanks [20]. Various risk assessment methods have been used in developing master logic diagrams on the various interactions between the system and subsystem of an LNG terminal particularly with the identified hazards. The results of the risk assessment leads to proposed relevant risk control measures that can prevent these fire from happening in the future. However, decision makers, operators and designers are faced with detailed analysis of which risk assessment may become a burden in some cases. Research has shown the importance of using zonal analysis as an efficient method to identify potential hazards in engineering system analysis, hence helping designers of LNG storage tanks to optimise their designs and in decision making process. Table 1 presents accidents in the LNG industry in Nigeria, USA, and Trinidad & Tobago.

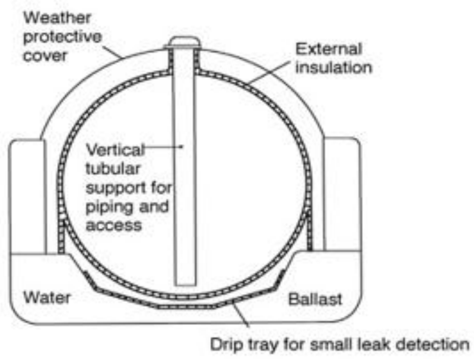

Figure 2. LNG storage tanks [20]

TABLE I. TYPICAL LNG ACCIDENTS [21,22]

Date	Ship/ Facility Location	Description
2000	USA	Lost control in the Savannah River and crashed into the LNG unloading pier at Elba Island. The Elba Island facility was undergoing reactivation but had no LNG in the plant. The Sun Sapphire suffered a 40-foot gash in her hull. The point of impact at the terminal was the LNG unloading platform. The LNG facility experienced significant damage, including the need to replace five 16 inch unloading arms
2004	Trinidad & Tobago	A gas turbine at Atlantic LNG's Train 3 facility exploded
2005	Nigeria	A 28 inch LNG underground pipeline exploded in Nigeria and the resulting fire engulfed an estimated 27 square kilometres
2008	USA	LNG tanker Catalunya Spirit loses propulsion. Tugs called upon to save the ship from foundering

B. *Zonal Analysis*

Reference [23] presented an innovative tool, the use of zonal safety analysis method that applies to future products in conceptual design and discusses the results of the application of zonal analysis to two different configurations of the electric secondary power system. Also, other researchers proposed an improved zonal safety analysis stating that ZSA method is not specific or definite enough to implement [24, 25]. In this research, hazard sources including both energy factors and failures of system hardware were analyzed [24]. Risk analysis was introduced to formulate rules of ZSA with an illustrative example using the undercarriage system on a certain airplane. Lastly, reference [25] presented a paper on an approach that combines the techniques for considering the interactions of logically unrelated systems in the same physical part (zone) of an aircraft with those able to identify failures that occur when multiple instances of a redundant system fail almost simultaneously, generally due to single cause. ZA is an analysis of the physical arrangement of the system and its elements in its installed or working area [25]. It complements many of the safety analysis approaches which examine only functions of systems, by considering functionally unrelated systems that are located close together [26]. The technique is used to determine a number of factors such as; determination of compliance with design rules e.g. correctly supported and mounted pipework, or cabling to reduce stress during operation, identification of potential cascade failures due to system interaction, identification of potential areas for system maintenance errors and identification of potential areas for system malfunction due to the environment [26]. It examines the layout of systems to determine whether the actual location of the equipment introduces a hazard, for example, placement of an aerial on a ships mast, or an electrical junction box mounted below a water pipe. It is also used to determine whether a fault at a particular location can affect the independence of the equipment [26].

III. METHODOLOGY

The aim of zonal analysis is to provide a detailed knowledge of the risk of occurrence of hazardous failure in a given area and the risk of propagation of a local effect to the whole area and possibly beyond. The basic scheme of a ZA is as follows: define the objective of the study (e.g. a type of hazard): for each zone, carry out an inventory of hazardous materials in the zone; collect data relative to process, segregation/separation criteria, detection / alarms, and emergency response; assume occurrence of failure and assess local and end effect as well as likelihood; and deduce risk picture for each zone [24]. The first step in zonal analysis is preparatory study with inputs by experienced maintenance experts, and LNG terminal operational level requirements and objectives. Again, hazard source analysis which include preparing list of components in zone using installation drawings and system description [24]. Second step is an analysis to determine interaction among equipment in a zone scenario model coupling hazard factors using intrinsic hazards. This also include examining the zone for effects in adjacent system [26]. The final step will include consequence of hazard, occurrence possibility of hazard and comprehensive assessment of hazards [19]. This leads to determining the effect on LNG terminal. The final report is the zonal analysis report requesting for corrective actions and design modification [24]. These reliant on the knowledge and experience of those persons compiling the lists and whilst they could provide significant safety benefits for systems and equipment, they depend heavily upon the ability of the analyst(s) [19]. Other hazards such as LNG release from equipment or pipeline caused by random phenomena such as wear and corrosion can lead to fire also need to be addressed using zonal analysis [19]. Typical hazard identification in a typical LNG loss of containment is presented in Table 2 which include structural failures, internal process failure, internal tank leads, corrosion, and over pressure.

TABLE II. LOSS OF CONTAINMENT HAZARD IDENTIFICATION

LOSS OF CONTAINMENT		
Structural failure Internal and process related	Loss of boundary containment bypass	Natural hazard
Inner tank leak Over pressure Cooling malfunction Under pressure Boil off removal malfunction Corrosion & collision	Overfilling Open when operation starts Open during operation	Seismic hazard Land Storm surge and flooding Earthquake

IV. ILLUSTRATIVE EXAMPLE

The main storage tanks of an LNG onshore terminal was taken as the zone investigated. The selected zone has limited space, with complex designs and factors that can lead to failure of the storage tanks as highlighted in Table 2. Hazard source and inputs from preparatory study such as consultation with experts, maintenance checklists were used to identify hazards scenarios. The Tema LNG terminal under construction was useful in getting detailed situational analysis and effects of storage tank failure or containment hazards. Zonal analysis is helpful in identifying possible common hazard causes in LNG terminal due to loss of containment. The interaction among equipment within the LNG storage tanks zone was helpful in identifying hazards using the three step approach in zonal analysis. Then, the risk of zonal hazard in a typical LNG onshore storage tank was evaluated and ranked. A part of the zonal analysis results are shown in Table 3. Identifying the routes by which hazards may spread in the LNG terminal may help develop control measures, and effects changes in design to reinforce compliances. A storage tank in operation may encounter natural hazards such as seismic, surge storm, lighting and flooding. Again if the storage and pipes are submerged underwater, it is possible for buoyancy force to lift the pipes or tanks causing damage. Hence it is imperative for the terminal site and design of the facilities to be located where no such special risk due to natural hazard may occur [19]. External hazards may include aircraft contact, fire, explosion or collision during operation. The LNG may be exposed to radiations and fire effects as well as explosion overpressure effects including flying debris arising from ignition of flammable gas leak in process units located adjoining an LNG tank or neighbouring facilities [19]. It is therefore necessary for the outer concrete structure of a full containment tank be resistant to external fires. Internal hazards may include; loss in containment can be due to catastrophic failure of inner tank leading to outer roof collapse; partial fracture of outer roof due to over-pressurization; catastrophic rupture of primary and secondary containment and serious leakage from inner tank [19]. Operational hazards may include overflow of tanks, lack or malfunctioning of detection devices, and rollover due to stratification i.e. the formation of two distinct layers of different density may occur due to boil off.

TABLE III. ZONAL ANALYSIS REPORT

Hazard	Cause	Who is at risk	Control measure	Risk after control			Additional risk control required	Residual risk		
				Severity	Probability	Rating		Severity	Probability	Rating
Over fill and inner tank leak	Filling tanks above their capacity leading to overflow into the annular space between the inner tank and the outer tank	Equipment	Identify specific tank to receive cargo high level alarm is fitted	5	2	Medium	Continuous level measurement on tank	2	1	low
Under pressure	Pump-out of liquid leads to variation in atmospheric pressure causes increased compressor suction due to control malfunction	Equipment	Low pressure alarm is fitted Continuous monitoring of tank pressure by duplex gauge	5	2	Medium	Low-low pressure will trip the boil off gas Compressors and in-tank pumps Vacuum relief valves are provided which are typically sized for maximum vapour flow arising from compressors and pumps in operation	2	1	low

V. RECCOMENDATION & CONCLUSION

Zonal analysis report presented in Table 3 provides a detailed knowledge of the risk of occurrence of failure due to filling tanks above their capacity leading to overflow. The given area of analysis is LNG storage tanks with focus of the annular space between the inner and outer tank and a method of pumping out of liquids. The risk of propagation of the local effect to the whole area leads to variation in atmospheric pressure which causes increased compressor suction due to control malfunction. This report helps in identifying operational hazards and preventive measures to be put in place. It further identifies the causes of hazard, who is at risk, control measures, risk after control, additional risk and residual risk. This provides the needs for corrective actions and design modification for a typical LNG terminal storage tanks. The residual risk and the after risk control provides a guide rating on which areas corrective measures are to be concentrated. The operational failure of filing tanks above their capacity leading to overflow into the annular space between the inner and outer. This report provides a brief overview of zonal analysis to be used to identify critical components in LNG terminal operations. This illustrative example on two (2) possible hazards in LNG storage tank can be extended to all high risk areas identified and with the results useful to change the maintenance procedures. A proper risk control measures can also be put in place to help improve operational manuals. The result of this report can also be of benefit to LNG storage tank designers.

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