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Study on two-level-yielding steel coupling beams for seismic-resistance of shear wall systems

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ABSTRACT

This paper proposes an innovative type of two-level yielding steel coupling beams (TYSCB) to improve the seismic performance of coupled shear wall systems. The proposed TYSCB consists of two key components: shear-yielding beam and bending-yielding beam. For a minor earthquake, the former is expected to yield to dissipate energy while the latter still stays in elastic to provide the stiffness demand. Under a severe earthquake, both the shear and bending-yielding beams are designed to yield to dissipate seismic energy. Experiments are carried out on four full-scale TYSCB specimens to investigate their seismic behavior and yielding mechanism. These specimens vary in lengths, heat treatments of welding joints, web forms and strengthening of end joints. The experimental results show that TYSCBs have fully developed hysteresis behavior and the preferred yielding sequence. The equivalent damping coefficients of all the tested specimens reach up to 45%. The energy dissipation ability increase by 94% with only 27.3% reduction in stiffness compared with traditional complete steel coupling beams under minor earthquakes. On the other hand, its stiffness can increase by 37.5% with only 44.1% reduction in energy dissipation capacity compared with fuse steel coupling beams under minor earthquakes. A trilinear hysteretic model is proposed to reasonably simulate the cyclic behavior of TYSCBs. A nonlinear finite element model is also developed and validated against the test results. The hysteretic and finite element models are to facilitate the application of TYSCBs in the seismic design of shear wall systems.

1. Introduction

Coupled shear walls have been widely used in high rise buildings, since they can provide efficient lateral stiffness and energy dissipation capacity [1,2]. The adjacent isolated walls in a coupled shear wall building are always connected by coupling beams throughout the height of the building, providing a coupling action. This coupling action has two benefits. One is to transfer the shear forces in coupling beams into the wall base, thus forming an additional moment to resist the seismic lateral load. The other advantage is that the coupling beam, as a more flexible member than the wall piers, may undergo inelastic deformations and damages when subjected to earthquakes, which contributes to energy dissipation and prevention of global structural collapse. However, traditional reinforced concrete (RC) coupling beams are prone to shear failure due to their small span-to-depth ratio, which makes them difficult to satisfy the demand of high ductility and perform good energy dissipation capacity [3]. Besides, the post-earthquake retrofit and strengthening are also expensive and time-consuming. To this end, steel coupling beams are preferred due to their excellent plastic deformation capacity.

There are mainly two types of steel coupling beams: the complete steel coupling beam [4–7] and the “fuse” steel coupling beam [8–10]. Complete steel coupling beams are always designed to keep elastic under a design earthquake [11] (defined as having a 10% exceeding probability in 50 years in China), and to yield under a severe earthquake (defined as having a 2% exceeding probability in 50 years in China). Eljadei [29] pointed out that reducing the strength of coupling beams (i.e. yielding under smaller earthquakes) could be a key in developing constructible design [12], since the whole system can benefit from the energy dissipation of coupling beams. However, it is difficult to design a complete steel coupling beam to dissipate energy under a relative low earthquake level. As an alternative, fuse steel coupling beams have been proposed to yield and dissipate energy under a minor earthquake (ME, with a 63% exceeding probability in 50 years in China) to dissipate energy earlier, since it can be easily designed to yield at a relative low load level. However, once the “fuse” coupling

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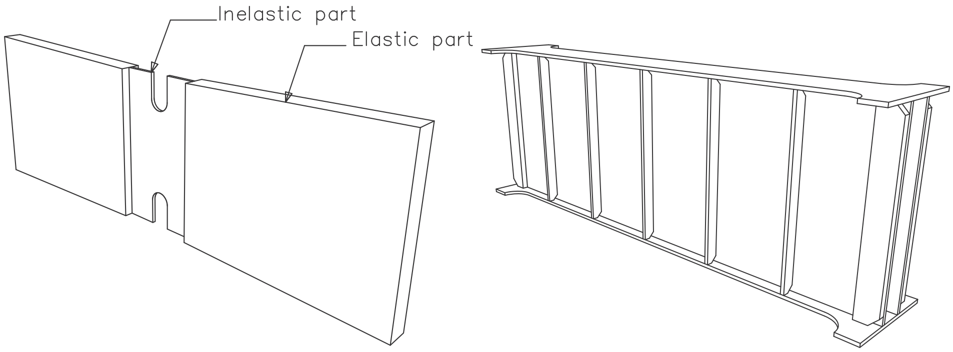
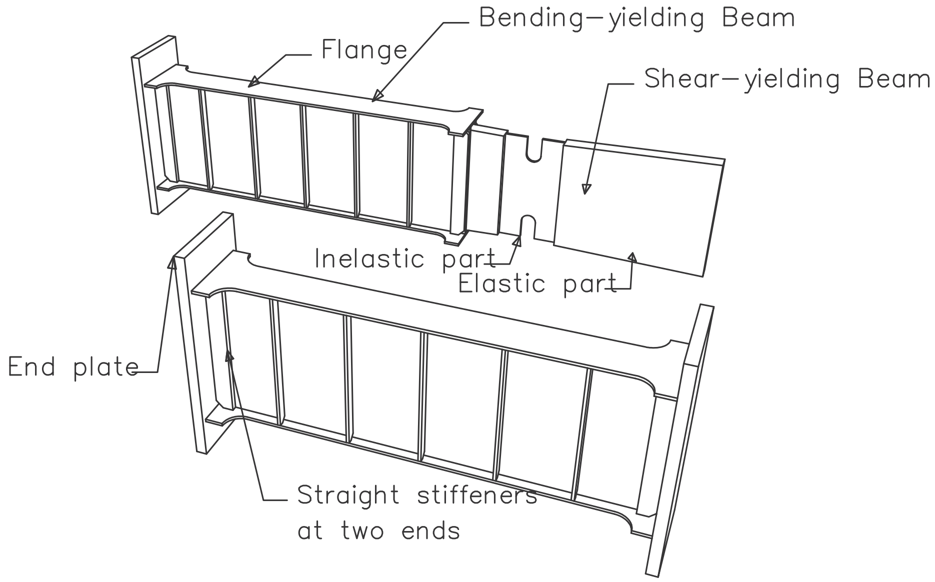
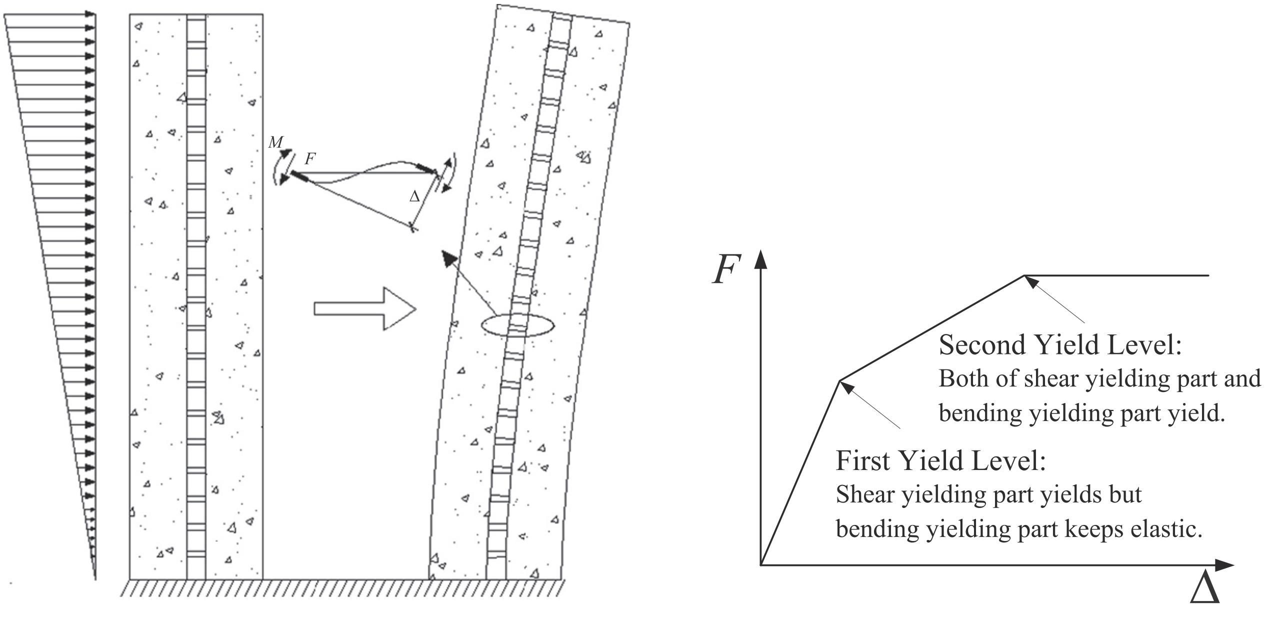


(a) Shear-yielding Beam (b) Bending-yielding Beam



(c) 3D View

Fig. 1. The configuration of TYSCB.



(a) The deformation of coupling beams in shear wall system (b) Shear Force-displacement relationship of TYSCB

Fig. 2. Basic concept and characteristics of TYSCB.