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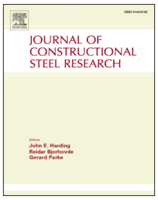

# Design of steel brace connection to an RC frame using Uniform Force Method

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Steel bracing is a viable alternative to a shear wall when designing or retrofitting reinforced concrete frames for seismic loads. Directly connecting the bracing system to the RC frame is the most cost effective method of joining the two systems together. In this paper, the design basis for such a connection is set out and controlled for accuracy and safety. To this end, numerical models of steel brace/RC frame connections are developed and verified against experimental results obtained from similar connections. The numerical models are then used to evaluate the efficiency of the analytical Uniform Force Method (UFM) used for connecting braces to steel frames and adopted here for connecting braces to RC frames. It is found that the UFM can be applied effectively and conservatively to design brace/RC frame connections. A detailed investigation on the level of overdesign is also carried out through parametric analyses of the main problem variables including the brace angle and dimensions of the gusset plate. It is found that, for most practical cases, the error in using the UFM analytical approach is less than 20%. Finally, necessary considerations for design of different components of the brace–frame connection are set out.

## 1. Introduction

The idea of using steel bracings as lateral resisting elements in RC frames has received some attention in recent years. The earlier works concentrated either on external bracing of the RC frames [1,2] or on indirect internal bracing through intermediary steel frames [3,4]. Both methods have a number of shortcomings, particularly in terms of application and cost. In 1997, Maheri and Sahebi [5] proposed a direct connection between steel bracing and RC frame in a manner similar to that used in steel frames. Further experimental [6–9] and numerical [10,11] works carried out by Maheri and colleagues showed the efficiency of the directly connected steel brace/RC frame systems in resisting the seismic loads and improving the seismic performance of the system. In their works, they experimented with different bracing systems including X-bracing and Knee-bracing [6] and studied the efficiency of a new compression release device, placed in the compression brace [9]. Also, Maheri and Akbari [10] evaluated the seismic behaviour factor for the brace/RC frame system used in calculating seismic force and Maheri and Ghaffarzadeh [11] proposed design principles for steel bracing of RC frames. Other works carried out by Tasnimi and Massomi [12] and Abou-Elfath and Ghobarah [13] have also shown that by using the appropriate forms of direct internal bracing with appropriate connections, good seismic performance could be expected from the steel brace/RC frame systems.

The efficiency of the directly connected brace–RC frame system depends on the ability of the connection between the two elements to successfully transfer the loads. This was highlighted in the results of the experiments reported by Maheri et al. [6]. To address this important issue an initial experimental investigation was conducted by Maheri and Hadjipour [7]. They carried out nonlinear static tests on full-scale models of three types of connections. They adopted the Uniform Force Method provisions for designing brace–steel frame connections to design their connection specimens. They showed that the connections and their elements were strong enough to withstand the forces and that the brace failure and rupture preceded the failure of the connection elements. However, they did not investigate the level of overdesign in the tested specimens and did not investigate the effects of design variables such as the size of the gusset plate and angle of the brace on the efficiency of the UFM for such connections.

Further to the work reported by Maheri and Hadjipour [7], in the present paper the effects of design variables and the general efficiency of UFM are investigated in detail through experimental and numerical evaluations and a design basis is set out for individual elements within the connection.

### 1.1. Types of connection

Although steel bracing of RC frames started as a measure for retrofitting existing buildings, it soon developed into a method for designing new buildings. Presently, therefore, different connections may be used depending on the type of application. A number of different connection types have been proposed [7]. In the present paper,

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two types of connections are considered; one designed particularly for use in new constructions and another for retrofitting existing buildings. These connection types, respectively named type (a) and type (b) are illustrated schematically in Fig. 1. Both connection types are corner connections for joining an X-brace system to the beam–column intersection in a frame. In these connections, the gusset plate is welded to two connecting plates which are fixed to the face of the RC members at the corner. In connection type (a), the connection between the connecting plates and concrete member is achieved through anchor or stud bars positioned in the RC members prior to casting. This type of connection is evidently suitable for new constructions. However, it can also be used for retrofitting existing frames. For this application, the concrete member needs to be appropriately drilled and the stud bars implanted in the concrete using epoxy resin. The connection type (b), however, is more effective for retrofitting purposes as the connecting plates can be more robustly fixed to the concrete member.

## 2. The Uniform Force Method

In steel framed buildings, the force between a diagonal brace member and the steel frame is transferred through the gusset plate. Bjorhovde and Chakrabarti [14] carried out nonlinear tests on full-size gusset plate connections. Using their test results and those of Gross and Cheok [15], they proposed a block shear model to predict the ultimate capacity of gusset plate connections in tension. To provide a safe and economical design for diagonal brace connections to steel frames, numerical models of gusseted connections were studied by Richard [16]. He showed that the force resultant on the gusset edge acts in the beam column joint region. Richard's findings provided a basis for a method, called the Uniform Force Method (UFM) to determine forces in the brace–steel frame connection. Later, Gross [17] conducted tests to study the behaviour of gusseted connections. Using the results of the above studies and those of an old study carried out by Whitmore on the gusset force distribution [18], Thornton [19] showed that the UFM predicts well both the design strength and the critical limit state of the connection in steel structures. This method is adopted by AISC for use in the AISC code provisions [20].

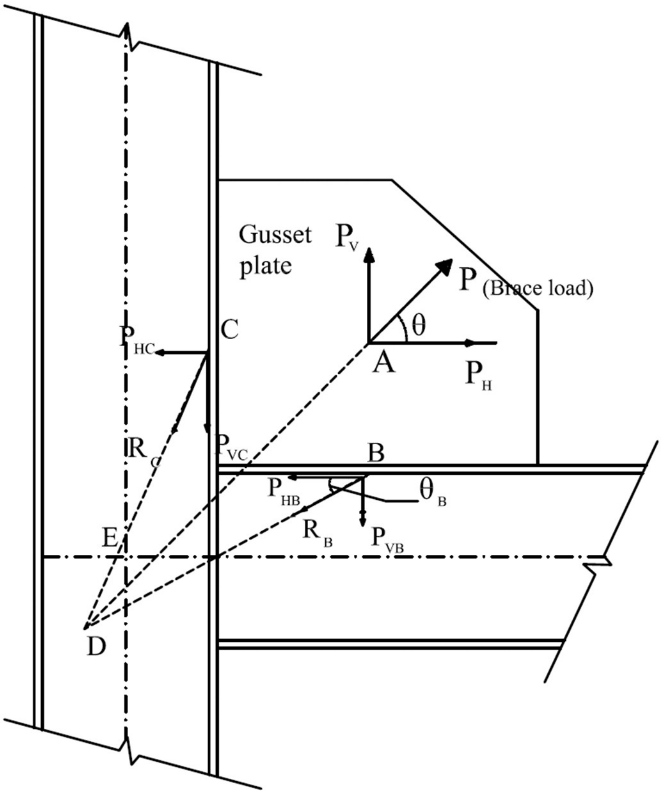

**Fig. 2.** The Uniform Force Method.

The Uniform Force Method is based on the geometry of connection. By defining a working point at the intersection of the centrelines of the beam, column and diagonal bracing (Fig. 2), the essence of this method is to select the geometry of the connection so that moment does not exist on the connection interface. The empirical relation for the force components at the interface of the gusset plate and beam, $R_B$, is defined in Eq. (1). The horizontal ($P_{HB}$) and vertical ($P_{VB}$) components of this force are calculated, respectively, using Eqs. (2) and (3); while the effective beam angle, $\theta_B$, is calculated using Eq. (4) for braces with angles ($\theta$) less than 45° with respect to the beam axis and Eq. (5), for brace angles between 45 and 90°. Writing equations of equilibrium for the connection, the horizontal and vertical components of the force at the interface of gusset plate and column are given, respectively, in Eqs. (6) and (7).

$$R_B = P \times \left[1.4 \times \left(\frac{a}{a+b}\right) - 0.1\right] \tag{1}$$

$$R_{HB} = R_B \times \cos\theta_B \tag{2}$$

$$R_{VB} = R_B \times \sin\theta_B \tag{3}$$

$$\theta_B = 0.6 \times \theta, \quad (\theta \le 45^\circ) \tag{4}$$

$$\theta_B = 27 + \left[8.5 - 20 \times \left(\frac{a}{a+b}\right)\right][45 - \theta], (\theta \ge 45^\circ) \tag{5}$$

$$P_{HC} = P_H - P_{HB} \tag{6}$$

$$P_{VC} = P_V - P_{VB}. \tag{7}$$

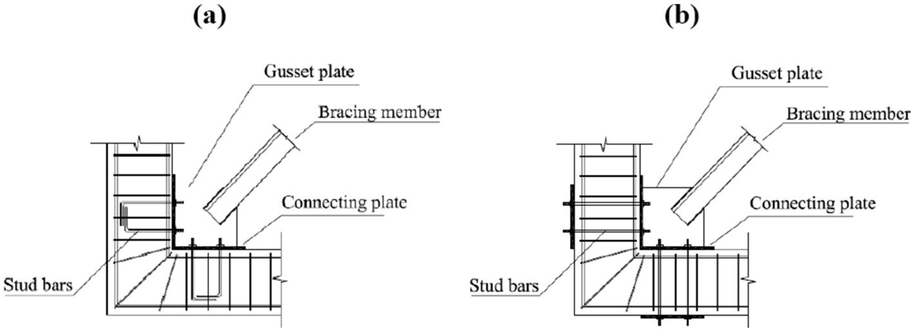

**Fig. 1.** Two types of connection for joining the bracing system to the RC frame.