

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|---|-------------------------|----|----------------|-----|----------------------|---|----------------------------------|---|----------------------|---|---------------------------|---|---------------------|---|--------------------------------|---|-----------------------------------------|---|---------------------------------|---|---------------------|---|-------------------------------------------------------|---|-----------------------------------------|---|-----------------------------------------------------|---|------------------------|---|-----------------------------------------------------------------------|---|---------------------------------------------------|---|--------------------------------------------------------|---|------------------------------|---|
| Title | FABIG Technical Note 6: Design Guide for Steel at Elevated Temperatures and High Strain Rates | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Publisher/Author | The Steel Construction Institute | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Publication Date | 2001 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Scope | <p>Executive Summary</p> <p>High strength steel is often used on offshore structures where there is a risk of accidental fire and blast loads. Design for fire requires knowledge of elevated temperature data while design for blast loads requires knowledge of high strain rate material data.</p> <p>This document provides guidance on elevated temperature and high strain rate material property data that is currently available for high strength steels used specifically for offshore structures. The guidance covers the data required to carry out both simplified design checks and advanced nonlinear analyses.</p> <p>The original research which led to the generation of material properties for BS 7191 Grade 355EMZ and Grade 450EMZ steels was sponsored by the Health and Safety Executive, Corus, Shell UK Exploration and Production and BP.</p> <p>Scope of this Document</p> <p>This document gives guidance on available elevated temperature and high strain rate material property data for high strength steels used specifically for offshore structures. The guidance covers the data required to carry out both simplified design checks and advanced nonlinear analyses.</p> <p>Elevated temperature and high strain rate data are presented and discussed for the structural steels specified in BS 7191, Weldable structural steels for fixed offshore structures, based on recent tests.</p> <p>Elevated temperature and high strain rate data are also presented for grades of stainless steels commonly used on offshore structures and topside facilities (Grade 1.401(304), 1.404 (316), 1.4462 (2205) and 1.4362 (SAF 2304)). These are based on recent tests undertaken with funding from the European Commission and stainless steel industry.</p> | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Table of Contents | <table> <tr> <td>FOREWORD</td> <td>i</td> </tr> <tr> <td>EXECUTIVE SUMMARY</td> <td>ii</td> </tr> <tr> <td>NOTATION</td> <td>iii</td> </tr> <tr> <td>1 INTRODUCTION</td> <td>1</td> </tr> <tr> <td> 1.1 Scope of this Document</td> <td>1</td> </tr> <tr> <td>2 DESIGN BASIS</td> <td>2</td> </tr> <tr> <td> 2.1 Design for Fire</td> <td>2</td> </tr> <tr> <td> 2.1.1 General</td> <td>2</td> </tr> <tr> <td> 2.1.2 Simplified methods</td> <td>2</td> </tr> <tr> <td> 2.1.3 Advanced non-linear methods</td> <td>3</td> </tr> <tr> <td> 2.2 Design for Explosions</td> <td>3</td> </tr> <tr> <td> 2.2.1 General</td> <td>3</td> </tr> <tr> <td> 2.2.2 Simplified single-degree-of-freedom model</td> <td>3</td> </tr> <tr> <td> 2.2.3 Advanced non-linear methods</td> <td>4</td> </tr> <tr> <td>3 ELEVATED TEMPERATURE MATERIAL PROPERTY DATA</td> <td>6</td> </tr> <tr> <td> 3.1 Introduction</td> <td>6</td> </tr> <tr> <td> 3.2 Methods to measure elevated temperature material properties</td> <td>6</td> </tr> <tr> <td> 3.2.1 Steady state (isothermal) test method</td> <td>6</td> </tr> <tr> <td> 3.2.2 Transient state (anisothermal) test method</td> <td>6</td> </tr> <tr> <td> 3.3 Carbon Steel Model</td> <td>6</td> </tr> </table> | FOREWORD | i | EXECUTIVE SUMMARY | ii | NOTATION | iii | 1 INTRODUCTION | 1 | 1.1 Scope of this Document | 1 | 2 DESIGN BASIS | 2 | 2.1 Design for Fire | 2 | 2.1.1 General | 2 | 2.1.2 Simplified methods | 2 | 2.1.3 Advanced non-linear methods | 3 | 2.2 Design for Explosions | 3 | 2.2.1 General | 3 | 2.2.2 Simplified single-degree-of-freedom model | 3 | 2.2.3 Advanced non-linear methods | 4 | 3 ELEVATED TEMPERATURE MATERIAL PROPERTY DATA | 6 | 3.1 Introduction | 6 | 3.2 Methods to measure elevated temperature material properties | 6 | 3.2.1 Steady state (isothermal) test method | 6 | 3.2.2 Transient state (anisothermal) test method | 6 | 3.3 Carbon Steel Model | 6 |
| FOREWORD | i | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| EXECUTIVE SUMMARY | ii | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| NOTATION | iii | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 INTRODUCTION | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.1 Scope of this Document | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 DESIGN BASIS | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.1 Design for Fire | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.1.1 General | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.1.2 Simplified methods | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.1.3 Advanced non-linear methods | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.2 Design for Explosions | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.2.1 General | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.2.2 Simplified single-degree-of-freedom model | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.2.3 Advanced non-linear methods | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 ELEVATED TEMPERATURE MATERIAL PROPERTY DATA | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.1 Introduction | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.2 Methods to measure elevated temperature material properties | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.2.1 Steady state (isothermal) test method | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.2.2 Transient state (anisothermal) test method | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.3 Carbon Steel Model | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| | | |
|-------|------------------------------------------------------------------------------------------------------------|----|
| 3.3.1 | Stress-strain relationships at elevated temperatures | 9 |
| 3.3.2 | Strain-hardening of steel at elevated temperatures | 10 |
| 3.3.3 | Thermal properties | 10 |
| 3.4 | Quenched and tempered steels | 11 |
| 3.5 | Thermo-mechanically Rolled Steel | 11 |
| 3.5.1 | Grade S355M | 11 |
| 3.5.2 | Grade S420M | 12 |
| 3.5.3 | Stress-strain relationship | 12 |
| 3.5.4 | Grade S460M | 13 |
| 3.6 | Tests on BS 7191 steels | 14 |
| 3.6.1 | 355EMZ steels | 14 |
| 3.6.2 | 450EMZ steel | 16 |
| 3.7 | Stainless steel model | 18 |
| 3.8 | Stainless steel grades | 19 |
| 3.8.1 | Grades 1.4301 (304) stainless steel | 19 |
| 3.8.2 | Grade 1.4404 (316L) stainless steel | 20 |
| 3.8.3 | Grade 1.4462 (2205) Duplex Stainless Steel | 21 |
| 3.8.4 | Grade 1.4362 (SAF 2304) Duplex Stainless Steel | 21 |
| 3.9 | Pressure Vessel steels (BS EN 10028) | 22 |
| 3.9.1 | BS EN 10 028-2 steels | 22 |
| 3.9.2 | BS EN 10 028-3 steels | 22 |
| 3.9.3 | BS EN 10 028-4 steels | 24 |
| 3.9.4 | BS EN 10 028-5 steels | 24 |
| 3.9.5 | BS EN 10 028-6 steels | 24 |
| 3.9.6 | BS EN 10 028-7 steels | 24 |
| 3.9.7 | Commentary on vessel steels | 26 |
| 3.10 | Piping steels | 27 |
| 4 | MATERIAL PROPERTY DATA FOR STEELS UNDER HIGH STRAIN-RATE LOADING | 28 |
| 4.1 | Introduction | 28 |
| 4.2 | Methods of measuring strain-rate effects | 28 |
| 4.2.1 | Quasi-static methods | 28 |
| 4.2.2 | Cam and wedge plastometers | 28 |
| 4.2.3 | Drop hammer | 28 |
| 4.3 | Structural Carbon Steels | 29 |
| 4.4 | Cowper-Symonds Relationship | 30 |
| 4.5 | Stainless steels | 31 |
| 4.6 | Strain rate tests | 33 |
| 4.6.1 | Tests on 355EMZ steel | 34 |
| 4.7 | Tests on 450EMZ steel | 36 |
| 5 | CODES OF PRACTICE AND STANDARDS | 37 |
| | APPENDIX A STRESS-STRAIN DATA AT ELEVATED TEMPERATURES | 40 |
| | APPENDIX B HIGH STRAIN RATE DATA FROM TESTS ON GRADE 355EMZ AND GRADE 450EMZ STRUCTURAL STEEL PLATES | 50 |
| | REFERENCES | 66 |