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Residual stress effect on link element of eccentrically braced frame

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ABSTRACT

The effects of residual stress on the performance of link elements as lateral force shield, particularly for earthquake load as in the Eccentrically Braced Frame (EBF), is the main focus of this research. Experimental tests were conducted in two stages: First, the residual stress measurement of the link element with Neutron Diffraction technique using the equipment of DN1 at Center of Science and Technology of Advanced Material - National Nuclear Energy Agency (PSTBM-BATAN); second, two links were tested, a standard link that corresponds with the AISC 341–10 and a modified link. Behaviors of both links were studied based on the residual stress distribution in the first stage. The magnitude of tensile stresses on and around the "k area" caused the initiation of crack on the standard link so that it decreases the performance of the link element. Modifications of the link by replacing the stiffener of the vertical web with the horizontal stiffener can avoid the initiation of crack that may occur on the web plate around the "k area" so that the performance of the link elements can be improved.

1. Introduction

The inelastic rotation capacity of the link element is amongst such other parameters of link performance as strength, stiffness, ductility, overstrength and the energy of dissipation. The AISC 341–10 [1] has regulated the distance and thickness of web stiffeners of the link, the relation between inelastic rotation capacity and the length of link element, the ratio of the thinness of the section and the loading pattern. That regulation is adopted from previous research conducted at the University of California Berkeley that is still valid until now [2–7].

Amount of research concerning the link performance were intensively studied both experimentally or numerically, for example, the settings of the distance of web stiffeners [8,9], the type of joint of the link to the column [10] that includes the addition of stiffeners on the link ends [11,12], the addition of stiffeners of the diagonal web of the link [13], and the replaceable link [14,15]. Furthermore, Prinz and Richards [16], Berman et al. [17] and Naghipour et al. [18] have studied the performance improvements of the link with reduction of web section or flanges link or known as the reduction web section (RWS) or reduced link section (RLS). In addition to the link model with WF profile, the link square, and built-up models have been studied by a number of researchers where these models generated good link performances, particularly for bridge pier [19–21].

Furthermore, a number of previous research [8,9,19–22] have found a crack on the link element that occurred on the web or flanges. The crack on the "k area" or failure on the web close to the stiffener, or is known as Heat Affected Zone (HAZ), is not only exhibited by the intermediate and long (flexure) link, but also on the short (shear) link, as studied by Okazaki et al. [8].

The k area is the joint area between web-stiffener and flange plates of the link element. The AISC 341–10 [1] stated that this area is used as the access of welding and is stipulated to have a width of 38 mm. The research by Budiono et al. [23] has shown that this area has high magnitude and distribution of tensile stress and is vulnerable to the failure of crack, as shown in Fig. 1.

Previously, number of researchers have reported the behavior of fracture, as shown in Fig. 1, and described subsequent efforts to avoid premature crack or crack initiation in this area. McDaniel et al. [19] reported that the crack initiation that occurred on the welding ends is caused by the high concentration of stress that occurred in the welding area of web-flanges plates and stiffeners. They suggested that the stress concentration may be decreased if the end of welding is four times of the width of the web from the flange plate. Okazaki et al. [8] also reported that number of specimens exhibited the initial behavior of crack that is started from the end of welding that subsequently developed to a fracture on the web plates. They concluded that this fracture is related to the toughness value of the k area. Furthermore, they suggested a gap between the end of welding and the flange plate as much as five times of the web plate thickness. Richards and Uang [24] has reported the crack that occurred in the k area was caused by the distance of stiffeners that are too close; furthermore, Richards and Uang [25] also concluded that the loading pattern also influenced the failure on the web plate. They proposed a new loading pattern that now is adopted in the

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Nomenclature

List of symbols

a_{hkl}	lattice constant wavelength
2θ	neutron diffraction angle
θ	half of the neutron diffraction angle
d_o	strain-free lattice spacing
d_{hkl}	lattice spacing
σ_i	stress in the x, y, z directions
E_{211}	Youngs modulus of elasticity for the plane of 211 from the Miller index
ν_{211}	Poisson's ratio for the plane of 211 from the Miller index
ε_x	strain in the x-direction
ε_y	strain in the y-direction
ε_z	strain in the z-direction
f_y	yield strength of the steel
f_u	ultimate tensile strength
t_f	flange thickness
t_s	stiffener thickness
t_w	web thickness
t_{sh}	horizontal web thickness
a	distance of stiffener
b	flange width
d	cross section depth
e	link length
V_p	plastic shear strength
M_p	plastic moment of link cross section
V_n	nominal shear of link

AISC 341–10 [1]. Chao et al. [26] performed a numerical study of the link behavior and concluded that the crack initiation is situated at the end of welding that is caused by warping of the stiffener plate. They suggested that avoidance of welding on the k area will increase the inelastic capacity of the link element. Dusicka et al. [27] also reported the initiation of crack on the web that is performed both experimentally from the built-up link and also numerically, where the end of welding of the stiffener with flange and the stiffener with web exhibited a high concentration of plastic strain. Furthermore, Gulec et al. [28] proposed a function to evaluate the damage and failure that occurred on the varying length of the link element.

The first hypothesis of this research is that the link fracture is caused by residual stress from the welding process that may cause hydrostatic stress effects on the HAZ in such a way that induces fracture failures. The crack is caused by a decrease in plastic deformation of the link element, which causes a failure (crack) that is sudden (brittle) both in the k area and the joint of plate ends during the cyclic loading. This effect caused the inelastic rotation capacity of the link that is stipulated in AISC 341–10 [1] cannot be achieved.

In terms of its application in civil engineering, the residual stress effects up to now do not explicitly measure on the joint between plates, particularly for steels of high quality. Hence, a good prediction of the residual stress effect due to welding is required for future use of the joint of plates. Furthermore, this research is performed in order to understand more details about the magnitude and distribution of the residual stress on and around the k area in the light of the performance improvements of the EBF link element, which to date, has not much investigated.

2. Experimental tests

The experimental tests in this study were conducted in two stages. The objective of the first test is to obtain the residual stress magnitude and distribution, whereas the second test is performed to study the behavior and performance of the EBF link element. Details of both tests are further described as follows:

2.1. Residual stress measurement

This study used a non-destructive method by the neutron diffraction techniques. Due to the absence of electricity charges, the neutron can interact with the nuclei of the atoms of the constituent material and is able to pass through the material until several centimeters deep. This unique characteristic allows the measurement of the direction of residual stress to be performed as desired. Details of the measurement are further described in Budiono et al. [23].

The residual stress measurement was performed using the Diffractometer Neutron DN1 equipment of PSTBM BATAN which is installed on the beam tube number 6 (S-6) in GA Siwabessy multipurpose reactor (RSG GAS) BATAN in Serpong. Two samples were used to varying extent of k area, which is 100 mm^2 or RSK 10 × 10 mm, and 200 mm^2 or RSK 20 × 10 mm as shown in Fig. 2. Details of the dimension of each of the samples are shown in Table 1.

Furthermore, direction and the points of measurement are shown in Fig. 3.

The measurement was conducted with a diffraction angle of 103° to the plane of 211 from the Miller's index with 1.836863˙ wavelength. The slit incident beam has 1 × 1 mm dimension and the detector beam has 3 mm radial collimator. Each of the measurement points was measured within 60 min in the normal direction and 90 min in the transversal and longitudinal directions. Details of distance of each of the measurement points are shown in Fig. 4. The measurement in this study was only conducted for the point 5, 6, 7, 8 and 9 as shown in Fig. 4.

The measured parameters are described in Table 2.

In this study, the fillet welding as is stipulated on the AISC 341–10 [1] was constructed between the stiffener plate, which is 136 × 34 mm and 10 mm thick, with the web and flange plates. The welding procedure is arranged in accordance with the American Welding Society [29]. Prior to the welding process, the surfaces of stiffener plate and profile were cleaned from dust and debris. The profile is supported by other plates on both ends in order to avoid distortion during the welding process. The welding begins with the

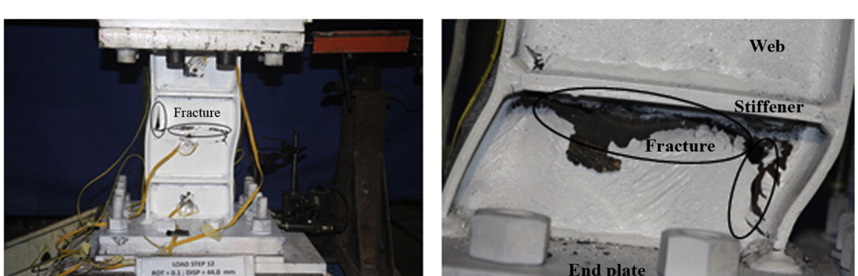

Fig. 1. The failure incident of "k area" of the link.