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Ductility and energy dissipation behavior of G20Mn5QT cast steel shear link beams under cyclic loading

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ABSTRACT

This paper presents the results of experimental and numerical simulation study of replaceable cast steel link beams under cyclic loading, including the ductility, strength, stiffness and energy dissipation of seven shear link specimens with and without circular perforations. Monotonic test of a G20Mn5QT cast steel link specimen was first carried out. Cyclic load testing of four G20Mn5QT cast steel link specimens are performed to investigate their failure mode, deformation and ultimate load carrying capacity, ductility, stiffness, and energy dissipation performance. Among these, two link specimens from the same cast steel batch were machined to form two different web perforation patterns in their web. Cast steel links without web openings show good ductility while perforating the link web offer a tool to reduce the link strength at the cost of ductility. The finite element analysis results of the G20Mn5QT cast steel shear links with and without web perforations are also presented and it is found that finite element simulation results are in good agreement with the experimental results.

1. Introduction

Growing interests in seismic design have been given to a strategy that involves the use of fuse-type replaceable energy dissipation devices with highly ductile performance while other members of the primary structural system are designed to have little or no damage under design level earthquakes [5,6]. For example, nonlinear behavior of the eccentrically braced frames (EBFs) is limited to replaceable link beams. The design of EBFs with replaceable links has been gaining attention in the past ten years. Using the replaceable link concept, structural designers have more flexibility to choose a proper section size for the steel link beam that best meets the capacity design requirements. The replaceable link design, which features a bolted extended end plate for ease of removal post a major earthquake, has been used in several 2011 Christchurch earthquake rebuild projects [12]. Link beams in EBFs are capable of developing large plastic deformation while the other structural members remain elastic. Using shear links is usually preferred because of its highly ductile performance and they have been used in structures such as buildings and bridges [9]. Because the plastic deformation will be confined within the link beam, damaged links can be quickly inspected and replaced following a major earthquake, significantly reducing the disruption time from inspecting and repairing damaged structures and extending its life span [7]. Conventional welded steel link beams are found to develop cracks in the welded intersection zone connecting transverse stiffeners to the link beam web plate [13–15].

The use of steel castings for structural applications has been becoming more popular [2]. Use of cast steel joints is reported to significantly improve the fatigue life of otherwise highly complex welded connections. Testing of cast steel connectors that fit between a tubular brace and a gusset plate are reported by [8] for application in seismic load resisting braced frames. Their laboratory test results from static and cyclic testing of concentrically loaded brace-connector assemblies showed that the use of a cast steel connector is a viable means of connecting to tubular brace members for seismic applications. Cast steel components have also been shown in previous research [1,16,17] to be capable of producing excellent ductility and stable energy dissipation as well as the versatility in shape afforded by the casting process. For example, Fleischman and Sumer [1] developed a cast steel modular connector for use as an energy dissipating element in steel moment-resisting frames. The modular connectors are meant to attach between the column and the flanges of a beam, and during earthquake the modular connector's 'arms', repeatedly deform plastically in double curvature flexure to dissipate seismic energy. This detail removes the need for field welding in the vicinity of the column panel zone and focuses inelastic demand to the arms of the cast modular connector. Half-scale prototype modular components that were tested exhibited improved

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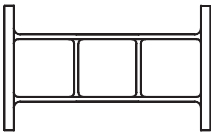
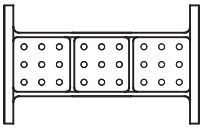
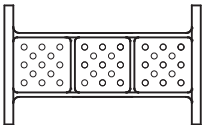
Table 1
Test specimen labeling and quantity.

	Label	Quantity	Web Perforation Pattern	Loading
Link w/o perforation	L0	1	No Perforation	Monotonic
	L1 L2	2		Cyclic
Perforated Link†	L-C-1	1		Cyclic
	L-C-2	1		

† Hole diameter is 20 mm for all web holes. Spacing between holes in L-C-1 is 60 mm and additional holes are added to L-C-2 to grid diagonals.

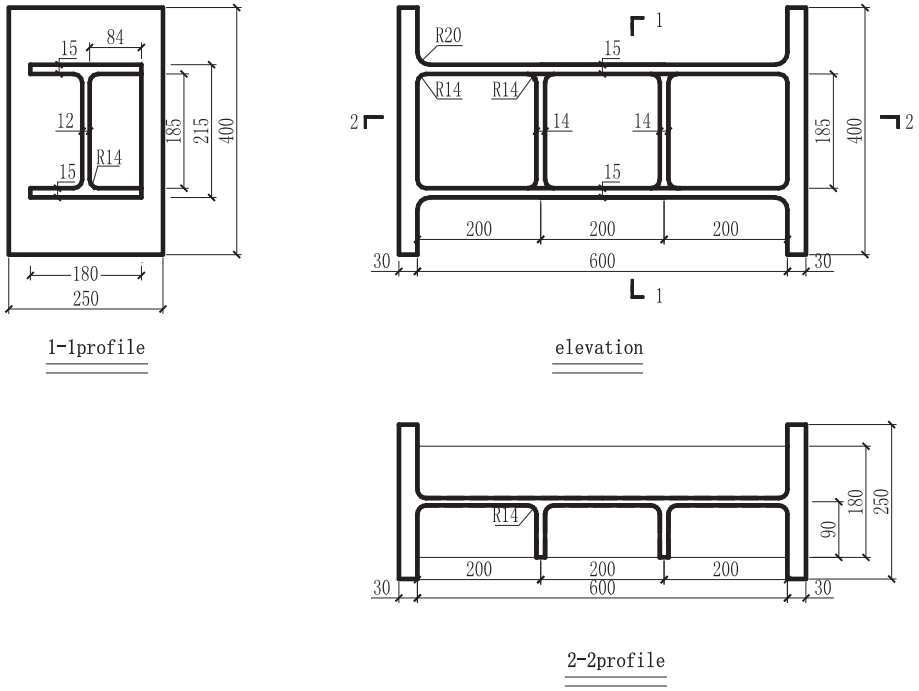


Fig. 1. Dimensions of cast steel link beam specimens without perforation (unit: mm).

ductility and exceeded qualifying rotational capacities for seismic-resistant, moment-resisting frames. Tong et al. [17] have also conducted experimental study of steel beam-to-column joints equipped with weld-free cast steel connectors used as replaceable energy-dissipating components. These joints were also shown to meet the classification criteria of semi-rigid joints in terms of stiffness, and the ductility, which was governed by fracture of energy dissipating elements, was found to be satisfactory.

A total of seven G20Mn5QT cast steel links were tested in this experimental study to investigate their hysteretic behavior and failure mode under cyclic load. For fuse devices, link beams made of hot-rolled sections are commonly used for lower cost and avoiding potential welding defects. Yet only limited sections of hot-rolled steel are available. One alternative solution to tune the properties of the link beams is to make perforations over the link beams' web area in order to achieve the desired mechanical properties. Usually stress concentrations would be introduced near web perforations of shear links, which would reduce the

Table 2
Chemical composition of G20Mn5QT cast steel for link specimens(%).

Material	C	Si	Mn	P	S	Cr	Ni	Mo
G20Mn5QT	0.19	0.45	1.38	0.0145	0.0075	0.175	0.035	0.03

Table 3
Material properties of G20Mn5QT cast steel.

Test Coupon	Ultimate Strength f_u (MPa)	Yield Strength f_y (MPa)	Percent Elongation (%)
Web	612.1	463.4	20.3
Flange	614.4	461.2	25.7
Untreated	568	401	32.5