Proceedings of the ASME 2012 Pressure Vessels & Piping Conference
PVP2012
July 15-19, 2012, Toronto, Ontario, CANADA

PVP2012-78483

DEVELOPMENT OF A WEB-BASED RBI PROGRAM FOR LNG PLANT CONSIDERING CRYOGENIC ENVIRONMENT

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ABSTRACT

Recently, Risk-Based Inspection (RBI) evaluation technique based on API 581 has become a preferred approach to determine economic feasibility and safety to plants. However, there are limitations of applying API 581 to Liquefied Natural Gas (LNG) plant because its liquefaction process is operated in cryogenic temperature under -162℃. It could affect the risk of main components in liquefaction process, but API code considered the temperature range of about -40~149℃ to evaluate the brittle fracture damage factor. The objectives of this paper are to develop a RBI program based on a web-based reality environment to resolve the above issue and to evaluate the risk of equipment in LNG plant. To achieve these, Minimum Design Metal Temperature (MBDT) region of impact test exemption curves were extended to about -196℃. Risk evaluation results considering cryogenic temperature and applicability of the proposed RBI program are fully discussed in the paper. The proposed RBI program will be useful to evaluate risk of the major components in cryogenic environment.

NOMENCLATURE

API	American Petroleum Institute
BFDF	Brittle Fracture Damage Factor
CAD	Computer-Aided Design
COF	Consequence of Failure
KGS	Korea Gas Safety Corporation
LNG	Liquefied Natural Gas
MDMT	Minimum Design Metal Temperature
PHP	Personal Hypertext Preprocessor
P&ID	Piping & Instrument Diagram
POF	Probability of Failure
PWHT	Post-weld Heat Treated
SQL	Structured Query Language
VR	Virtual Reality
WRE	Web-based Reality Environment
XVL	eXtensible Virtual world description Language

INTRODUCTION

Liquefied Natural Gas (LNG) is a preferred resource in terms of an environmental affinity, a competitive price and a diversification of fuel. In Korea, several research programs are carried on for LNG plants for localization and accumulation of the core technology. Especially, in case of operating facilities in LNG plant at high temperature, high pressure and cryogenic environment, an unexpected accident can evolve into a serious accident. To prevent this, Risk Based Inspection (RBI) technique considering correlation between Probability of Failure (POF) and Consequence of Failure (COF) by operating equipment is on the rise as the proper methodology.

The RBI evaluation programs have been proposed by several researches. API 580/581 codes in American Petroleum Institute (API) are the most widely used [1]. Especially, The RBI procedure of API 581 is applied to oil refineries and gas plants. Because most of processes in LNG plant except liquefaction process in cryogenic environment are similar to processes of petrochemical plant, it is possible to apply API 581 code in LNG plant [2, 3].

In Korea, KGS-RBI [4, 5] was developed by Korea Gas Safety Corporation (KGS) and Sungkyunkwan University using API BRD 581 code. Recently, the theory to check safety in petrochemical facilities and Windows based computer program were developed in the USA and Europe and was spread rapidly. Programs developed in a foreign country were T-OCA (Tischuk, USA) [7], ORBIT (DNV, Norway), RISKWISE (S2Partnership, UK), CREDO (credosoft, USA) and RDMIP (APTECH Engineering Services, Inc., USA).

However, most of these programs are not considering equipment in cryogenic environment and a web-based RBI monitoring system using 3D Computer-Aided Design (CAD) model, and a web-based RBI monitoring system for LNG plant has not been proposed yet.

The objectives of this paper are to develop proposed RBI program for LNG plant, so-called the LNG-RBI. It is proposed which runs on a Web-based Reality Environment (WRE). The proposed system provides the RBI evaluation for LNG plant under concurrent working environment using internet. This system includes cryogenic material properties database and proposed POF estimation procedure for LNG plant.

RBI EVALUATION BASED ON API RP 581

In accordance with API RP 581, quantitative RBI and its damage factor are summarized however qualitative RBI does not exist [3]. To develop the qualitative RBI module of LNG-RBI, API BRD 581 was reviewed and adopted [2]. The RBI methodology defines the risk of operating equipment as the combination of two separate terms:

$$Risk(t) = POF(t) \cdot COF(t) \tag{1}$$

where,

t = time

$POF(t)$ = the probability of failure for time

$COF(t)$ = the consequence of failure for time

The primary difference between the qualitative and quantitative approaches is the level of resolution. The qualitative approach requires less detailed information regarding the facility and, consequently, its discriminative ability is quite limited. The qualitative approach is normally used to rank operating facilities or major equipment of them to determine priorities for further quantitative RBI. On the other hand, the qualitative RBI provides specific risk values for each equipment and component parts, etc. In accordance with the amount of information, a level of comprehensive inspection plan can be established for the process facilities [2, 3].

API RP 581 code was published in 2008 and it shows various systematic procedure of quantitative RBI incorporating with relationship between equipment and failure mechanism. Especially, types of fixed devices are divided into four categories such as pressure vessel and piping, atmospheric storage tanks, pressure relief device and heat exchanger tube bundles. Each category has a different risk calculation procedure of quantitative RBI because major failure mechanism of each fixed device is different [3].

NECESSITY OF LNG-RBI CONSIDERING CRYOGENIC ENVIRONMENT

POF estimation

In API RP 581, the POF is estimated by determining a generic failure frequency, damage factor and management systems factor as shown in Eq. (2).

$$P_f(t) = gff \cdot D_f(t) \cdot F_{MS} \tag{2}$$

where,

$P_f(t)$ = the probability of failure

gff = a generic failure frequency

$D_f(t)$ = a damage factor

F_{MS} = a management systems factor

In the case of LNG plant, the characteristic of all materials included in equipment which operates in cryogenic environment should be reflected when calculating the POF. The characteristic of material to be considered are brittle fracture in cryogenic temperature as below -196℃.

Damage factors reflect a relative level of concern about the component based on the stated assumptions in each of the applicable paragraphs of the API RP 581. Damage factor estimates are currently provided for the following damage mechanisms.

a) Thinning - D_f^{thin}

b) Component Linings - D_f^{elin}

c) External Damage - D_f^{extd}

d) Stress Corrosion Cracking - D_f^{scc}

e) High Temperature Hydrogen Attack - D_f^{htha}

f) Mechanical Fatigue (Piping Only) - D_f^{mfat}

g) Brittle Fracture - D_f^{brit}

Fig. 1 shows the proposed Brittle Fracture Damage Factor (BFDF) determination procedure of semi-quantitative POF. In order to consider the characteristics of all materials in cryogenic environment, extended BFDF function is used at STEP 5 in this procedure. The use of extended BFDF function in the calculation procedure can be considered a good method to complement the conservative method prescribed API RP 581 code [3].

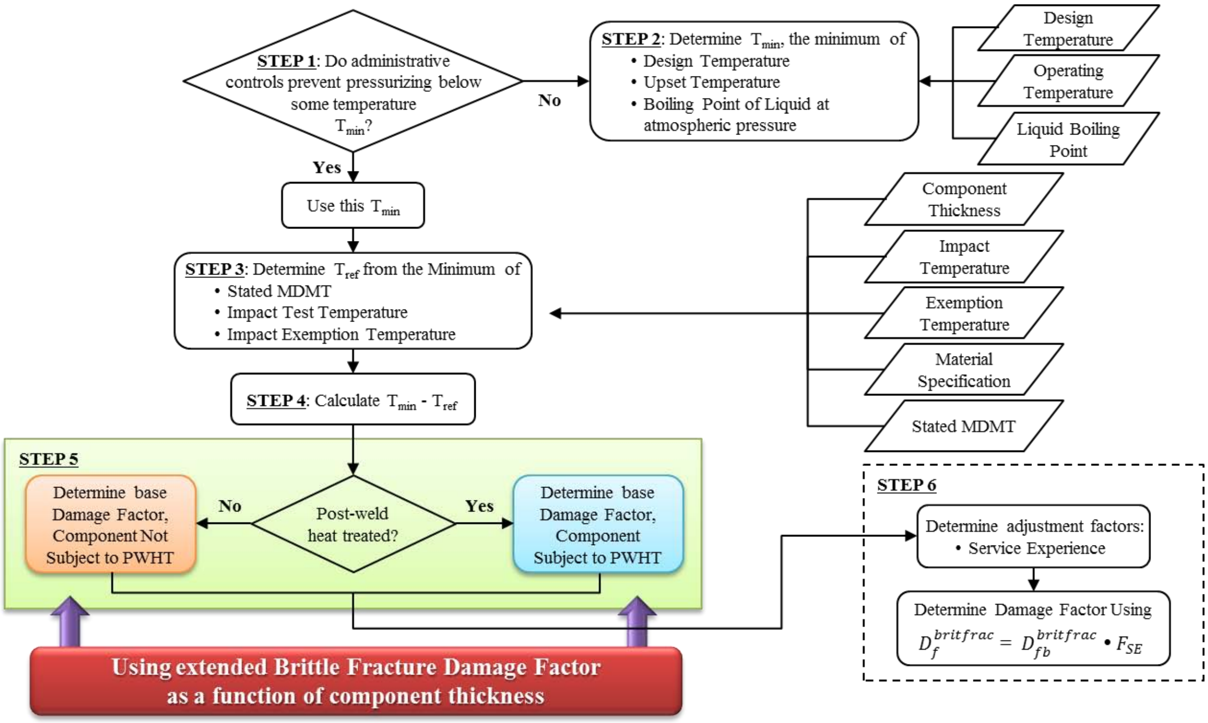


FIG. 1 Determination of the Brittle Fracture Damage Factor

Extended Brittle Fracture Damage Factor function using multilayer neural network

The extended BFDF as function of component thickness is determined by using multilayer feedforward neural network based on multi-valued neurons (MLMVN) and a backpropagation learning algorithm. To determine appropriate BFDF, the MLMVN algorithm is implemented in proposed POF estimation procedure. Fig. 2 shows a feedforward neural network with a single output neuron and with one hidden layer for calculating BFDF [12].

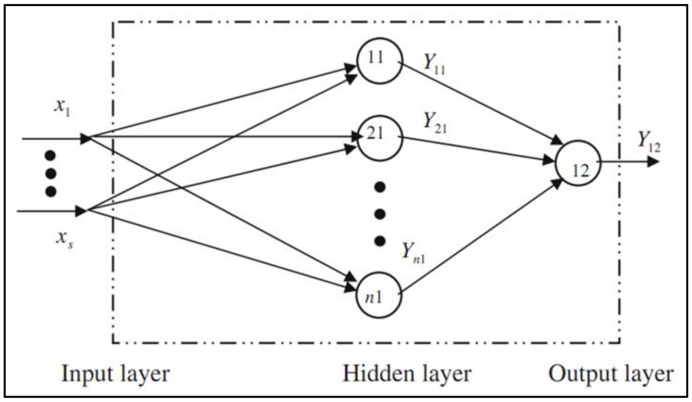


FIG. 2 A feedforward neural network with a single output neuron and with one hidden layer for calculating BFDF

Feedforward networks often have one or more hidden layers of sigmoid neurons followed by an output layer of linear neurons. Multilayers of neurons with nonlinear transfer functions allow the network to learn nonlinear relationships between input and output vectors. The linear output layer is most often used for function fitting problems.

The layer number determines the superscript on the weight matrix. The appropriate notation is used in the two-layer hyperbolic tangent sigmoid transfer function / linear transfer function network shown Fig. 3.

This network can be used as a general function approximator. It can approximate any function with a finite number of discontinuities arbitrarily well, given sufficient neurons in the hidden layer.

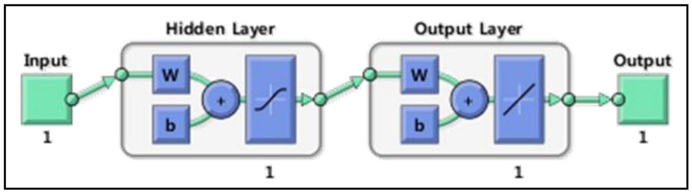


FIG. 3 MLMVN algorithm in neural network training tool of MATLAB

Fig. 4-5 shows extended BFDF as a function of component thickness subjected to PWHT using linear extrapolation and MLMVN algorithm. In accordance with API RP 581, difference between the minimum temperature and the reference temperature range is from 38℃ to -73℃ [11]. However, LNG plant includes some processes in cryogenic environment. For this reason, in order to estimate the appropriate BFDF of components in cryogenic environment, BFDF function using linear extrapolation and multilayer neural network are extended considering wide temperature range: from 38℃ to -200℃. The results estimated by extended BFDF function using multilayer neural network were mostly lower than those from linear extrapolation.

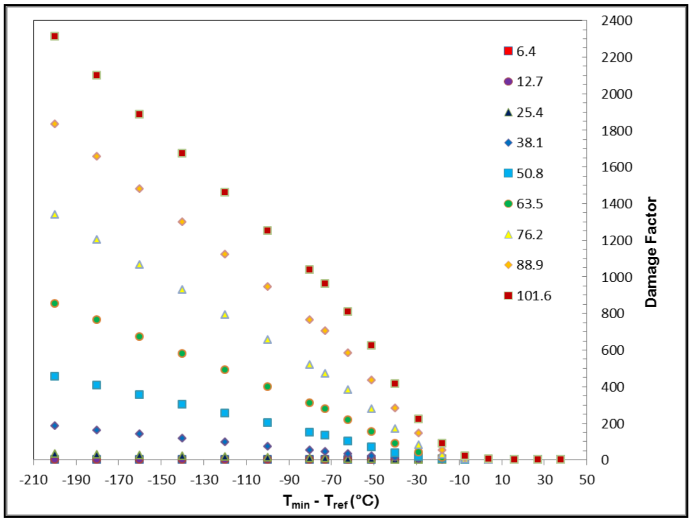


FIG. 4 Extended Brittle Fracture Damage Factor, component subject to PWHT using MLMVN algorithm

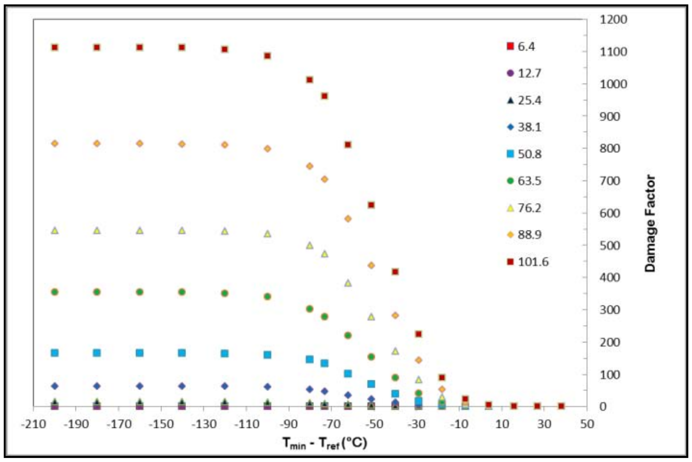


FIG. 5 Extended Brittle Fracture Damage Factor, component subject to PWHT using linear extrapolation

Fig. 6 shows the energy transition curves of 2-mm V-notch Charpy tests for low carbon steel commonly used in cryogenic environments [6]. In this figure, as the temperatures decreases, the absorbed energy values tend to converge on the specific energy values. It is similar with the tendency of extended BFDF function using multilayer neural network. Since BFDF is associated with impact test to determine the toughness, therefore, extended BFDF function using multilayer neural network could be considered more reasonable than extended BFDF function using linear extrapolation.

DEVELOPMENT OF PROPOSED RBI PROGRAM FOR LNG PLANT

A RBI program using proposed Brittle Fracture Damage Factor estimation procedure for LNG plant has been developed. It is possible to evaluate a risk in which the characteristic of equipment in cryogenic environment are reflected using the developed program. The developed program consists of two parts: risk evaluation and risk coloring system [10].

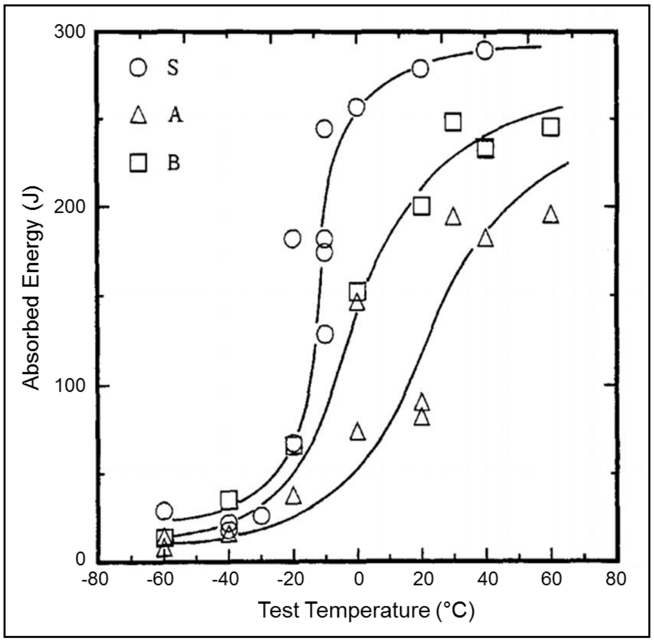


FIG. 6 Energy transition curves of 2-mm V-notch Charpy tests for respective series [6]

Personal Hypertext Preprocessor (PHP) 5.2.9, JavaScript, Structured Query Language (MySQL) 5 and eXtensible Virtual world description Language (XVL) player Pro 10 have been used for developing the proposed RBI program: configuration of web-based windows, implementation of algorithms and development of databases. Fig. 7 shows the 3-tier structure of the proposed RBI program, which is widely accepted in current web-based evaluation systems [8, 9].

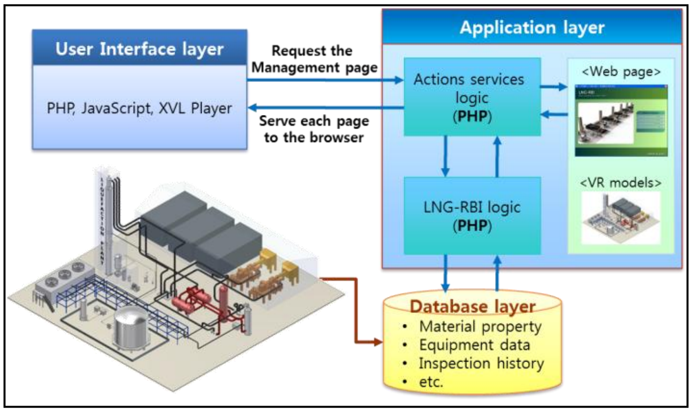
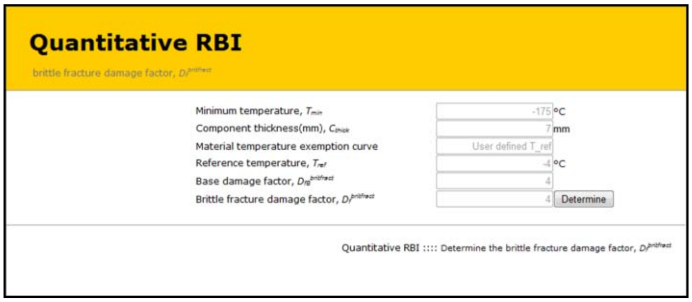


FIG. 7 3-tier structure of proposed RBI program

Brittle Fracture Damage Factor evaluation module

Fig. 8 shows main window of BFDF evaluation module. This module was developed based on API RP 581 and implemented with the proposed POF estimation procedure.



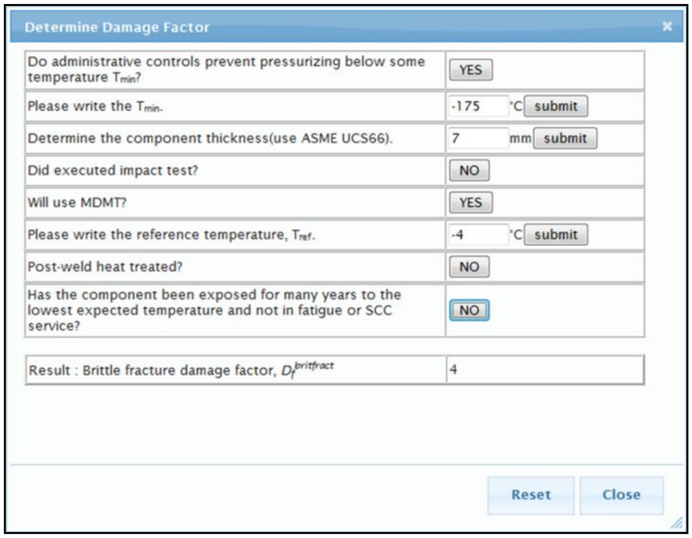
Quantitative RBI

brittle fracture damage factor, $D_f^{britfract}$

Minimum temperature, T_{min}	-175 °C
Component thickness(mm), C_{thick}	7 mm
Material temperature exemption curve	User defined T_ref
Reference temperature, T_{ref}	-4 °C
Base damage factor, $D_{fB}^{britfract}$	4
Brittle fracture damage factor, $D_f^{britfract}$	4

Quantitative RBI :::: Determine the brittle fracture damage factor, $D_f^{britfract}$

FIG. 8 Main window of Brittle Fracture Damage Factor evaluation module



Determine Damage Factor

Do administrative controls prevent pressurizing below some temperature T_{min}?	YES
Please write the T_{min}.	-175 °C
Determine the component thickness(use ASME UCS66).	7 mm
Did executed impact test?	NO
Will use MDMT?	YES
Please write the reference temperature, T_{ref}.	-4 °C
Post-weld heat treated?	NO
Has the component been exposed for many years to the lowest expected temperature and not in fatigue or SCC service?	NO

Result : Brittle fracture damage factor, $D_f^{britfract}$ 4

FIG. 9 Window of determination of Brittle Fracture Damage Factor

The information of specific data to calculate the minimum temperature and reference temperature – design temperature, operating temperature and liquid boiling point for calculation of the minimum temperature and component thickness, impact temperature, exemption temperature, material specification, stated Minimum Design Metal Temperature (MDMT) for calculation of the reference temperature – can be maintained using this module.

Proposed RBI Program

The proposed RBI program consists of qualitative RBI, semi-quantitative RBI and quantitative RBI evaluation modules in which cryogenic temperature as well as high temperature are derived automatically. The qualitative RBI, semi-quantitative RBI and quantitative RBI evaluation is evaluated depending on four fixed devices categories such as pressure vessel & piping, atmospheric storage tanks, pressure relief devices and heat exchanger tube bindles.

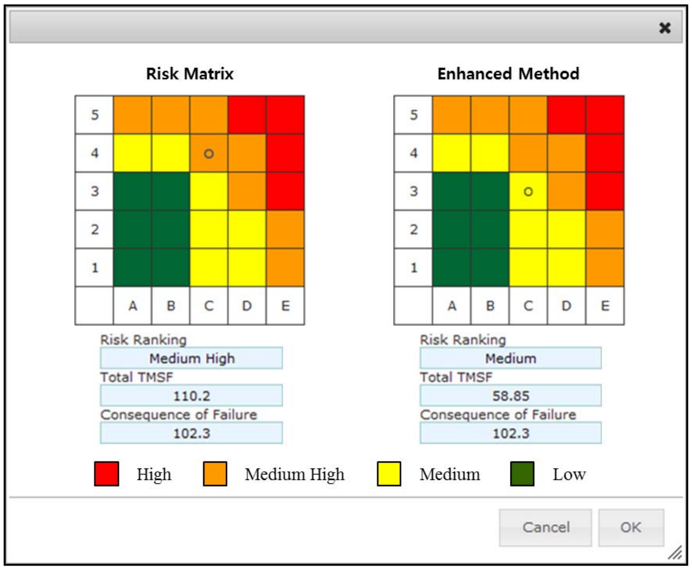
Especially, semi-quantitative RBI and quantitative RBI evaluation modules have been implemented with the proposed POF estimation procedure. Also, an extended BFDF as a function of component thickness which can consider brittle fracture properties of materials has been developed. The result windows of semi-quantitative RBI module are shown in Figs. 10-11.

APPLICATION OF PROPOSED RBI PROGRAM FOR LNG PLANT

In order to verify the applicability of proposed RBI program, the resultant risk evaluation for LNG plant was carried out. The equipment used for the verification was components list of main process for LNG plant as shown in Table 1. The developed RBI program has been applied to evaluate the risk of 110 parts of components with proper information based on piping and instrument diagram (P&ID).

TABLE 1
COMPONENTS LIST OF MAIN PROCESS FOR LNG PLANT CONSIDERED IN THE PRESENT WORK

Process Unit	No. of Components
Acid Gas Removal	30
Dehydration	17
Mercury Removal	1
Liquefaction	8
Fractionation	13
Refrigeration	30
Nitrogen Rejection	6
Refrigerant Storage	5



	Risk Matrix	Enhanced Method
Risk Ranking	Medium High	Medium
Total TMSF	110.2	58.85
Consequence of Failure	102.3	102.3

🟥 High 🟧 Medium High 🟨 Medium 🟩 Low

FIG. 10 Comparison of risk matrices between proposed RBI methods using MLMVN and linear extrapolation

Risk evaluation includes risk ranking, total damage factor and consequence of failure. In the risk matrix tab, the consequence and probability categories are arranged such that the highest risk components are toward the upper right-hand corner. Probability category (i.e. 1, 2, 3, 4, 5) is expressed in terms of the total damage factor and area-based consequence category (i.e. A, B, C, D, E) is expressed in terms of consequence area [1].

Fig. 10 shows the comparison of risk evaluation between proposed RBI using MLMVN method and proposed RBI using linear extrapolation method. The results estimated by proposed RBI using MLMVN method were mostly lower than those evaluated by proposed RBI using linear extrapolation. In the cases of some equipment, however, there were differences in the evaluation results. To provide a reasonable explanation to this, evaluation of the real risk of equipment in cryogenic environment through discussing with field engineers was necessary.

Fig. 11 shows result window of risk coloring system. VR model using XVL functions as navigator for LNG plant. Moreover, after risk evaluation of LNG plant, results of risk matrices and damage factors are expressed visually on the web page [8].

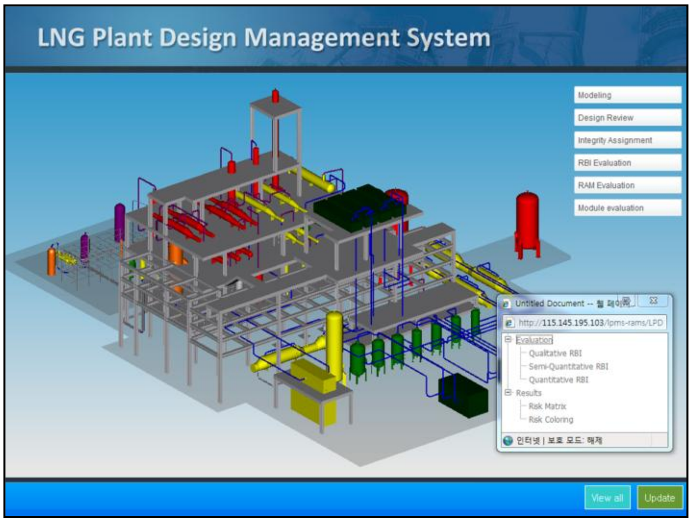


FIG. 11 Result window of risk coloring system

CONCLUSIONS

In this paper, a proposed RBI program was developed and has been applied to evaluate the risk of equipment in LNG plant that is operated in cryogenic environment. Thereby, the following conclusions have been derived.

(1) A proposed procedure to estimate POF using extended BFDF function was proposed for LNG plant.

(2) The developed proposed RBI program is considered in cryogenic temperature as well as high temperature are derived automatically.

(3) The developed web-based RBI program using extended BFDF, VR plant and risk coloring system has been successfully applied to evaluate the risks of main equipment in LNG plant.

The resultant risks of the web-based RBI program in LNG plant demonstrate appropriate applicability. For a more proper application, BFDF should be extensively determined by the experts.

ACKNOWLEDGEMENT

This research was supported by a grant from the LNG Plant R&D Center funded by the Ministry of Land, Transportation and Maritime Affairs (MLTM) of the Korean government.

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