Bauforschung

Gebrauch von nichtrostenden Stählen - Untersuchung zur Festlegung einheitlicher Regeln. Annex S.

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Abschlußbericht zum Forschungsvorhaben "Annex S: Gebrauch von nichtrostenden Stählen - Untersuchung zur Festlegung einheitlicher Regeln" (DIBt Nr. IV 1-5-649/91)

Inhalt

Anlagen

1. Situation

Nichtrostende Stähle werden in Deutschland z.T. in großen Mengen in zahlreichen Anwendungsgebieten eingesetzt. Im Bauwesen kommen sie neben dekorativer Anwendung (Fenster, Dachrandblenden etc.) vor allem mit Blick auf die Tragfähigkeit als Verankerungsmittel für Fassadenplatten sowie für den Druckbehälterbau in Betracht.

Darüberhinaus wird der konstruierende Bauingenieur häufig vor das Problem gestellt, für Bauteile und sogar ganze Bauwerke aus Gründen der Korrosionsgefahr nichtrostenden Stahl verwenden zu müssen.

In Deutschland wird die Anwendung der vier gebräuchlichsten nichtrostenden Stahlsorten durch die Zulassung Z-30.44.1 des DIBt (vormals IfBt) /1/ geregelt. Grundlage für die Zulassung bilden die vier Normen DIN 17440, DIN 17441, DIN 17455, DIN 17456 /2/, /3/, /4/, /5/ -Technische Lieferbedingungen für die verschiedenen Erzeugnisformen- und DIN 267 Teil 11 (Nachfolgenorm DIN ISO 3506 /6/) für die Verbindungsmittel. Daneben gibt es von der EGKS die Euronorm prEN 10088 Teil 1 bis 3 /7/, die ebenfalls die technischen Lieferbedingungen behandelt. DIN 17440 bzw. DIN 17441 und prEN 10088 sind bis auf kleine Abweichungen conform. Die Bemessung nach DIBt-Zulassung beruht auf DIN 18800 Teil 1 (Ausgabe März 1981) /8/ sowie bei Stabilitätsuntersuchungen auf DIN 4114 /9/, wobei für die ω-Zahlen eine Berechnungsformel in der Zulassung angegeben ist.

Der ENV 1993-1-1 Eurocode 3: Teil 1.1 /10/ enthält zur Zeit noch keine Angaben über die Anwendung der nichtrostenden Stähle.

2. Vorgehensweise bei der Erstellung des Annex S für die Bemessung von Tragwerken aus nichtrostenden Stählen

Um ein einheitliches sowie bauaufsichtlich und international anerkanntes Regelwerk zu erhalten, besteht in einer ersten Phase die Aufgabe im wesentlichen darin, den gegenwärtigen Stand allgemein anerkannter Regeln der Technik für die Verwendung nichtrostender Stähle in Deutschland und den anderen europäischen Mitgliedsländern zusammenzustellen, miteinander zu vergleichen und in das Grenzzustandskonzept des ENV 1993-1-1 Eurocode 3 zu übersetzen.

Das Ziel ist der Entwurf eines Anhanges S - Der Gebrauch von nichtrostenden Stählen -, der in der Weiterentwicklung des ENV 1993-1-1 Eurocode 3 aufgenommen werden soll.

Die Vorgehensweise zur Erstellung des Entwurfes war wie folgt:

1. Zusammenstellung allgemein anerkannter Regeln der Technik

   Die wichtigsten Grundlagen hierfür sind:
   - vorhandene Zulassungen, auch im Ausland,
   - die Untersuchungsergebnisse, die zu diesen Zulassungen geführt haben,
   - internationale Normen und
   - im Schrifttum veröffentlichte Versuchsergebnisse

2. Vergleich der Regelwerke mit Blick auf
   - Anwendungsgebiet (z.B. Korrosionsklimata, Erzeugnisformen, Parameterumfang und -grenzen etc.)
   - Werkstoffkennwerte (z.B. charakteristische Werte der Festigkeiten etc.)
   - Sicherheitselemente (z.B. Bemessungswerte der Festigkeit, γ-Faktoren)
   - Qualitätssicherung (Verarbeitung, Korrosionsschutz etc.)
   - Auswirkung auf die Konstruktion
   - anwendungsfreundliche Handhabung
   - Ermüdungsverhalten

3. Übertragung in das Grenzzustandskonzept des ENV 1993-1-1 Eurocode 3.

3. Wichtigste Festlegungen im Annex S

3.1 Materialeigenschaften

Im Annex S des ENV 1993-1-1 Eurocode 3 werden ausschließlich austenitische und austenitisch-ferritische nichtrostende Stähle behandelt. Das charakteristische Spannungs-

Dehnungs-Verhalten dieser Stähle ist in **Bild 1** wiedergegeben. Die Materialeigenschaften werden in Kapitel 3 des Annex S behandelt (s. Anlage Hauptdokument, Background Documentation und Appendix A).

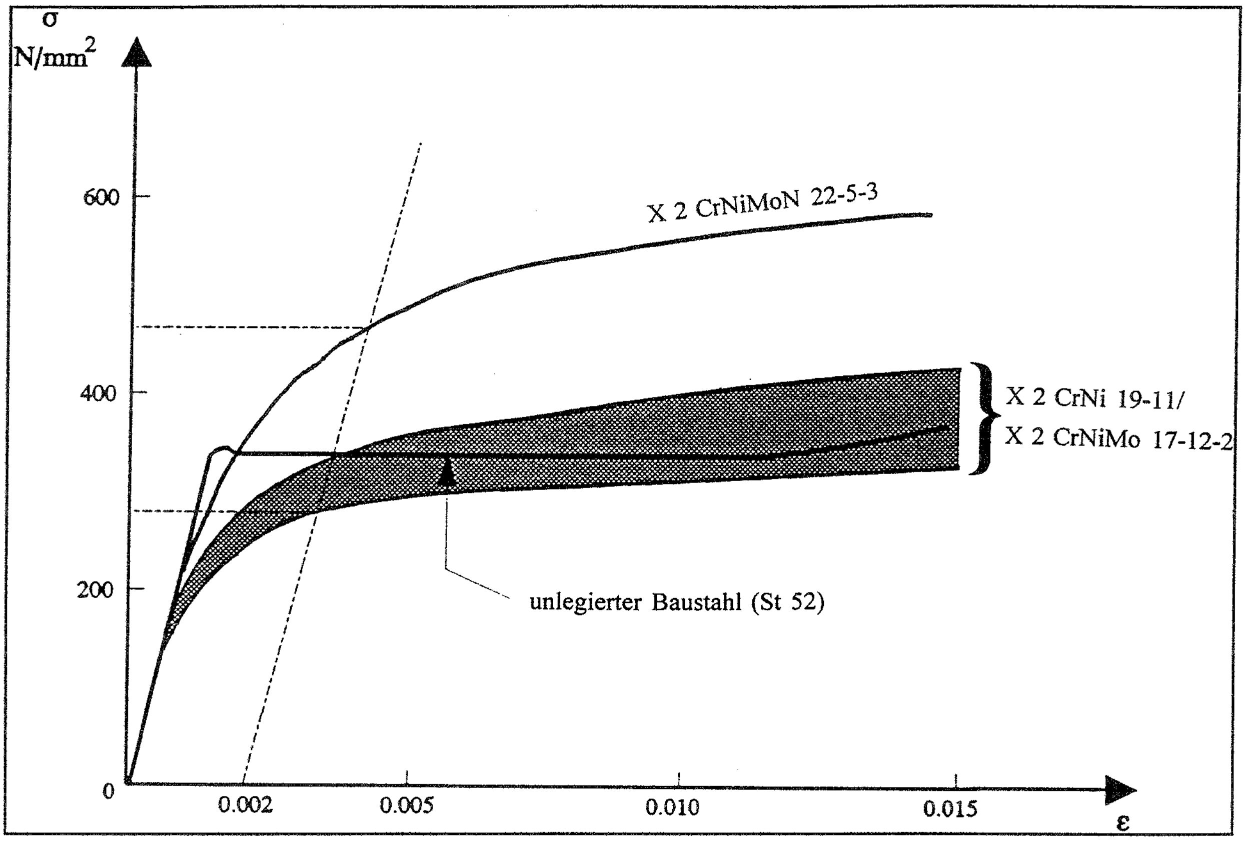


Bild 1: Charakteristische Spannungs-Dehnungs-Kurven für nichtrostende austenitische und austenitisch-ferritische Stähle

Die Einteilung der nichtrostenden Stähle erfolgt in Annex S nach Festigkeitsklassen analog zum ENV 1993-1-1 Eurocode 3. Als Bemessungswerte werden die 0.2%-Dehngrenze und die minimale Zugfestigkeit herangezogen. Um die höheren Festigkeiten nach einer Kaltverfestigung zu nutzen, sind im Annex S Kaltverfestigungsstufen mit definierter Streckgrenze und Zugfestigkeit analog zur Zulassung Z-30.44.1 des Deutschen Institut für Bautechnik angegeben.

3.2 Haltbarkeit und Gebrauchsfähigkeit

Neben der Gebrauchsfähigkeit wird in Kapitel 4 des Annex S insbesondere die Haltbarkeit aufgrund der besonderen Anforderungen an nichtrostende Stähle behandelt (s. Anlage Hauptdokument und Appendix B).

3.3 Bemessungsmethode

3.3.1 Allgemeines

Gegenüber der Methode der zulässigen Spannungen, die noch die Grundlage des IfBt-Zulassungsbescheid von 1989 bildet, wird im Annex S, entsprechend der Philosophie des ENV 1993-1-1 Eurocode 3, das Grenzzustandskonzept als Bemessungsmethode für nichtrostende Stähle zugrundegelegt.

Das Kapitel 5 "Grenzzustand der Tragfähigkeit" basiert auf den entsprechenden Kapiteln des ENV 1993-1-1 Eurocode 3: Teil 1.1 und des ENV 1993-1-3 Eurocode 3: Teil 1.3 /11/ "Dünnwandige Bauteile" (s. Anlage Hauptdokument und Background Documentation).

3.3.2 Klassifizierung

Die maximalen Breite-zu-Dicke-Verhältnisse (b/t) nach Tabelle S.5.1, Blätter 1 bis 4 des Annex S sind entweder dem ENV 1993-1-3 Eurocode 3: Teil 1.3 oder der ASCE Cold Form Stainless Steel Specification /12/ entnommen worden, je nachdem welche der Werte geringer ist.

Wirksame Querschnittswerte für Querschnitte der Klasse 4

Die wirksamen Querschnittswerte für Querschnitte der Klasse 4 werden nach den Tabellen 3.1 und 3.2 des ENV 1993-1-3 Eurocode 3: Part 1.3 bestimmt (**Tabellen 1.1 und 1.2** auf den Seiten 6 und 7). Der Abminderungsfaktor ρ in der Formel zur Bestimmung der wirksamen Breite $b_{eff} = \rho \cdot \bar{b}$ ergibt sich hierbei wie folgt:

$\rho = 1.0$ für Plattenschlankheit $\bar{\lambda}_p \leq 0.673$

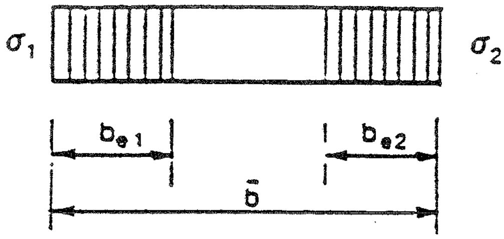
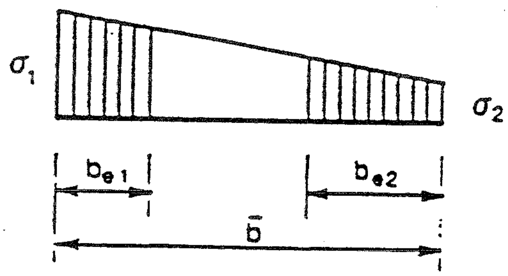
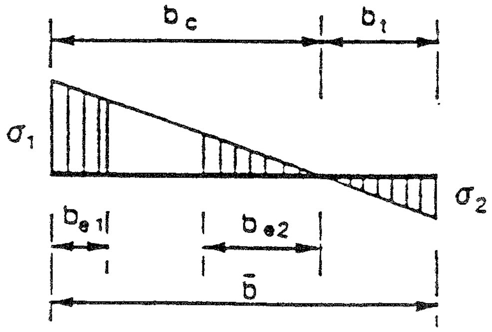
$\rho = (1.0 - 0.22/\bar{\lambda}_p)/\bar{\lambda}_p$ für Plattenschlankheit $\bar{\lambda}_p > 0.673$

wobei

$$\bar{\lambda}_p = 1.052 \cdot \frac{b_p}{t} \sqrt{\frac{\sigma_{com}}{E \cdot k_\sigma}}$$

σ_{com} = kritische Plattenbeulspannung

k_σ = Beulwert entsprechend dem Spannungsverhältnis ψ gemäß Tabelle 3.1 des ENV 1993-1-3 Eurocode 3: Teil 1.3 (**Tabellen 1.1 und 1.2** auf den Seiten 6 und 7).

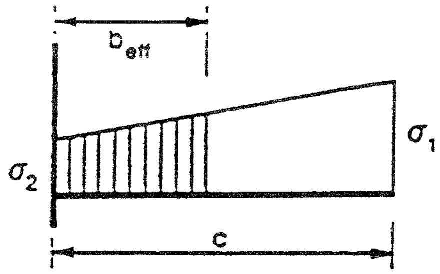
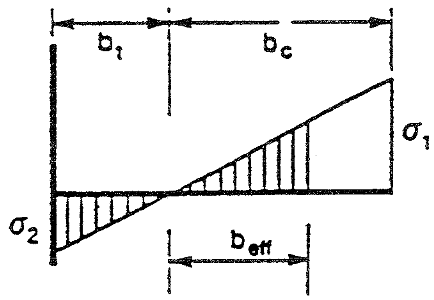
<table>
<tr><th colspan="2">Tabelle 1.1 Beidseitig gestützte druckbeanspruchte Teile</th></tr>
<tr><th>Spannungsverteilung
(Druck positiv)</th><th>wirksame Breite b_{eff}</th></tr>
<tr><td>
</td><td><u>$\Psi = -1$:</u>
$b_{eff} = \rho \bar{b}$
$b_{e1} = 0{,}5 b_{eff}$
$b_{e2} = 0{,}5 b_{eff}$</td></tr>
<tr><td>
</td><td><u>$1 > \psi \geq 0$:</u>
$b_{eff} = \rho \bar{b}$
$b_{e1} = 2 b_{eff}/(5 - \psi)$
$b_{e2} = b_{eff} - b_{e1}$</td></tr>
<tr><td>
</td><td><u>$\psi < 0$:</u>
$b_{eff} = \rho\, b_c = \rho \bar{b}/(1-\psi)$
$b_{e1} = 0{,}4 b_{eff}$
$b_{e2} = 0{,}6 b_{eff}$</td></tr>
</table>

$\psi = \sigma_2/\sigma_1$	1	$1 > \psi > 0$	0	$0 > \psi > -1$	-1	$-1 > \psi > -2$
Beulwert $k\sigma$	4,0	$8{,}2 / (1{,}05 + \psi)$	7,81	$7{,}81 - 6{,}29\psi + 9{,}78\psi^2$	23,9	$5{,}98(1-\psi)^2$

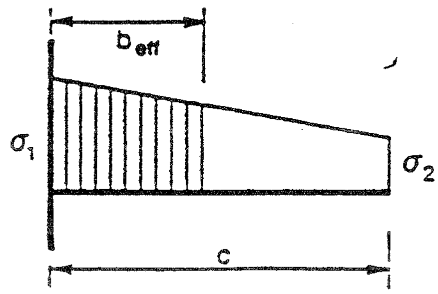
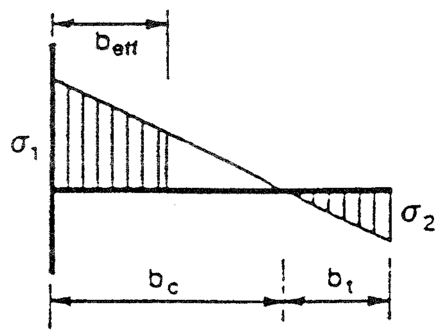
Alternativ für $1 \geq \psi \geq -1$:

$$k_\sigma = \frac{16}{[(1+\psi)^2 + 0{,}112(1-\psi)^2]^{0{,}5} + (1+\psi)}$$

Tabelle 1.2 Einseitig gestützte druckbeanspruchte Teile

Spannungsverteilung (Druck positiv)	Wirksame Breite b_{eff}
	<u>$1 > \psi \geq 0$:</u> $b_{eff} = \rho\ c$
	<u>$\psi < 0$:</u> $b_{eff} = \rho\ b_c = \rho\ c/(1 - \psi)$

$\psi = \sigma_2 / \sigma_1$	1	0	-1	$1 \geq \psi \geq -1$
Beulwert k_σ	0,43	0,57	0,85	$0{,}57 - 0{,}21\ \psi + 0{,}07\ \psi^2$

Spannungsverteilung (Druck positiv)	Wirksame Breite b_{eff}
	<u>$1 > \psi \geq 0$:</u> $b_{eff} = \rho\ c$
	<u>$\psi < 0$:</u> $b_{eff} = \rho\ b_c = \rho\ c/(1 - \psi)$

$\psi = \sigma_2 / \sigma_1$	1	$1 > \psi > 0$	0	$0 > \psi > -1$	-1
Beulwert k_σ	0,43	$0{,}578 / (\psi + 0{,}34)$	1,7	$1{,}7 - 5\ \psi + 17{,}1\ \psi^2$	23,8

Mittragende Gurtbreiten (Effect of shear lag)

Bei der Bestimmung der Querschnittswerte werden mittragende Gurtbreiten nach Kapitel 4.4.4 des ENV 1993-1-3 Eurocode 3: Teil 1.3 berücksichtigt.

3.3.3 Beanspruchbarkeiten der Querschnitte

Die Brutto- und Nettoquerschnittswerte werden analog dem ENV 1993-1-1 Eurocode 3: Teil 1.1 ermittelt. Für Effekte aus Lochexzentrizität wird im Annex S zusätzlich ein Reduktionsfaktor k_A angegeben:

$$k_A = 1 - \frac{d}{b}\left[1 - \frac{2e}{b}\right]$$

mit

d = Lochdurchmesser

e = Randabstand

b = Querschnittsbreite.

Der Nachweis, daß die grundlegenden Baustahlregeln auch auf nichtrostende Stähle anwendbar sind, basiert auf Versuchsreihen /13/ an Zugbauteilen mit variabler Lochanordnung (9 Versuche) und Versuchen mit Schraubverbindungen (6 Versuche), wo Versagen im Nettoquerschnitt auftrat. Die Ergebnisse dieser beiden Versuchsreihen sind in **Bild 2** wiedergegeben. In diesem Bild werden die Ergebnisse mit der empfohlenen Bemessungslinie (γ_m = 1.0) für zugbeanspruchte Bauteile nach Eurocode 3 verglichen. Obwohl die Ergebnisse nahe an der 45°-Linie liegen, wird aus Kompabilitätsgründen zum Eurocode 3 der 0.9-Faktor in der Bemessungsformel beibehalten (siehe **Bild 2**).

3.3.4 Stabilitätsnachweise für Bauteile

Knicken

Der Grenzwert der Beanspruchbarkeit gegen Knicken von druckbeanspruchten Bauteilen ergibt sich analog zum Eurocode 3 zu:

$$N_{b.Rd} = \frac{\chi \, \beta_A \, A \, f_y}{\gamma_{M1}}$$

mit

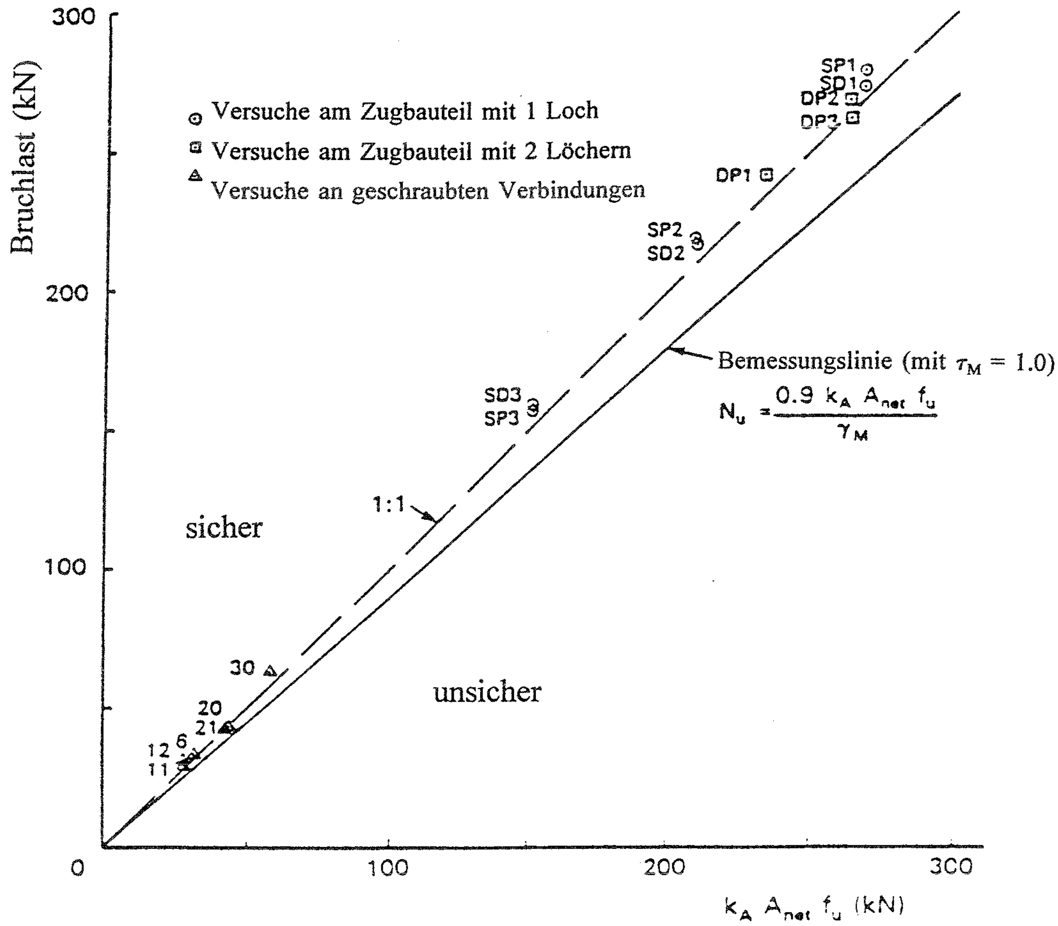


Bild 2: Versuchsdaten für Versagen im Nettoquerschnitt aus /13/

$\beta_A = 1$ für Querschnitte der Klasse 1, 2 und 3

$\beta_A = A_{eff}/A$ für Querschnitte der Klasse 4

$\chi =$ Abminderungsfaktor für den maßgebenden Stabilitätsfall

Die Konstanten α (Imperfektionsbeiwert) und $\bar{\lambda}_0$ (Bezugschlankheit) in der Formel zur Bestimmung des Abminderungsfaktors nach Kapitel S.5.4.2 des Annex S sind aus vorhandenen Versuchsdaten über nichtrostende Stähle gewonnen worden (s. Tabelle S.5.2 des Annex S und Anlage Background Documentation).

Nachweise gegen Schubbeulen

Der Nachweis gegen Schubbeulen der Stege basiert auf einem vereinfachten Verfahren des Eurocode 3 unter Berücksichtigung überkritischer Auswirkungen.

Versuchsergebnisse /14/, die an kurzgespannten Balken aus nichtrostendem Stahl mit unterschiedlichen Steghöhen ermittelt wurden, sind in **Bild 3** im Vergleich mit empfohlenen Bemessungskurven für nichtrostende Stähle und Kurven für unlegierte Stähle nach Eurocode 3 dargestellt.

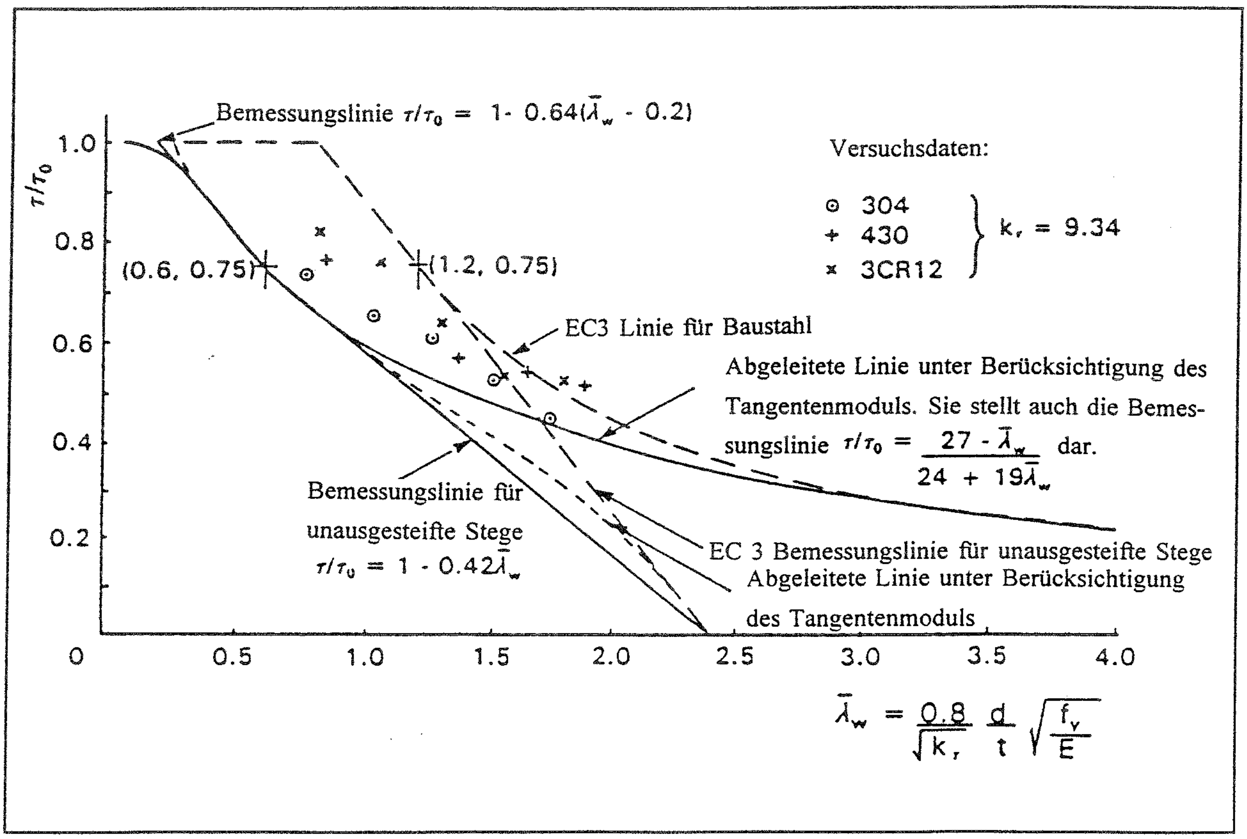


Bild 3: Schubtragfähigkeit von Profilstegen /14/

Quersteifen

Die Bemessungsdruckkraft in der Quersteife wird analog zum Eurocode 3 wie folgt ermittelt:

$N_s = V_{Sd} - d_w\, t_w\, \tau_{bb}$ jedoch $N_s \geq 0$

mit

V_{Sd} = Bemessungsquerkraft im Bauteil

τ_{bb} = Anfangsschubbeulfestigkeitdes Steges.

Die Anfangsschubbeulfestigkeit τ_{bb} ist in Tabelle S.5.6 des Annex S angegeben.

3.4 Verbindungen

3.4.1 Schraubverbindungen

Verbindungen zwischen Bauteilen aus nichtrostenden Stählen werden genauso ausgeführt wie die aus unlegierten Baustählen. Aus diesem Grund sind im Annex S Empfehlungen angegeben, die durch Verifizierung von Bemessungsregeln des Eurocode 3: Teil 1.1 mit Versuchen an nichtrostenden Stählen entwickelt wurden.

Modifizierungen sind im Annex S für die Bestimmung der Nettoquerschnittsfläche und für die Bemessung überlappter Verbindungen, bei denen die Schrauben in einer Reihe quer zur Belastungsrichtung liegen, vorgenommen worden.

Die Lochaufweitung wird in angemessener Weise zur Vermeidung eines getrennten Nachweises der Gebrauchstauglichkeit begrenzt, indem ein reduzierter Wert der Zugfestigkeit f_u' zur Begrenzung der Lochaufweitung unter der Traglast eingeführt wird:

$$f_u' = 0.5 \cdot f_y + 0.6 \cdot f_u$$

mit

f_y = 0.2%-Dehngrenze des Materials

f_u = Zugfestigkeit des Materials.

Für geschweißte Verbindungen wurden die Bemessungsregeln des ENV 1993-1-1 Eurocode 3: Teil 1.1 übernommen.

3.5 Ermüdung

Vergleiche der Versuchsdaten für Verbindungen aus nichtrostendem Stahl (/15/ - /19/) mit Versuchsdaten für Verbindungen aus unlegiertem Baustahl /20/ zeigen gute Übereinstimmung im Tragverhalten (s. Anlage Background Documentation), so daß die Bemessungsregeln sowie die Kerbfalltabellen im Kapitel 9 des Eurocode 3 übernommen werden können.

4. Zusammenfassung

Als Ergebnis der Forschungsarbeit ist festzuhalten:

1. Grundlage für die Erarbeitung des Annex S bildeten hauptsächlich die Normen DIN 17440, DIN 17441, DIN 17455, DIN 17456, prEN 10088 Teil 1 bis 3, der IfBt-Zulassungsbescheid Z-30.44.1 und das Design Manual for Structural Stainless Steel vom Steel Construction Institute /13/.

2. Durch Vergleiche von Versuchen für nichtrostende Stähle mit Versuchen für unlegierte Baustähle konnte gezeigt werden, daß die grundlegenden Bemessungsregeln des ENV 1993-1-1 Eurocode 3: Teil 1.1 auf nichtrostende Stähle anwendbar sind.

3. Im Annex S des ENV 1993 Eurocode 3 wird die Bemessung nichtrostender Stähle nach dem Konzept der Grenzzustände der Tragfähigkeit und der Gebrauchstauglichkeit durchgeführt. Die Abkehr vom Konzept der zulässigen Spannungen, auf dem z.B. die IfBt-Zulassung Z.30.44.-1 basiert, ist damit vorgenommen.

4. Empfehlungen bezüglich der Fertigung, Handhabung und Dauerhaftigkeit nichtrostender Stähle sind in den Appendices A bis C zum Annex S gegeben und gehören nicht zum Bestandteil, da der Annex S in erster Linie eine Bemessungsnorm darstellt. Weitergehende Informationen werden in den Arbeitsgruppen des CEN/TC 121/SC 4/WG 5 "Welding guidelines for stainless steels" und des CEN/TC 135/WG 10 "Execution of steel structures, Part 1: General rules and rules for buildings" erarbeitet.

Aachen, 2. Dezember 1993

G. Sedlacek

Prof. Dr.-Ing. G. Sedlacek

5. Normen und Literatur

/1/ Deutsches Insitut für Bautechnik: Bauteile und Verbindungsmittel aus nichtrostenden Stählen, Zulassungsbescheid Z-30.44.1 vom 01. Februar 1989, Berlin

/2/ DIN 17440: Nichtrostende Stähle; Technische Lieferbedingungen für Blech, Warmband, Walzdraht, gezogenen Draht, Stabstahl, Schmiedestücke und Halbzeug, Juli 1985

/3/ DIN 17441: Nichtrostende Stähle; Technische Lieferbedingungen für kaltgewalzte Bänder und Spaltbänder sowie daraus geschnittene Bleche, Juli 1985

/4/ DIN 17455: Geschweißte kreisförmige Rohre aus nichtrostenden Stählen für allgemeine Anforderungen; Technische Lieferbedingungen

/5/ DIN 17456: Nahtlose kreisförmige Rohre aus nichtrostenden Stählen für allgemeine Anforderungen; Technische Lieferbedingungen

/6/ DIN ISO 3506: Verbindungselemente aus nichtrostenden Stählen, Technische Lieferbedingungen, Dezember 1992

/7/ prEN 10088: Nichtrostende Stähle

- Teil 1: Verzeichnis der nichtrostenden Stähle, Entwurf Juni 1993
- Teil 2: Technische Lieferbedingungen für Blech und Band für allgemeine Verwendung, Entwurf Juni 1993
- Teil 3: Technische Lieferbedingungen für Halbzeug, Stäbe, Walzdraht und Profile für allgemeine Verwendung, Entwurf Juni 1993

/8/ DIN 18800 Teil 1: Stahlbauten, Bemessung und Konstruktion, März 1981

/9/ DIN 4114 Blatt 1: Stahlbau; Stabilitätsfälle (Knickung, Kippung, Beulung), Berechnungsgrundlagen, Vorschriften, Juli 1952xx

/10/ ENV 1993-1-1 Eurocode 3: Bemessung und Konstruktion von Stahlbauten Teil 1.1: Allgemeine Bemessungsregeln, Bemessungsregeln für den Hochbau, April 1992

/11/ ENV 1993-1-3 Eurocode 3: Design of Steel Structures Part 1.3: Cold formed thin gauge Members and Sheeting, Draft January 1993

/12/ American Society of Civil Engineers: LRFD Specification for the Design of Cold-formed Stainless Steel Structural Members, ASCE, 1991

/13/ Dier, A. F., SCI: Joint Industry Study, Design Manual for Structural Stainless Steel, Revision 0, Document No. SCI-RT-256, December 1991

/14/ Carvalho, E. C. G.; van den Berg, G. J.; van der Merwe, P.: Local Shear Buckling in Cold-Formed Stainless Beam Webs, Structural Stability Research Council, Annual Technical Session, Proceedings, April 1990

/15/ Dawes, M.G.: Static and Fatigue Tests on Welded Stainless Steel. British Welding Research Association Research Bulletin 7 (12), 1966

/16/ Honeycomb, J. and Gooth, T.G.: The Effect of Microcracks upon the Mechanical Properties of Austenitic Stainless Steel Weld Metals. Metal Construction 5 (4) 140, 1973

/17/ Anon: Data Sheets on Fatigue Crack Propagation Properties for Butt Welded Joints SUS 304-HP (18Cr-8Ni) Hot Rolled Stainless Steel Plate, NIRM Fatigue Data Sheet No 54. National Research Institute for Metals, Tokyo, 1986

/18/ Yajima, H. et al.: Corrosion Resistance and Fatigue Strength of Stainless Steels for Chemical Tankers. Mitsubishi Heavy Industrial Technical Review, 25 (3) 185-190, 1988

/19/ James, E.A. and Jubb, J.E.M.: The Fatigue Strength of Fillet Welded Joints in 18-8 Type Austenitic Steels at Ambient and Low Temperatures. Australian Welding Journal, Nov/Dec 10 (7), 19-21, 1972

/20/ The Welding Institute: Fitness for Purpose Assessment of Misalignment in Transverse Butt Welds Subject to Fatigue Loading. The Welding Institute Research Report 279/1985

EUROCODE 3 PART 1

ANNEX S - THE USE OF STAINLESS STEELS

Draft
March 1993

ANNEX S THE USE OF STAINLESS STEELS

S.1 SCOPE

(1) This Annex gives supplementary provisions extending the application of ENV 1993-1-1 Eurocode 3: Part 1.1 to stainless steels in accordance to the material specifications in Chapter S.3.

(2) The rules in ENV 1993-1-1 Eurocode 3: Part 1.1 may be applied unless otherwise specified in sections S.3 to S.9.

(3) Sections S.3 to S.9 supplement the corresponding Chapters of ENV 1993-1-1 Eurocode 3: Part 1.1, together with the related Annexes as follows:

S.2	Notations and defintions	
S.3	Materials	Chapter 3 and Annexes B and C
S.4	Serviceability and Durability Limit State	Chapter 4
S.5	Ultimate Limit State	Chapter 5 and Annexes E and F
S.6	Connections Subject to Static Loading	Chapter 6 and Annexes J, K, L and M
S.7	Fabrication	Chapter 7
S.8	Design Assisted by Testing	Chapter 8 and Annex Y
S.9	Fatigue	Chapter 9

S.2 NOTATIONS AND DEFINITIONS

(1) Unless otherwise stated in the following, the vocabulary of heat treatment terms for ferrous products used in prEN 10052 applies.

(2) Guidelines for the treatment including heat treatment are given in prEN 10088.

S.3 MATERIALS

S.3.1 Structural Steels

S.3.1.1 General

(1) This code deals with austenitic, austenitic-ferritic and ferritic stainless steels.

(2) The material properties given in this section are those required for the purpose of design. Other properties are given in prEN 10088.

(3) The design rules specified hereafter are restricted to materials corresponding to strength classes Fe E 480 ($f_y \leq 480$ N/mm²).
If a higher strength can be proved, see section S.3.1.3, this may only be taken into account in the design rules, when justified by appropriate tests.

S.3.1.2 Material properties for stainless steel

(1) As characteristic values for the yield strength f_y the 0.2%-proof stress shall be taken. The characteristic value of the tensile strength f_u shall be the minimum value expected for the relevant steel grade.

(2) The nominal values of the yield strength f_y and the tensile strength f_u for stainless steel dependent on the strength class are given in table S.3.1 for normal delivery condition (heat treatment condition) in accordance with prEN 10088 Part 2 (flat products) and Part 3 (long products).

Table S.3.1 Nominal values of the yield strength f_y and the tensile strength f_u for stainless structural steel to prEN 10088.

Nominal strength class according to EN 10027	steel grades to be considered	Micro-structure [1])	product form							
			C [2])		H [3])		P [4])		B [5])	
			Thickness t mm [6])							
			$t \leq 6$ mm		$t \leq 12$ mm		$12mm \leq t \leq 75mm$		$t \leq 250$ mm	
			f_y	f_u	f_y	f_u	f_y	f_u	f_y	f_u
			N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2
Fe E 220	1.4301 1.4307 1.4541	A	220	520	200	520	200	500	180	460
Fe E 240	1.4401 1.4404 1.4539 1.4571	A	240	530	220	530	220	520	200	500
Fe E 260	1.4016	F	260	450	240	450	240 [7])	430 [7])	240 [8])	400 [8])
Fe E 280	1.4003	F	280	450	280	450	250 [7])	450 [7])	260 [8])	450 [8])
Fe E 290	1.4311 1.4406 1.4439 1.4529	A	290	580	270	580	270	580	270	580
Fe E 320	1.4547	A	320	650	300	650	300	650	300	650
Fe E 350	1.4318	A	350	650	330	650	330	630	-	-
Fe E 420	1.4362	D	420	600	400	600	400	630	400	600
Fe E 480	1.4462	D	480	660	460	660	460	640	450 [9])	650 [9])

[1]) A = austenitic, D = austenitic-ferritic, F = ferritic
[2]) C = cold rolled strip
[3]) H = hot rolled strip
[4]) P = hot rolled plate
[5]) B = bars and rods
[6]) t is the nominal thickness of the element.
[7]) For thicknesses above 25 mm up to 75 mm the mechanical properties can be agreed.
[8]) $t \leq 100$ mm
[9]) $t \leq 160$ mm

(3) As an alternative, the nominal values specified in prEN 10088 for a larger range of thicknesses may be used.

(4) The same values may be adopted for structural hollow sections made of stainless steels.

S.3.1.3 Material properties for strips, plates and bars made of stainless steel in work hardened condition

(1) If a higher strength of stainless steel can be proved by work hardening, this may be taken into account in the design.

(2) The nominal values of the yield strength and the tensile strength for the levels of work hardening defined in prEN 10088 Part 2 and Part 3, as given in the tables S.3.2.1 and S.3.2.2, may be applied.

Note: The aforementioned strength classes for work hardened stainless steels are proposed to be included in prEN 10088.

Table S.3.2.1 Nominal values of higher strengths f_y and f_u for work hardened stainless structural steel to prEN 10088 Part 2 (flat products)

level of work hardening	yield strength f_y (N/mm²)	tensile strength f_u (N/mm²)	steel grades to be considered
C 700	350	700	1.4301, 1.4401, 1.4541
C 850 [2])	530	850	1.4301, 1.4318, 1.4401[1]), 1.4541
C 1000 [2])	750	1000	1.4301, 1.4318
C 1150 [2])	900	1150	1.4301
C 1300 [2])		1300	1.4301

[1]) For higher f_u values see EURONORM 151-2
[2]) See clause S.3.1.1 (3)

Table S.3.2.2 Nominal values of higher strengths f_y and f_u for work hardened stainless structural steel to prEN 10088 Part 3 (long products)

level of work hardening	yield strength f_y (N/mm²)	tensile strength f_u (N/mm²)	steel grades to be considered
C 700	350	700	1.4301, 1.4307, 1.4401, 1.4404
C 800 [2])	500	800	1.4301[1]), 1.4307[1]), 1.4401, 1.4404[1])

[1]) The maximum diameter for this tensile level shall be agreed at the time of enquiry and order; it should not be greater than 25 mm.
[2]) See clause S.3.1.1 (3)

(3) The use of the tables S.3.2.1 and S.3.2.2 is restricted to a maximum thickness of 6 mm for cold rolled strips and of 20 mm for cold formed bars.

(4) When welding work hardened stainless steels, it shall be proved, whether the defined level of work hardening can be kept, otherwise the strengths according to table S.3.1 have to be applied.

S.3.1.4 Material properties

(1) The following properties may be assumed in the analysis of members and cross-sections:

Austenitic steels
Elastic modulus, E [N/mm²]: 200000
Shear modulus, G [N/mm²]: 77000

Austenitic-ferritic steels
Elastic modulus, E [N/mm²]: 205000
Shear modulus, G [N/mm²]: 79000

Ferritic steels
Elastic modulus, E [N/mm²]: 220000
Shear modulus, G [N/mm²]: 85000

(2) For calculating deflections at the serviceability limit state the secant modulus appropriate to the stress in the member shall be used, see S.4.4.

(3) Typical room temperature physical properties of the selected grades in the annealed condition are shown in table S.3.3.

(4) Expert advice should be sought if a non-magnetic application is required.

Table S.3.3 Room temperature physical properties, annealed condition

steel designation No.	Density (kg/m^3)	Thermal expansion 20 - 100°C x $10^{-6}/K$
1.4301	7900	16
1.4016	7700	10
1.4318	7900	16.4
1.4401	7980	16.5
1.4404	8000	16.5
1.4571	7980	16.5
1.4541	7900	16
1.4462	7850	13
1.4003	7700	10.5

S.3.1.5 Fracture toughness

(1) The austentic stainless steels, as covered in this Annex, are not susceptible to brittle fracture and are tough down to the minimum temperatures defined in Annex C.

> Note: A background document for low temperature application will be prepared.

S.3.1.6 Combination with other materials

(1) See chapter S.6.

S.3.2 Bolts

S.3.2.1 General

(1) Bolts and nuts shall conform with Reference Standard 3 (ISO 3506), see Annex B, ENV 1993-1-1 Eurocode 3: Part 1.1.

(2) The nominal values of the mechanical properties for austenitic grade fasteners are given in table S.3.4 in accordance with ISO 3506.

(3) The characteristic values of strength may be taken from table S.3.4.

(4) Pending the issue of the EN ..... the specified data should be assessed by a proper QA system with samples from each batch of fasteners.

S.3.2.2 Preloaded bolts

(1) High strength bolts made of stainless steel shall not be used as friction grip fasteners unless test results prove their acceptability in a particular application. In such cases the long term effects shall be taken into account by appropriate reduction factors to the preload $F_{p.Cd}$.

S.3.3 Welding Consumables

(1) All welding consumables shall conform with Reference Standard 4, see Annex B, ENV 1993-1-1 Eurocode 3: Part 1.1.

(2) The specified yield strength and ultimate tensile strength of the filler metal shall both be either greater than or equal to the corresponding values specified for the steel grade being welded.

Table S.3.4 Mechanical properties of austenitic grade fasteners to ISO 3506					
material group	Grade +	Property class	range of diameter	Bolts: Stress at 0.2% permanent strain [1] f_{yb} (N/mm²)	Bolts: Tensile strength [1] f_u (N/mm²)
austenitic	A1, A2, A4	50	≤ M 39	210	500
	A2, A4	70	≤ M 20 [2] > M 20 to ≤ M 30	450 250	700 500
	A2, A4	80	≤ M 20 [2]	600	800

Note: Specified values are minima.

[1] All values are calculated and related to the tensile stress area.

[2] For property classes 70 and 80, values must be agreed with the manufacturer for lengths greater than 8 diameters or for sizes greater than M30 and M20 respectively.

+ see Annex B, Reference Standard 3 (ISO 3506)

(3) The characteristic values of strength may be taken from table S.3.4.

(4) Pending the issue of the EN ..... the specified data should be assessed by a proper QA system with samples from each batch of fasteners.

S.3.2.2 Preloaded bolts

(1) High strength bolts made of stainless steel shall not be used as friction grip fasteners unless test results prove their acceptability in a particular application. In such cases the long term effects shall be taken into account by appropriate reduction factors to the preload $F_{p.Cd}$.

S.3.3 Welding Consumables

(1) All welding consumables shall conform with Reference Standard 4, see Annex B, ENV 1993-1-1 Eurocode 3: Part 1.1.

(2) The specified yield strength and ultimate tensile strength of the filler metal shall both be either greater than or equal to the corresponding values specified for the steel grade being welded.

(3) The corrosion resistance of the weld shall be adequate for the service environment. In general this will require that the corrosion resistance of the weld shall not be less than that of the parent material.

S.4 DURABILITY AND SERVICEABILITY LIMIT STATES

S.4.1 General

(1) For defining the serviceability limit states for steelwork of stainless steel the limiting values recommended in Chapter 4, ENV 1993-1-1 Eurocode 3: Part 1.1 may be used.

(2) In estimating deflections, recognition of the nonlinear nature of the stress strain curve and possible creep shall be made.

(3) To restrict non reversible deflections in bolted connections the stresses in net sections or bolts may be limited to the yield strength for rare load combinations.

(4) The different stainless steel alloys shall be selected according to the corrosion resistance required for the environment in which the structural members are used, see S.4.2.

(5) Unless the material is used for architectural purposes local appearance of corrosion such as tarnishing or pitting or crevice corrosion may be of no significance and general corrosion in polluted atmospheres may be acceptable due to small corrosion rates. Where stainless steels may come into contact with aggressive chemicals, e.g. as liners in chimneys, or in the specific atmosphere containing chlorine in voids above swimming pools corrosion and stress corrosion cracking may be of great importance.

(6) The following recommendations apply to different atmospheric corrosivity only; where stainless steel may be exposed to chemicals or unnormal conditions might prevail, expert advice should be sought (e.g. from the producer).

(7) The basic requirement to obtain a optimal corrosion resistance is a metallic clean surface.

(8) Before using stainless steels oxide layers and annealing colours due to hot forming, heat treatment or welding shall be removed as soon as possible.

S.4.2 Choice of Materials

(1) The stainless steels in table S.3.1, except the steels 1.4439 and 1.4539, shall not be used for loadbearing members in atmospheres containing chlorine as in voids above swimming pools.

(2) For other atmospheric applications, table S.4.1 offers a guide to the suitability of materials from a corrosion point of view.

(3) In the choice of the alloy consideration should be given to possible future developments which may alter the corrosivity of a particular environment.

(4) The steel 1.4003 can be used as a corrosion inert structural steel in normal atmosphere. If higher requests are made to the outward appearance of this steel a coating is necessary.

Table S.4.1 Suggested grades for atmospheric applications												
Steel type	Location											
	Rural			Urban			Industrial			Marine		
	L	M	H	L	M	H	L	M	H	L	M	H
1.4301, 1.4311, 1.4541	√	√	√	√	√	(√)	(√)	(√)	X	√	(√)	X
1.4401, 1.4404, 1.4406, 1.4571, 1.4362	0	0	0	0	√	√	√	√	(√)	√	√	(√)
1.4439, 1.4462, 1.4529, 1.4539, 1.4547	0	0	0	0	0	0	0	0	√	0	0	√

L - Least corrosive conditions within that category, e.g. tempered by low humidities, low temperature.

M - Fairly typical of that category.

H - Corrosion likely to be higher than typical for that category, e.g. increased by persistent high humidity, high ambient temperatures, particularly aggressive air pollutants.

O - Potentially over-specified from a corrosion point of view.

√ - Probably the best choice for corrosion resistance and cost.

X - Likely to suffer excessive corrosion.

(√) - Worthy of consideration if precautions are taken (i.e. specifying a relatively smooth surface and if regular washing is carried out).

(5) For bolting materials, grade A4 is equivalent in corrosion resistance to 1.4401, 1.4404, 1.4439, 1.4539 and 1.4571 in table S.4.1 and grade A2 is equivalent to 1.4301, and 1.4541. Grade A1 is of lower corrosion resistance and should not be used according to the criteria in S.6.2.1.

(6) Rolled threads should be selected in preference to machined threads.

S.4.3 **Design for Corrosion Control**

(1) The most important step in preventing corrosion problems is selecting an appropriate grade of stainless steel with suitable fabrication procedures for the given environment. However, after specifying a particular steel, much can be achieved in realising the full potential of the steel's resistance by careful attention to detailing.

(2) The following is a check list for consideration. Not all points would give the best detail from a structural strength point of view and neither are the points intended to be applied in all environments. In particular, in environments of low corrosivity or where regular maintenance is carried out, many would not be required.

a. Avoid dirt entrapment by (see Figure S.4.1):

- orientating angle and channel profiles to minimise the likelihood of dirt retention
- providing drainage holes, ensuring they are of sufficient size to prevent blockage
- avoiding horizontal surfaces
- specifying a small slope on gusset stiffeners which nominally lie in a horizontal plane
- using tubular and bar sections (sealing tubes with dry gas or air where there is a risk of harmful condensates forming)
- specifying smooth finishes.

b. Avoid crevices by (see Figure S.4.2):

- using welded rather than bolted connections
- using closing welds or mastic fillers
- preferably dressing/profiling welds
- preventing biofouling (Note, that chlorination of the water may cause pitting).

c. Reducing likelihood of stress corrosion cracking in those specific environments where it might occur by:

- minimising fabrication stresses by careful choice of welding sequence
- shot peening (avoiding the use of iron/steel shot).

d. Reduce likelihood of pitting by:

- removing weld splatter
- pickling stainless steel to remove unwanted welding products. Strongly oxidising chloride-containing reagents such as ferric chloride should be avoided; rather a pickling bath or a pickling paste, both containing a mixture of nitric acid and hydrofluoric acid, should be used. After pickling thorough rinsing with water should be made. Welds should always be cleaned up to restore corrosion resistance.
- avoiding pick-up of carbon steel particles (e.g. use workshop areas and tools dedicated to stainless steel)
- following a suitable maintenance programme.

e. Reduce likelihood of bimetallic corrosion by:

- electrical insulation
- using paints appropriately
- minimising periods of wetness.

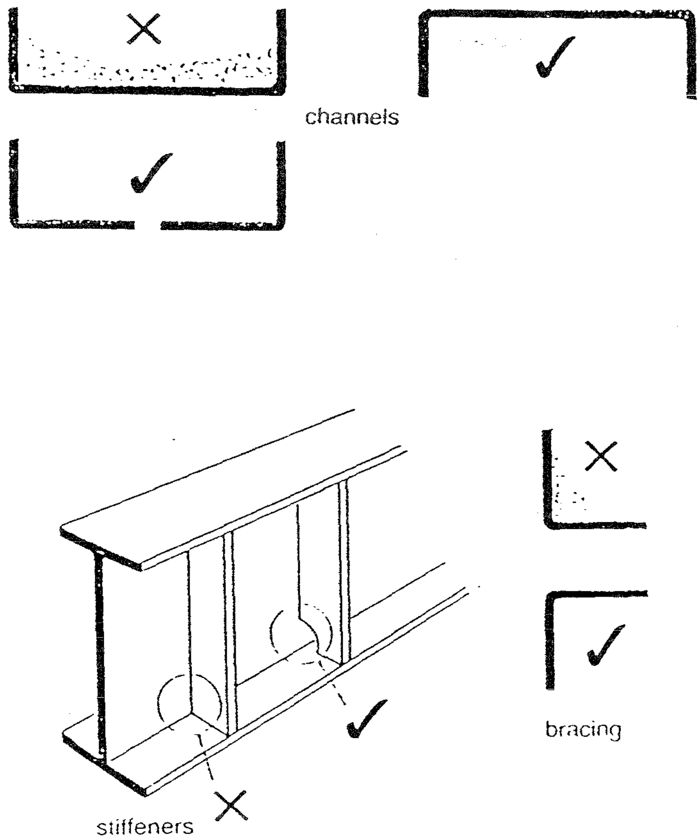


Figure S.4.1: Avoiding dirt entrapment

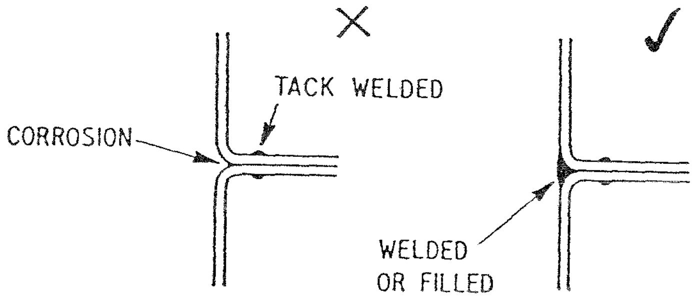


Figure S.4.2: Avoiding crevices

S.4.4 **Determination of Deflections**

(1) The effects of the non-linear stress/strain behaviour of stainless steels and the effectiveness of the section shall be considered in estimating deflections.

(2) In the case of Class 4 cross-sections and/or members subject to shear lag, it is appropriate, as a first estimate, to use the effective section based on the effective widths established to S.5.2.3 and/or S.5.2.4. As a refinement it is possible to use an effective section based on the effective buckling widths determined for the actual stress in the elements by taking ϵ in S.5.2.3 (but not in S.5.2.4) as:

$$\epsilon = \left[\frac{235}{\sigma}\,\frac{E}{210\,000}\right]^{1/2}$$

where:

σ = actual stress in the element in the associated effective cross-section.

(3) The deflection of elastic beams may be estimated by structural theory except that the secant modulus of elasticity should be used instead of elastic modulus. The secant modulus, E_S, varies with the stress level in the beam and should be ascertained for the member with respect to the rolling direction. If the orientation is not known, or can not be ensured, then it should be assumed to be in the rolling direction (i.e. the longitudinal direction).

The value of the secant modulus may be obtained as follows:

$$E_S = (E_{S1} + E_{S2})/2$$

where

E_{S1} = secant modulus corresponding to the stress in the tension flange

E_{S2} = secant modulus corresponding to the stress in the compression flange

Values of the secant moduli E_{S1} and E_{S2} for the appropriate orientation and stress ratio may be estimated from the following equation

$$E_{Si} = \frac{E}{1 + 0.02\,\frac{E}{\sigma_i}\left(\frac{\sigma_i}{f_y}\right)^n} \qquad i = 1,2$$

for which the values n should be provided by the producer. Table S.4.2 gives some indicative values.

(4) As a simplification it is allowed to neglect the variation of E_S along the beam provided the minimum value E_S is considered.

Table S.4.2 Values of n to be used for determining secant moduli			
strength class	Constant	Longitudinal direction	Transverse direction
Fe E 220 A	E n	200 000 6.5	200 000 8.5
Fe E 240 A	E n	200 000 7.00	200 000 9.0
Fe E 480 D	E n	205 000 5.0	205 000 5.0
E in N/mm^2			

Drafting Note: Values for other grades to be supplied

S.5 ULTIMATE LIMIT STATE

S.5.1 General

(1) The provisions given in Chapter 5 of ENV 1993-1-1 Eurocode 3: Part 1.1 also apply to stainless steel given in table S.3.1 except where special requirements are given in this section.

(2) If plastic global analysis is carried out, connections at or adjacent to plastic hinge locations shall be shown either to have sufficient rotational capacity to allow the formation of the mechanism or to be capable of resisting the additional moment (above the plastic moment) caused by strain hardening during hinge rotation.

(3) Where repeated fluctuating loads are applied to a structure its resistance to fatigue shall be checked according to Chapter S.9.

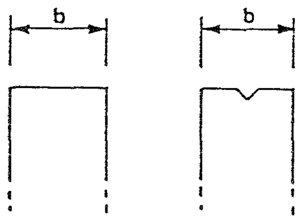
S.5.2 Classification of Cross-sections

S.5.2.1 Maximum width-to-thickness ratios

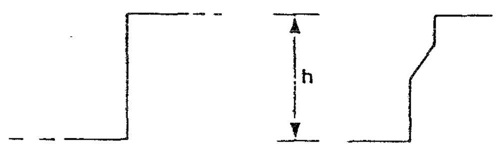
(1) The recommendations in this section apply to cross-sections with the dimensional limits according to ENV 1993-1-3 Eurocode 3: Part 1.3 except:

- Flat element or intermediately stiffened element connected along both edges to webs or flanges:

$b/t < 400$



$h/t < 400$



where b is mid line flat width
h is mid line flat depth

(2) If visual distorsions of flat elements may be disturbing in the serviceability limit state, smaller b/t ratios are recommended.

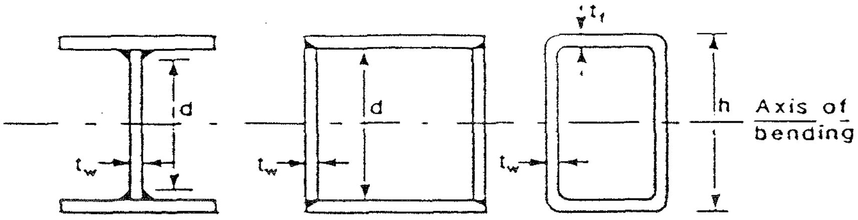
S.5.2.2 Classification

(1) Elements are classified as Class 1, 2 or 3 depending upon the limits set out in table S.5.1. Those elements which do not meet the criteria for Class 3 elements are classified as Class 4.

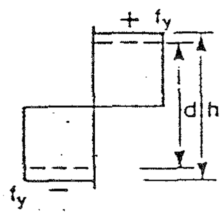
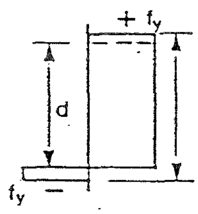
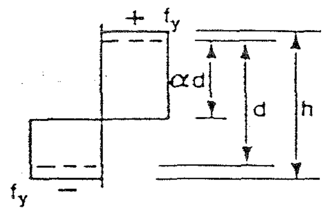
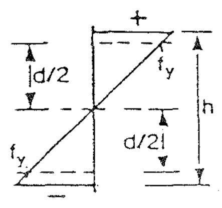
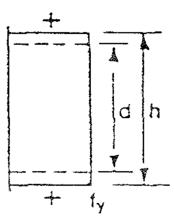
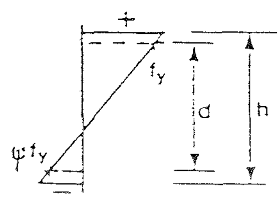
Drafting Note:
a) Table S.5.1 needs extending to cover tubulars.

Table S.5.1: Maximum width-to-thickness ratios for compression elements (Sheet 1)

a. <u>Webs:</u> (internal elements perpendicular to axis of bending)



$d = h - 3t$ $[t = t_f = t_w]$

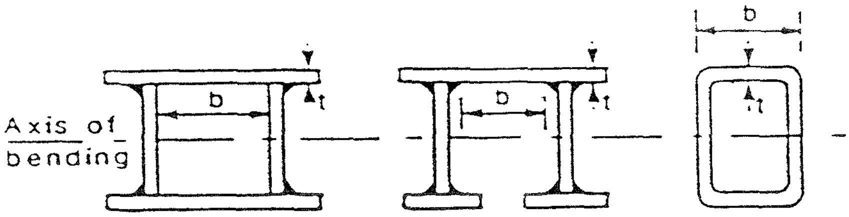
Class	Web subject to bending	Web subject to compression	Web subject to bending and compression
Stress distribution in element (compression positive)			
1	$d/t_w \leq 56.0\ \epsilon$	$d/t_w \leq 25.7\ \epsilon$	when $\alpha > 0.5$: $d/t_w \leq 308\ \epsilon/(13\alpha - 1)$ when $\alpha \leq 0.5$: $d/t_w \leq 28\ \epsilon/\alpha$
2	$d/t_w \leq 58.2\ \epsilon$	$d/t_w \leq 26.7\ \epsilon$	when $\alpha > 0.5$: $d/t_w \leq 320\ \epsilon/(13\alpha - 1)$ when $\alpha \leq 0.5$: $d/t_w \leq 29.1\ \epsilon/\alpha$
Stress distribution in element (compression positive)			
3	$d/t_w \leq 74.8\ \epsilon$	$d/t_w \leq 30.7\ \epsilon$	$d/t_w \leq 15.3\ \epsilon\sqrt{k_\sigma}$ For k_σ see EC3, table 5.3.2

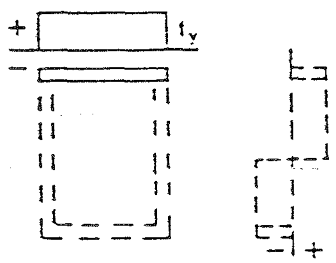
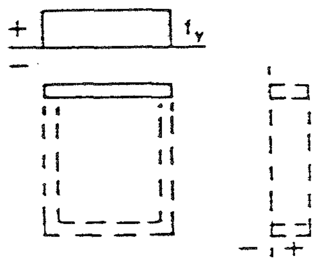
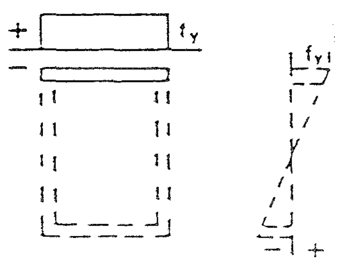
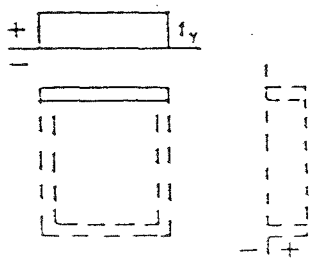
$\epsilon = \left[\frac{235}{f_y} \cdot \frac{E}{210\ 000}\right]^{1/2}$ [1]	Grades according to chapter S.3 (table S.3.1 and S.3.2)

[1]) ϵ-values for design using specified values (see S.3.1.2 and S.3.1.3)

Table S.5.1: Maximum width-to-thickness ratios for compression elements (Sheet 2)

b. <u>Internal flange elements:</u> (internal elements parallel to axis of bending)



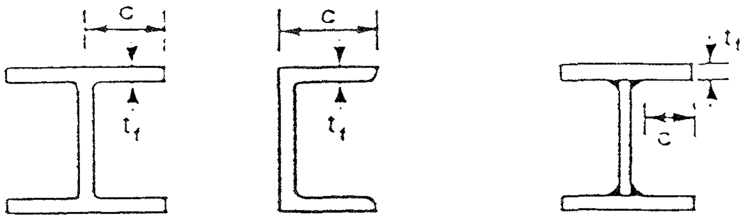
Class	Type	Section in bending	Section in compression
Stress distribution in element and across section (compression positive)			
1	Rolled Hollow Section Other	$b/t \leq 25.7\ \epsilon$ $b/t \leq 25.7\ \epsilon$	$b/t \leq 25.7\ \epsilon$ $b/t \leq 25.7\ \epsilon$
2	Rolled Hollow Section Other	$b/t \leq 26.7\ \epsilon$ $b/t \leq 26.7\ \epsilon$	$b/t \leq 26.7\ \epsilon$ $b/t \leq 26.7\ \epsilon$
Stress distribution in element and across section (compression positive)			
3	Rolled Hollow Section Other	$b/t \leq 30.7\ \epsilon$ $b/t \leq 30.7\ \epsilon$	$b/t \leq 30.7\ \epsilon$ $b/t \leq 30.7\ \epsilon$

$\epsilon = \left[\frac{235}{f_y} \cdot \frac{E}{210\ 000} \right]^{1/2}$ [1]	Grades according to chapter S.3 (table S.3.1 and S.3.2)

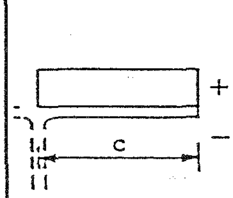
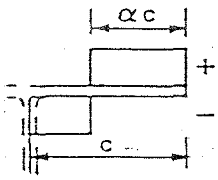
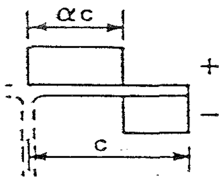
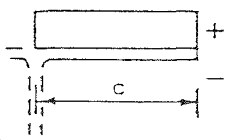
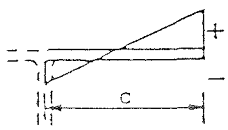
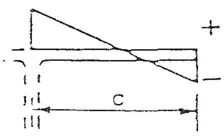
[1]) ε-values for design using specified values (see S.3.1.2 and S.3.1.3)

Table S.5.1: Maximum width-to-thickness ratios for compression elements (Sheet 3)

c. <u>Outstand flanges:</u>

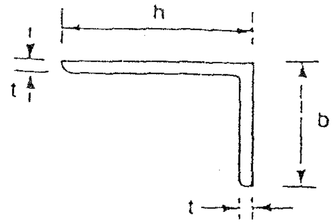
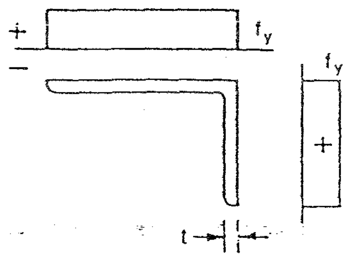


Cold formed sections Welded sections

Class	Type of section	Flange subject to compression	Flange subject to compression and bending: Tip in compression	Flange subject to compression and bending: Tip in tension
Stress distribution in element (compression positive)				
1	Cold formed	$c/t_f \leq 10.0\,\epsilon$	$c/t_f \leq \frac{10\,\epsilon}{\alpha}$	$c/t_f \leq \frac{10\,\epsilon}{\alpha\sqrt{\alpha}}$
	Welded	$c/t_f \leq 9.0\,\epsilon$	$c/t_f \leq \frac{9\,\epsilon}{\alpha}$	$c/t_f \leq \frac{9\,\epsilon}{\alpha\sqrt{\alpha}}$
2	Cold formed	$c/t_f \leq 10.4\,\epsilon$	$c/t_f \leq \frac{10.4\,\epsilon}{\alpha}$	$c/t_f \leq \frac{10.4\,\epsilon}{\alpha\sqrt{\alpha}}$
	Welded	$c/t_f \leq 9.4\,\epsilon$	$c/t_f \leq \frac{9.4\,\epsilon}{\alpha}$	$c/t_f \leq \frac{9.4\,\epsilon}{\alpha\sqrt{\alpha}}$
Stress distribution in element (compression positive)				
3	Cold formed	$c/t_f \leq 11.9\,\epsilon$	$c/t_f \leq 18.1\,\epsilon\sqrt{k_\sigma}$	
	Welded	$c/t_f \leq 11.0\,\epsilon$	$c/t_f \leq 16.7\,\epsilon\sqrt{k_\sigma}$	
			For k_σ see EC3, table 5.3.3	

$\epsilon = \left[\frac{235}{f_y} \cdot \frac{E}{210\,000}\right]^{1/2}$	Grades according to chapter S.3 (table S.3.1 and S.3.2)

[1]) ϵ-values for design using specified values (see S.3.1.2 and S.3.1.3)

Table S.5.1: Maximum width-to-thickness ratios for compression elements (Sheet 4)	
d. Angles Refer also to (c) "Outstand flanges" (see Sheet 3).	 (Does not apply to angles in continuous contact with other components)
Class	Section in compression
Stress distribution across section (compression positive)	
3	$h/t \leq 11.9\,\epsilon$; $(b + h)/2t \leq 9.1\,\epsilon$
$\epsilon = \left[\frac{235}{f_y} \cdot \frac{E}{210\ 000}\right]^{½}$	Grades according to chapter S.3 (table S.3.1 and S.3.2)
[1]) ϵ-values for design using specified values (see S.3.1.3 and S.3.1.3)	

S.5.2.3 Effective widths of elements in Class 4 cross-sections

(1) The reduction factor ρ shall be calculated according to ENV 1993-1-1 Eurocode 3: Part 1.1, chapter 5.3.5, or ENV 1993-1-3 Eurocode 3: Part 1.3, chapter 3.2.

S.5.2.4 Effects of shear lag

(1) The effects of shear lag shall be taken into account according to ENV 1993-1-3 Eurocode 3 Part 1.3, chapter 4.4.4.

S.5.3 Resistance of Cross-sections

S.5.3.1 General

(1) The work-hardening associated with cold forming operations will generally increase the cross-sectional resistance. It is suggested that when the benefits of work-hardening are to be utilised, the cross-sectional resistances should be calculated with the values

defined by the levels of work-hardening according to chapter S.3.1.3. The thickness for flat products is then limited to 6 mm and for other products to 20 mm.

(2) Under exceptional circumstances, it may be permissible to utilise the strain hardening effects also for annealed austhenitic material, see Section S.5.3.2.

S.5.3.2 Utilisation of work-hardening behaviour for annealed austhenitic material

(1) In certain circumstances, such as beams in accidental design situations, it may be permissible to recognise the benefits of the work hardening properties of annealed stainless steel more fully in design.

(2) This may be achieved by utilising the enhanced yield strength f_y according to table S.3.2 in place of the yield strength f_y according to table S.3.1 in all calculations. It is recommended that the following restrictions should be observed:

- The cross-section should be of Class 2 as calculated by using the enhanced yield strength f_y in place of the normal yield strength f_y when calculating ϵ in table S.5.1.
- The beam is under major axis bending only
- The member concerned is not subject to instability caused by buckling (flexural, torsional, lateral-torsional or distortional), again using the enhanced proof stress in all calculations.
- Connections to adjacent members and the members themselves are sufficiently strong to realise the enhanced resistance of the member.

S.5.3.3 Net section

(1) The net area of a section or element of a section should be taken as its gross area less appropriate deductions for all openings, including holes for fasteners. In the deductions for fasteners, the nominal hole diameter should be used.

(2) When holes are not staggered, the area to be deducted from the gross sectional area should be the maximum sum of the sectional areas of the holes in any cross-section at right angles to the direction of stress. If the holes are not disposed symmetrically about the centreline of the section an effective net area, obtained by multiplying the net area by a reduction factor (k_A), should be used. For a single hole:

$$k_A = 1 - \frac{d}{b}\left(1 - \frac{2e}{b}\right)$$

d = hole diameter
e = edge distance
b = width of section

when holes are staggered, see Figure S.4.1, the net effective area should be taken as the lesser of:

- the net effective area for non-staggered holes
- the gross area less [the sum of the sectional areas of all holes in any line extending progressively across the member of part of the member], plus [$s^2t/4p$ but not more than 0.6s for each gauge space in the chain of holes, where s and p are respectively the staggered pitch and the gauge as defined in Figure S.5.1].

(3) For sections such as angles with holes in both legs, the gauge should be measured along the centre of the thickness of the material.

S.5.3.4 Angles in tension

(1) In the case of angles connected through one leg, the eccentricity can be ignored and the member treated as axially loaded by using an effective area, taken as:

A_{net} = net area of connected leg + ½ gross area of the shorter leg.

S.5.4 Buckling resistance of member

S.5.4.1 General

(1) For flexural buckling, torsional buckling, flexural torsional buckling, distorsional buckling or lateral torsional buckling the rules in ENV 1993-1-1 Eurocode 3: Part 1.1 and ENV 1993-1-3 Eurocode 3: Part 1.3 apply unless specified otherwise in the following.

S.5.4.2 Flexural buckling

(1) The reduction factor accounting for buckling may be obtained as specified in Eurocode 3: Part 1.1, chapter 5.5.1.4 taking account of α and $\bar{\lambda}_0$ - values as given in table S.5.2:

$$\chi = 1/(\phi + (\phi^2 - \bar{\lambda}^2)^{½}) \text{ but } \chi \leq 1$$

where:

$$\phi = 0.5\,(1 + \alpha\,(\bar{\lambda} - \bar{\lambda}_o) + \bar{\lambda}^2)$$

$$\bar{\lambda} = \frac{\ell}{i}\,\frac{1}{\pi}\sqrt{\frac{f_y\,\beta_A}{E}}$$

ℓ	=	effective length of member (see below)
i	=	radius of gyration of the gross cross-section
α	=	imperfection factor defined in table S.5.2
$\bar{\lambda}_0$	=	limiting slenderness defined in table S.5.2
β_A	=	1 for Class 1, 2 or 3 cross-sections
β_A	=	A_{eff}/A for Class 4 cross-sections

Table S.5.2 Values of α and $\bar{\lambda}_0$ for flexural buckling

Type of member	α	$\bar{\lambda}_0$
Cold-formed	0.49	0.40
Cold-formed, seam welded tubulars and square hollow sections	0.49	0.40
Fabricated by welding	0.76	0.20

(2) The effective length ℓ of a compression member with both ends effectively held in position laterally, may conservatively be taken as equal to its actual length. Alternatively, the effective length may be determined by reference to Annex E.

S.5.4.3 Lateral torsional buckling

(1) The reduction factor accounting for lateral torsional buckling may be obtained as specified in ENV 1993-1-1 Eurocode 3: Part 1.1, chapter 5.5.2 taking account of α_{LT} values as given in table S.5.3:

$$\chi_{LT} = 1/(\phi + (\phi^2 - \bar{\lambda}_{LT}^2)^{1/2}) \text{ but } \chi_{LT} \leq 1$$

where:

$$\phi = 0.5\,(1 + \alpha\,(\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^2)$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{\beta_W W_{pl.y} f_y}{M_{cr}}} = \frac{\lambda_{LT}}{\pi}\sqrt{\frac{f_y\,\beta_W}{E}}$$

α	=	imperfection factor defined in table S.5.3
M_{cr}	=	elastic critical moment for lateral torsional buckling (see below)
β_W	=	1 for Class 1 or Class 2 cross-sections
β_W	=	$W_{el.y}/W_{pl.y}$ for Class 3 cross-sections
β_W	=	$W_{eff.y}/W_{pl.y}$ for Class 4 cross-sections

Table S.5.3 Values of α for lateral torsional buckling	
Type of member	α
Cold-formed	0.34
Cold-formed, seam welded tubulars and square hollow sections	0.34
Fabricated by welding	0.76
in absence of test data	0.76

(2) For Angles, the y axis should be taken as the u axis

(3) Information for the calculation of M_{cr} (or for the direct calculation of λ_{LT}) are given in informative Annex F of ENV 1993-1-1 Eurocode 3: Part 1.1.

(4) Where the non-dimensional slenderness $\bar{\lambda}_{LT} \leq 0,3$ no allowance for lateral torsional buckling is necessary.

(5) A beam with full restraint does not need to be checked for lateral torsional buckling.

S.5.5 Shear Resistance

(1) The shear resistance is either limited by the shear plastic resistance (see Eurocode 3: Part 1.1, Chapter 5.4.6) or the shear buckling resistance. Where specified minimum proof stress values f_y are used, shear buckling should be considered for webs having:

$$d_w/t_w \quad > 17.3\epsilon$$

where $$\varepsilon = \sqrt{\frac{235}{f_y} \cdot \frac{E}{210000}}$$

(2) The design shear buckling resistance, $V_{b.Rd}$, may be obtained from:

$$V_{b.Rd} \quad = \quad d_w \, t_w \, \tau_b/\gamma_{M1}$$

where τ_b = the characteristic value of the mean shear strength given in table S.5.4 as a function of $\bar{\lambda}_w$

Table S.5.4: Characteristic value of the mean shear strength		
$\bar{\lambda}_w = \frac{0.8}{\sqrt{k_\tau}} \frac{d_w}{t_w} \sqrt{\frac{f_y}{E}}$	τ_b for an unstiffened web with stiffeners only at the supports	τ_b for a web with transverse stiffeners including at the supports
$\bar{\lambda}_w \leq 0.2$	$f_y/\sqrt{3}$	$f_y/\sqrt{3}$
$0.2 < \bar{\lambda}_w \leq 0.6$	$(1-0.63(\bar{\lambda}_w-0.2))f_y/\sqrt{3}$	$(1-0.63(\bar{\lambda}_w-0.2))f_y/\sqrt{3}$
$\bar{\lambda}_w > 0.6$	$(1-0.42\bar{\lambda}_w)\ f_y/\sqrt{3}$	$\frac{27 - \bar{\lambda}_w}{24 + 19\ \bar{\lambda}_w}\ f_y/\sqrt{3}$
Note: k_τ is defined in 5.6.3, EC3		

S.5.6 Web Crushing, Crippling and Buckling

(1) As a guide, table S.5.5 indicates the need for checking a particular mode depending on the type of section and load application.

Table S.5.5: Checks for local strength of web			
Type of section	Crushing	Crippling	Buckling
Welded fabrication:			
1) load resisted by web shear	✓	✓	
2) load taken out through opposite flange	✓		✓
Cold formed:		✓	✓

(2) In the absence of any experimental data for stainless steel webs, it is recommended that reference is made to carbon steel rules, e.g. Eurocode 3: Part 1.1 and 1.3.

S.5.7 Transverse stiffeners

(1) At supports or at intermediate positions where significant loads are applied, the buckling resistance should exceed the reaction or load. At other intermediate positions, the compression force N_s in the stiffener may be obtained from:

$$N_s = V_{Sd} - d_w\ t_w\ \tau_{bb} \quad \text{but } N_s \geq 0$$

where:

V_{Sd}	=	the design shear force in the member
τ_{bb}	=	the initial shear buckling stress of the web; the lower value of τ_{bb} for the two panels adjacent to the stiffener to be taken.

The initial shear buckling stress, τ_{bb}, may be found from table S.5.6.

Table S.5.6: Initial shear buckling stress

$\bar{\lambda}_w = \frac{0.8}{\sqrt{k_\tau}} \frac{d_w}{t_w} \sqrt{\frac{f_y}{E}}$	τ_{bb}
$\bar{\lambda}_w \leq 0.2$	$f_y/\sqrt{3}$
$0.2 < \bar{\lambda}_w \leq 0.75$	$(1-0.64(\bar{\lambda}_w-0.2))f_y/\sqrt{3}$
$0.75 < \bar{\lambda}_w \leq 2.2$	$\frac{3.6 - \bar{\lambda}_w}{3.2 + 1.6\,\bar{\lambda}_w} f_y/\sqrt{3}$
$\bar{\lambda}_w > 2.2$	$\frac{1}{\bar{\lambda}_w^2} f_y/\sqrt{3}$

Note: k_τ is defined in 5.6.3, EC3

(2) The effective cross-section to use in the buckling check should include the stiffener plus a width of web plate of $11\,\epsilon\,t_w$ either side of the stiffener. At the ends of the member the dimension of $11\,\epsilon\,t_w$ should be limited to that available.

S.6. CONNECTION DESIGN

S.6.1 General Recommendations - Durability

(1) The design of connections, in particular, needs the most careful attention to maintain optimum corrosion resistance.

This is especially so for connections that may become wet from either the weather, spray, immersion, or condensation, etc. The possibility of avoiding or reducing associated corrosion problems by locating connections away from the source of dampness should be investigated. Alternatively, it may be possible to remove the source of dampness; for instance, in the case of condensation, by adequate ventilation or by ensuring that the ambient temperature within the structure lies above the dew point temperature.

Where it is not possible to prevent a connection involving carbon steel and stainless steel from becoming wet, consideration should be given to preventing galvanic corrosion. The use of carbon steel bolts with stainless steel structural elements should always be avoided. In bolted connections which would be prone to an unacceptable degree of corrosion, provision should be made to isolate electrically the carbon steel and stainless steel elements. This entails the use of insulating washers and possibly bushes; typical suitable details are shown in Figure S.6.1. The material forming the insulation should be sufficiently robust to prevent the steel from coming into contact during loading.
With respect to welded connections involving carbon and stainless steels, it is generally recommended that any paint system applied to the carbon steel should extend over the weldment and cover some area of the stainless steel if the connection is potentially subject to corrosion.

Care should be taken in selecting appropriate materials for the given environment to avoid crevice corrosion in bolted joints.

By welding the parent material properties may change reducing corrosion resistance (weld decay). The heating and cooling cycle involved in welding affects the microstructure of all stainless steels, though some grades more than others. This is of particular importance for austhenitic - ferritic materials, see table S.3.1. It is essential that suitable welding procedures and consumables are used and that qualified welders undertake the work.

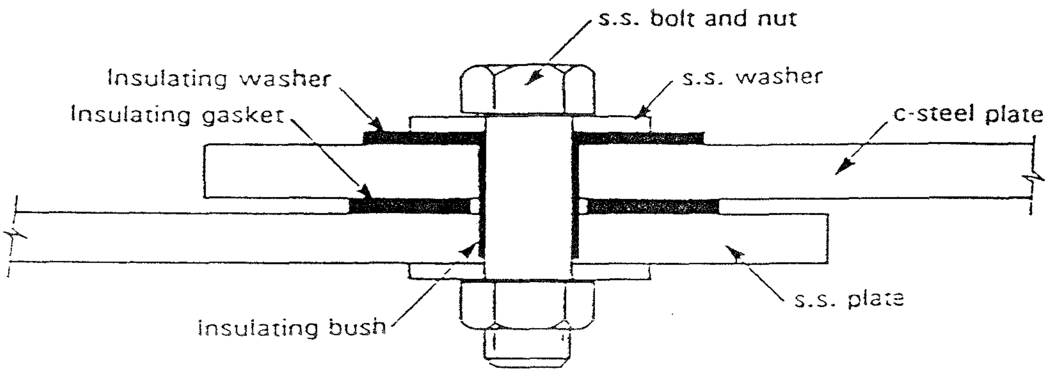


Figure S.6.1: **Typical detail for connecting dissimilar materials (to avoid galvanic corrosion)**

(2) The provisions given in ENV 1993-1-1 Eurocode 3: Part 1.1, chapter 6, also apply to stainless steel grades except where special requirements are given in this section.

(3) Connections subject to fatigue shall also satisfy the requirements given in ENV 1993-1-1 Eurocode 3: Part 1.1, chapter 9, and in Section S.9.

S.6.2 Bolted Connections

S.6.2.1 General - constructional rules

(1) Fasteners have to be at least so resistant to corrosion in the long term under service conditions as the connected parts.

(2) Loads and corrosion influences under service conditions have to be registered as complete and exact as possible.

(3) All connections have to be performed smooth and without any gap between the connected parts.

(4) Intermediate layers, which have to transmit loads in the connection, have to be avoided except for connections involving carbon and stainless steels (S.6.1).

(5) Larger diameter washers than for carbon steel should be used.

S.6.2.2 Connected parts

S.6.2.2.1 Holes

(1) Holes can be formed by drilling or punching. However, the cold working associated with shearing or punching increases the susceptibility to corrosion and therefore

caution should be exercised in using punched holes in aggressive environments (e.g. heavy industrial and marine settings). In such environments and at dynamic loads with risk for corrosion fatigue, the punched holes should be annealed.

The maximum clearance in standard holes are:

1mm for M12 and M14 bolts
2mm for M16 to M24 bolts
3mm for M27 and larger bolts

S.6.2.2.2 Position of holes

(1) Edge distance is defined as the distance from the centre of a hole to the adjacent edge of the connecting part at right angles to the direction of stress; end distance is similarly defined but in the direction in which the fastener bears.

(2) The minimum value of the end distance, e_1, or that of the edge distance, e_2, (see Figure S.6.2) should be taken as 1.5d, where d is the nominal bolt diameter. Note that the end distance may require to be larger than this to provide adequate bearing resistance, see S.6.2.3.

(3) The maximum value of the end or edge distance should be restricted to the larger of 12t or 150mm, where t is the thickness of the thinner outer ply.

(4) A minimum centre to centre bolt spacing of 2.5d in the direction of stress, p_1, (see Figure S.6.2) is recommended. The corresponding recommended minimum spacing, p_2, normal to the direction of stress is 3d.

(5) The maximum spacing of bolts in any direction should be such that local compressive buckling of the plies is prevented.

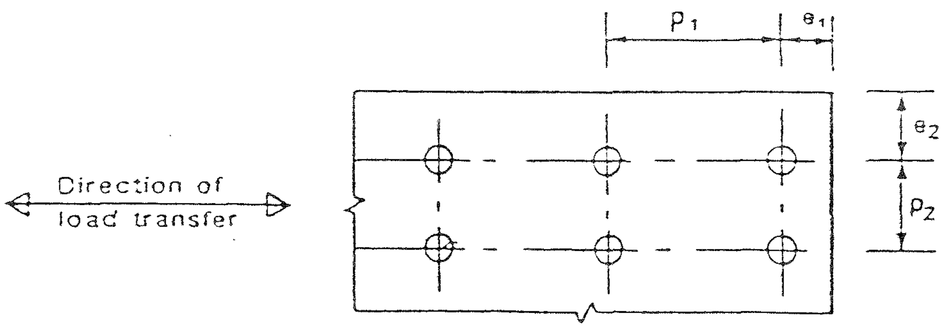


Figure S.6.2: Symbols for defining position of holes

S.6.2.3 Bearing resistance

(1) The strength formulae in Eurocode 3: Part 1.1 and 1.3 may be used when f_u is substituted by f_u', as the resistance of a bolted connection in stainless steel will usually be governed by serviceability criteria in which the hole elongation at serviceability loads is to be limited. In order to avoid carrying out a separate check for serviceability it is recommended to place a limit on hole elongation at ultimate load by using a reduced value of f_u, i.e. f_u'.

To limit hole elongation at ultimate load:

$$f_u' = 0.5\, f_y + 0.6\, f_u$$

S.6.2.4 Tension capacity

(1) The tensile capacity of the connected part subject to collinear forces should be based on the lesser of:

- the ultimate resistance of the net section which may be taken as:

$$N_{u.Rd} = \frac{0.9\, k_r\, A_{net}\, f_u}{\gamma_{M2}}$$

where:

k_r = $(1 - 0.9r + 3rd/s)$ but ≤ 1

r = the force transmitted by the bolt or bolts at the section considered, divided by the tension force in the member at that section

d = nominal bolt diameter

s = spacing of bolts perpendicular to line of stress. In the case of a single bolt at the section considered, s = width of sheet or plate

A_{net} = net area or effective net area (see S.5.3.3)

- the plastic resistance of the gross section:

$$N_{pl.Rd} = \frac{A\, f_y}{\gamma_{M0}}$$

(2) If ductile behaviour is required then the plastic resistance must be less than the net section ultimate resistance.

S.6.2.5 Shear capacity of fasteners

(1) The shear resistance of a bolted connection is dependent on the number of shear planes and their position along the bolt. For each shear plane the shear resistance in the absence of tension can be determined as follows:

a. for shear plane in the unthreaded portion

$$F_{v.Rd} = \frac{0.6\ f_{ub}\ A}{\gamma_{Mb}}$$

where A is the shank area

b. for shear plane passing in threaded portion

$$F_{v.Rd} = \frac{0.6\ f_{ub}\ A_s}{\gamma_{Mb}}$$

where A_s is the tensile stress area

(2) The bearing resistance and tensile resistance of fasteners should be determined as in ENV 1993-1-1 Eurocode 3: Part 1.1 and ENV 1993-1-3 Eurocode 3: Part 1.3.

(3) For the combination of tension and shear the rules in ENV 1993-1-1 Eurocode 3: Part 1.1 apply.

S.6.3 Welded Connections

S.6.3.1 General

(1) The provisions given in ENV 1993-1-1 Eurocode 3: Part 1.1 also apply to the stainless steel grades.

(2) It is recommended that intermittent fillet welds, and intermittent partial penetration butt welds should not be used. Partial penetration butt welds should be avoided whenever possible and particularly for welds in tension, in aggressive marine and heavily polluted environments, in fatigue situations or where capillary action might occur.

S.7. FABRICATION

S.7.1 General

The purpose of this Section 7 is to highlight relevant aspects of stainless steel fabrication for the design engineer, including recommendations for good practice. It also allows a preliminary assessment to be made of the suitability of a fabricator to perform the work.

Stainless steel is not a difficult material to work with. However, in some respects it is different from carbon steel and should be treated accordingly. Many fabrication and joining processes are similar to those used for carbon steel, but the different characteristics of stainless steel require special attention in a number of areas. It is important that effective communication is established between the designer and fabricator early in the project to ensure that appropriate fabrication practices can and will be adopted.

An overriding objective is to maintain the steel's corrosion resistance. It is essential that precautions are taken, at all stages of storing, handling, forming and welding to minimise mechanical or other damage of the surface (i.e. the oxide layer). Although essential, the precautions are simple and, in general, are a matter of good engineering practice.

It is important to preserve the good surface appearance of stainless steel throughout fabrication. Not only are surface blemishes unsightly, but they are usually unacceptable and prove time-consuming and expensive to correct. Whereas surface blemishes will normally be hidden by paint in carbon steel structures, this will only be rarely so in the case of stainless steel structures.

The structural form may be dictated by the availability of materials. It should be recognised that the available range of hot rolled stainless steel sections is more limited than for carbon steel. This results in a greater use of cold formed and welded members than is normally encountered. Also, because of brake press length capabilities, only relatively short lengths are possible which leads to an increased use of splices. In detailing joints, consideration should be given to clearances for bolts near bend radii and to potential fit up problems arising from weld distortion.

S.7.2 Storage and Handling

Generally, greater care is required in storing and handling stainless steel than carbon steel to avoid damaging the surface finish (especially bright annealed or polished finishes) and to avoid contamination by carbon steel and iron. Storage and handling procedures should be agreed between the relevant parties to the contract in advance of any fabrication and in sufficient detail to accommodate any special requirements. The procedures should cover, for instance, the following items:

- The steel should be inspected immediately after delivery for any surface damage.
- The steel may have a protective plastic or other coating. This should be left on as long as possible, removing it just before final fabrication. The

protective covering should be called for in the procurement document if it is required (e.g. for bright annealed finishes).

- Storage in salt-laden humid atmospheres should be avoided. Storage racks should not have carbon steel rubbing surfaces and should, therefore, be protected by wooden, rubber or plastic battens or sheaths. Sheets and plates are preferably stacked vertically; horizontally stacked sheets may get walked upon with a risk of iron contamination and surface damage.

- Carbon steel lifting tackle, e.g. chains, hooks, and cleats should be avoided. Again, the use of isolating materials, or the use of suction cups, will prevent iron pick-up. The forks of fork lift trucks should also be so protected.

- Contact with chemicals including undue amounts of oils and greases (which may stain some finishes) should be avoided.

- Ideally, segregated fabrication areas for carbon steel and stainless steel should be used. Only tools dedicated to stainless steel should be employed, this particularly applies to grinding wheels and wire brushes. Note that wire brushes and wire wool should be of stainless steel and preferably an austenitic grade (e.g. do not use ferritic stainless steel brushes on austenitic stainless steel).

- As a precaution during fabrication and erection, any sharp burrs must be removed.

- Consideration should be given to any requirements needed in protecting the finished fabrication during transportation.

S.7.3 **Forming**

S.7.3.1 Hot forming

to be developed

S.7.3.2 Cold forming

Stainless steel is readily shaped by commonly used cold forming techniques such as bending, spinning, pressing and deep drawing. For structural applications press brake bending is the most relevant technique though, for high volume thin gauge products, roll forming may be more economic.

Again, the power requirement for bending stainless steel will be higher than for bending geometrically similar carbon steel members due to work hardening (by about 50% in the case of the austenitic steels or more in the case of 1.4462 (duplex 2205)). Also, stainless steel has to be overbent to a slightly higher degree than carbon steel to counteract the effects of springback. For complex cross-sections it is prudent to involve the fabricator as early as possible in the design.

Stainless steel's high ductility allows small radii to be formed, as low as half the thickness in annealed materials. However, it is generally recommended to adopt the following as minima:

2t for 1.4301, 1.4401, 1.4404, 1.4541 and 1.4571 grades
2.5t for 1.4462 (duplex 2205)

where t is the thickness of the material.

When bending tubulars the following guidance may be given:

- the outer tube diameter to wall thickness ratio should not exceed 15 (to avoid costly tooling).

- the bend radius (to centreline of tube) should not be less than 2.5D where D is the outer diameter

- any welding bead should be positioned close to the neutral axis to reduce the bending stresses at the weld.

S.7.4 **Cutting**

Care is needed in marking out plates and sheets to avoid wastage in cutting. Note that more wastage may result if the material has a polishing grain (or a unidirectional pattern) which has to be maintained in the fabrication. Some marking pens/crayons will prove difficult to remove, or cause staining, if used directly on the surface (rather than on any protective film); checks should be made that they are satisfactory.

Stainless steel may be cut using usual methods, e.g. shearing and sawing, but power requirements will be greater than that used for similar thicknesses of carbon steel due to work hardening. If possible cutting (and machining in general) should be carried out when the metal is in the annealed (softened) state to limit work hardening and tool wear.

For cutting straight lines, guillotine shearing is widely used. By using open ended guillotines, a continuous cut greater in length than the shear blades can be achieved although at the risk of introducing small steps in the cut edge.

Plasma arc techniques are also used and are particularly useful for cutting thick plates and profiles and where the cut edges are to be machined, e.g. for weld preparation. Oxyacetylene cutting is not satisfactory for cutting stainless steel unless a powder fluxing technique is used.

Abrasive water jet cutting could also be used. This method is excellent in cases where no metallurgical (thermally induced) changes in the material is required.

S.7.5 **Welding**

S.7.5.1 General

The welding of stainless steels is widely and successfully carried out using normal processes.

General cleanliness and the absence of contamination are important for attaining good weld quality. Oils or other hydrocarbons and wax crayon marks should be removed to avoid their decomposition and the risk of carbon pick-up. The weld should be free from zinc in the case of connections with stainless and galvanised unalloyed steels, including that arising from galvanised products, and from copper and its alloys. (Care needs to be taken when copper backing bars are used; a groove should be provided in the bar immediately adjacent to the fusion area.) Contamination of weld pool caused by sulfur residue should be avoided to reduce the risk of hot cracking in austenitic stainless steels.

It is more important in stainless steel than carbon steel to reduce sites at which crevice corrosion may initiate. Welding deficiencies such as undercut, lack of penetration, weld spatter, slag and stray arc strikes are all potential sites for corrosion and should thus be minimised. Stray arc strikes or arcing at loose earth connections also damage the passive layer, and possibly give rise to preferential corrosion thereby ruining the appearance of a fabrication.

Where the weld appearance is important, the engineer should specify the as-welded profile and surface condition required. This may influence the welding process selected or the post weld treatment. Consideration should also be given to the location of the weld; is it possible to apply the appropriate post weld treatment? Heat treatment on austhenitic stainless steels welded joints should be avoided

Heat input and interpass temperatures need to be controlled to minimise weld distortion (see S.7.5.4) and to avoid potential metallurgical problems (see S.7.5.5).

The application of an appropriate welding specification is of fundamental importance; failure to do so could seriously undermine the structural and corrosion performance of the welds. The specification selected may be company or product based, or originate from a national or international standard. If there is no suitable specification available, advice from a welding engineer should be sought. The specification should contain the following elements:

- verification of the welding method by detailing the derivation and testing requirements of weld procedures
- the qualifications of welders
- the control of welding operations during preparation, actual welding and post-weld treatment
- the level of inspection and non-destructive testing techniques to be applied
- the acceptance criteria for the permitted level of weld defects.

Provided that suitable procedures are followed, welding problems should not occur. However, the engineer should be aware that welding distortion is generally greater in stainless steel than in carbon steel, see S.7.5.4.

S.7.5.2 Processes

As mentioned above, the common fusion methods of welding can be used on stainless steel. Table 7.1 shows the suitability of various processes for thickness ranges, etc.

In G welding, the shielding gas can be pure argon or mixture between Argon and some percenteges of Oxygen, Hydrogen or Carbon dioxide according to the base metal and the weld position involved (e.g. for vertical and overhead position Argon should be used).
For Flux cored arc welding the relevant shielding gases should be Argon (for all positions), Carbon dioxide (for flat positions only) and their mixture.
The risk of Carbon pick up (important for Extra Low Carbon (ELC) stainless steels) may take place in case of G-welding with Carbon dioxide shielding gas. In case of W-welding the shielding gas is exclusively Argon. In both Gad W processe for one side welded joints backing shielding gas should be used. In case of duplex steels Nitrogen might be used.

Table S.7.1: Welding processes and their suitability

Weld process	Suitable product forms	Types of welded joints	Material thickness range (mm)	Weld positions	Suitable shop/site conditions
E	All	All	3[1] or greater	All	All
G	All	All	2[1] or greater	All	All[2]
W	All	All	Up to 10mm maximum	All	All[2]
S	All	All	3[1] or greater	preferably flat positions	All
RESISTANCE (spot welding)	Sheet only	All	3mm maximum appropriate	All	All

Notes:
1. Depends upon type of weld joint used.
2. More sensitive to weather than other processes and better environmental protection is required.

S.7.5.3 Welding consumables

Commercial consumables have been formulated to give weld deposits of equivalent strength and corrosion resistance to the parent metal and to minimise the risk of solidification cracking. A guide to consumable designations is given in tables S.7.2 to S.7.4. Standardized and licensed welding consumables are interchangeable, because they are checked for suitability in different cases of application. For specialist applications, such as unusually aggressive environments or where non magnetic properties are required, the advice of steel producers and manufacturers of consumables should be sought. All consumables should be kept free from contaminants and stored according to the manufacturer's instructions.

Table S.7.2: Austenitic based weld consumables for un- and low alloyed steel to stainless steel transition joints				
Joint materials		Weld process and welding consumable (steel designation No.) according to EN ...		
Material A	Material B	G filler wire	W filler wire	E electrodes
un-, low alloyed steel	Steel grades according to table S.3.1	1.4370	1.4370	1.4370

If welded connections are subjected to heat treatment after welding or if they are used at temperatures over 300°C, the nickel based welding consumables should be used for un- and low alloyed steel to stainless steel transition joints.

Table S.7.3: Nickel based weld consumables for un- and low alloyed steel to stainless steel transition joints at temperatures over 300°C or at heat treatment after welding				
Joint materials		Weld process and welding consumable (steel designation No.) accordiung to EN ...		
Material A	Material B	G filler wire	W filler wire	E electrodes
Un-, low alloyed steel	Steel grades according to table S.3.1	2.4806, 2.4831	2.4806, 2.4831	2.4620, 2.4621
Notes: Nickel based weld consumables should not be used with stainless consumables when welding a transition joint.				

Table S.7.4: Stainless steel weld consumables for arc welding processes					
	Material B				
Material A	X 2 Cr 11 1.4003	X 4 CrNi 18-10 1.4301	X 6 CrNiTi 18-10 1.4541	X 4 CrNiMo 17-12-2 1.4401	X 6 CrNiMoTi 17-12-2 1.4571
	Steel designation-No. of the suitable welding consumables according to EN ...				
X 2 Cr 11 1.4003	1.4370				
X 4 CrNi 18-10 1.4301	1.4316				
X 6 CrNiTi 18-10 1.4541	1.4551				
X 4 CrNiMo 17-12-2 1.4401	1.4430				
X 6 CrNiMoTi 17-12-2 1.4571	1.4576				

Drafting Note: Other steelgrades not shown in table S.7.4 to be supplied

S.7.4.4 Welding distortion

In common with other materials, stainless steel suffers from distortion on welding. The types of distortion (angular, bowing, shrinkage etc.) are similar in nature to those found in carbon steel structures. However, the distortion of stainless steel, particularly of austenitic grades, is greater than that of carbon steel due to higher coefficients of thermal expansion and lower thermal conductivities (which lead to steeper temperature gradients), see section S.3.1.4.

Welding distortion can only be controlled, not eliminated. Action may be taken by the designer and the fabricator as follows:

a) Designer actions

- Remove the necessity to weld.
- Reduce the extent of welding.
- Reduce the area of welds. For instance in thick sections, specify double V, U or double U preparations in preference to single V.
- Use symmetrical joints.
- Design to accommodate wider dimensional tolerances.

b) Fabricator actions

- Use efficient clamping jigs. If possible the jig should incorporate copper or aluminium bars to help conduct heat away from the weld area.
- When efficient jigging is not possible, use closely spaced tack welds laid in a balanced sequence.
- Ensure that good fit up and alignment is obtained prior to welding.
- Use the lowest heat input commensurate with the selected weld process, except when welding two Duplex-steels.
- Use balanced welding and appropriate sequences (e.g. backstepping and block sequences).

S.7.4.5 Metallurgical considerations

to be developed

S.7.4.6 Post weld treatment

It is best, both technically and commercially, to produce the structure in the as-welded condition. However, some post weld treatment may sometimes be necessary as discussed in the following paragraphs. It is important to define the required post weld treatment for avoiding cost overruns and possible poor service performance.

The processes usually employed for weld dressing are wire brushing, finishing and/or grinding. The amount of dressing should be minimised by the fabricator and if possible limited to wire brushing. This is because the heat produced in finishing and grinding can affect the corrosion resistance. Note that wire brushes and abrasives should be iron free. Wire brushes and abresives or grinding wheels should be strictly for use on austhenitic material and not previously used on ferritic steels.

In general annealing colours have to be removed. It can only be an exception to leave it in its place. It need not be removed when the stainless steel offers a good margin of resistance for the particular environment. However, where this is not so or where the tint is not acceptable on aesthetic grounds, the tint may be removed by pickling or glass bead blasting. Pickling may be carried out by immersion in a bath or by using pastes in accordance with the manufacturer's instructions.

Peening the surface of a weld is a beneficial post weld treatment. It introduces compressive stresses into the surface which improves fatigue and stress corrosion cracking resistance and aesthetic appearances.

The action of removing metal during substantial machining will give rise to stress relieving and hence distortion of the as-welded product. In those cases where the distortion is such that dimensional tolerances can not be achieved, a thermal stress treatment will be required. Generally, this will only be an option for small sized components and only for low carbon grades or stabilised grades to avoid sensitisation.

S.8 DESIGN ASSISTED BY TESTING

S.8.1 General

(1) The usual precautions and requirements for test procedures and results evaluation appertaining to carbon steel testing also apply to stainless steel testing.

(2) The provisions given in Eurocode 3 (Part 1.1 Chapter 8, Annex Y and Appendix to Part 1.3) are also valid for stainless steel grades.

(3) Supplementary provisions are given in the applicable European standards for material tests, "Euronorm 2: Tensile test on steel" and "Euronorm 11: Tensile test on steel sheet and strip less than 3 mm thick".

S.8.2 Tests on Members

(1) It is recommended that member tests should be full scale or as near to full scale as possible depending on test facilities and that the specimens are manufactured by the same fabrication processes to be used in the final structure.

(2) Since stainless steel may exhibit anistropy it is recommended that the specimens are prepared from the plate or sheet in the same orientation (ie. transverse or parallel to the rolling direction) as intended for the final structure. If the final orientation is unknown or cannot be guaranteed, it may be necessary to conduct tests for both orientations and take the less favourable result.

(3) Stainless steel displays higher ductility and greater strain hardening than carbon steel and therefore the test rig capabilities may need to be greater than those required for testing carbon steel members of equivalent material yield strength. This not only applies to rig loading capacity but also to the ability of the rig to allow greater deformation of the specimen.

(4) It should be noted that at higher specimen loads the effects of creep become more manifest and it may be such that strain or displacement readings do not stabilise within a reasonable time.

S.9 FATIGUE

S.9.1 General

(1) The provisions given in ENV 1993-1-1 Eurocode 3: Part 1.1, chapter 9, also apply to stainless steel grades except where special requirements are given in this section.

S.9.2 Assessment by S-N Curves

(1) For notch cases exposed to air at ambient temperatures the classifications given in ENV 1993-1-1 Eurocode 3: Part 1.1, chapter 9, may be used.

S.10 FIRE DESIGN

(1) For fire design reference is made to ENV 1993-1-2 Eurocode 3: Part 1.1.

Lehrstuhl für Stahlbau
RWTH Aachen

Aachen, 02.12.1993

Abridged version of the research report "Annex S: The Use of Stainless Steels - Investigations for establishing unified European rules" (Order of the DIBt Nr. IV 1-5-649/91)

Eurocode 3 has been published by CEN as a European prenorm (ENV) in April 1992. This ENV - Eurocode 3 concerns essentially rules for buildings. It also gives certainly basis rules, such as flexural buckling, shear buckling, fatigue and fasteners, which also can be used in other application fields.

Since ENV - Eurocode 3 is still restricted to the use of the materials Fe 360 to Fe 510, it was early demanded to give rules in Eurocode 3 for other groups of steel. The other groups of steel should be taken into account in the Annexes. Annex S is planned for structural stainless steels.

A

In this Annex S additional rules are specified, which have only to be considered for these steels in the application of ENV - Eurocode 3.

Works on Annex S took place at the Steel Construction Institute (SCI) in Ascot, United Kingdom, which has got the order from the Offshore Industry to develop a design manual and which want to use the results of this work for Annex S and at the Institute of Steel Construction (Lehrstuhl für Stahlbau), Technical University (RWTH) Aachen, which has got the order for preliminary works on Annex S after contacting the Deutsche Institut für Bautechnik (DIBt) in Berlin and the Edelstahl-Vereinigung in Düsseldorf. A cooperation with the SCI and the involvement of ECISS/TC 23/SC 1 (European Committee for Iron and Steel Standardization) and EURO INOX in Zürich were first results of this order.

Results of the research are:

1. The basis for the preparation of Annex S are mainly the standards DIN 17440, DIN 17441, DIN 17455, DIN 17456, prEN 10088 Part 1 to 3, the IfBt-Zulassungsbescheid Z-30.44.1 and the SCI-Design Manual for Structural Stainless Steels.

2. Comparisons between tests with stainless steels and tests with steels Fe 360 to Fe 510 have shown, that the basic design rules of ENV 1993-1-1 Eurocode 3: Part 1.1 can be adopted for structural stainless steels.

3. The design of structural stainless steels has been transmitted in the procedures of serviceability limit states and ultimate limit states.

4. Recommendations regarding fabrication, erection and durability are given in the Appendices A to C of Annex S. Additional information are given by the working groups of CEN/TC 121/SC 4/WG 5 "Welding guidelines for stainless steels" and CEN/TC 135/WG 10 "Execution of steel structures, Part 1: General rules and rules for buildings"

Annexe S: Application de l' acier inoxydable - recherches pour la determination des règles Européennes harmonisées

L' Eurocode 3, qui était publié comme ENV 1993 - 1.1 par CEN pour l' application à titre d'essai, ne traite que des aciers de construction non alliées.

Cet ENV - Eurocode 3 concerne des bâtiments en substance. Il contrent aussi des règles de base pour les autre champs d' application par exemple pour le flambement, le voilement, la fatigue et les moyens d' assemblage.

Lorsque l' ENV - Eurocode 3 est limité aux aciers Fe 360 à Fe 510 jusqu' á present, on a exigé de bonne heure de developper aussi des règles pour des autre qualitée d' acier. Ces règles seront inclues dans des annexes, d' en Annexe S fût prevue pour des acier inoxydables.

L' annexe S specifie des règles supplementaires, qui sont a tenir à compte si l' Eurocode 3 est appliqué a telles aciers.

Les travaux pour l' annexe S avaient lien a l' SCI (Steel Construction Institute), qui avait reçue un commande de developper un manuel de dimensionement de la part de l' industrie Offshore, et à l'institut de construction métallique de RWTH a Aix-la-Chapelle (RWTH Aachen) qui etait chargé par l' association "Edelstahlvereinigung" et le "Deutsche Institut für Bautechnik - DIBT".

Ces commandes étaient la base pour la cooperation entre le RWTH Aachen et le SCI avec particiation de ECISS/TC 23/SC1 (European Committee for Iron and Steel Standardisation) et Euro Inox à Zurich.

Les resultats de cette cooperation de recherche sont les suivants:

1. La base pour la developpement de l' Annexe S étaient les normes DIN 17440, DIN 17441, DIN 17455, DIN 17456, pr EN 10088 partie 1 à 3, le certificat Z - 30.44.1 édité par le DIBT et le "Design Manuel for Structural Stainless Steel" du SC3.

2. On a montré par des comparaisons des resultats d' expériences avec des aciers inoxydables et avec des aciers non-alliés, que la plus part des règles fondamentables de l' ENV 1993 - 1 - 1 - Eurocode 3 partie 1.1 peut être aussi applicé pour des aciers inoxydables.

3. La dimensionement avec l' Annexe S se fait selon la conception des limits ultimes et des limits de utilisation. On a quitte la conception des contraintes admissibles qui était la base du certificat Z.30.44.-1 de DIBT.

4. On a inclue dans des annexes a l' Annexe S des recommandations A, B, C pour la fabrication, le traitement et la durâbilité des aciers inoxydables, qui en future seront remplacées par des régles speciale, élaboré par les groupes de travail CEN/TC 121/SC4/WG5, "Welding guidelines for stainless steels" et CEN/TC 135/ W610 "Execution of steel structures, Part 1: General rules and rules for buildings".