RELIABILITY OF NON-DESTRUCTIVE TESTING METHODS

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ABSTRACT

This contribution regards the results of an evaluation of the reliability of radiography (X-rays and gamma-rays), manual-, and mechanised/automated ultrasonic examination by generally accepted codes/rules, with respect to detection, characterization and sizing/localization of defects.

The evaluation is based on the results of examinations ,by a number of teams, of 30 test plates, 30 and 50 mm thickness, containing V, U, X and K-shaped welds each containing several types of imperfections (211 in total) typical for steel arc fusion welding, such as porosity, inclusions, lack of fusion or penetration and cracks.

Besides, some results are presented obtained from research on advanced UT-techniques, viz. the time-of-flight-diffraction and flaw-tip deflection technique.

GENERAL

The results contained in this contribution stem from a cooperative research project (1983-1987) in the Netherlands under the auspices of the Netherlands Institute of Welding with contributions from industrial and research organizations and the Dienst voor het Stoomwezen (Dutch authority for boilers and pressure vessels), sponsored by the Ministry of Economic Affairs. Details are provided in a series of reports in Dutch (1) and comprised in (2) in English.

Main aim of the project was to obtain a better understanding of the reliability of usual methods for non-destructive testing as applied for quality control of welded structures.

The main items and results are reviewed in a series of figures, with complementary text.

OUTLINE AND RESULTS

- Methods investigated

  Fig.1. shows the 3 methods that were investigated and the aspects considered, i.e. detection, characterization, sizing and localization.

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CSNI Workshop on Complementary Rules of Fracture Mechanics and NDE in Safety Assessment of Components, Wuerenlingen, Switzerland, 3-5 October 1988.

- **Test plates and reference defects.**

Fig.2. provides information about the test plates with defects. During fabrication of the welds and implantation of the various defects the type, location and size of the defects were carefully reported.
Afterwards, over 40% of the defects were investigated by destructive examination. Results justified the conclusion that the reference-defects could reliably be used for evaluation of the NDT results. As a matter of course, the various NDT-investigators had no knowledge of the intended nor of the actual defects.

Fig.3. shows the various types of defects with their (IIW) classification code, their number (as percentage of the total), and the range of their sizes.

- **Radiographic examinations.**

Fig.4. shows the main aspects of the radiographic examination.

Fig.5. gives the results of the radiographic examinations with the 300 kV X-ray technique (the more sensitive technique) in terms of percentage of detected defects with respect to existing defects.
The significant differences per type should be noticed.

Fig.6. provides some further results with regard to the evaluation of the radiographic examinations.

- **Manual ultrasonic examinations.**

Fig.7. In this figure some relevant information is listed with regard to these examinations. Several aspects have been examined at evaluating the results, a major item being the detection probability. This item is elucidated in

Fig.8. showing that many defects are not recorded. About 12% of the defects was not recorded by any team.

Fig.9. shows a typical representative example of the influence of defect size on detectability, illustrating the conclusion that defect size has no, and at least no clear, influence on detection probability.
Defect size here is represented by the surface (length x height) of the actual reference defect. Besides, this figure illustrates the considerable differences between the various scores (spread; numbers between brackets).

Fig.10. illustrates the conclusion that characterization of detected defects (according to IIW) yields rather poor results. The numbers in this figure are the average percentage of correct characterizations.
Including the results illustrated above, the evaluation of the results lead to a number of conclusions reviewed in

Fig.11. These conclusions point at an unsatisfactory performance, which is believed to be representative for actual practice, thus causing much concern.
A cooperative follow-up project is started in the Netherlands (3).

- **Mechanised/automated ultrasonic examination.**

3 Advanced systems for mechanised/automated ultrasonic inspection have been applied to the same 30 testplates described above. These are the P-scan system (SVC, Danmark), the Rotoscan system (RTD, Netherlands) and the Sutars system (SRI, USA). For the P-scan system 2 different scanning techniques have been applied, viz. M.W.S. (manual scanning of the weld; the manipulator with probe is operated manually) and A.W.S. (automatic scanning of the weld; the manipulator is operated automatically).
Here too, detection probability is an important item.
Fig.12. shows this probability in terms of reported defects as percentage of existing defects. The scores appear to be relatively high, except for the Sutars-system. This exception is supposed to be caused in part by differences in procedures and reporting levels.
Size and type of the defects appear to influence the detection. For P-scan and Rotoscan probability of detection is in the order of 70 to 100% for non-planar defects, irrespective of size. Planar-flaw detection appears dependant on flaw size, with scores of 0-35% up to 30 mm^2 and 60-100% for the larger flaws.

Like for the methods discussed before, the results of these systems have been evaluated with respect to various aspects;

Fig.13. lists some of the main conclusions.

COMPARISON OF THE 3 NDT-METHODS

Because of the restricted scope of the investigations, the conclusions stated hereafter must be considered with due care. However, in general they seem to be in line with other studies and with expert opinions from practice.

- Radiography vs. manual ultrasonic.

Here the best X-ray results are compared with the average manual ultrasonic results in terms of their respective detection probabilities (scores) for the various defect types.

Fig.14 shows the results, illustrating the obvious conclusion that radiography is more reliable for detection of non-planar defects whereas UT is more reliable for real planar defects, i.e. lack of fusion.

Fig. 15 lists this conclusion, together with some other conclusions derived from comparing the results of both methods.

- Manual vs. mechanised/automated ultrasonic examination

Leaving out the results of the Sutars-system for reasons indicated before, the scores of the other two mechanised/automated ultrasonic systems have been compared with the average results of the manual ultrasonic examinations.

Fig.16 shows the results. The conclusion is evident that manual ultrasonic examination scores considerably lower.

GENERAL CONCLUSIONS

Some general conclusions result from the evaluations.

Radiography scores considerably better than manual ultrasonic examination for non real planar defects, and yields considerably better consistency. The relatively better scores of manual ultrasonics for real planar (crack-like) flaws are rather low in an absolute sense; this is the more of concern since such flaws often are the most dangerous with regard to structural integrity.

Both techniques fail to detect a considerable number of flaws that are unacceptable conform codes/rules.

Mechanised/automated UT scores rather high, be it at the expense of time and costs. Application of this method deserves promotion for relevant situations.

Manual ultrasonic examination, with an average detection score of about 50%, shows unsatisfying performance and needs improvement, the more since this method tends towards wider application

APPENDIX: TOFD AND FTR TECHNIQUES

"Time of Flight Diffraction" (TOFD) and
"Flaw Tip Reflection" (FTR) are ultrasonic techniques with particular applicability for crack sizing.
Using the test plates with reference flaws described before, applicability and accuracy of both techniques have been studied in conjunction with the foregoing evaluation-project.
Results are reported in (4).

The importance of these investigations was stretched by the poor results for flaw sizing obtained within the evaluation-project. Accurate flaw sizing is most important if the question of necessity of repair has to be answered, e.g. by a fracture-mechanics based fitness-for-purpose analysis.

Only some general results are provided here.

- Although not of primary importance, the methods provide a reasonably high detection probability.
- Both methods provide reliable height-measurements; under favourable circumstances the accuracy is ± 2 mm.
- The TOFD-method has a dead zone of 5-10 mm below the surface. For the FTR-method this zone is smaller, about 5 mm.
- Sizing of the length appeared difficult.
- For simple geometries, both methods appear applicable with standard or relatively simple equipment.

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Because of their high potential, both methods deserve further development with regard to aspects such as equipment, optimal procedures, length-sizing technique and establishment of reliability and consistency, e.g. by round-robin investigations.

REFERENCES

(1) NIL-NDO Project: "Evaluation of some NDT-methods at welds with defects", Final Report.
J.W. van der Heijden, editor.
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(In Dutch. Contains references to sub-reports on various details. Available from N.I.L., Laan van Meerdervoort 2 B, 2517 AJ The Hague, NL).

(2) Evaluation of some NDT-methods on test plates with welds containing flaws, J.W. van der Heijden, L.A.J.L. Sarton.
To be published as IIW-document.

(3) NIL-NDO project "optimizing US methods".
(For information and possibilities for cooperation contact N.I.L.; see (1)).

(4) Report of flaw-sizing measurements by the TOFD and FTR technique.
J. Boogaard, J.W.v.d. Heijden, S. Terpstra, F.H.Th. Wiegant.
Report NDO 87-03, October 1987, Netherlands Institute of Welding, The Hague, NL.
(In Dutch. For availability see (1)).

METHODS EVALUATED:
-radiography using X-rays and rays
-manual ultrasonic examination
-mechanised/automated ultrasonic examination

PERFORMANCE EVALUATED REGARDING:
-defect detection
-defect characterisation
-sizing and localisation
fig.1 SCOPE OF INVESTIGATIONS

- 30 TEST PLATES OF C-STEEL, 30 AND 50 mm THICKNESS.
- V,U,X AND K-SHAPED WELDS
- EACH WELD 6-7 DEFECTS OVER 400 MM
- TOTAL: 211 REFERENCE DEFECTS IN 12 M WELDMENT

FIG.2. TEST PLATES AND DEFECTS

Porosity/wormholes (Aa,Ab)	14	various	ø 2-3
slag-inclusions/lines (Ba,Bb)	25	5-60	1.5-3.0
lack of fusion (C)	16	8-60	2-8
incompl.penetration (D)	15	10-125	1-5
cracklike defects (Ea,Eb)	25	10-45	3-6

fig.3 REFERENCE DEFECTS

- EACH WELD WITH 4 RADIATION SOURCES:
  . 300 AND 420 KV X-RAYS
  . IR-192 AND CO-60 gamma-rays
- TECHNIQUE FOR EACH SOURCE CF."CLASS B" OF DIN 54111, PART 1
- 4 EXPERIENCED FILM READERS;
  . REPORT INDICATIONS
  . INTERPRETE THEM
  . ASSESS ACCEPT/REJECT CF; CRITERIA ASME B&PV CODE SECT.8, DIV.1

FIG.4 RADIOGRAPHIC EXAMINATION

thickn.	Aa/Ab	Ba/Bb	C	D	Ea	Eb
30 mm	99	95	38	53	75	-
50 mm	93	79	22	54	4	85

FIG.5 RADIOGRAPHY: SCORES AS % OF EXISTING, 300 KV

-DETECTION PROBABILITY:
 .HIGH FOR VOLUM.DEFECTS,TRANSV.CRACKS, UNDERCUTTING
 .LOWER FOR PLANAR FLAWS
-X-RAY TECHNIQUES MORE RELIABLE
-LARGE SPREAD ASSESSMENT RESULTS BETWEEN READERS
-CLASSIFICATION (CF.IIW) RATHER INACCURATE

FIG.6 RESULTS RADIOGRAPHIC EXAMINATIONS

-ROUND-ROBIN TRIAL BY 8 TEAMS
-LEVEL 2 QUALIFIED EXAMINATORS
-STANDARD EQUIPMENT,FAVOURABLE CONDITIONS
-4 STRICT, WRITTEN, PRODURES, CONFORM:
 .HP 5/3 (AD-MERKBL.HP 5/3,INCL.ANN.1;FRG)
 .T0202 (DUTCH RULES B&PV;NL)
 .ASME (ASME; S VIII DIV.1, SV ART.4,5)
 .API (API-RP2X, 1980, SUPPL.1981,LEVEL A)
-EACH TEAM 1 TO 3 SPECIFIC PROCEDURE

FIG.7 MANUAL US EXAMINATIONS

THICKN.	AVERAGE	LOWER	UPPER
30 mm	56	37	72
50 mm	44	12	68

FIG.8 MANUAL US; SCORES
RECORDED AS % OF EXISTING

A = L x H (mm2)	THICKN. 50 mm, PLANAR DEFECTS
30	46 (+ 23) %
30 - 55	46 (∓ 32) %
55 - 100	49 (∓ 29) %
100	43 (± 27) %

FIG.9 MANUAL US;
RECORDED AS % OF EXISTING

thickn.	Aa/Ab	Ba/Bb	C	D	Ea,K	Eb
30 mm	9%	45	64	43	15	-
50 mm	2	42	61	43	13	10

fig.10 MANUAL US; AVERAGE % CORRECT CHARACTERIZATIONS

.RATHER POOR DETECTION-PROBABILITY
.12% MISSED BY ALL TEAMS
.NO HIGHER PROBABILITY FOR LARGER DEFECTS
.DEFECT-CHARACTERIZATION UNRELIABLE
.LOW UNIFORMITY DEFECT ACCEPTABILITY
.SIZING IS VERY INACCURATE
.ABSENCE OF CONSISTENCY BETWEEN TEAMS
.PLANAR FLAWS OFTEN NOT RECOGNIZED
.INFLUENCE PROCEDURE ON RESULTS UNCLEAR
.DETECTION PROBABILITY ABOUT EQUAL FOR PLANAR AND NON-PLANAR DEFECTS
.LOCALIZATION REASONABLY ACCURATE

FIG.11 MANUAL US: CONCLUSIONS

SYSTEM	DETECTION PROBABILITY: 30 mm	50 mm
P-SCAN (A.W.S.)	90 %	70 %
P-SCAN (M.W.S.)	85 %	65 %
ROTOSCAN	80 %	80 %
SUTARS	50 %	40 %

FIG.12 DETECTION PROBABILITIES MECHAN./AUTOM. UT

-RELATIVE HIGH DETECTION PROBABILITY
-SIZE AND TYPE DO INFLUENCE DETECTION
-RATHER ACCURATE LOCATION IN WELD DIRECTION; LESS IN OTHER DIRECTIONS
-NO CAPABILITY FOR DEFECT CHARACTERIZATION
-SIZING RESTRICTED TO LENGTH, WITH MODERATE ACCURACY

FIG.13 MECHANISED/AUTOMATED UT

Flaw type	30 mm		50 mm	
	radiogr.	ut	radiogr.	ut
Aa/Ab	99	52	93	55
Ba/Bb	95	63	79	35
Ea/Eb	75	61	39	36
D	53	46	54	43
C	38	50	22	63

Fig.14 COMPARISON OF SCORES (%): RADIOGRAPHY VS. MANUAL UT

-rejectable defects undetected by both methods
-radiography better for nonplanar defects; ut better for real planar defects.
-better conformity for radiography than for ut

Fig.15 COMPARISON RADIGRAPHY AND MANUAL UT

	30 mm	50 mm
MANUAL	56	44
P-SCAN AWS	90	70
P-SCAN MWS	85	65
ROTO-SCAN	80	80

FIG.16 COMPARISON OF SCORES (%): MANUAL VS.MECHANISED UT

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