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A new model to simulate joint shear behavior of poorly detailed beam–column connections in RC structures under seismic loads, Part I: Exterior joints

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ABSTRACT

A new model that can simulate the shear behavior of reinforced concrete connections in structures subjected to seismic loads is proposed. The model uses limiting principal tensile stress in the joint as the failure criteria so that due consideration is given to the axial load on the column. The spring characteristics are based on the actual deformations taking place in the sub-assemblage due to joint shear distortion. The model can be easily implemented in any commercial nonlinear analysis package and does not need any special element or subroutine. The model is more rational than the rotational spring models and at the same time being easier to implement in analysis than the multiple spring models. The formulations to obtain the spring characteristics are given in the paper. Currently the model is used to perform nonlinear static analysis for the joints, however, the same can be utilized for the nonlinear dynamic analysis too with an associated hysteretic rule. Highly promising results are obtained using the proposed model for the cases against which the model is validated. This paper focuses on the modeling of exterior joints. An extension to interior joints will be presented later.

1. Introduction

Under the action of seismic forces, beam–column joints are subjected to large shear stresses in the core. These shear stresses in the joint are a result of moments of opposite signs on the member ends on either side of the joint core. Typically, high bond stress requirements are also imposed on reinforcement bars entering into the joint. The axial and joint shear stresses result in principal tension and compression that leads to diagonal cracking and/or crushing of concrete in the joint core. These stresses in the joint core are resisted by the so-called strut and tie mechanism [1–3]. To prevent the shear failure of the joint core by diagonal tension, joint shear reinforcement is needed, which is therefore prescribed by the newer design codes [4–6]. Moreover, these codes prescribe a large anchorage length of the bars terminating in case of exterior joints, so that a bond failure may be avoided. However, a vast majority of the structures world-wide consist of structures designed prior to the advent of seismic design codes.

It has been identified that the deficiencies of joints are mainly caused due to inadequate design to resist shear forces (horizontal and vertical) and consequently by inadequate transverse and vertical shear reinforcement and of course due to insufficient anchorage capacity in the joint. Therefore, inadequate transverse reinforcement and insufficient anchorage in the joint are two major problems of the joints designed as per non-seismic guidelines [7]. These problems have been highlighted, in recent past, by the damage observed in devastating earthquakes in different countries. The two major failure modes for the failure at joints are (a) joint shear failure and (b) end anchorage failure (Fig. 1). A typical example of a beam–column joint failure during the 1999 Turkey earthquake is shown in Fig. 2 [8].

While designing a structure, conventionally, the joint core is considered as rigid and the frame members are assumed to be connected forming a single node that symbolizes the joint. New codes [4,5,9] suggest an indirect approach to design the joint by limiting the joint shear stresses. However, again in older codes, no such provisions existed. Even in the case of nonlinear displacement based analysis (e.g. Pushover) all the plastic rotations are assumed to occur in the beams and/or columns forming the joint core. Although this assumption is reasonable for the structure subjected to static gravity loads, the same assumption does not hold good for the structures subjected to seismic loads, since under earthquake loads, high shear forces gradually soften the joint core making it non-rigid.

Even though now it is well-known that the beam–column joints, especially the poorly designed ones, behave highly nonlinearly during the earthquakes, still the analysis approach mainly

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