

EFFECTS OF THE WELD ELECTRODE ON THE FRACTURE BEHAVIOR OF WELDED STEEL BEAM-TO-COLUMN JOINTS

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Abstract - Crack-like defect occurs in the weld region or heat-affected-zone of beam-to-column connections widely. They may cause unexpected serious damage in the steel welded buildings. Most of these place at the connection where the column flange meets the beam bottom flange. The assessment of these defects is entirely related to the reliability of the whole structure. In this study, the fracture behavior of the welded steel structure including the defects subjected to loading has been investigated, and the conditions free from brittle fracture have been tried to carried out using the SINTAP Defect Assessment Procedure. The effects of the weld electrodes on the fracture behavior of the structure have been observed.

Keywords - SINTAP, welded steel beam-to-column connection, electrode, fracture.

1. INTRODUCTION

The presence of a defect such notch, a crack or some other stress raiser makes structural materials susceptible to brittle fracture. It is important to pay attention to the effects of defects and large plastic deformation on the fracture analysis of seismic damaged welded steel structures. Steel structures must have appropriate energy absorption by plastic deformation without brittle fracture. Brittle failure causes remarkable decrease of energy absorption ability of the steel structure, and it may lead to collapse of the whole structure. For the reliability of the structure, it is important to use steel and weld material having enough fracture toughness.

Nakagomi et al. [1] studied on the beam-to-column connection considering mechanical property of the structural steel and weld material. They tested to see the effects of the toughness of structural steel and weld metal on the plastic deformation capacity and the behavior of fracture of the specimen.

Paterson et al. [2] examined the materials of construction of welded steel beam-to-column connection, its controlling material properties, the possible variation in the material properties, and the corresponding structural integrity.

Kuntiyawichai et al. [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.

Azuma et al. [4] investigated beam-to-column connections with weld defects tested under cyclic loads and evaluated the fracture toughness properties of numerically modeled weld defects.

Righiniotis et al. [5] simplified two-dimensional crack model 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.

In this study, welded steel beam-to-column connections including crack-like defects are investigated by using the SINTAP Procedure Level II, European Flaw Assessment

Procedure, for mis-matched structures. In order to examine the effects of the toughness of weld metal, two different weld electrodes are used, namely E70TG-K2 and relatively tougher E-7018. The limit load for the welded steel connection is determined by the Net-Section-Collapse Method (NSC).

The aim of this study is an assessment of the safety of the welded beam-to-column connections under earthquake loads in order to avoid the brittle fracture.

2. PROBLEM DEFINITION

The welded steel structure examined in this study is given in Figure 1. As shown in the figure, the connection consists of a W30×99 beam connected to a W14×176 column with welding operation. The model is the common connection used before the Northridge earthquake. The materials of beam and column are both A 572 steel Gr. 50 and the flange welds are made with E70TG-K2 and E-7018 electrodes. Two electrodes having different fracture toughness are used in order to determine the effect of the material properties of weld electrodes on the fracture behavior. The material properties of base and weld metals are given in Table 1.

Table 1. Material properties of base and weld metal

	Yield Strength (MPa)	Ultimate Strength (MPa)	Elasticity Modulus (GPa)	CVN (J)
Weld (E70TG-K2)	485.8	605.6	201.2	98
Weld (E7018)	485.8	555.2	202.4	185
Base Metal (A 572)	347	433.7	204.1	267

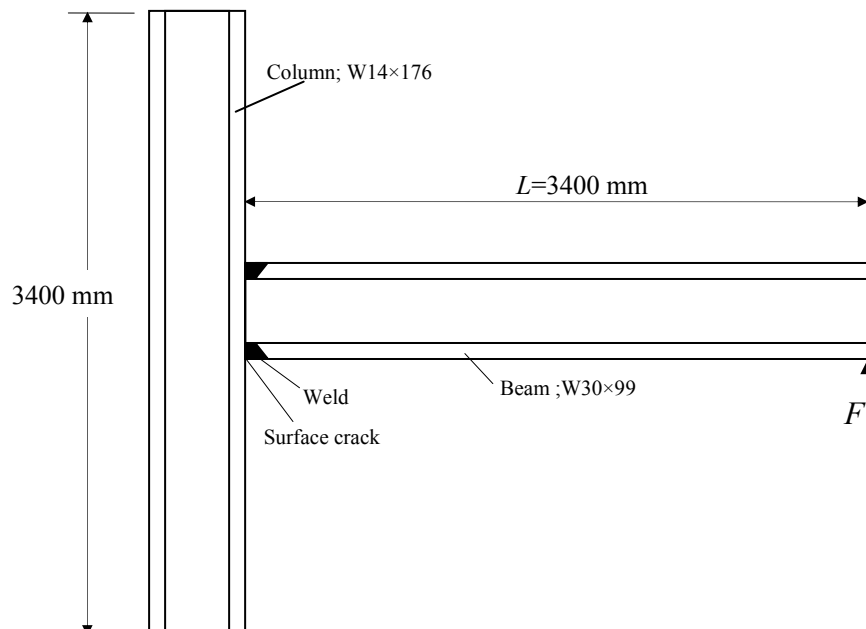


Figure 1. Beam-to-column configuration

The elliptical surface crack is placed in the heat-affected zone beneath the beam bottom flange. Dimensions of the surface crack are shown in Figure 2.

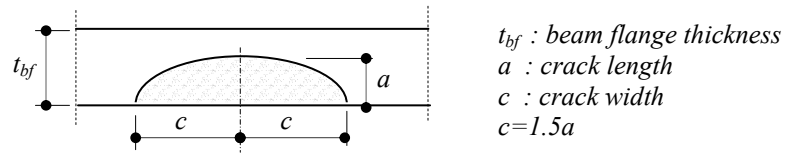


Figure 2. Dimensions of the semi-elliptical surface crack

3. THEORY

3.1 Fracture Toughness Estimation

Notch and fracture toughness are measured by a variety of means, such as the Charpy V-notch (CVN) test, the Crack Tip Opening Displacement (CTOD) fracture toughness test, etc. The CVN test is a very common method for characterizing the notch toughness. CVN test typically characterizes notch toughness by the amount of energy absorbed by the specimen.

Due to expense and size limitations associated with fracture toughness tests, it is useful to make estimations of fracture toughness from CVN toughness requirements. The empirical correlation between CVN and K_{mat} , material fracture toughness, is as follow [6]:

$$K_{mat} = \sqrt{\frac{E(0.53CVN^{1.28}) \times 0.2^{(0.133CVN^{0.256})}}{1000(1-\nu^2)}}$$

where K_{mat} in $MPa\sqrt{m}$ and CVN in Joule.

3.2. Limit Load Estimation

The limit load, which is main input for the SINTAP procedure, is determined by using the Net-Section-Collapse (NSC) Method for beam-to-column connection under loading. This method is very useful for determining the limit load of the complicated structures.

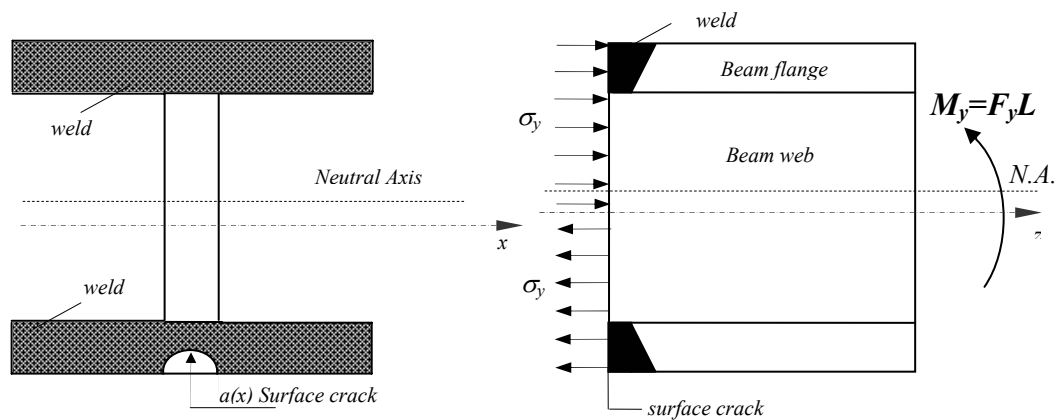


Figure 3. Resulting stress distribution under loading

The NSC Method is based on the static equilibrium of forces and moments. The limit load can be determined as follow [7, 8 ,9]

$$F_y + \sum (\sigma_y^W A^W + \sigma_y^B A^B) = 0$$

$$M_y + \sum (\sigma_y^W A^W a^W + \sigma_y^B A^B a^B) = 0$$

Where F_y and M_y are the limit load and the limit moment of the connection, respectively. σ_y^W and σ_y^B are the yield strength of the base and weld materials.

3.3. Stress Intensity Factor Formulations

The stress intensity factor for arbitrary loading may be expressed in the general form for Mode I as [10],

$$K_I = \sigma \sqrt{\pi a} Y(a/t_{bf})$$

where σ is the remotely applied stress.

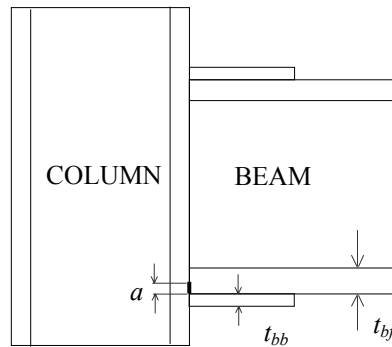


Figure 4. The beam-to-column connection with the surface crack

Stress magnification factor, which is related to specific a/t_{bf} ratios for the bending, is given by [5]

$$Y(a/t_{bf}) = 944.85 \left(\frac{a}{t_{bf}} \right)^6 - 2290.5 \left(\frac{a}{t_{bf}} \right)^5 + 2168.2 \left(\frac{a}{t_{bf}} \right)^4 - 1003.2 \left(\frac{a}{t_{bf}} \right)^3 + 237.75 \left(\frac{a}{t_{bf}} \right)^2 - 27.098 \left(\frac{a}{t_{bf}} \right) + 2.1681$$

K_I can be expressed for a semi-elliptical weld defect under bending [5]

$$K_I = \sigma \sqrt{\frac{\pi a}{Q}} Y \frac{Y_1}{Y_2}$$

Y_1 and Y_2 are given by [3]

$$Y_1 = 1.0807 \left(\frac{\frac{a}{t_{bf}}}{\frac{a}{t_{bf}} + \frac{t_{bb}}{t_{bf}}} \right)^{-0.3299} \quad Y_2 = 1.12$$

Q is the elliptical shape correction factor given by [5]

$$Q(a/c) = 1 + 1.464 \left(\frac{a}{c} \right)^{1.65}$$

3.4 The SINTAP Procedure

The SINTAP Procedure evaluates structural integrity for European industry and its main output is flaw assessment [11]. It has been developed by GKSS Research Center in Germany for mismatched welded structures. The SINTAP mismatch procedure provides confidence in assessment of defective weld strength mismatched structures. [12, 13, 14]

3.4.1 Basic Equations

The SINTAP Procedure includes FAD (Failure Assessment Diagram) and CDF (Crack Driving Force) routes. In the FAD route, a failure line is constructed by normalizing the crack tip loading (or applied stress intensity factor) with respect to the material's fracture toughness. In the CDF route, the material resistance against the crack growth (R-Curve) is compared with the crack tip loading in the component. In this paper, FAD approach is used. Figure 5 explains the FAD route.

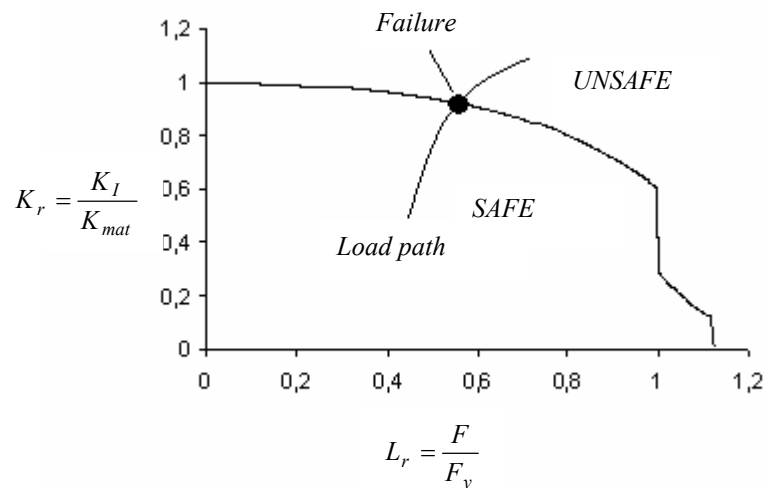


Figure 5. FAD approach for crack initiation

The basic equation in the FAD approach is:

$$K_r = f(L_r)$$

where L_r is the ratio of the applied load, F , to the plastic yield load, F_Y calculated by the NSC method:

$$L_r = \frac{F}{F_Y}$$

Confidence in the structure requires that

$$K_r = \frac{K_I}{K_{mat}} \leq f(L_r)$$

where K_I is the stress intensity factor of the structure, and K_{mat} is the fracture toughness of the material.

4. RESULTS

In this paper, welded steel beam-to-column connections are examined by using the SINTAP Procedure Level II, European Flaw Assessment Procedure. Two different electrodes are used, namely E70TG-K2 and relatively tougher E-7018 in order to examine the effects of the toughness of weld metal. The limit load of the connection, which is required by the SINTAP procedure, is determined by the Net-Section-Collapse Method (NSC).

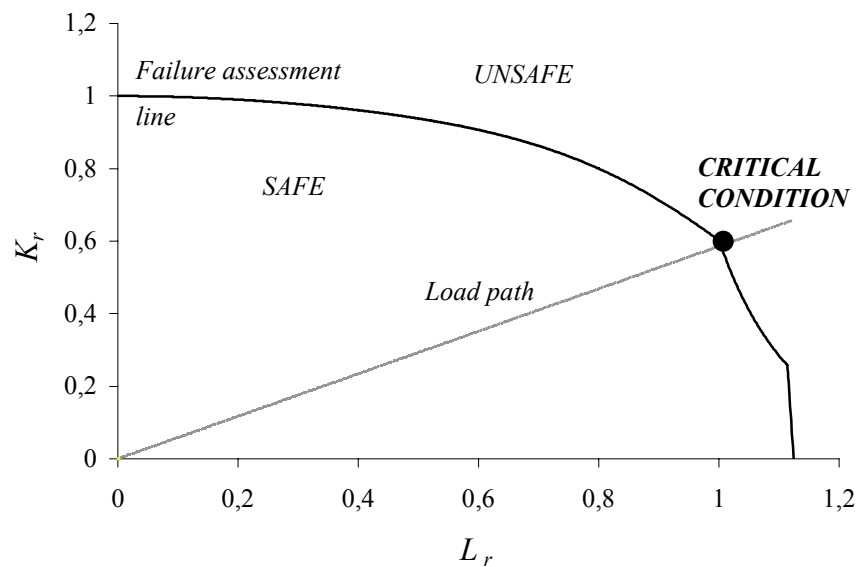


Figure 6 SINTAP Level II (mismatch)-FAD route

Figure 6 shows the FAD route for welded steel structure containing surface elliptical cracks. Critical condition occurs at the points where load path intersects the FAD curve as shown in Figure 6. This situation is determined by considering the change of both the crack length and the load. It can be concluded that the structure is safe if the work condition for the structure is below the failure assessment line.

Table 2. Limit load values (N)

Type of electrode	Limit load value, F_Y (N)	Maximum load value, F_{max} (N)
E70TG-K2	379067	426260
E-7018	379067	417996

Table 2 presents the limit and maximum load values of welded steel connection for both electrodes, E70TG-K2 and E-7018. It is seen that the limit load values are equal because the yield strength values of both electrodes are equal. The maximum load value

of the connection increases when E70TG-K2 electrode is used because the ultimate strength of E70TG-K2 electrode is higher than that E-7018. The structure collapses even if the structure is free from the defects when the applied load reaches to the maximum load.

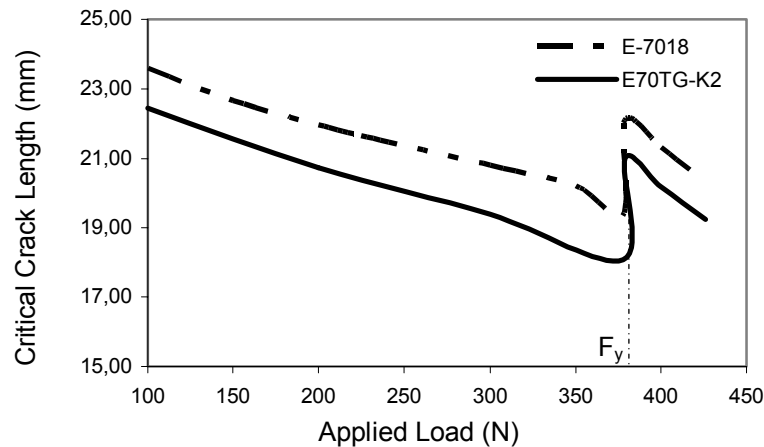


Figure 7 Variation of the critical crack length sizes with applied load

Figure 7 shows the change of the critical crack length with the applied load. Although their limit load values are equal, the critical crack length size permitted in the structure is larger when the electrode E-7018 is used. As seen from the figure, the critical crack length decreases until the applied load reaches to the limit load. However, there is some increase in the critical crack size after the yielding occurs. When the ligament collapse occurs, crack length becomes larger than that in the elastic region close to limit load.

If the crack length for any loading condition stays under the curve, the structure is considered safe. Otherwise, brittle fracture may occur unexpectedly.

Additionally, the use of the SINTAP procedure provides the confidence to assess the defects in welded steel beam-to-column connections in a rather short time compared with the other methods. This procedure also provides us to examine the effect of the material properties of electrode or base metal, different crack size, or any variable in considerably reducing the time of analysis.

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