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Fracture assessment procedure developed in Japan for steel structures under seismic conditions

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ABSTRACT

The Engineering Standard, WES 2808, has been developed in Japan for assessing the brittle fracture of steel-framed components at the earthquake. This paper describes the key contents of WES 2808 and demonstrates the application to beam-to-column connections. WES 2808 includes two unique ideas: (1) a reference temperature concept for the evaluation of the material fracture toughness under cyclic and dynamic loading, and (2) an equivalent CTOD concept for the correction of CTOD toughness for constraint loss in structural components. A skeleton strain is employed to define the pre-strain prior to fracture during cyclic loading. The revision of WES 2808 has been done in 2017 to expand the range of use and to improve the accuracy of CTOD toughness correction on the basis of ISO 27306-2016. It is shown that fracture strains of beam-to-column subassemblies predicted by WES 2808 are in a good agreement with those measured.

1. Introduction

The Kobe great earthquake, happened in 1995, caused a considerable damage to steel-framed structures. Beam-to-column connections, column welds and bridge piers failed in a brittle manner: see the report by Toyoda [1]. During the earthquake, structures sustain a large cyclic and dynamic straining, which leads to a substantial decrease in the resistance to brittle fracture. According to the post-Kobe earthquake investigation by Hashida et al. [2] and APD Committee [3] in JWES

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Nomenclature

Principal symbols

a	depth of surface crack or depth of edge through-thickness crack
a_0	initial crack length of standard fracture toughness specimen
c	length of surface crack
$\bar{c}$	length of equivalent through-thickness crack in infinite plate
e	active strain in cyclic loading
e_f	global strain (active strain) at fracture
$e_{f,local}$	local strain at fracture
e_{local}	local strain in assumed crack area in strain concentration zone
$\dot{e}$	active strain rate
$\dot{e}_0$	active strain rate in static condition (= 10^{-4} /s)
$\dot{e}_{local}$	local strain rate
E	Young's modulus
K	stress intensity factor
K_ε	strain concentration factor
m	Weibull shape parameter
N	number of load cycle during cyclic loading
R_Y	yield-to-tensile ratio (= σ_Y/σ_T)
S_r	strength mismatch ratio in welds (= $\sigma_T^{WM}/\sigma_T^{BM}$)
t	plate thickness
T	service temperature of structural component
T_0	room temperature
ΔT_{PD}	temperature shift of fracture toughness caused by pre-strain and dynamic loading
v	loading rate
W	width of standard fracture toughness specimen
β	equivalent CTOD ratio, defined by δ/δ_{struc}, that links CTODs of standard fracture toughness specimen and structural component at the same Weibull stress level
β_0	equivalent CTOD ratio for a reference size of crack
β_{CSCP}	equivalent CTOD ratio for center surface crack panel
β_{CTCP}	equivalent CTOD ratio for center through-thickness crack panel
β_{ESCP}	equivalent CTOD ratio for edge surface crack panel
β_{ETCP}	equivalent CTOD ratio for edge through-thickness crack panel
δ	CTOD of standard fracture toughness specimen with crack depth ratio of $a_0/W = 0.5$
δ_{cr}	critical CTOD of standard fracture toughness specimen (CTOD fracture toughness)
δ_{struc}	CTOD of a crack in structural component
$\delta_{cr,\ struc}$	critical CTOD of a crack in structural component
ε_{pre}	pre-strain
$\varepsilon_{pre,\ local}$	local pre-strain
ε_Y	yield strain
σ_f	flow stress (= $(\sigma_Y + \sigma_T)/2$)
$\Delta\sigma_f^{PD}$	flow stress elevation caused by pre-strain and dynamic loading
σ_T	tensile strength of material
σ_{T0}	tensile strength at room temperature in static condition
σ_{T0}^{pre}	static tensile strength at room temperature with pre-strain
σ_T^{BM}	tensile strength of base metal
σ_T^{WM}	tensile strength of weld metal
σ_Y	yield strength of material
σ_{Y0}	yield strength at room temperature in static condition
σ_{Y0}^{pre}	static yield strength at room temperature with pre-strain
σ_Y^{BM}	yield strength of base metal
σ_Y^{WM}	yield strength of weld metal
σ_W	Weibull stress

Principal abbreviations

BM	base metal
CSCP	center surface crack panel
CTCP	center through-thickness crack panel
CTOD	crack tip opening displacement
ESCP	edge surface crack panel

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