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Buckling control of cast modular ductile bracing system for seismic-resistant steel frames

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ABSTRACT

The buckling behavior of a new ductile bracing concept for steel structures is examined. The system makes use of cast components introduced at the ends and the center of the brace to produce a special bracing detail with reliable strength, stiffness and deformation capacity. The system takes advantage of the versatility in geometry offered by the casting process to create configurations that eliminate non-ductile failure modes in favor of stable inelastic deformation capacity. This paper presents analytical research performed to determine the buckling strength and buckling direction of the bracing element based on the geometries of the cast components. Limiting geometries are determined for the cast components to control the buckling direction. Design formulas for buckling strength are proposed.

1. Introduction

A cast modular ductile bracing system is under development as an alternative to steel special concentric braced frames (SCBFs). The system, termed a cast modular ductile bracing system (CMDB), produces a controlled energy-dissipation mechanism through the use of specially detailed cast steel components introduced at the ends and the center of the brace. These components are designed to produce controlled stable and ductile plastic hinge regions when the bracing element undergoes buckling and straightening cycles during seismic loading.

The steel SCBF is a popular seismic resistant system. However recent research has indicated a number of seismic performance issues [1] related to: member low-cycle fatigue life; fracture at connections; induced distortion in the surrounding members, and unbalanced shear load in the beam [2]. Improvements to SCBFs have been proposed [2–4] and new innovative systems have been proposed as alternatives to SCBFs [5–8]. The CMDB system falls into the latter group.

Ward et al. [9] have presented the CMDB component geometries that produce ductile mechanisms leading to greater low-cycle fatigue life and greater post-buckling strength. These designs were shown to have the potential for improved seismic response in comparison to a SBCF. A necessary further step in developing the CMDB prototype design is the ability to: (1) reliably control the buckling direction to ensure the desired post-buckling mechanism; and, (2) adequately predict the CMDB critical load. This paper presents analytical research to establish the relationship between CMDB geometry and these behaviors. Design expressions for buckling strength and required geometry for buckling control are proposed.

2. Casting modular ductile brace concept

Fig. 1 shows a schematic of the CMDB system in the evaluation frame used for this paper. The CMDB bracing element is constructed by inserting cast components at the ends and center of HSS (Hollow Structural Section) members. The components, termed the end and center (cast ductile) components, or EC and CC, are shown in detail in the next section. For simplicity, the CMDB design is developed using a single diagonal configuration, as is commonly done in research. However, the system is anticipated to be used in chevron or X-brace configuration, which represents a more accommodating case in terms of tolerance.

Ward et al. [9] demonstrated analytically that the CMDB system can develop a stable and ductile plastic mechanism in the post-buckling region. Fig. 2(a) shows the controlled plastic mechanism developed in the CMDB analytical model, in which dark regions of the contour plot are elastic, while the lighter regions indicate the plastic hinge regions contained in the specially designed cast components (EC and CC).

Ward et al. [9] compared the performance of the CMDB system to a SCBF of similar strength and bay geometry under cycling loading protocols. The accumulated plastic strain comparison is shown in Fig. 2(b), with the hatched area representing the predicted fracture range. The lower strain demand in the CMDB is due to the spreading of the inelastic demands in the special cast component, and the elimination of strain concentrations and local buckling in the HSS.

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