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Prediction of fracture behavior of steel beam-to-column connections with weld defect using the SINTAP

Binnur Gören Kiral*, Seçil Erim

Dokuz Eylul University, Department of Mechanical Engineering, 35100, Bornova, Izmir, Turkey

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Abstract

This paper aims to determine accurate and quick defect assessment of welded steel beam-to-column connections and to examine the effect of the different connection types and the electrode types having different toughness on their fracture behavior using the Structural Integrity Assessment Procedure (SINTAP) for European countries. The SINTAP-Level II developed for confidence in welded structures with defects is used. The procedure described in this study allows assessing the maximum crack size permitted in the welded connection under seismic loading without occurrence of brittle fracture. The results obtained from the present study agree well with those of the other studies.

Keywords: SINTAP; Welded beam-to-column connection; Fracture toughness; Stress intensity; Brittle fracture

1. Introduction

The Marmara earthquake on August 17, 1999 of 7.4 magnitude caused a devastating catastrophe and thousands of people died in the numerous collapses of concrete buildings. The predominant structural system used for buildings in Turkey consists of reinforced concrete frames with unreinforced masonry infills. This structural system is used for all building heights and occupancies, from single story commercial to multi-storey residential and office buildings. Industrial buildings are either reinforced concrete (cast in place or pre-cast) or steel frame structures.

An alternative to concrete, steel, by far the most expensive construction material in Turkey, has been used in industrial structures. Some were damaged by this earthquake and only a few collapsed. The main collapse generally occurred at the beam-to-column connection in the form of tear-off the welded beam-to-column connection, fractures of brace connections and buckling of braces. Other collapses included failure of anchor bolts at column bases and structural instability under overturning forces.

A proper application of steel is useful in seismic areas; however there exist some problems to be solved. The 1994 Northridge and 1995 Kobe earthquakes resulted in unexpected and serious damage in a very large number of welded steel moment resisting connections, which were specially designed to respond in a ductile manner to have appropriate energy absorption by plastic deformation in the seismic conditions. The post-earthquake investigations brought out that the design and material properties of the connections were the causes of the brittle fractures. Many fractures occurred starting from the weld root in the beam bottom flanges [1].

Extensive studies have been carried out to develop ductile beam-to-column connection details for the use in seismic areas. Azuma et al. [2] investigated beam-to-column connections with weld defects tested under cyclic loading and evaluated the fracture toughness properties of numerically modeled weld defects. Kuntiyawichai and Burdekin [3] studied the effects of dynamic loading on both fracture toughness specimens under rapid loads and cracked connections in steel framed structures under earthquake loads using the Finite Element Method.

* Corresponding author. Tel.: +90 232 388 31 38; fax: +90 232 388 78 68.
E-mail address: binnur.goren@deu.edu.tr (B. Gören Kiral).

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Nomenclature

a	crack length
a_i^W	distance from the centroid of the beam web to the neutral axis
a_i^F	distance from the centroid of the beam flange to the neutral axis
c	crack width
F	applied load
F_y	limit (yield) load
$f(L_r)$	failure assessment curve function
I	moment of inertia for area
L_r	F/F_y
K_I	stress intensity factor
K_r	K_I/K_{mat}
K_{mat}	material fracture toughness
M_y	limit (yield) moment
t_{bb}	cover plate thickness
t_{bf}	beam flange thickness
σ	remotely applied stress

Righiniotis et al. [4] examined two-dimensional crack models for assessing the fracture of bottom flange welds in steel beam-to-column connections and presented the formulation of the approximate expressions for the stress intensity factors related to the cracked geometry accounting for typical stress conditions.

However, there remain some problems to be solved for clarifying the engineering fracture assessment method. The aim of this study was to assess the safety of welded steel beam-to-column connections under earthquake loads in order to avoid the brittle fracture. In this regard, maximum loads and the critical crack length of each connection are determined and compared for each connection type under various loading conditions. Additionally, the effect of the material properties of different base and weld metal on the fracture behavior of the steel structure is examined. Finally, improvement of the welded steel structure to withstand the earthquake is aimed for using the analytical methods.

2. Analysis procedures

In this study, the Net-Section-Collapse (NSC) and Structural Integrity Assessment Procedure (SINTAP) methods were applied to welded steel structures in order to determine their fracture behavior under instantaneous intense earthquake loads. Determining the connection model was the first step of the analysis. The NSC method was used for obtaining the limit load values of the connection. The yield and ultimate strength values of base and weld materials should be known for the NSC method. The SINTAP requires the formulation of stress intensity factor of each connection, fracture toughness values of base and weld material and the limit load. SINTAP gives the fracture behavior of connection under loading.

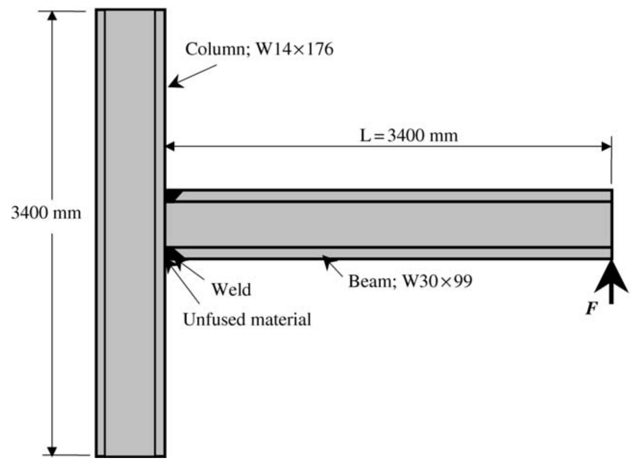

Fig. 1. Beam-to-column configuration.

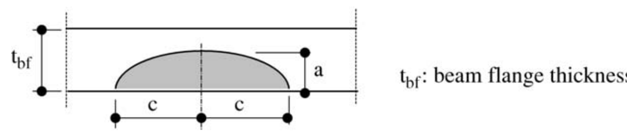

Fig. 2. Dimensions of the semi-elliptical surface crack.

3. Beam-to-column connection and crack models

The welded steel structure subjected to earthquake loads is given in Fig. 1. As shown in the figure, the connections investigated consist of W30 × 99 beams connected to W14 × 176 columns with welding operation. The materials of beam and column are both A 572 steel Gr. 50 [5]. Four different weld metals are used (E70T-6, E71T-8, E70TG-K2 and E7018) and the flange welds are made using the Flux Core Arc Welding (FCAW) process [6].

The welded steel structure is subjected to vertical force at the end of the beam. This force, which causes the bending moment, is assumed to simulate the earthquake loads. Experience shows that only the tensile stress normal to the crack is important in causing fatigue or fracture in steel structures although cracks can be loaded by shear [7]. Therefore, only this loading case was considered.

Semi-elliptical surface cracks are placed through the heat-affected zone at the connection where the column flange meets the bottom flange of the beam. The dimension of the semi-elliptical surface crack is given in Fig. 2; where a denotes the crack length. For simplification, the relation between the half crack width, c and crack length, a, i.e. the crack shape, a/c, is taken as a constant [7].

In this study, c is proposed,

$$c = 1.5a. \tag{1}$$