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Autor(en): **Murzewski, Janusz W.**

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Quality Assurance of Welded Structures

Assurance de la qualité des constructions soudées

Qualitätssicherung bei geschweissten Konstruktionen

Janusz W. MURZEWSKI
Prof. Dr.
Politechnika Krakowska
Kraków, Poland

Janusz Murzewski, born 1928, received his civil engineering degree at Politechnika Krakowska, 1955. In 1959/60 he was fellow of the Applied Mathematics Division at Brown University, USA. 1963–70 – chairman of Department of Mathematics, since 1970 – head of Dep. of Metal Structures in Kraków. He is author of the book «Safety of Building Structures» and more than 200 papers.

SUMMARY

According to new concepts, the fraction of welds which should be subjected to radiographic and/or ultrasonic control depends on the nature of the loads and consequences of failure. Three classes of structures are defined and not every welding workshop is suitable for carrying out each class of weld. Classification of safety has been discussed by some international organizations. It may give differences in design strengths depending on consequences of failure and coefficients of variation of both loads and material properties.

RÉSUMÉ

Selon de nouveaux concepts, les soudures qui doivent être soumises au contrôle radiographique ou ultrasonique dépendent de la nature des charges et des conséquences d'une éventuelle rupture. On définit trois classes de structures; tous les postes de soudure ne seront pas autorisés pour chaque classe. La classification de la sécurité est discutée par des organisations internationales. Cela conduit à des résistances de calcul différentes en fonction des conséquences de rupture et des coefficients de variation des charges et propriétés des matériaux.

ZUSAMMENFASSUNG

Der Umfang der mittels Röntgenstrahlen oder Ultraschall zu prüfenden Schweissnähte sollte nach neueren Vorstellungen von der Belastungsart und den Konsequenzen eines allfälligen Versagens abhängig gemacht werden. Drei Bauwerksklassen werden definiert. Nicht jede Werkstatt darf für alle Klassen Schweissarbeiten ausführen. Die Klassifizierung wurde von verschiedenen internationalen Gremien diskutiert und es ist vorgesehen, die Rechenwerte der Festigkeiten von den Folgen eines Versagens, dem Variationskoeffizienten der Beanspruchung sowie den Baustoffeigenschaften abhängig zu machen.

1. INTRODUCTION

Structural failure are often originated by rupture of welded connections. Butt welds in tension condition happen to be the weak points, the most frequently. Mechanical properties of the weld material may be quite good in average, even better than the properties of original steel members but there is a little more probability of random defects in welds although approved welders may guarantee their quality. Formerly, design codes for welded structures recommended a reduction of stresses in welds under tension ~20%. The reduction used to be achieved by additional plates or other elements which could increase the cross-section at a joint. Such usage has been abandoned, because additional elements give stress concentration points and they do not make connections any safer. Nowadays, the whole cross-section of a member shall be rather overdimensioned if the welded joints are just at the point where the stress would reach the design strength. However, quality control of welds becomes more and more appreciated in the last decades thanks to developments in radiographic and ultrasonic techniques. Therefore standard specifications admit no strength reduction of welds provided that the modern testing methods are applied. Recently, a proposition is under discussion, to get rid of any stress analysis of butt welds but to introduce an intensive quality control by means of physical methods. However, it is an economic question, because costs of the entire weld testing may be excessive. That is why a classification of welded structures and quality control differentiation are suggested [1]. Draft specifications of the Polish Committee for Standardization PKNMiJ are given under discussion recently [2]. Similar recommendations have been already elaborated in other Central-European countries. The new rules presented in the next chapter are simplified a little in order to keep attention on the main topics of safety classification.

2. CLASSIFICATION OF WELDED STRUCTURES

An option will be given to designers in some cases of welded joints (e.g. groove welds subject to tension)

- either the design strength shall be reduced
- or a radiographic and/or ultrasonic control of joints shall be ordered.

There are added detailed specifications of control requirements in construction [2]. Two indices are defined in order to decide about extent of the control

- ZA depends on nature of loads as well as stress level in comparison with the limit strength of a structural element under consideration (Table 1),
- ZB depends on economic damage in comparison with the average Annual Salary (AS) as well as probability of loss of human life in consequence of a structural failure (Table 2).

Nature of loads	Stress level ratio <50%	50-80	>80%
Static	0	0	1
Dynamic	0	1	2
Fatigue	1	2	3

Table 1 Index ZAcalibration

Material losses	Danger for life improb.	probable	very pr.
<1 AS	0	2	4
1 - 10	2	4	6
>10 AS	4	6	8

Table 2 Index ZBcalibration

The index ZAis the criterion for determination of the fraction of welds which should be subject to a radiographic and/or ultrasonic control as well as the permissible defectiveness of welds (Table 3).

The sum ZA+ZBdefines the class of a structural element. The maximum value defines the class of structure Z,

$$Z = \mathrm{Max}\ (ZA+ZB)\,, \quad (1)$$

Three classes are proposed (Table 4). The fabricaton shops shall be devided in three categories. Only the I-st category plants shall be licenced to construct welded structures of any class

ZA	Fraction of radiographic/ultrasonic tests	Permissible defectiveness class
3	min 50%	max 2
2	min 25%	max 3
1	min 10%	max 4

Table 3 Quality control requirements

Z	Safety class of the structure	Category of welding shop
>7	1	I
3-7	2	I and II
<3	3	I, II and III

Table 4 Safety classification

Implementation of the new system of quality assurance of welded structures is not easy. The problem of workshop categorization is very controversial. There are needs for a more systematic inspection and quality control in building steel structure. It should approach perhaps the quality control system which is achieved by ship classification organizations such as the Lloyd's Register or Det Norske Veritas.

3. PROBLEM OF SAFETY DIFFERENTIATION

Safety classes of welded structures (Table 4) are analoguous to ones recommended by the Joint-Committee on Structural Safety, JCSS, for any civil engineering structure. Consequences of failure, i.e.

- material damage in comparison with initial costs,
- loss of human life and limb,

were discussed as the criteria of classifiation [3]. Somwhat different criteria are given by the Nordic Committee on Building Regulations NKB [4] for Ultimate Limit States, ULS, (Table 5) and the German Institute for Standardization, DIN [5] for the ULS and SLS - Serviceability Limit States (Table 6)

Failure consequences	Failure type (ULS)		
	ductile (strain hardening)	ductile (no extra capacity)	brittle and instability
Less serious	3.1	3.7	4.2
Serious	3.7	4.2	4.7
Very serious	4.2	4.7	5.2

Table 5 Safety Index β according to NKB

Class	U L S			S L S		
	Risk to human life	Economic consequences	β	Economic consequences	Impediments in use	β
1	no	sligth	4.2	sligth	sligth	2.5
2	exists	considerable	4.7	considerable	considerable	3.0
3	great	great	5.2	great	severe	3.5

Table 6 Safety indices β according to DIN

The index β is a semiprobabilistic measure of safety defined for independent load and material properties as follows

$$\beta = (\bar{R} - \bar{S}) / \sqrt{\sigma_R^2 + \sigma_S^2} \quad , \qquad (2)$$

where $\bar{R}$ - mean capacity of the structural system,
$\bar{S}$ - mean peak load during the service life,
σ_R - standard deviation of the random capacity R ,
σ_S - standard deviation of the random load S .

A random safety margin, Δ , is defined as follows,

$$\Delta = R - S \qquad (3)$$

and the safety index β is the reciprocal of its coefficient of variation (c.o.v.)

$$\beta = 1/v_\Delta \quad , \qquad (4)$$

where $v_\Delta = \sigma_\Delta / \bar{\Delta}$ - the normal c.o.v. according to the definition of probablity

If the Gauss probability distributions are assumed for random variables R and S the probability of failure P is a function of index β (Table 7)

β	5.2	4.7	4.2	3.0	2.5	2.0
P	1*E-7	1*E-6	1*E-5	1*E-3	5*E-3	1*E-2

Table7 Relation of probability of failure and safety index

The formula (1) has a meaning for the level-2 probability based design, so called. A more practical safety classification, suitable to level-1, i.e. Load and Resistance Factor Design (LFRD), has been recommended by the Soviet Building Design Standard GOSSTROY [6] (Table 8).

Structural class	Degree of importance	Examples of structures	Reduction coefficient for design strength
I	Very great national and/or social importance	Main structures of power and metallurgical plants Stacks of height > 200 m TV towers, theaters, kindergartens, hospitals, museums etc.	1.0
II	Important	Structures not included to classes I nor III	0.95
III	Limited importance	Stores of agricultural products, chemicals, coal etc. 1 storey residential buildings, electric line supports etc.	0.9

Table 8 Safety classes according to GOSSTROY

A similar but more detailed list of this type is given in the Polish draft of welded structures classification [2] . It is extended to other civil engineering structures. It may help, together with index ZA , to precise the quality control classification. However, the sense of safety clasifications according to Tables 5, 6 and 8 is to influence the structural analysis and to dimension the structural members adequately and not to differentiate the control requirements. This is the main difference between the two approaches Both have the same goal: to moderate the probability of failure according to its consequences. One point seems to be not right in the welded structure classificatin: the nature of loads should influence the value of design strength and/or workmanship rules and not the safety classes themselves.

4. CONCLUSIONS

Structural analysis and adequate dimensioning of structural elements for the loads acting upon and possible consequences of failure are usually good measures for quality assurance. But there are also other measures which enable to keep the probability of failure on a necessary low level. This is a more intrinsic control system (radiographic and/or ultrasonic tests in the case of welds) which can be adjusted to differentiated safety requirements. The requirements depend on material losses KM and risks to human life. The latter can be replaced by the value KA of life insurance policy. This gives one argument of safety classification

$$K = KM + KA \,. \qquad (5)$$

The other one is the fluctuation of random variables (actions and material properties) and in the case of particular types of structures :

- the coeficient of variation of loads v_S and not necessarily the nature of loads (static-dynamic). The value v is important in partial safety factors calibration procedures (LFRD) as well as the level-2 probability considerations. Such conclusion is also derived from a solution of optimization problem of design values R^* , S^*. The solution, given in Ref. [7], is such that the hazard scale, so called, should keep its specific value 1/k for each structural class

$$h(R^*)\cdot R^* = h(S^*)\cdot S^* = 1/k, \qquad (6)$$

where $h(R^*)$ - risk that the random capacity R downcrosses a design value R^* ,

$h(S^*)$ - risk that the random load S upcrosses a design value S^* ,

k - index of capitalized economic and social consequences of structural failure.

The hazard functions h(.) depend on types of probability distributions. E.g., there are equations

$$h(R^*)\cdot R^* = \sqrt[u_R]{1/\gamma_R} \,, \qquad h(S^*)\cdot S^* = \sqrt[u_S]{1/\gamma_S} \qquad (7)$$

for the Extreme Value probability distributions (the Weibull and the Frechet, respectively)

γ_R , γ_S - the partial safety factors,

u_R , u_S - the dimensionless parameters of variations (proportional to the normal c.o.v.'s).

Thus the c.o.v's /v_S or u_S / of anticipated loads, acting on a structure should be taken under consideration in the quality assurance programmes.

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