# LNG Loading Lines Surge Analysis for ESD System Application

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***Abstract*— PT BADAK has recently implemented an Emergency Shutdown System (ESD) for the ship LNG Loading Arms. When the ESD System activates, it creates a pressure surge on the LNG Loading Lines, which may exceed the design pressure, therefore, it may lead to a failure of the Loading Lines. To overcome this pressure surge, the ESD system initiates several sequential actions to protect the line from severe surge pressure. Nevertheless, if the ESD system malfunctions, the resulting surge pressure has been found to be higher than the pipeline design pressure. PT BADAK performed some data collection and analyses for several cases of the ESD activation scenarios to obtain the maximum surge pressure. Then, the collected data of the surge pressure is compared to the design pressure of the LNG loading lines. The result shows that at in some cases the maximum surge pressure exceeds the initial design pressure. To overcome this problem, additional surge protection devices need to be installed to avoid LNG loading line failures due to ESD activation. This paper will present the initial Loading Line design specifications, a brief discussion of the ESD function, data collection results of the pressure surge due to ESD activations, and discuss the additional protection systems that are required to avoid Loading Line failures due to surge pressure.**

***Index Terms*—LNG, surge, emergency, shutdown, ESD**

## I. Introduction

The LNG loading line piping system consists of transfer lines from the storage tanks to the loading arms for transferring LNG to the ship vessels. The piping system contains loading pumps at the storage tanks, transfer valves for optimal arrangement of LNG distribution, expansion bellows for thermal expansion protection and loading arms for transferring LNG to the ship vessels. In addition, an emergency shutdown (ESD) system is provided to protect the system in case of emergency.

During LNG loading, the main emergencies that may occur are product leakage leading to a potential fire hazard. In the event of line breakage or fire, emergency shutdown of the storage tank system is initiated from the dock and results in closure of the transfer valves, opening of loading arm's vent valves and shutdown of the loading pumps.

Additional steps can be taken to further secure the storage system by initiating the ESD activation from the main control room. Activating the loading arm ESD system from any location results in the shutdown of the tank loading system as well as the shutdown of each of the LNG loading arms. Each arm is isolated with its own ESD valve, and is vented automatically. ESD valves in the main transfer headers at the dock are also closed. A PERC (powered emergency release coupler) system is also provided to prevent damage to the loading arms in ship movement situations.

The shutdown system when activated initiates a rapid closure of the ESD valves, this sudden change in liquid velocity as the result of the quick closing transfer valves could lead to the built-up of pressure causing surge or liquid hammer within the piping. Since the design pressure of the existing piping system has been limited to 15.5 $kg/cm^2$, the surge pressure built-up as the result of ESD activation must be limited to less than the piping design pressure to avoid LNG loading line failures.

Several cases of LNG loading ESD activation and ESD malfunction possibilities need to be analyzed in order to ensure that the surge pressure does not exceed the design pressure of LNG loading line. In the next section of this paper, the maximum surge pressure of each case will be calculated by applying the AFT (Advanced Flow Technology) Impulse Software. In case of high surge pressure that exceeds the LNG loading line design pressure, additional surge protection must be provided to avoid LNG loading line failures.

## II. LNG Loading Line ESD System

Based on the existing LNG loading line specifications, the ESD system was designed to rapidly respond to emergency cases without exceeding the specified design pressure of LNG loading line, with a 30-seconds closure time for the main transfer valves and pump transfer valves, and a 20-seconds closure time for the loading arm transfer valves. Surge pressure at both the pump discharge check valves and upstream of the ESD valves at the loading dock can be limited to below 15.5 $kg/cm^2G$ when the existing surge protection system works properly.

The shutdown of the loading arms occurs when one or more of the following events takes place (refer to Figure-1) :

1) Manual activation from the Panel in the Loading Dock control room, or DCS in the main control room (in case of product leakage or fire).
2) Automatic activation due to loading arm over-travel (due to ship movement).

Activation of the ESD, will then be followed by the following actions :

1) Closure of the main valve on each loading arm.
2) Opening of the vent valve on each loading arm.
3) Closure of both main transfer valves near the dock entrance.
4) Stoppage of the loading pump in use.

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5) Closure of the pump transfer valves at the LNG storage tanks.
6) Closure of the ball valves in the PERC system.

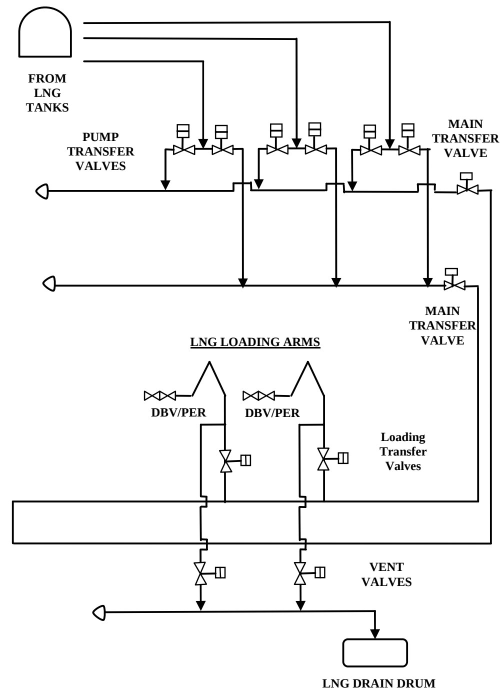


Fig 1. LNG Loading Configuration

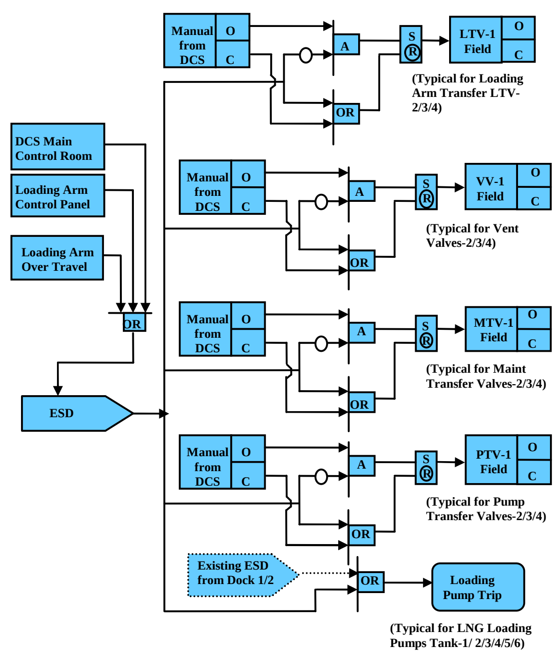


Fig.2. Simplified ESD System Logic

Events 2 and 4, (vent valves opening and the stopping of the loading pumps) are the surge protection actions for the loading lines. Stopping the loading pumps isolates the system liquid volume, while opening the vent valves releases the built up surge pressure due to ESD activation. An alarm indications in the DCS will sound in both the main control room and the loading dock control room, indicating the origin of the trip, (ship or shore).

The shutdown condition will remain in effect until the system is manually reset from the loading dock control room. If the trip was activated by the loading arm over-travel, the PERC will be energized for those arms in service thereby disconnecting the arms from the ship and automatically closing the double-ball valves.

As mentioned earlier, the activation of the ESD system resulting in the quick closing of the transfer valves will generate a pressure surge. The specified valve closure times ensures that the resulting surge pressure will not exceed the LNG loading line design pressure.

However, the surge pressure can only be limited below the loading line design pressure if the ESD system works properly. If the ESD system malfunctions, further analysis to find the maximum surge pressure is required. Additional surge protection must be provided in order to avoid failure of the LNG loading lines.

## III. Surge Analysis of The LNG Loading Line ESD

Surge or liquid hammer, as it is commonly known, is the result of a sudden change in liquid velocity. Liquid hammer usually occurs when a transfer system is quickly started, stopped or is forced to make a rapid change. Any of these events can lead to a catastrophic system component failure.

The following surge analysis of the LNG loading lines was done for both proper and improper (malfunction) ESD system activations. For a proper ESD system activation, the following actions will be initiated :

1) PERC valves close in 5 seconds.
2) Loading arm transfer valves close in 20 seconds.
3) Main transfer valves close in 30 seconds.
4) Pump transfer valves close in 30 seconds.
5) Vent valves on loading arms open in 5 seconds.
6) Loading pumps trip.

The following improper or malfunction of the ESD system were also analyzed :

1) Loading pumps do not trip during ESD activation
2) Vent valves do not open during ESD activation
3) Neither loading pumps trip nor vent valves open during ESD activation.
4) One of the loading pumps does not trip during ESD activation
5) One of the vent valves does not open during ESD activation.

## IV. Analytical Model of the LNG Loading Lines

Figure-3. shows the simplified isometric drawing of the LNG loading lines. Lengths of the pipe segments are rounded to the next multiple of 10 meters corresponding to the requirement of the method of analysis. The farthest storage tanks from the jetty, 24D-1/2 are assumed to be in operation in this analysis, because the longer pipe length, the higher maximum surge pressure will be generated.

The AFT-Impulse Version 3.0 software, is utilized to simulate the transient phenomena throughout the piping system. The analysis results will be tabulated showing the maximum surge pressure for each case of ESD activation. For the surge pressure built up during ESD activation, the time-history of surge pressure is shown on the graphs.

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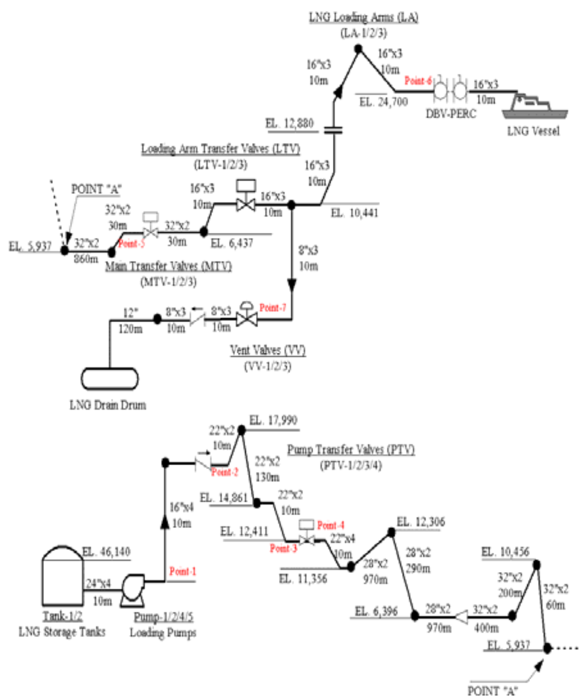


Fig. 3. Analytical Model of LNG Loading Lines

## V. Fluid Properties and Characteristics of the Piping System Components

The fluid properties of LNG have to be defined for input to the AFT-Impulse software. The following are fluid properties of LNG :

1) Operating Temperature, -160$^o$ C
2) Specific Weight, 462 kgf/m$^3$
3) Viscosity, 0.157 cP
4) Vapor Pressure, 0.07 kgf/cm$^2$G
5) Bulk Modulus, 8.65 x 107 kgf/m$^2$

The characteristics of the LNG loading line components such as the Loading Pumps and Valves, are also defined for the analysis. These values contribute a significant effect to the surge pressure during ESD activation. The Loading pump performance curve, rotation speed and rotating-inertia are all inputted to the software to define the loading pump's working and trip conditions.

The Cv value is used to define the valve's opening and closing condition. The characteristics of the valves actuated by the ESD are tabulated as follows :

TABLE I
CHARACTERISTICS OF LNG LOADING LINE VALVES

| Item | Type | Size | Closing Time (Sec) | CV at 100% Open |
|---|---|---|---|---|
| Pump Transfer Valve | Butterfly | 22” | 30 | 17700 |
| Main Transfer Valves | Butterfly | 32” | 30 | 35300 |
| Loading Arm Transfer Valves | Butterfly | 16” | 20 | 9420 |
| Vent Valves | Globe | 8” | 5 (opening) | 760 |
| DBV/PERC Valves | Double Ball | 16” | 5 | 9420 |

## VI. Surge Analysis Evaluation and Results

There are six cases of ESD activation for both proper and malfunction cases of the ESD system. The resulting maximum surge pressures for those cases are tabulated as follows (refer to Figure-3 for maximum surge pressure location points) :

TABLE II
RESULTING MAXIMUM SURGE PRESSURES

| Case | Loading Pump | ESD at PERC | Pump Transfer Valves | Main Transfer Valves | L/A Transfer Valves | Vent Valves | Maximum Surge Pressure (kg/cm$^2$G) |
|---|---|---|---|---|---|---|---|
| Case-1 | Stop | Close (5 sec.) | Close (30 sec.) | Close (30 sec.) | Close (20 sec.) | Open (5 sec) | 13.36 At point-7 |
| Case-2 | Running | Close (5 sec.) | Close (30 sec.) | Close (30 sec.) | Close (20 sec.) | Open (5 sec) | 19.31 At point-4 |
| Case-3 | Stop | Close (5 sec.) | Close (30 sec.) | Close (30 sec.) | Close (20 sec.) | Keep Close | 21.81 At point-7 |
| Case-4 | Running | Close (5 sec.) | Close (30 sec.) | Close (30 sec.) | Close (20 sec.) | Keep Close | 28.99 At point-4 |
| Case-5 | 3 pumps stop, 1 pump running | Close (5 sec.) | Close (30 sec.) | Close (30 sec.) | Close (20 sec.) | Open (5 sec) | 13.89 At point-3 |
| Case-6 | Stop | Close (5 sec.) | Close (30 sec.) | Close (30 sec.) | Close (20 sec.) | 2 Valves open, 1 Valve close | 13.57 At point-7 |

Case-1 represents the proper working of the ESD system. In this case, loading pumps in use will trip at the time of ESD activation, and vent valves will fully open in 5 seconds. The resulting maximum surge pressure is 13.36 kg/cm$^2$G at point-7 (upstream of the vent valves) which is below the design pressure of the LNG loading lines (15.5 kg/cm$^2$G). The vent valves release the surge pressure into the LNG drain drum, while flow from the LNG storage tanks will gradually stop when the loading pumps trip. The resulting surge pressure can be maintained below the design pressure. The time history of maximum surge pressure build up is shown on the following graph :

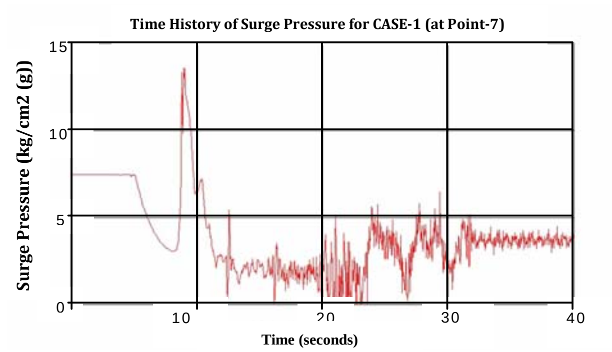


Fig. 4. Maximum Surge Pressure for Case-1

Case-5 and Case-6 represents the improper working of the ESD system. In these cases, one of the loading pumps does not trip or one of vent valves does not open during ESD activation from ESD at PERC, the resulting maximum surge pressures are 13.89 and 13.57 kg/cm$^2$G , which are still below the design pressure. In case-5, only 1 of the four pumps continues to run, and does not a produce a high enough flow rate to generate sufficient surge pressure to exceed the design pressure, even though no vent valves are open. In case-6, 2 of the three vent valves opening will be enough to release the surge pressure even though all four pumps are still running.

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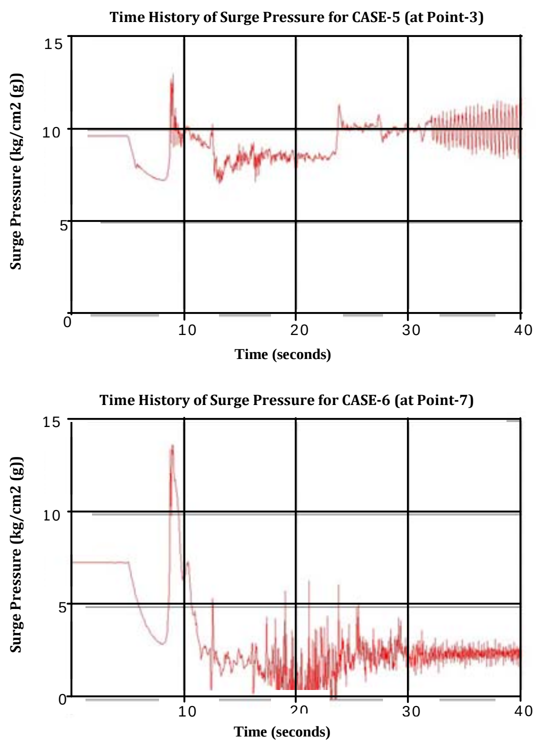


Fig. 5. Maximum Surge Pressure for Case-5 and Case-6

Case-2 and Case-3 also represent the improper working or malfunction of the ESD system. In these cases, neither loading pump shut off nor vent valves opening work properly during ESD activation from ESD at PERC. The maximum resulted surge pressures for these cases are 19.31 and 21.81 kg/cm$^2$G respectively, which are higher than LNG loading line design pressure of 15.5 kg/cm$^2$G.

When the ESD is activated and closes the loading arm's DBV in 5 seconds, a return wave occurs and flows back to the storage tank with sonic speed. Consequently, the velocity of the flow in the pipe experiencing this return wave will become zero and raise the pressure.

In the Case-2 scenario, the pressure rise will be released into the LNG drain drum through the vent valves, which will be opened during ESD activation, however, the flow downstream of return wave, which should travel backward to the storage tanks if the loading pumps stop, will meet the continuous flow from running loading pumps instead.

This condition will lead to the occurrence of surge pressure at point-4 (downstream of the pump transfer valves) that exceeds the design pressure of LNG loading lines.

Case-3 (the loading pumps trip while the vent valves will not open during ESD activation), results in maximum surge pressure occurring at point-7 (upstream of the vent valves), where the rising pressure upstream of the return wave cannot be released through the closed vent valves.

As the loading pumps shutoff works properly and trip the pumps at the time of ESD activation, the upstream flow of the return wave will have space to reduce it's pressure rise and return to steady-state conditions.

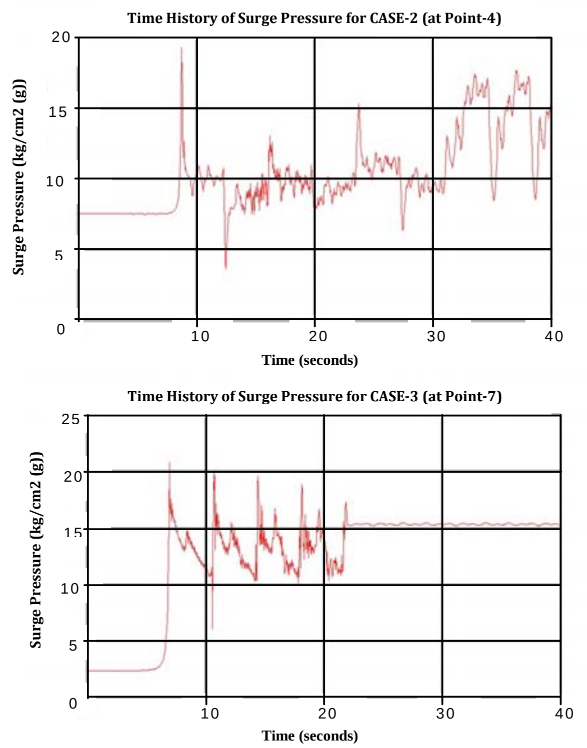


Fig. 6. Maximum Surge Pressure for Case-2 and Case-3

The worst-case scenario is represented by Case-4, where not all loading pumps will trip and not all vent valves will open during the ESD activation. In this case, there will be no protection for the built-up surge pressure, therefore, the maximum resulting surge pressure for this case is the highest, 28.99 kg/cm$^2$G.

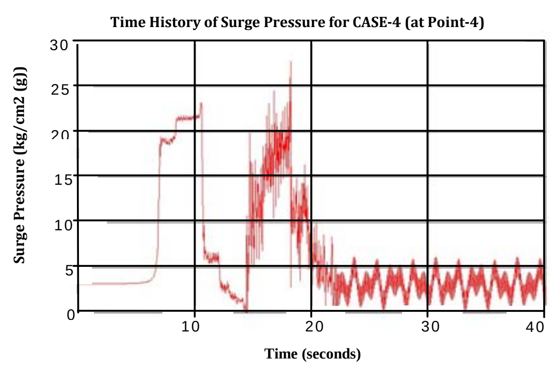


Fig. 7. Maximum Surge Pressure for Case-4

## VII. Surge Pressure Protection System

When the ESD system is initiated and the ESD valves start to close, simultaneously the following functions are activated to protect the system from surge pressure :

1) The loading pumps are stopped.
2) The vent valves are opened.

Based on surge analysis results, it is calculated that the built-up surge pressure will not exceed the design pressure of the loading lines when the ESD system works properly, however if the ESD system malfunctions, the resulting surge pressure will exceed the design pressure that will lead to the


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failure of loading lines. Additional protection to overcome this surge problem caused by ESD malfunction is required.

To overcome the surge pressure problem, pressure safety valves have been provided on the loading lines both for steady-state and transient condition. These pressure safety valves are the final protection when vent valves opening and the loading pumps trip system cannot be activated due to ESD malfunction and or mechanical failure. In this case, LNG as the result of surge pressure will be released to the LNG drain drum through the pressure safety valves, the accumulated LNG in the drain drum will be sent to flare.

To improve the reliability of above surge protection system and to minimize the wasted or flared LNG, additional surge protection is proposed to be installed. This additional surge protection will activate during ESD malfunction, prior to reaching the set pressure of the pressure safety valves. The following instrumentation should be provided on loading lines ( Figure-8 and Figure-9, show the location of pressure switches on the loading lines and a simplified ESD system logic diagram) :

1) Pressure switch between the main transfer valve and the loading arm's transfer valve, which functions to trip the loading pumps and open the vent valves.
2) Pressure switch at the upstream of the main transfer valve, which functions to trip the loading pumps.

As mentioned earlier, Case 2, 3 and 4 show the malfunction cases of the ESD system, where one or both of the surge protection actions (loading pumps trip and vent valves open) do not work properly. Based on surge analysis results, the maximum surge pressures are higher than the loading line design pressure. In such cases, the pressure switch between the main transfer valve and the loading arm's transfer valve will be activated at the set pressure of 10.0 kg/cm$^2$G, and stops the loading pumps and opens the vent valves. The maximum surge pressure is 13.92 kg/cm$^2$G, which is lower than loading line design pressure as shown in Figure-10, Time History of Surge Pressure for Pressure Switch Case.

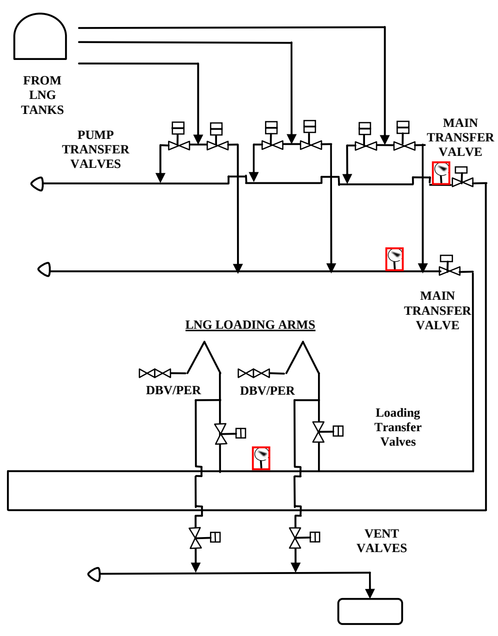


Fig 8. Location of Pressure Switch Installation

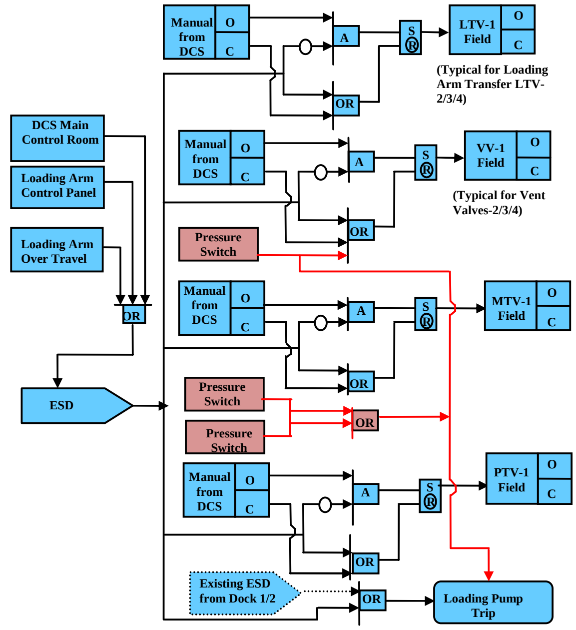


Fig.9 . additional Pressure Switch on ESD Logic

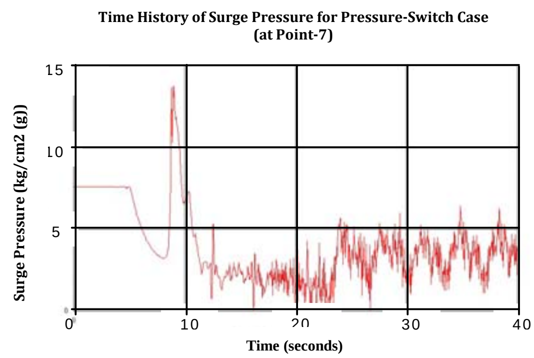


Fig. 10. Maximum Surge Pressure for Pressure Switch Case

## VIII. Conclusion

Surge pressure as the results of water hammer or hydraulic transient phenomena is the momentary increase in pressure, which occurs in a liquid system when there is a sudden change of direction or velocity of the liquid. The surge pressure can lead to a catastrophic failure of pipeline when it is higher than design pressure of the pipeline.

In the LNG loading line case, the sudden change of liquid velocity comes from rapid closing of the transfer valves caused by emergency shutdown system (ESD) activation. The ESD activation, then initiates the sequential actions to stop the loading pumps and opens the loading arm's vent valves as an effort for surge protection system.

When the ESD malfunction, the loading pumps will not trip and the vent valves will not open. Therefore, the resulted surge pressure will increase quite high, exceeding the design-pressure, that may lead to the failure of the loading line.

From the economical stand point, design practice, as well as considering the installation and maintenance ease, the conventional devices for mitigating the surge pressure cannot be employed, when handling a substance where no liquid is allowed to escape or to be wasted.


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Therefore, it was proposed to improve the existing surge protection by installing additional instrumentation as a sequential back-up when the existing protection system fails. As a result, in order to improve the reliability of the existing surge protection system, pressure switches were installed on the loading line, which function to trip the loading pumps and opens the vent valves at specified set pressure when the main surge protection fails.

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