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Trends Identified Between Successful and Unsuccessful Candidates that have Participated in the Japanese Performance Demonstration (PD) Program of Stress Corrosion Cracking (SCC) Depth Sizing

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ABSTRACT

The 1st Japanese Performance Demonstration (PD) qualification examination started in March of 2006 and was operated by the Performance Demonstration (PD) center of Central Research Institute of Electric Power Industry (CRIEPI). As of December 2012, 36 examination sessions have been completed and 44 out of 48 candidates have passed the examination. The total number of tests administered including re-tests was 87.
A reason for failure is “the incorrect choice of the crack tip echo”. Candidates cannot differentiate the weld to base metal interface echoes and crack branch echoes from the actual crack tip echo. It was noted that depth sizing using phased array and conventional angle beam tip diffraction techniques is the most effective way to pass the examination. A statistical analysis shows that the average depth sizing error is 0.33mm with a standard deviation of 1.92mm for the successful applicant. The primary reason for failure is the overestimation of the crack depth.

KEYWORDS

Performance Demonstration, Ultrasonic Testing, IGSCC, Phased Array, Qualification, Depth Sizing, Specimen, Tip Echo, Statistical Analysis

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1. Introduction

In 2000, Japan Society of Mechanical Engineers (JSME) published the first edition of a fitness-for-service (FFS) code. The FFS code has been endorsed by the Nuclear and Industrial Safety Agency (NISA) and it has been in effect since October 2003 [1]. In June 2005, the first Japanese PD standard, NDIS0603 "Qualification and certification of personnel for performance demonstration of ultrasonic testing system", was issued [2]. NDIS0603 is fundamentally similar to Appendix VIII to Section XI of the ASME Boiler and Pressure vessel code in its structure with some modifications reflecting Japanese findings of IGSCC in 316L stainless steel weld.

In March of 2006, the 1st Japanese PD qualification examination session started[3]. As of November 2012, 36 examination sessions have finished and 44 out of 48 candidates have passed the examination.

2. PD System in Japan

2.1. Operating organization

Fig.1 shows the organizations that participated in the Japanese PD qualification examination system designed for the crack depth sizing in austenitic stainless steel piping welds in nuclear power plants.

The Japanese Society of Non-Destructive Inspection (JSNDI) certification body receives direction from the PD Advisory Committee. The members of PD Advisory Committee consist of academic experts and staff from the government and public inspection organization. The PD Advisory Committee reviews activities of the PD related organizations and provides them with

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recommendations. Another important role of the PD Advisory Committee is international coordination of the PD system.

The PD certification body certifies PD related organizations. JSNDI serves as the PD certification body. The PD certification body of JSNDI is comprised of two committees, the PD certification committee manages the PD system and the PD scheme committee focuses on future activities within the PD system.

The PD qualification body organizes the qualification examination, i.e. prepares and maintains the test specimens, the test facility and the quality control documents. The PD examination center operates the PD qualification examination under the direction of the PD qualification body. The PD Center of CRIEPI takes the role of the PD qualification body and the PD examination center.

The PD training center has two functions in the PD system. One is to train the personnel who have failed at the first qualification attempt and plan to perform another qualification attempt within 30 days. The other is annual training for license renewal. Japan Power Engineering and Inspection Corporation (JAPEIC) and Electron Science Institute (ESI) have been qualified as PD training Centers.

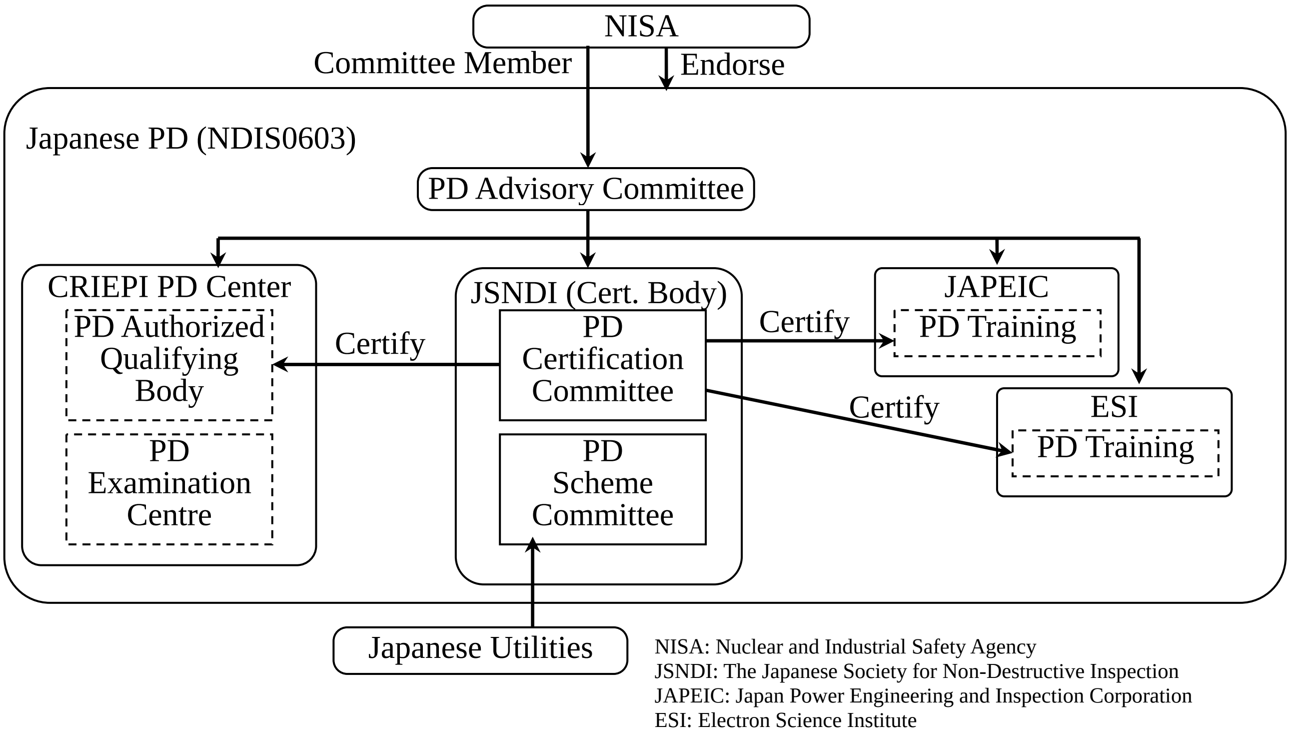

Fig. 1 Organization of Japanese PD qualification examination

2.2. Outline of qualification examination

Although the Japanese PD standard NDIS0603 is basically similar to ASME Code Section XI, Appendix VIII, some adaptations are brought in to reflect Japanese operating experience relating to IGSCC in 316L stainless steel welds. These adaptations are;

(1) All the cracks in the test sample should be IGSCC
(2) At least one IGSCC should be deeper than 15mm
(3) At least one IGSCC should penetrate into the weld material
(4) No undervalue of more than -4.4mm should be permitted

Below is an outline of the Japanese PD qualification examination.

- The qualification test specimens are butt welded austenitic pipes with artificially introduced IGSCC.

- Weld crown conditions are ground flush.
- Total of more than 10 IGSCC flaws must be included in each of the following three pipe sizes (Table.1).

Table 1 Pipe Size for test

Nominal Diameter	Nominal Thickness	Thickness at weld
600mm	38mm	35mm
350mm	28mm	25mm
150mm	13mm	10mm

Cracks in the depth sizing sample set shall be distributed according to the requirements in Table 2. The remaining cracks shall be within any of the following categories.

Table 2 Distribution of crack depth

Crack depth *h* (% wall thickness)	Minimum percentage
$0<h\leq 30\%$	20%
$30<h\leq 60\%$	20%
$60<h<100\%$	20%

For a candidate, the allowable examination time is 5 days per 10 specimens and 8 hours per one specimen. The test specimens are given out one at a time, each specimen must be completed on the same day when the candidate receives the specimen for examination.

Acceptance criteria are;

- ✓ Root mean square error (RMSE): less than 3.2mm
- ✓ Critical miscall: less than -4.4mm

The RMSE is derived from the following formula:

$$\mathrm{RMSE} = \left[\frac{\sum_{i=1}^{n}(m_i - t_i)^2}{n}\right]^{1/2} \tag{1}$$

m_i : Measured IGSCC depth t_i : True IGSCC depth
n : Number of IGSCC

Each PD certification remains valid for one year and can be extended to a maximum of 5 years if the qualified personnel completed the PD training at an approved PD training center.

3. Test Result

3.1. Number of Candidate

The first PD qualification examination started in March of 2006, and during the past 6 years, 48 personnel took the examination with a total of 44 personnel passing the examination. A total of 87tests have been administered (this total includes retests). Fig.2 shows the history of the numbers of candidates and successful applicants from March 2006 to November 2012. This figure shows that the number of candidates performing qualification activities in each period has decreased gradually over the past 6 years. It should be noted that the required number of qualified personnel to support the Japanese nuclear industry was almost satisfied within the first 18 months of the PD qualification examination process. After this period, the number of candidates performing the qualification examination during each period stabilized as candidates was primarily performing the examinations to support future activities within their organizations.

Although the pass rate of each period shows fluctuation, the data appears to present a gradual improvement in pass rates as time goes on. From the information obtained by interviews with the candidates, this improvement seems to be the result of educational efforts within their organizations.

Fig. 3 shows the relationship between RMSE and the average measurement errors of all the successful candidates. Approximately 70% of all successful candidates performed depth measurements on the IGSCC with average errors of 1mm or less. This shows that depth sizing of IGSCC flaws can be performed with a high level of accuracy.

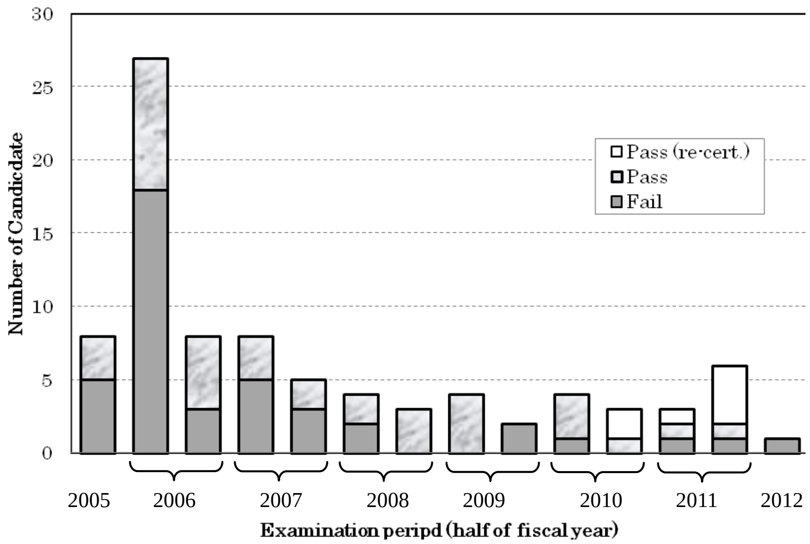

Fig.2 Number of candidates and successful applicants

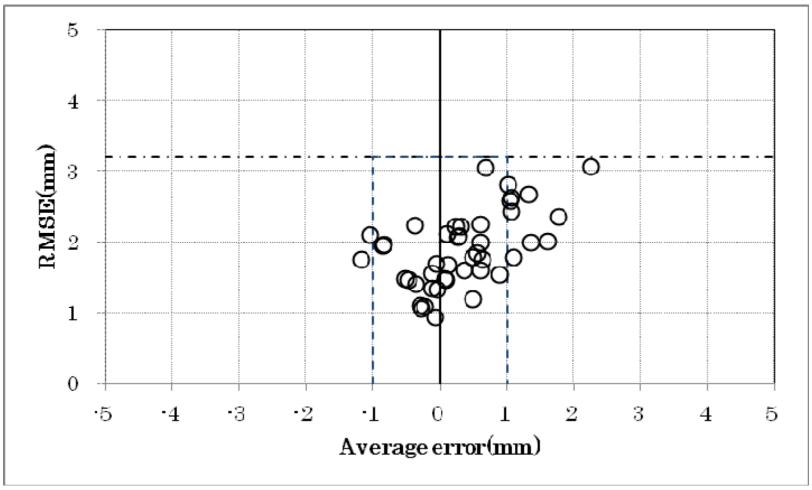

Fig. 3 RMSE vs. Average measurement error (Successful Candidates)

3.2. Sizing Procedure

Fig. 4 shows the number of applicants, successful candidates and certification holders in

December of 2012 for various types of crack depth sizing procedures used in the PD qualification examinations. In the figure, "Conventional UT" refers to manual scanning techniques with conventional A-scan type UT instrument and conventional angle beam tip diffraction techniques. Conventional UT consists of various types of angle beam transducers for crack tip identification and high angle longitudinal transducers for performing crack depth classifications. "Phased array" refers to phased array examinations using either linear or matrix phased array transducers with encoded or automated scanning systems. Although several types of phased array systems were used in the qualification examinations, all the procedures used similar data collection and analysis methods. The majority of the candidates used the "Phased array + conventional UT" type procedure.

The test result shown in Figure 4 indicates that the "Phased array + conventional UT" are the most successful procedure. Using only the conventional procedure, a total of three (3) candidates passed the examination in the first examination period. No candidate passed the examination qualification in the second (2nd) period utilizing the conventional UT procedure. No candidate has performed the examination utilizing the conventional UT procedure recently. Therefore, there is no individual with certifications for the conventional UT procedure as of December of 2012.

"Phased array" is a procedure for performing depth sizing of IGSCC flaws utilizing phased array techniques as the primary source of data collection. At present, the pass rate of "Phased array" procedures is still low and indicative of the fact that the phased array procedures require some type of improvements before they can be utilized.

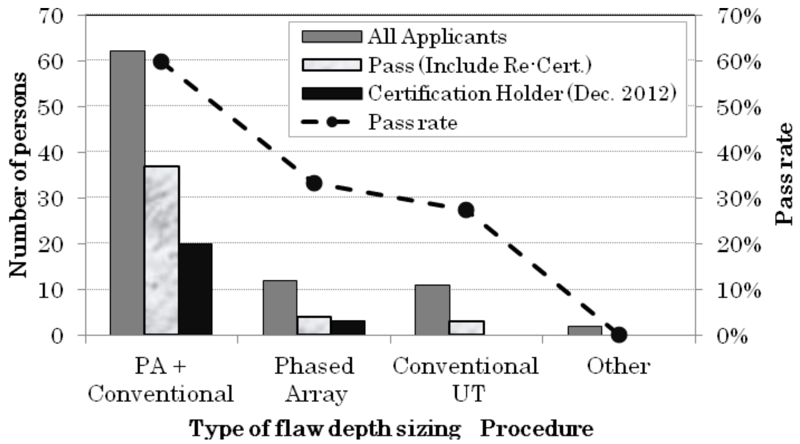

Fig. 4 Type of flaw depth sizing procedure

3.3. Statistical Analysis of Sizing Reliability

In order to clarify the depth sizing reliability, the PD center performed a statistical analysis using the 870 depth sizing data points. Table 3 shows the statistical analysis result of the IGSCC depth sizing error. The mean error and the standard deviation of successful candidates were 0.33mm and 1.92mm respectively, while the mean error and the standard deviation for failed candidates were 1.05 mm and 4.87 mm, respectively.

The bar chart shown in Figure 5 displays the relationship between the frequency and the distribution of depth sizing errors of all candidates. Figure 5 also contains the probability density curves of all candidates, both passed and failed, calculated from each standard deviation. From Figure 5, it can be presumed that the mode of frequency is about 0 and the frequency distribution is almost symmetrical. However, the frequency distribution has been obviously biased to the plus side in the part in skirts of the distribution mountain. The overestimation of the IGSCC depth should be pointed out as one potential reason for this bias. This overestimation could be caused by the lack of skill of the examiner to differentiate the base metal to weld metal interface echo and the IGSCC tip echo.

Moreover, the possibilities of human error is also incontrovertible because candidate is exposed to the stress of the potential for a -4.4mm critical miscall, which could cause the examiners to bias their measurements to the deeper value.

Table 3 Statistical analysis of PD result

Candidate group	Mean error μ (mm)	Standard deviation σ (mm)
All	0.68	3.70
Pass	0.33	1.92
Fail	1.05	4.87

It is not necessary for the UT examiner to be very careful not to make -4.4mm critical miscall when the successful PD applicant subsequently measures IGSCC depth in actual operations [4]. $P(x)$ which is the probability that the measurement of a successful PD applicant will make a -4.4mm critical miscall, is derived from the $N\,(0.33,1.92^2)$ and the following equation [5].

$$P(x) = \int_{-\infty}^{-4.4} \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \qquad (2)$$

$P(x)$ is calculated to be 0.007 (0.7%) from this Equation (2). Furukawa et al have reported that the maximum probability that a -4.4mm critical mistake will be made when a successful PD applicant measures IGSCC depth sizing is 5% [6]. These results indicate that a successful Japanese PD applicant will measure crack depth with sufficient precision and reliability.

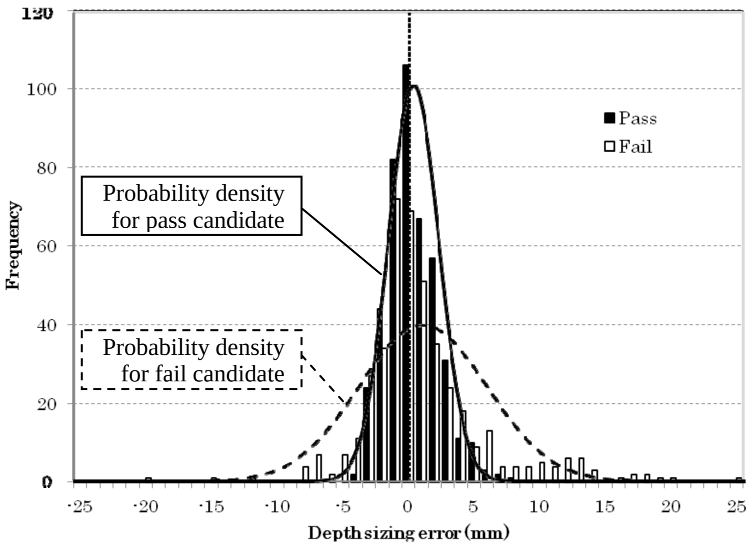

Fig. 5 Distribution of depth sizing error

3.4. Which acceptance criteria is affect to failed candidate

Fig. 6 shows the various reasons for the candidates failed PD examination attempts. As mentioned in Section 2.2, Japanese PD examination regulation has two acceptance criteria. One is the critical miss call, which requires that all flaws cannot be under sized by an amount greater than

-4.4mm. The other acceptance criteria are RMSE should be less than 3.2mm and the candidate should perform depth sizing of at least 10 IGSCC cracks. When the test set includes 10 IGSCC cracks, if the candidate sizes one IGSCC crack with +10.1mm error, and sizes the other nine IGSCC cracks without error, the resultant RMSE will be greater than 3.2mm. Therefore, another critical miss call is an overestimation of +10.1mm when performing depth sizing.

From the information obtained by interviews with the candidates, most of the failed candidates were extremely wary of the -4.4mm critical miss call. But Fig. 6 shows that for the failed candidates, the -4.4mm critical miss call is only cause for 19% of the failures. Over 80% of the unsuccessful candidates failed to the inability to meet the requirement of an RMSE less than 3.2mm. Almost half of the failures have resulted from the +10.1mm sizing overestimation. And 30% of all failures are a result of the candidates inability to meet the RMSE less than 3.2mm in conjunction with a -4.4mm critical miss call.

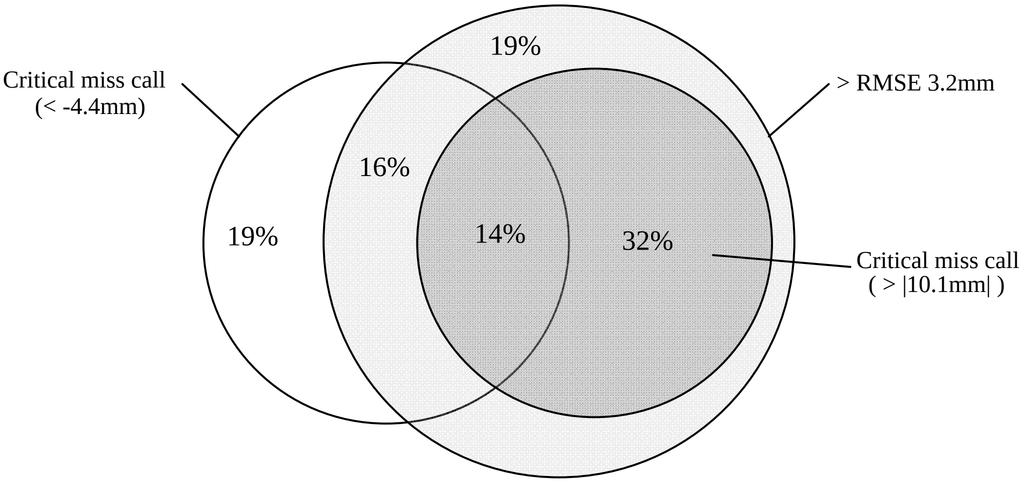

Fig. 6 The reasons of failed candidate

4. Conclusion

The Japanese PD qualification examination for flaw depth sizing started in March of 2006 and during the following 6 years, 44 out of 48 candidates have passed the examination. The outcome of Japanese PD is as follows;

(1) The average depth sizing error is 0.33mm with the standard deviation of 1.92mm for the successful candidates.

(2) It was clarified that the "Phased array + conventional UT" are the most successful procedure.

(3) The average depth sizing error was +1.05mm for unsuccessful candidates. Reasons for candidate failure include the candidates inability to discriminate the crack tip echo along with the overestimation of the flaw due to the candidate being wary of the -4.4mm critical miss call.

(4) Most failed candidates were extremely wary of a -4.4mm critical miss call, but a -4.4mm critical miss call only accounted for the cause of 19% of all failures.

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