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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

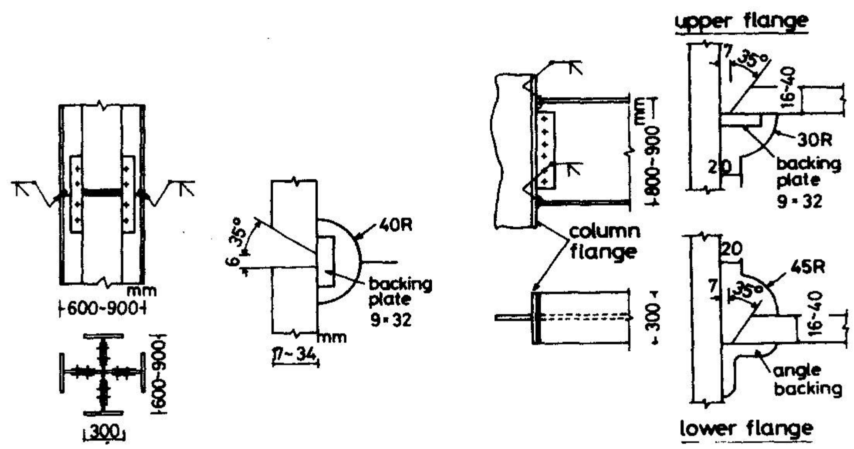
In recent years ultrasonics has been applied to a greater extent for weld inspection. It can locate cracks with relative ease and the equipment is low in cost. Especially it is quite suitable for field use as the equipment is portable.

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(Laboratory test) is shown in Fig.2, and that between the indicated flaw length by radiographic inspection(xL) and actual flaw length is shown in Fig.3.

Frequency distributions of estimation errors made by ultrasonic and radiographic inspection are shown in Figs.4 and 5 respectively. Obviously radiographic inspection is more reliable than ultrasonics.

Relationship between the flaw length as measured on a ultrasonic and actual 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 ultrasonic inspection for Case 1. is 71.2 mm^2 and that for A-building(Case 2) is 197.5 mm^2, direct comparison of these is impossible since the number of samples are different each other. However, the test of significance 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 between the judgement done

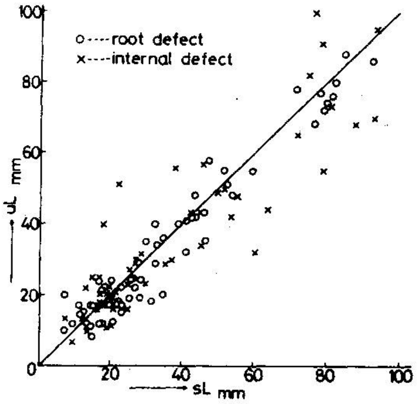


Fig.2 Relation Between sL and uL

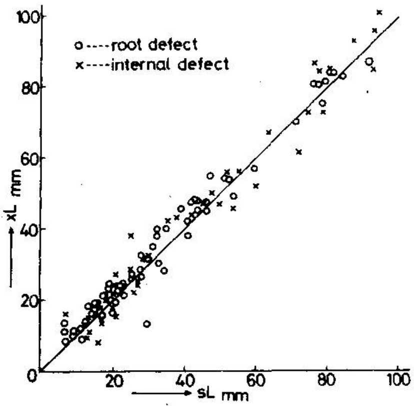


Fig.3 Relation Between sL and xL

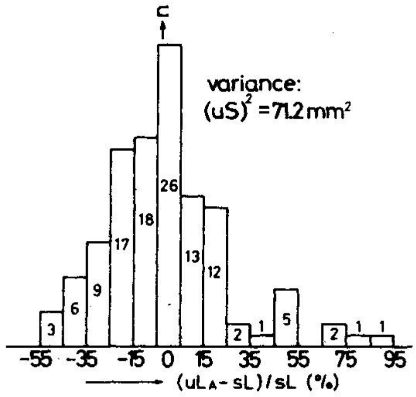


Fig.4 Error Histogram of Ultrasonic Evaluation

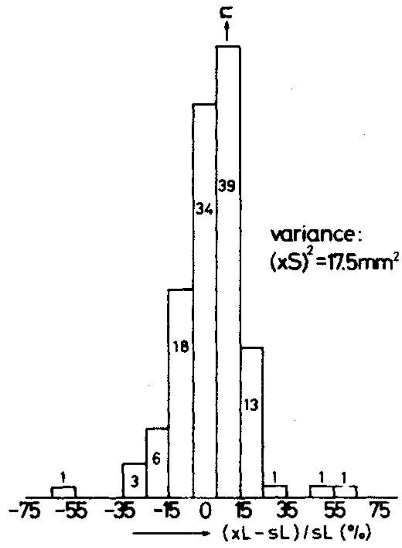


Fig.5 Error Histogram of Radiographic Evaluation

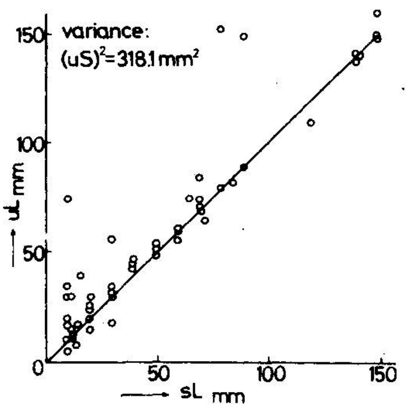


Fig.7 Relation Between sL and uLB for B-Building

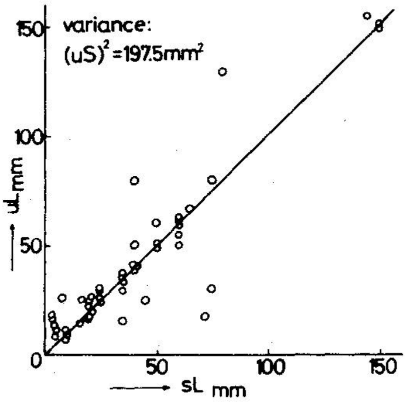


Fig.6 Relation Between sL and uLA for A-Building

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

(1) Contingency Table

Broken at → Mark ↓	Base metal	Weld	Totals
1.2.3	27	36	63
4	2	51	53
Totals	29	87	116

(2) Testing Independence { $\chi_1^2(0.05)=3.84$}

$\chi^2=21.41>\chi_1^2(0.05)$; not independent

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

1b) Marked 3,4, rejectable

(1) Contingency Table

Broken at→ Mark ↓	Base metal	Weld	Totals
1.2	19	23	42
3,4	10	64	74
Totals	29	87	116

(2) $\chi^2=14.38>\chi_1^2(0.05)$; not independent

(3) 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

(1) Contingency Table

Broken at → uL ↓	Base metal	Weld	Totals
≤ 5/8 t	23	18	41
> 5/8 t	6	69	75
Totals	29	87	116

(2) Testing Independence

$\chi^2=32.71>\chi_1^2(0.05)$; not independent

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

2b) Based on Actual Flaw Length

(1) Contingency Table

Broken at→ xL ↓	Base metal	Weld	Totals
≤ 5/8 t	24	13	37
> 5/8 t	5	74	79
Totals	29	87	116

(2) $\chi^2=46.05>\chi_1^2(0.05)$; not independent

(3) 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 Zuverlässigkeitsgrad sollte einen besseren Ausgleich zwischen dem Risiko des Benützers und dem Risiko des Herstellers gewährleisten.

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