II

Reliability in Welded Joints through Ultrasonic Inspection

Contrôle de qualité des soudures à l'aide d'essais ultrasoniques

Zuverlässigkeit von Schweißungen durch Ultraschall-Untersuchung

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1. INTRODUCTION

In recent years ultrasonics has been applied to a greater extent for weld inspection. It can locate cracks with relative ease and the equipment is low in cost. Especially it is quite suitable for field use as the equipment is portable.

To make a satisfactory evaluation of a weld flaw, it is important not only that it be detected, but that it be characterized as fully as possible. If the size of a defect is underestimated, resisting capacity of a joint and thus serviceable life of the structure may be overestimated resulting in the increase of user's risk. In opposite case, it imposes unnecessary repair works of weldments, and it will impose the excessive expense on the owner or the producer. On the basis of this view point, this paper will discuss the reliability of ultrasonic inspection. In Section 2, flaw lengths indicated by ultrasonic inspection and radiographic inspection are compared with actual flaw length, and the accuracy of each prediction is examined. In Section 3, the strength of the weld is correlated against the flaw as measured on a ultrasonic.

2. ACCURACY OF FLAW LENGTH DETECTED BY ULTRASONIC AND RADIOGRAPHIC INSPECTION

Case 1. On 116 test pieces in which different types and sizes of defects were included artificially in weldments, ultrasonic and radiographic inspection were applied to detect the flaw length. The results of tension tests carried out subsequently gave information on the breaking strength of welded joints and actual size of defects.

Case 2. Field ultrasonic inspection on two buildings were carried out. Among a number of test records, 57 samples in A-building and 54 samples in B-building were refered here, defects of which were estimated to be serious and these weldments were gouged

(a) Column Splice
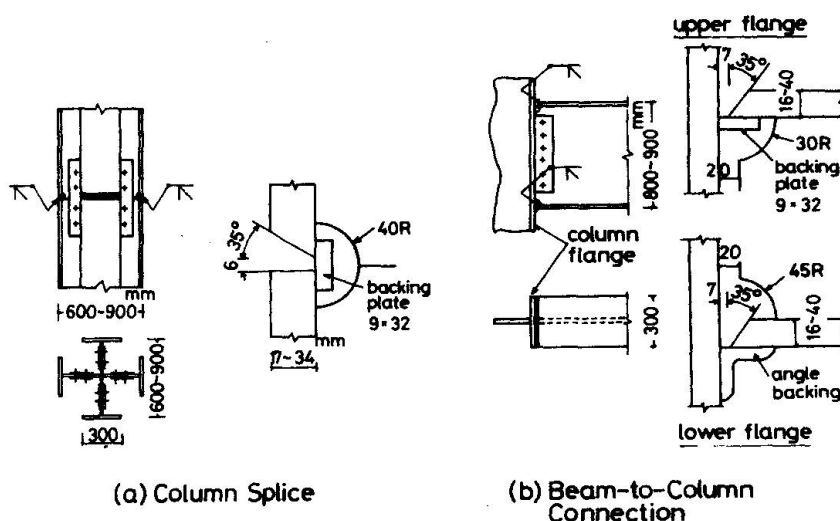
(b) Beam-to-Column Connection

Fig.1 Details of Welded Joints

to check the actual defect
sizes and then rewelded.
The details of welded joints
which were the subject of
inspection are shown in
Fig.1.

Relationship between
the indicated flaw length
by ultrasonic inspection(uL)
and actual flaw length(sL)
measured in Case 1(Labora-
tory test) is shown in Fig.2,
and that between the indic-
ated flaw length by radio-
graphic inspection(xL) and
actual flaw length is shown
in Fig.3.

Frequency distribut-
ions of estimation errors
made by ultrasonic and
radiographic inspection are
shown in Figs.4 and 5 res-
pectively. Obviously radio-
graphic inspection is more
reliable than ultrasonics.

Relationship between
the flaw length as measur-
ed on a ultrasonic and act-
ual flaw length is shown in
Fig.6 for the case of field
inspection of A-building,
and that for B-building is
shown in Fig.7(Case 2).

Variance in ultrason-
ic inspection for Case 1.
is 71.2 mm² and that for A-
building(Case 2) is 197.5
mm²,direct comparison of
these is impossible since
the number of samples are
different each other.
However,the test of signi-
ficance had shown that the
laboratory test(Case 1) is
more accurate than the
field test(Case 2).

3. CORRELATION BETWEEN THE
   INDICATED FLAW LENGTH
   AND THE STRENGTH OF WELD

The strength of the
weld is correlated against
the flaw length as measured
on ultrasonics using 116
samples as mentioned in
Case 1 of previous section.

The relationship bet-
ween the judgement done
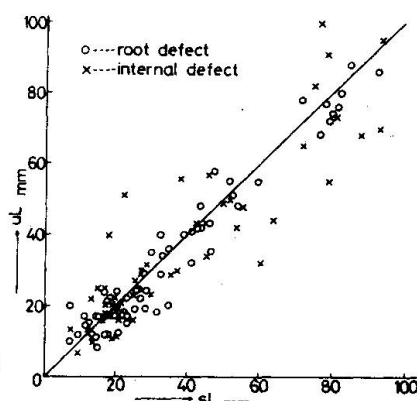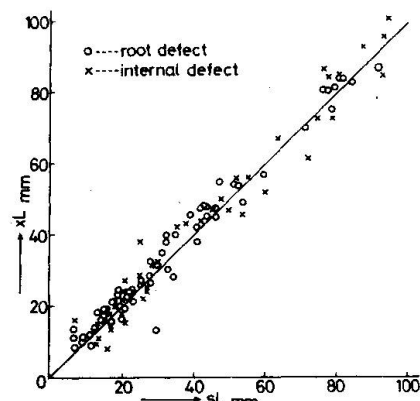

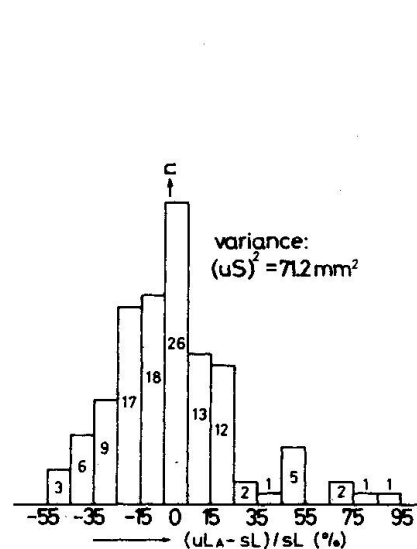Fig.2 Relation Between sL and uL

Fig.3 Relation Between sL and xL

Fig.4 Error Histogram of Ultrasonic
Evaluation
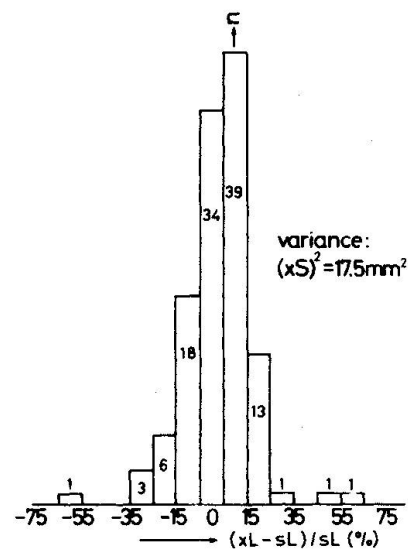

Fig.5 Error Histogram of Radiographic
Evaluation
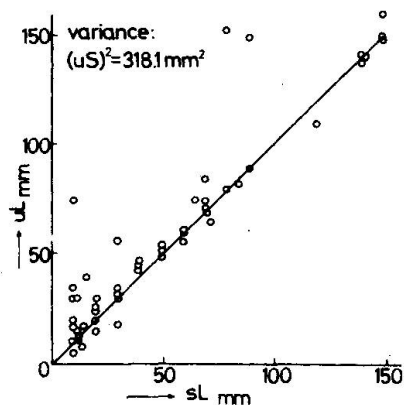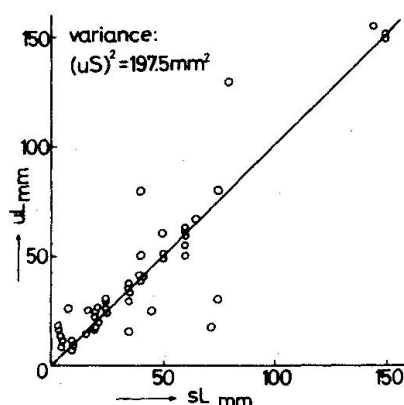

Fig.7 Relation Between sL and uLв for
B-Building

Fig.6 Relation Between sL and uLᴀ for
A-Building

according to the acceptance criterion specified by the Architectural Institute of Japan(A.I.J. see Appendix) and the strength of the welded joints is shown in Table 1,where samples are subdivided into two groups according to the criterion that whether a test piece is broken in base metal or in weldment. If joints marked 4 points shall be rejectable,the result becomes as shown in Table 1a,and if joints marked 3 or 4 points shall be rejectable,the result becomes as shown in Table 1b. In this table,(1) is a contingency table in which test data are classified according to breaking strengths on the one hand and evaluation marks on the other,(2) is the result of "test of independence" on the basis of χ^2-distribution, user's risk and producer's risk brought from the judgement are shown in (3).
The results of χ^2-tests with a level of significance of 5% had shown that,for both cases,there is some association between the evaluation mark and the strength of weld. If one adopts the acceptance criterion shown in Table 1a,the user's risk becomes larger,on the contrary if one adopts that shown in Table 1b,the producer's risk becomes larger.

Table 1. Correlation of Tensile Strength With Reference Flaws by AIJ Standard

1a) Marked 4,rejectable			1b) Marked 3,4, rejectable		
(1) Contingency Table					
Broken at → Mark ↓	Base metal	Weld | Totals	Broken at→ Mark ↓	Base metal	Weld | Totals
1.2.3	27	36 | 63	1.2	19	23 | 42
4	2	51 | 53	3,4	10	64 | 74
Totals	29	87 | 116	Totals	29	87 | 116

(2) Testing Independence { $\chi_i^2(0.05)=3.84$ }

$\chi^2 =21.41> \chi_i^2(0.05)$;
    not independent

$\chi^2 =14.38> \chi_i^2(0.05)$;
    not independent

(3) Producer's risk(α) = 6.9%
   User's risk(β) = 41.4%

   Producer's risk(α) = 34.5%
   User's risk(β) = 26.4%

Table 2. shows the result of similar analysis,where only the indicated flaw lengths are adopted as a parameter neglecting the effect of echo height on the cathode ray tube. The acceptance criterion is that when a flaw length exceeds 5/8 times the thickness of base metal,the sample shall be rejectable(5/8 t is the mean value of indicated flaw lengths M_1 and M_2 specified by AIJ Standard,see Appendix).

Table 2. Correlation of Tensile Strength With Flaw Length

2a) Based on Indicated Flaw Length			2b) Based on Actual Flaw Length		
(1) Contingency Table					
Broken at → uL ↓	Base metal	Weld | Totals	Broken at→ xL ↓	Base metal	Weld | Totals
≤ 5/8 t	23	18 | 41	≤ 5/8 t	24	13 | 37
> 5/8 t	6	69 | 75	> 5/8 t	5	74 | 79
Totals	29	87 | 116	Totals	29	87 | 116

(2) Testing Independence

$\chi^2=32.71> \chi_i^2(0.05)$;
    not independent

$\chi^2=46.05> \chi_i^2(0.05)$;
    not independent

(3) Producer's risk(α) =20.7%
  User's risk(β) =20.9%

   Producer's risk(α) =17.2%
   User's risk(β) =14.9%

Flaw lengths as measured on the ultrasonics are used in Table 2a,and actual flaw lengths are used in Table 2b. In both cases,the results of χ^2-tests had shown that there is some association between the flaw length and the strength of weld. User's risk and producer's risk are better balanced than in the case of Table 1. The ratio of miss-judgements to total samples is 24/116 when reference flaw lengths are used(Table 2a),and is 18/116 when actual flaw lengths are used(Table 2b),and it might appear at first glance that the judgement based on actual flaw length is more reliable. However,the result of "tests of significance" had shown that this difference is not significant.

4. CONCLUSIONS

1) The accuracy of flaw evaluation by ultrasonic inspection is a little bit inferior than that by radiographic inspection. However,taking account of other advantages,ultrasonic inspection is practically useful.   .
2) An acceptance standard for ultrasonics is well related to the strength of welded joints. The acceptance level should be set to obtain the better balance between the user's risk and the producer's risk.
3) The further research needed are;
   i) Development of improved methods to classify flaw types(cracks,incomplete fusion,inclusions etc.,)and to evaluate flaw heights.
   ii) Correlation of flaw types and sizes with the reduction of strength and ductility of welded joints.

Appendix–Standard for Ultrasonic Testing of Steel Structure Groove Welds.
        Architectural Institute of Japan(AIJ),1973

Evaluation of Flaw
        Flaw shall be evaluated in accordance with the indicated defect length discriminated by values of S,M_1,M_2 and L in Table A1 relative to the thickness of base metal to be welded together,and Table A2 depending on the region to which the maximum echo height belongs.

Table A1.Classification of Indicated Defect Lengths

Indicated flaw length(mm) → Thickness of base metal(mm)↓	S	M_1	M_2	L
From 9 to 20	5	10	15	20
Over 20 to 48	t/4	t/2	3t/4	t
Over 48	12	24	36	48

Table A2.Evaluation Marks of Flaws

Indicated flaw length → Max. echo height ↓	$\leq S$	$>S$ to M_1	$>M_1$ to M_2	$>M_2$ to L	$>L$
Region II	0	1	2	3	4
Region III	1	2	3	4	4

Judgement for Acceptance or Rejection
        In conformity to the criteria given above,those marked 4 points shall be judged rejectable. Provided however that in case there are two or more flaws including a flaw of 3 points,a portion of 300 mm containing such flaws shall be considered,and it shall be judged rejectable if the total points within this range are equal to or exceed 6 points.

SUMMARY

The usefulness of ultrasonics for weld inspection was investigated using
data on laboratory test and field inspection. It has been shown that;
1) ultrasonics can estimate the flaw length with practically reasonable accuracy,
2) an acceptance standard for ultrasonics is well related to the strength of
welded joints. The acceptance level should be set to obtain the better balance
between the user's risk and the producer's risk.

RESUME

L'utilité d'un examen ultrasonique des soudures a été étudiée sur la base
de résultats d'essais de laboratoire et de chantier. Il a été démontré que:
1) l'examen ultrasonique permet de détecter la longueur des fissures avec bonne
précision, 2) une norme de qualité pour l'examen ultrasonique est bien en
relation avec la résistance des soudures. Des normes devraient être établies
en tenant compte d'un meilleur équilibre entre les risques de l'utilisateur
et du constructeur.

ZUSAMMENFASSUNG

Der Nutzen des Ultraschalls bei Schweissprüfungen wurde unter Auswertung
von Laborversuchen und an der Baustelle untersucht. Es zeigt sich, dass:
1) Ultraschall die Länge von Rissen mit praktisch hinreichender Genauigkeit
abschätzen lässt, 2) eine Standardisierung für Ultraschallprüfungen mit der
Festigkeit von Schweissungen in guter Beziehung steht. Der Zuverlässigkeits-
grad sollte einen besseren Ausgleich zwischen dem Risiko des Benützers und
dem Risiko des Herstellers gewährleisten.

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