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Equation for achieving efficient length of link-beams in eccentrically braced frames and its reliability validation

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ABSTRACT

This study addresses the question of selecting efficient length of link-beam for the models with eccentrically braced frames, broadly used seismic-resisting systems, in view of minimizing the amount of dispersion in structural responses. The evaluation has been conducted by the help of the proposed equations considering different height of structures subjected to far and near-field ground motions. In addition, reliability assessment of the EBF frames supports validating proposed equations considering failure probability for each model by the help of β-unzipping method. There is very acceptable conformity for the efficient length of link-beam achieved based on deterministic analyzing by the help of the proposed equations and probabilistic analysis by the help of β-unzipping method which illustrates accuracy and practicality of the introduced equations.

1. Introduction

Performance-based earthquake engineering (PBEE) provides a quantitative basis in assessment of the seismic performance of structures and aims at the design of structures achieving expected acceptable performance levels during probable future earthquakes [1]. One of very frequently used quantitative performance assessment method is the fully probabilistic methodology of Pacific Earthquake Engineering Research (PEER) Center that is divided into four basic stages accounting for the following: ground motion hazard of the site, structural response of the building, damage of building components and setting up decision variables (DVs) like economic loses, which could be employed by stakeholders to make more informed design decisions [2]. The outcomes of each stage serve as input to the next stage.

The deviation in each stage of performance evaluation causes deviation in the decision variables in the final stage; therefore one of researcher's attempts is to reduce the deviations at each stage. Many approaches have been followed for this purpose like developing new intensity measures which have been employed in the first stage and also dealing with many different engineering demand parameters to encounter as slight deviation in structural responses as it is possible. The approach, parameter or method which contributes to the least deviation in engineering demand parameters is illustrated as the most efficient one. One approach for reducing deviations in structural responses is adjusting structural design specifications and utilizing appropriate seismic systems. One of prevalently employed seismic systems are eccentrically braced frames (EBF) which are very well-organized structures for resisting earthquakes as they combine ductility, a distinguished characteristic of moment frames, and stiffness associated with braced frames [3].

Great optimization attempts in the previous works devoted to design phase of the EBF systems, like optimizing maximum dissipating energy in the link beams subjected to some design specifications like section of link beams, section of stiffeners in link beams, location of stiffeners and … [3–5] mainly depends on engaged design code or minimizing frame weight based on the geometry of the eccentrically braced frames or other design specifications [6–8]. In this paper, the only specification of the frame that is going to be determined by the optimum amount is the length of link-beam which is a preliminary presumed parameter in design phase of EBF frames and it is not reliant on presumed design provisions. Designating strategies for declining the dispersion in the response of systems, one could substitute any design pattern based on any design code. In the other words, the design process is not the chief concern of view for this paper.

One of the useful guides at the early stage of design earned by the experience and followed by many designers and also researchers is to choose a link length of about 1.5 to 2.0 times the nominal beam depth [9]. Link beams are typically selected to satisfy the minimum web area required to resist the shear from an eccentric brace. Using this guide, one should presume the size of beam in the initial step; In the other words, designer drives to the exhausting try-and-error procedure;

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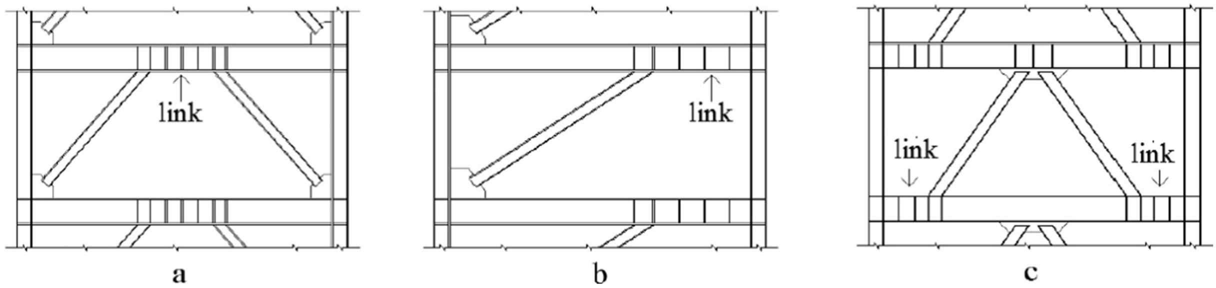

Fig. 1. Samples of eccentrically braced frames.

however, the proposed equations in this study are not reliant on any design specifications and could be independently defined in the primarily design phase.

Although the variability alone cannot form a measure of structural performance, its minimizing provides more reliable structural results and so performance.

This study aims to assess the amounts of deviation in structural responses through proposing some equations for computing dispersion amounts based on the length of link-beams in EBF systems. In view of these equations, one could achieve to the efficient length of link-beam considering minimum dispersion of structural responses.

Obtaining the equations of variability of results according to the length of link beam, the optimum amount of link beam could be computed and also validated. Validating the achieved equations has been conducted through application of a common reliability framework. The reliability framework addresses and processes uncertainties in input variables to provide estimates of uncertainty in vulnerability of system's failure as well as it requires at least the definition of a central value and a measure of dispersion [10]. Therefore, according to reliability assessment by the use of the variance of data, one tries to obtain increasingly accurate representations of the significant failure regions and use these representations to arrive at an estimate of system failure probability. So, by providing failure probability of a system, deviation of responses could be recognized in a reverse procedure. Comparing the deviations got from analytical approach from the proposed equations and probabilistic approach utilizing reliability concepts could be manipulated to validate the results from the equations.

Although according to the previous works in this field, the scattering of the structural response is not one of the main indexes considered in design but this paper shows that, the difference between the scattering of geometrically short and long links is striking especially under near-field records. The view considered in this work is noble in researches that helps to select one of preliminary considerations of design not only based on optimizing some response factors like minimizing drift or maximizing energy dissipating, load carrying or link-beam rotational capacity; but also, based on minimizing the dispersion on the responses.

2. Eccentrically braced frames

Steel braced frame is one of the structural systems used to resist lateral loads in multistoried buildings. Steel bracing is economical, easy to erect, occupies less space and has flexibility to design for meeting the required strength and stiffness whereas they may interfere with architectural features [11].

Concentrically braced frames (CBFs) are prevalent in moderate seismic regions, both because of their high stiffness-to-weight ratio, and because of the ease with which they can be designed and evaluated by the equivalent lateral force method. The concentric bracings increase the lateral stiffness of the frame and usually decrease the lateral drift. However, increase in the stiffness may attract larger inertia forces due to earthquake. Further, while the bracings decrease the bending moments and shear forces in columns, they increase the axial compression in the columns to which they are connected. Eccentrically braced frames (EBFs) can offer equivalent advantages as CBFs, while also providing significant ductility capacity, and greater flexibility with architectural openings. These systems improve both lateral stiffness of the system and energy dissipation capacity. Moreover, many existing steel buildings need to be retrofitted to overcome the deficiencies of lateral resistance whereas EBF systems are the ideal systems for this purpose in view of the compatibility with the existing architectural plan [12–14]. Eccentrically braced frame has been used as it has a well-established reputation as high-ductility system and has the potential to offer cost-effective solutions in moderate seismic regions [15]. They can also be sometimes used to advantage in avoiding large and costly connections which may results solely from the geometric requirements [9]. In these systems braces in each span are located with distance in longitudinal axis of beam or with distance by beam to column connections [16]. The vertical component of the bracing forces due to earthquake causes lateral concentrated load on the beams at the point of connection of the eccentric bracings [17]. Samples of eccentrically braced frames could be seen in Fig. 1.

Properly detailed links in EBFs having adequate strength and stable energy dissipation act as structural fuses to dissipate the earthquake induced energy in a building in view of a stable manner. All the other structural components (beam segments outside of the link, braces, columns, and connections) are proportioned following capacity design provisions to remain essentially elastic during the design earthquake [18].

The length of link-beams affects the type and mechanism of contributed hinges as presented in the free-body diagram in Fig. 2. Flexural hinges form at two ends of the link when both of the end moments reach the plastic moment, M_p and shear hinge is said to form when the shear reaches V_p both could be computed in view of the capacity of link member based on the selected design recommendation.

A balanced yielding condition corresponds to the simultaneous formation of flexural hinges and a shear hinge ($M_A = M_B = M_p$ and $V = V_p$). The corresponding link length is:

$$e_0 = \frac{2M_p}{V_p} \tag{1}$$

Test results also showed that a properly stiffened short link can strain harden and develop shear strength equal to $1.5V_p$ [19–22]. The end moments of a link that has yielded in shear can continue to increase

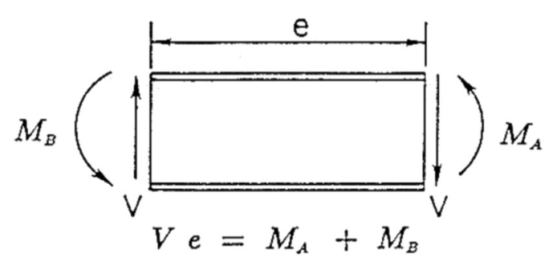

Fig. 2. Link deformation and free-body diagram.