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Original Research Article

Moment capacity and fire protection of the welded plate joint for precast members

Pattamad Panedpojaman *, *Pattharasit Jina*, *Suchart Limkatanyu*

Department of Civil Engineering, Faculty of Engineering, Prince of Songkla University, Songkhla 90110, Thailand

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ABSTRACT

Specimens of reinforced concrete (RC) cantilever beams connected by a welded plate joint to an RC main beam were investigated. Load tests and fire tests were conducted to examine structural behavior and fire resistance of the joint. Under flexural load, the main failure modes of the joint were splitting of the welded plate and rebar yielding. The joint moment capacity depended on ability of the joint to resist tensile forces in the beam rebars. The ultimate loads were about 50% and 70% of corresponding cast-in-place specimens, for the joints with 4-mm and 6-mm thick plates, respectively. To simply estimate the moment capacity, the plate in its width direction was modeled as a beam with fixed ends, and the forces in tensile rebars acted as point loads. The proposed computation of the moment capacity was validated with the tests and with FE simulations, for both moment magnitudes and failure types. By using fire tests, fire protections of the joint such as thin or thick mortar plaster, or a flexible sealant, were investigated. The thick plaster and the sealant provided fire resistances exceeding 2 h. However, the flexible sealant coped better of these two with the separating and swelling behaviors.

1. Introduction

Instead of traditional cast-in-place methods, which are laborious, precast reinforced concrete systems are now widely used in construction to avoid labor costs. Precast concrete members offer various advantages over cast-in-place members [1–3], such as easier implemented overall quality control, ready supply of good quality aggregates, and better quality control of the concrete under factory conditions than at construction site. On the other hand, the joints or connections or precast members are usually problematic. The connection joints can reasonably be considered the weakest most critical points of a precast concrete structure, with concerns about their capacity and stability. The highest priority in this respect is on joints between primary structural members, such as joints of beams and columns or of beams and beams.

Various types of joints are found between precast concrete members used in buildings, and welded joins are widely applied. However, in a welded joint the quality of welding must be under strict control. Welded joints have been developed since 1990 [4,5], and as the simplest cases, the connections of welded plates and billet connectors were investigated early for their structural behavior under monotonic loads [4–6]. These

* *Corresponding author*. Tel.: +66 865971834.
E-mail address: ppattamad@eng.psu.ac.th (P. Panedpojaman).
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connections proved satisfactory for semi-rigid designs, as reported in [7].

In typical current practice in Mexico, welded reinforcement is used to connect precast concrete members into moment-resisting frames [8]. Tests under cyclic lateral loading of welded reinforcement type beam-column connections have been conducted [9], and limited inelastic behavior was observed for positive moment. Fracture of the welded reinforcement was observed at a low positive moment after unloading from peak negative moment. In finite element analysis of the connection under cyclic lateral load [8], the beam-column connections with welded longitudinal reinforcement showed local embrittlement of the steel, resulting in brittle failure of the connection.

Ways to connect a precast middle beam and cantilever beams have been developed. These cantilever beams extend out from the columns of a structure, and the precast middle beam is placed on the cantilever beams. Shear and moment capacities of welded lap splicing joints for this type of connection were investigated in [1]. Within the connection region, the top rebars of a beam are continued by lap splicing and its bottom rebars are continued by welding steel plates, for the middle and the cantilever beams. After placing the middle precast beam on the cantilever beams so that the rebars connect, plate welding and concrete casting finish the connection. Load testing of such connection [1] showed improved shear and bending performance.

A type of connection for a precast middle beam and cantilever beams with welded plates has been developed as a dry joint [10,11]. The connections consist of two steel plates at the beam tips, one being at the top and the other at the bottom. These are welded to the steel plates anchored in the precast middle beam. Side surfaces of the members are also welded with steel plates to further connect the members. Based on an experimental investigation [11], these connections performed well under reversed cyclic loading. Strength, stiffness and energy dissipation of such structure were comparable to those of a monolithic member. Very large deformations took place in the members without side plates, and the load carrying capacity was reduced significantly. The side plates were an important part of the connection for resistance to reversed cyclic loads.

As described above, various types of welded joints were found in the literature that describes potential applications of welded systems in connecting precast members. In constructing comparatively light weight buildings, such as houses, warehouses etc., simple precast concrete connections of welded steel plates, as shown in Fig. 1, with or without billet connectors, have been applied for column or beam members. On using welded plate joints, the steel plates are directly welded to reinforcing steel of the precast members, or the steel plates are welded with L shaped dowel bars and embedded in the precast members. The welded plate joint is also considered a dry joint without cast-in-situ concrete. This type of joint is the focus of the current study.

The literature on structural behavior of and design methods for welded plate joints is rather limited. Moment capacities of the joints are of particular concern, due to complicated failure mechanisms. Boonklom [12] investigated the maximum moment capacity and the cyclic behavior of

Fig. 1 – Electric welding of a welded plate joint.

beam-column connections. From experimental results it was concluded that the moment capacities for precast members with welded plate joints and with cast-in-place joints were 0.79 and 0.52 fold, respectively, those of whole cast-in-place members. Thawonpaisanchewa [13] examined the structural behavior of welded plate joints used in beam-column connections, in terms of their failure patterns and moment–rotational angle relationships. Failure of a specimen was initiated by the separation of the welded plate from the precast member. Concrete cracks at the connection gradually propagated with increasing load. Diagonal cracks at the joint were found in the column. Finite element models were used to investigate the force transfer mechanisms at the connections. The results suggested that ductility or efficiency in resisting moment of the beam-column connection could be improved by use of a thicker steel plate in the welded plate joint. However, moment capacity designs for the joint were not provided.

In the literature on welded plate joints, only the influence of plate thickness on the structural behavior has been investigated. The influence of other parameters on structural behavior of the joint is poorly known. Furthermore, fire resistance of the joint has not been examined, while reinforced concrete members can provide fire resistance without fire protection materials. However, the welded plate joints are potentially weak points in the system, since mechanical properties of steel are significantly more degraded by heat than those of concrete. Without fire protection a steel joint might fail quickly in a severe fire. Fire protection of the joints receives only little attention in current construction practice.

To promote safe practices in joints of precast concrete members, this study aimed to investigate their structural behavior and to develop design methods for the moment capacity, through both experimental and numerical investigations. Furthermore, the failure behavior and the fire resistance of such joints were also investigated in this study.

2. Load test experiments

To investigate the failure behavior of welded plate joints, load tests were conducted with seven beam–beam connections. A brief summary of the experimental investigation and the test variables is given in the following.