The Application of the Fault Tree Analysis Principle in the Seismic Secondary Fires Disaster of Storage Tanks

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SUMMARY:
The fire disaster of storage tanks is serious secondary disaster after earthquake. The big disasters were induced by storage tanks fire in the Niigata Earthquake (Japan 1964) and Izmit Earthquake (Turkey, 1999). In this paper, the fault tree analysis model was built on the basis of studies on the seismic secondary fire disaster of storage tanks. There are two necessary causes leading to the fire event. One is the leakage of liquid inside tanks. Another is the source of light fire in the surroundings of leakage liquids. Therefore, some main factors(the damage degree of storage tank and its subsidiary facilities after earthquake, the damage of electric system, the collisions because of vibration, etc) induced fires were considered in the process of building model. Then, the model was applied in the fires risk assessment of storage tank after earthquake. It is helpful to assistant make decision in the earthquake prevention and disaster reduction works of cities.

Keywords: the Secondary Fire Disaster, Fault Tree Analysis principle, Storage Tank

1. INTRODUCTION

The seismic secondary fire is a common disaster after destructive earthquake. The huge losses of the people’s life and property are caused by the earthquake and induced secondary fire disasters. The loss of secondary fire is even more than the loss induced by the earthquake in some time.

The oil depot and tank farm are the important areas for preventing seismic secondary fires in cities. The enormous losses people’s life and property will be induced storage tank fires after earthquake. There were examples of tank fires in the past earthquakes. The fires were induced by the leakage of oil in the oil depot in the Niigata Earthquake (Japan 1964). 5 oil depots and some residences were burned down in the fire. The most dramatic fire was at the Tupras oil refinery in Izmit Earthquake (Turkey, 1999). The tank farm fire enveloped 6 tanks, with the ensuing heat damaging other tanks as well. The fire lasted 3 days and nights.

In recent years, the demand of finished product oil increases day by day with the development of economy in China. The scale and amount of storage tanks also significantly increase. The oil depot is the business enterprise of the oil storage and sales. It is important function in the market supply of oil. The huge losses of people production, living, property will be induced by oil tank fires after earthquake especially destructive earthquake occurrence. The fault tree of storage tank secondary fire is established in the paper. The cause of storage tank secondary fire is analyzed and the precautions are given. It is very important to preventing the secondary and daily fire of tank farm, guaranteeing the safe production of oil depot, supplies of product oil market and developing the region economy.

2. THE PRINCIPLE OF FAULT TREE ANALYSIS

Fault tree analysis (FTA) techniques were first developed at Bell Telephone Laboratories in the early 1960's. Since this time they have been readily adopted by a wide range of engineering disciplines as one of the primary methods of performing reliability and safety analysis.FTA is a top down, deductive failure analysis in which an undesired state of a system is analyzed using boolean logic to combine a series of lower-level events. This analysis method is mainly used in the field of safety engineering and reliability engineering to determine the probability of a safety accident or a particular system level (functional) failure.

Fault trees graphically represent the interaction of failures and other events within a system. Basic events at the bottom of the fault tree are linked via logic symbols (known as gates) to one or more TOP events. These TOP events represent identified hazards or system failure modes for which predicted reliability or availability data is required.

Fault tree diagrams (FTD) are logic block diagrams that display the state of a system (top event) in terms of the states of its components (basic events). Like reliability block diagrams (RBDs), fault tree diagrams are also a graphical design technique, and as such provide an alternative to methodology to RBDs.

An FTD is built top-down and in term of events rather than blocks. It uses a graphic "model" of the pathways within a system that can lead to a foreseeable, undesirable loss event (or a failure). The pathways interconnect contributory events and conditions, using standard logic symbols (AND, OR etc). The basic constructs in a fault tree diagram are gates and events, where the events have an identical meaning as a block in an RBD and the gates are the conditions.

FTA involves five steps. Obtain an understanding of the system, Define the top event to study, Construct the fault tree, Evaluate the fault tree, qualitative analysis and reliability evaluation.

3. THE SEISMIC DAMAGE EXPERIENCE OF STORAGE TANKS

It should know the damage characteristics of storage tanks in earthquake for applying FTA to storage tanks secondary fire firstly. The leakage of oil is indispensable for the secondary fire of storage tanks. The seismic damage of storage tanks and its’ subsidiary conjunction facilities is the main cause of leakage of oil. There are several main damage forms induced leakage by summarizing the seismic damage experience of storage tanks in history earthquakes. One is " elephant foot type failure " of the tank wall bottom and rhombus un-stabilization of tank wall. It results in the serious outside bulging of tank wall. One is the breach between crest and wall conjunction of tanks. One is the damage of weld seam between the bottom board and anchor firmware. The storage tank fire is induced by the damage form in Niigata Earthquake (Japan 1964). One is the damage of oil pipe joint and tank’s attachment. Another is the damage and un-stabilization of tank induced by the foundation settlement and liquefaction in soft soil.

These damage forms don’t always result in the leakage of oil of course. It is possible to leakage especially when the damage is more serious. Then, the fire of tank may occur.

4. CONSTRUCT THE FAULT TREE OF STORAGE TANK SECONDARY FIRE

The causes and logic relation of storage tank fires were known on the basis of analyzing the datum of tank secondary fires and daily fires. Then, the top event (storage tank secondary fire) of fault tree was determined. The direct cause of tank secondary fire is the leakage of oil that is induced by the damage of tank and its’ subsidiary conjunction facilities in earthquake. The collision sparks can be taken place because of the vibration frequency inconformity between equipments at the same time. Moreover, electric sparks easily be seen because of the damage of electric appliances equipments on the earthquake spots. The probability of open fires in earthquake is more than in normal times as a result of flurried peoples. All of those demonstrated that the sources of catching fire were obvious on the increase in earthquake. The next events were determined by using the gradually logic inference method on the light of considering the characteristics of tank secondary fires. The logic relations of top event and all basic events were given on the analogy of this. Then, the fault tree diagram of storage tank secondary fire was constructed. The detail tree diagram is seen in the **Figure 1.**

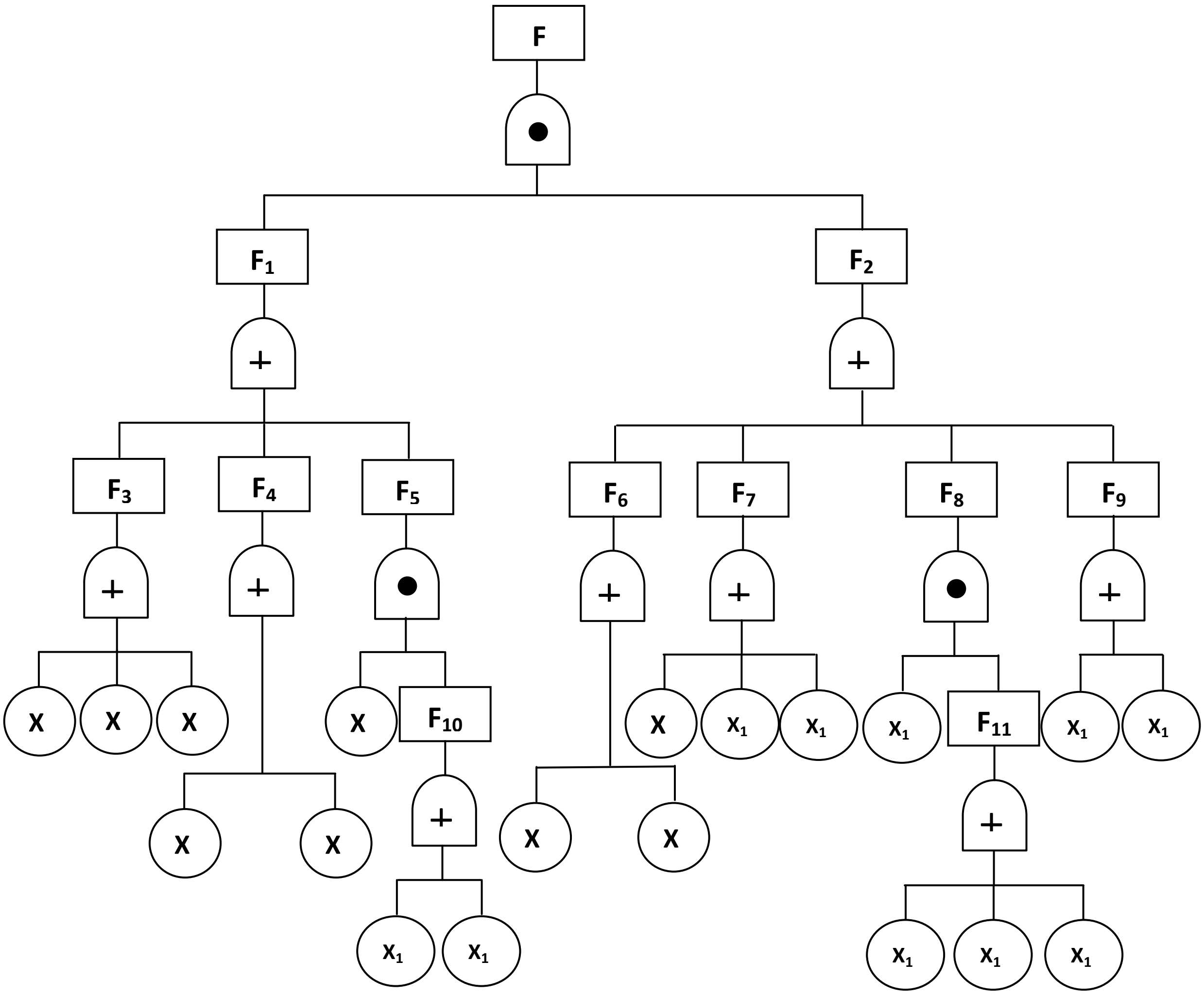
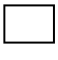
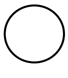
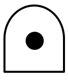


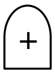
Figure 1. Fault tree diagram of storage tank secondary fire

In the **figure 1**, the symbols are used to represent various events and describe relationships

 "Rectangle" represents top event and middle events.

 "Circle" represents basic events.

 "Logic or gate" represents a situation in which any of the events shown below the gate (input gate) will lead to the event shown above the gate (output event).

 "Logic and gate" represents a situation in which any of the events shown below the gate (input gate) must be present for the event shown above the gate (output event) to occur.

In the tree diagram, there are 31 events. *F* stands for the top event, F_1~F_{11} stand for the middle events. X_1~X_{11} represent for basic events. The events and its' mean are shown in table 1.

Table 1. the Events of Fault Tree of Storage Tank Secondary Fire

Symbols	Events	Symbols	Events	Symbols	Events
F	Storage tank secondary fire	F_{11}	Failure of arrester	X_{11}	Others collision
F_1	Leakage of oil	X_1	Angulation of tank body	X_{12}	Ceraunograph
F_2	Source of catching fire	X_2	Fissure of tank body	X_{13}	Spark of vehicle tail gas
F_3	Leakage from tanks	X_3	Damage of tank body seal	X_{14}	snipe
F_4	Leakage from valve and flange	X_4	Damage of valve and flange	X_{15}	Damage of Electric systmen
F_5	Leakage from pipe	X_5	Displacement of tank body	X_{16}	Damage of control system
F_6	Electrostatic spark	X_6	Damage of pipe	X_{17}	No arrester
F_7	Collision spark	X_7	Electrostatic discharge in earthquake	X_{18}	Damage of arrester
F_8	Electric spark	X_8	Electrostatic discharge of tank body	X_{19}	Disconnection of earth wire
F_9	Open fire	X_9	Collision between tank body and facilities		
F_{10}	Failure of control system	X_{10}	Collision between tank body and ground		

5. QUALITATIVE ANASLYSIS OF FAULT TREE OF STORAGE TANK SECONDARY SECONDARY FIRE

The analysis task is how to solve the whole least path sets and least cut sets in the fault tree of storage tank secondary fire. Least cut sets is fewer than least path sets if there are "and gate" more than "or gate" in fault tree. It shows the system relative safety. The system is relative dangerous on the contrary. There are 3 "or gate" and 9 "and gate" in the fault tree. So the qualitative analysis had better starting with least path sets. Least path sets represent necessary the lowest path sets that the top doesn't occur.

There are 4 least path sets in fault of storage tank secondary fire. The details are shown as followed.

$$P_1 = \{X_1, X_2, X_3, X_4, X_5, X_6\}$$

$$P_2 = \{X_1, X_2, X_3, X_4, X_5, X_{15}, X_{16}\}$$

$$P_3 = \{X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, X_{13}, X_{14}\}$$

$$P_4 = \{X_7, X_8, X_9, X_{10}, X_{11}, X_{17}, X_{18}, X_{19}, X_{13}, X_{14}\}$$

4 least path sets provide 4 countermeasures for taking precautions against storage tank secondary fire on the visual point of view. To prevent P_1 occurrence is an economic method investigating 4 least path sets. To prevent P_1 is need to prevent X_1, X_2, X_3, X_4, X_5, X_6 occurrence. But the 6 events are induced by the damage of tank body and its' subsidiary conjunction facilities in earthquake. Therefore, to provide the anti-seismic ability of storage tank and to increase anti-seismic measure are the basic means for mitigating the secondary fire of storage tank.

6. CONCLUSION

The fault tree of storage tank secondary fire is established on the basis of the macroscopic seismic damage experience of storage tanks in the paper. There are 31 events, 3 “or gate” and 9 “and gate” in the tree diagram. Then, 4 least path sets are given by analyzing the fault tree. Those least path sets can provide scientific basis for controlling the storage tank secondary fire. The main causes resulted in storage tank fire are determined by analyzing the event importance degree. Some main causes include the leakage of oil induced by the damage of tank body and its’ subsidiary conjunction facilities, the collision spark in unconformity vibrations and the electric spark induced by the damage of electric system, and so on. Then, the appropriate precautions measures can be taken to decrease the probability of storage tank secondary fire.

FTA is a simple, clear and direct-vision method for effectively analyzing and estimating accidents. It is also a centre link for evaluating reliability and safety analysis. In the paper, FTA is adopted to evaluate the storage tank secondary fire. It is an attempt on seismic secondary fire. The result of safety evaluation can be given by combining the seismic response analysis of storage tanks.

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