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Seismic response of exterior RC wide beam–narrow column joints: Earthquake-resistant versus as-built joints

A.M. Elsouri [a], M.H. Harajli [b,*]

[a] Department of Civil and Environmental Engineering at the American University of Beirut (AUB), Beirut, Lebanon
[b] Department of Civil and Environmental Engineering, American University of Beirut, Bliss Street, P.O. Box 11-0236, Riad El Solh, Beirut, Lebanon

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ABSTRACT

This paper presents the results of a two-part experimental investigation undertaken for evaluating the seismic behavior of exterior wide beam–narrow column connections of the type constructed in Middle Eastern region. In the first part of the investigation, two full-scale gravity – load designed or "as-built" joints were tested under quasi-static cyclic loading. The joints failed prematurely by developing joint shear failure at considerably low drift ratios between 1.0% and 1.5% and therefore their resistance against lateral earthquake load was deemed insignificant. In the second part of the investigation, guided by the test results of the as-built joints, two additional "earthquake-resistant" joints were tested. The corresponding joints were designed assuming gravity load similar to the "as-built" joints, except that their reinforcing detailing were slightly improved particularly by adding transverse steel reinforcement within the joint core and increasing the development lengths of the beam reinforcement, partly in accordance with the recommendations of ACI 318-08 and ACI-ASCE 352-02. Despite violating the requirements of joint dimensions set forth in ACI 318-08, the "earthquake-resistant" joints performed considerably better than the "as-built" joints by preventing or delaying joint shear failure; developing higher lateral load, deformation, and energy absorption and dissipation capacities; and displaying stable overall hysteretic response.

1. Introduction

The predominant RC building structural system in Middle Eastern countries is composed of monolithic one-way flexible ribbed slab, supported over wide beams, i.e., beams that have a depth equal to that of the slab (Figs. 1 and 2). In addition, and because of the architectural need for space, the beams frame into narrow columns having a section aspect ratio between 2.0 and 4.0 so as to merge with the infill block walls. The concrete strength for most of these buildings varies between about 15 and 25 MPa. Unfortunately, despite being a region of moderate to high seismic hazard [10], the majority of RC building structures in this part of the world are designed and detailed for gravity load only and with no regards to the seismic activities in the region. While the design and construction practice of ribbed slab-wide beam system have been proven to be efficient and cost effective and past experience demonstrates a good serviceability record, the resistance of the beam–column joints in this structural system against lateral earthquake load is believed to be largely inadequate.

While the ACI Building Code 318-08 [1] or ACI-ASCE Committee 352-02 [2] allows the use of wide beam–column joints in regions of seismic hazard, it places restrictions on their use due to the insufficient information available about their behavior under the effects of earthquake loads. A number of experimental studies have been carried out on wide and shallow beam–column joints [3–5,7–9,11–16,19,21]. However, unlike the wide beam–narrow column joints of the type under investigation, most of the studied joints were already designed for earthquake loads and do satisfy to a large extent the dimensions limits and reinforcement detailing requirements set forth in recognized codes of practice (ACI 318-08 [2]). Furthermore, the provisions of ACI Committee 352R-02 [3] for seismic design of regular or wide beam–column joints are all based on tests conducted using rectangular columns having section aspect ratios less than 2 or greater than 0.5. Consequently, due to the inadequate amount of research performed on similar joints (aspect ratio less than 2 or greater than 0.5), the experimental observations and conclusions reported in these studies as well as the ACI Committee 352-02 [3] guidelines for seismic design may not be applicable for the joints under investigation.

In this paper, the results of a two-part experimental evaluation which was carried out [6] for evaluating the seismic behavior of exterior wide beam–narrow column joints are presented. The first part of the investigation concentrated on the performance of "as-built" joints, that is, joints that are designed and detailed with no account to earthquake loads. Based on experimental observations

* Corresponding author. Tel.: +961 1 350000; fax: +961 1 744 462.
E-mail address: mharajli@aub.edu.lb (M.H. Harajli).

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derived from the first part, the second part of the investigation focused on exploring the potential of enhancing the seismic performance of the same joints by improving their steel detailing but without imposing significant changes in their design and construction practices. Two full-scale exterior "as-built" joints and, subsequently, two "earthquake-resistant" joints were tested under quasi-static cyclic loading. These joints represent the building frame systems F1 and F2 shown in Fig. 1 in which the column larger side is constructed parallel or perpendicular to the beam axis, respectively. The as-built joints were designed for gravity load and the reinforcement was detailed accordingly. The earthquake-resistant joints were also designed for gravity load, but the reinforcement detailing was improved to satisfy part of ACI 318-08 [1] provisions and ACI 352-02 [2] recommendations for earthquake-resistant structures in regions of moderate and high seismic hazard.

2. Experimental program

2.1. Test specimens

Both of the "as-built" and the "earthquake-resistant" specimens tested in this investigation simulated the joints of full-scale building frame systems of types F1 and F2 as shown in Fig. 2. The joints were designed to represent typical exterior beam–column joints in the first floor of a 5 story building. The gravity loads used in design were 10 kPa for dead loads and 2.5 kPa for Live loads. Other design parameters are summarized in Tables 1 and Figs. 1 and 2.

2.1.1. As-built joints (EJ-F1, EJ-F2)

Dimensions, areas and detailing of the longitudinal and transverse steel reinforcement in the beams and columns of the as-built joints (EJ-F1 and EJ-F2) are summarized in Table 1 and Fig. 3. Commercially available Grade 60 steel bars (design yield strength of 415 MPa) having 14 mm and 16 mm diameter were used as the beam and column longitudinal reinforcement. The transverse steel reinforcement consisted of typically used plain 8 mm diameter stirrups provided outside the joint core in both the beams and columns at a spacing of 200 mm. The concrete cover to the longitudinal reinforcement in the beams and columns was maintained at 33 mm. Some of the reinforcement details that are pertinent to local design and construction practice for gravity-load design include the complete absence of shear reinforcement within the joint core, the lap splice of column reinforcement at the base of the column, the short development length of the beam bottom and top reinforcement inside the core beyond the beam–column interface sections for the joints of type F2, the amount of the positive bottom

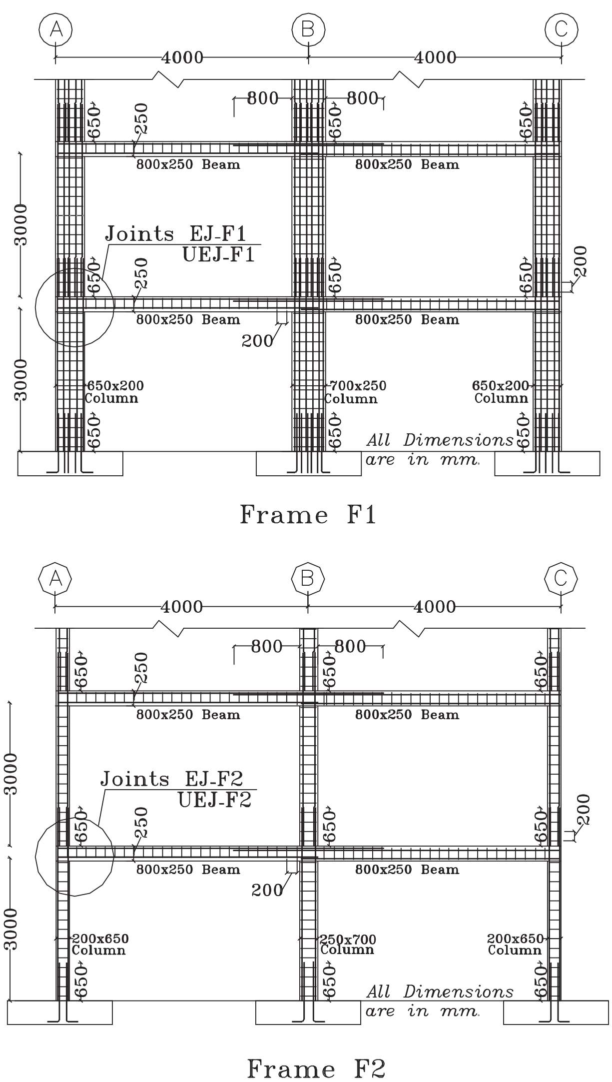

Fig. 1. Building frame system for joints of type F1 and F2.

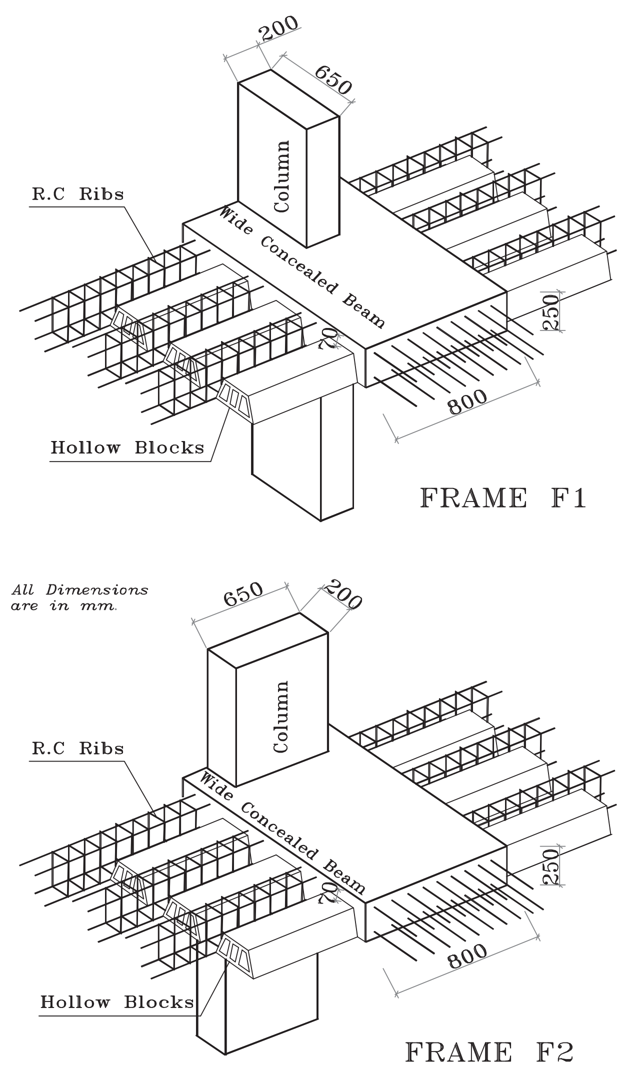

Fig. 2. Typical RC ribbed slab-wide concealed beam systems for exterior joints.