STIFFNESS DEGRADATION IN STRUCTURE RESPONSE CALCULATION DUE TO SEISMIC EXCITATION

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Abstract

A method integrating the effect of stiffness degradation is presented in this study. The degradation model is constructed based on the cyclic loading experimental result of beam-column connection for bolted joint steel structure. The identification of the decrease of the joint stiffness is carried out as a function of a damage variable. Finally, one can use this model into a classical equation of motion by taking stiffness degradation phenomena into account.

Keywords: stiffness degradation, joint stiffness, bolted joint, damage.

Abstrak

Suatu metode yang memperhitungkan efek dari penurunan kekakuan dibahas dalam kesempatan ini. Model penurunan ini dibentuk berdasarkan hasil test eksperimental dari suatu model sambungan balok-kolom untuk sambungan baut struktur baja. Identifikasi dari penurunan kekakuan sambungan sebagai fungsi dari variabel kerusakan dapat dimodelkan. Pada akhirnya, model ini dapat diaplikasikan ke dalam persamaan gerak klasik dengan memperhitungkan fenomena penurunan kekakuan tersebut.

Kata kunci: penurunan kekakuan, kekakuan sambungan, sambungan baut, kerusakan.

1. INTRODUCTION

Complex destructive phenomena take place in structures during earthquake excitations. The damage generated can be translated into a damage variable which takes the local destructive effects into account in a global manner.

In accordance with engineering practice, the seismic action to be considered in design is expressed in terms of pseudo-acceleration at the fundamental frequency of the structure under consideration. Due to the deterioration of steel and concrete materials, and subsequently, to the alteration of the dynamic characteristics of the structure under earthquake loading, this spectral value can turn out to be a misleading parameter for characterizing the seismic damage potential. Indeed, it is well recognized that, in civil engineering structure, as the damage increases, the alteration of the mechanical characteristics leads to modal characteristic changes.

As damage increases within the structure, the alteration of the mechanical characteristics yields modal characteristics changes. In this way, Chen et al. (Chen et al., 1995) investigated the structural damage by means of the identification method of modal changes. At a critical damage level, they indicated that a decrease of the fundamental frequency up to 10% can be expected for steel structures. For reinforced concrete structures, the

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fundamental frequency reduction, related to the structural damage can be significantly larger. Pseudodynamic tests carried out at the European Laboratory for Structural Assessment (JRC-Ispra) in fact showed fundamental frequency reductions of more than 60% (Brun et al., 2003; Miranda et al., 2002). Such fundamental frequency decrease strongly influences the dynamic response of the structure subjected to a seismic excitation. This simple structure, reinforced in accordance with nuclear requirements, has been adopted in this work. A simplified modeling, attempting to capture the main features of the non-linear global behavior of the shear wall, has been previously proposed. This approach, briefly presented here, is based on the coupling concept between the decrease of the fundamental frequency and an appropriate damage variable for the shear wall. The coupling relation is identified through a finite element modeling using a local approach for the description of the constitutive material behavior.

In the steel structure, the decrement of stiffness is undergone mostly in beam-column connections of the structure. A modern approach to frame design based on the behavior of the beam–column connection (Eurocode 3, 1996) has shown that the joint stiffness exhibits as a stiffness intermediate between ‘fully rigid’ and ‘pinned’ behavior, although in conventional designs, it is assumed to be a rigid connection. Since the beam–column connection behaves as a semi rigid connection, an initial value of joint stiffness exists. Ahmed et al. (Ahmed et al., 1997) propose a method for calculating the initial stiffness of a composite flush endplate connection, based on the assumption that the key parameters which influence the initial stiffness are the bolts and the column web at the level of the beam flange.

As known, the damage occurs in the weaker parts of a structure and in the case of portal frames, as used in civil engineering, fatigue damage generally occurs at its junctions. This indicates the importance of studying the resistance and fatigue damage of the beam–column connection in portal frame structures. Experimental tests for predicting the resistance of the beam–column connection have been published (Bernuzzi et al., 1996; Popov et al. ,2002) with the aim of identifying the key parameters of resistance of the beam–column connection. Some numerical studies have also been carried out using the finite element method to observe the behavior of the fracture mechanism (Thakirov et al., 2002; Ju et al., 2004).

In the case of repeated loading, a phenomenon of degradation in semi-rigid junction stiffness can be observed. In the case of a bolted joint connection, Bernuzzi et al. (Bernuzzi et al., 1996) show in a cyclic test the existence of the degradation phenomenon in junction stiffness. They identify energy dissipation as the parameter for degradation of connection performance.

On the basis of those arguments, this paper looks at the effect of stiffness degradation in the bolted joint connection. As stated by Brun et al (Brun et al., 2003)., the damage parameters of the structure due to seismic excitation can be chosen as the maximum response. Hence, in this study, the stiffness is considered changing since the response exceeds certain value. The model is build based on the experimental result of Tsai et al. (Tsai et al., 1995).

2. STIFFNESS DEGRADATION DUE TO DAMAGE

In order to derive a simplified model taking into account the damage evolution in time, the damage undergone by the structure is characterized at a global level. The maximum rotation in beam-column connection seems to be a good parameter to evaluate the damage. Park and Ang (Park et al., 1995) proposed to complete this damage variable with a second term taking into account the dissipation under loading cycles. Among several authors, Fardis (Fardis, 1994) concluded the relevance of this variable to reproduce the failure of the structure subjected to flexural forces. However, one can notice that the weighting coefficient associated with the energetic term appeared very low. Therefore, the contribution of the energy term in the Park & Ang's indicator becomes negligible in comparison to the displacement term. Furthermore, the Park & Ang's indicator is essentially calibrated for flexural failures, so it is less suited for shear failures (Williams et al., 1995). Eventually, the finite element modeling used in this present study is not always capable of reproducing the experimentally observed dissipation during seismic loading (Ile, 2000). As a result, a damage variable based on computed energy dissipation derived from finite element numerical results would not be pertinent. In contrast, the prediction of global quantities as top displacement and force are reliable. All these considerations lead to the idea of adopting the maximum displacement (denoted X) as the damage variable.

The simplified model proposed in this work is based on changes in structure stiffness according to the damage variable X . Since the portal frame exhibits a semi rigid connection, the changes in joint stiffness degradation is described in terms of maximum rotation. With this objective, a parametric study concerning the excitation is carried out in the following.

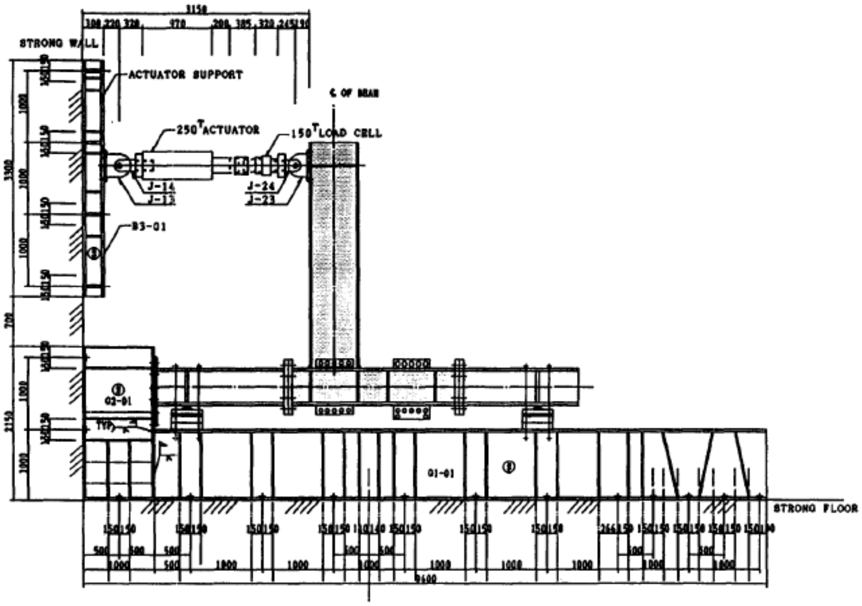

Figure 1. Experimental set-up for beam-column moment connection tests (after Tsai et al., 1995)

The model is carried out on the basis of Tsai's experimental work (Tsai et al, 1995). The detail connection can be seen in Figure 2. Meanwhile, the experimental produces the relation between rotation and applied loading (see Figure 3). In this experimental, one can identify the changes of the stiffness by applying the secant stiffness during the experimental. Since the cyclic loading is performed, one can see clearly that the increment of rotation affects the diminution of stiffness.

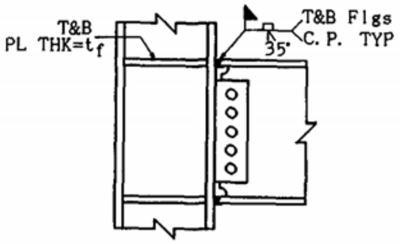

Figure2. Connection details for specimens (after Tsai et al., 1995)

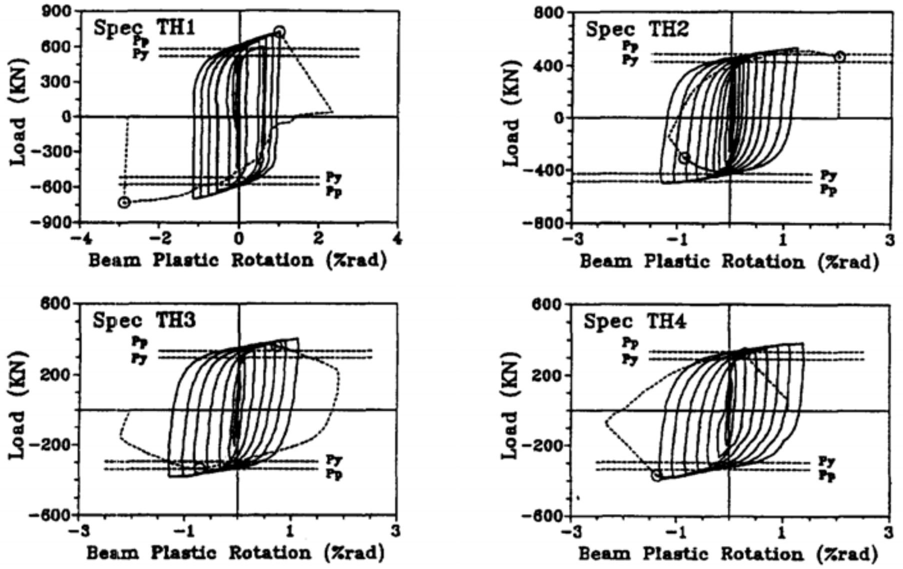

Figure 3. Beam rotation versus cantilever load relationships (after Tsai et al., 1995)

The joint stiffness degradation model can modeled as exponential curve as a function of rotation maximal and it can be seen in Figure 4.

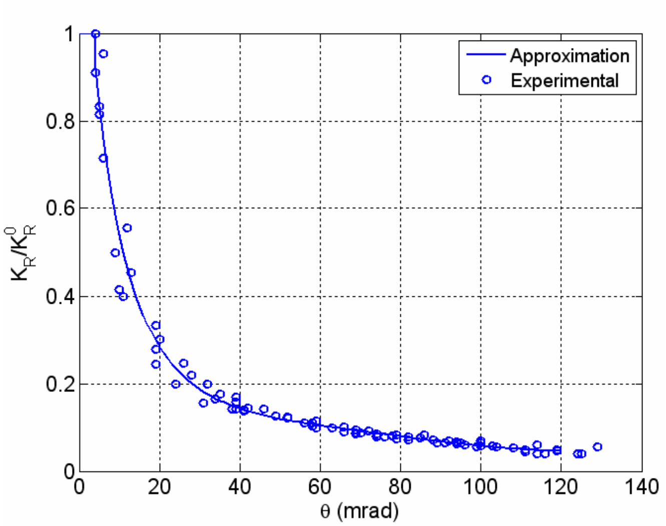

Figure 4. Stiffness degradation model based on Tsai's experimental result

3. NUMERICAL METHOD CONSIDERING STIFFNESS DEGRADATION

Knowing the joint stiffness degradation phenomena, one can introduced a non linear equation of motion as:

$$M\ddot{u}(t)+C\dot{u}(t)+K\left[K_R(X)\right]u(t)=F(t) \qquad (1)$$

where M, C, K are mass, damping and stiffness of the structure respectively. The changes occurs to K_R which is defined as joint stiffness. It changes as a function of X where in this simulation, this parameters is defined as the maximum joint's rotation.

This idea is based on the previous work (Tani et al., 2005), and with this method, one can avoid the difficulty of non linear simulation by the changes directly its stiffness. In this case, the simple portal frame model which has stiffness connection is applied as illustrated in Figure 5 below.

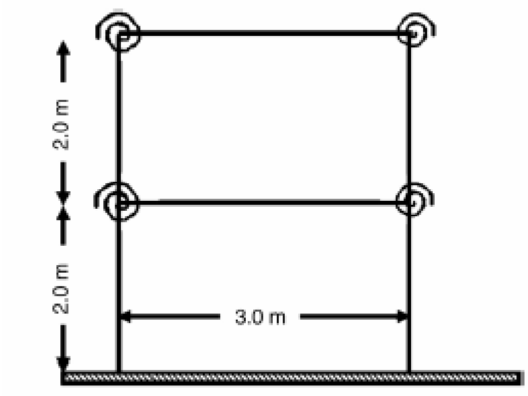

Figure 5. Portal frame structures

The structure model is implemented within the mathematical MATLAB software (Matlab, 1999). The non linear dynamic computation is carried out. On a time period, the resolution of the differential equation of motion Eq. (1) is realized by means of an explicit fourth-order Runge–Kutta type algorithmic scheme, available within the MATLAB software and using fine time steps of 0.001 s. One can summarize the procedure as:

- For the first time step corresponding to the time interval $\left[t_0,t_1\right]$: The joint stiffness is equal to $K_R{}^0$. The differential equation of motion Eq. (1) is solved with the initial conditions: $u(t_0)=0$ and $\dot{u}(t_0)=0$
- For the *N* time step corresponding to the time interval $\left[t_{N-1},t_N\right]$: The connection stiffness is equals to: $K_R=K_R^0(X)$ with $X=\max\limits_{0<t\le t_{N-1}}\left|\theta(t)\right|$.

For each time step, the differential equation of motion is integrated with an updated joint stiffness. Non linear phenomena are taken into account through the changes of the fundamental frequency as a function of the updated damage variable X .

4. PORTAL FRAME STRUCTURE UNDER SEISMIC EXCITATION

In this study, the most common El Centro seismic excitation is applied into the portal frame model. It has peak ground acceleration of 3.1276 m/s^2 as illustrated in Figure 6.

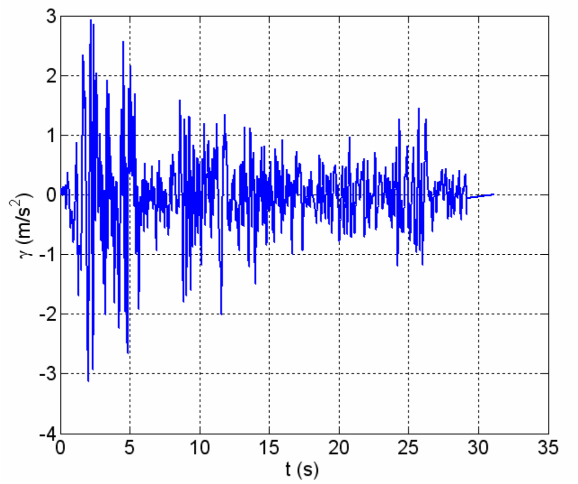

Figure 6. El Centro acceleration

Since in this example, the base acceleration $\gamma(t)$ is applied, then the equation of motion (Eq. (1)) becomes:

$$M\ddot{u}(t)+C\dot{u}(t)+K[K_R(X)]u(t)=M\gamma(t) \tag{2}$$

The classical linear method in solving equation of motion does not take into account the changes of stiffness. Thus, one needs to apply non linearity simulation which affects time consummation.

The result shows the different response (see Figure 7 and Figure 8) for 1st and 2nd floor rotation of the proposed method and the classical method respectively. The differences are caused by the changes of the joint stiffness during the seismic excitation.

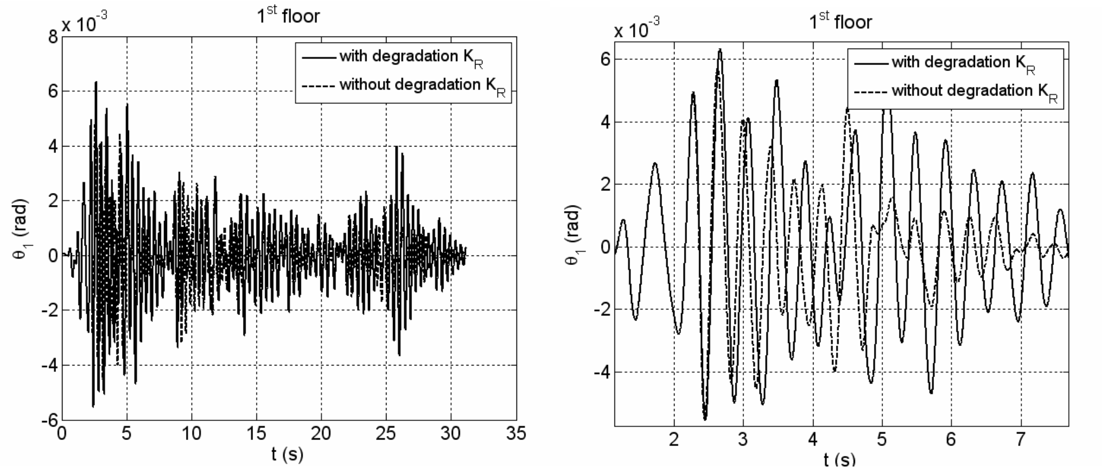

Figure 7. Response of rotation at 1st floor

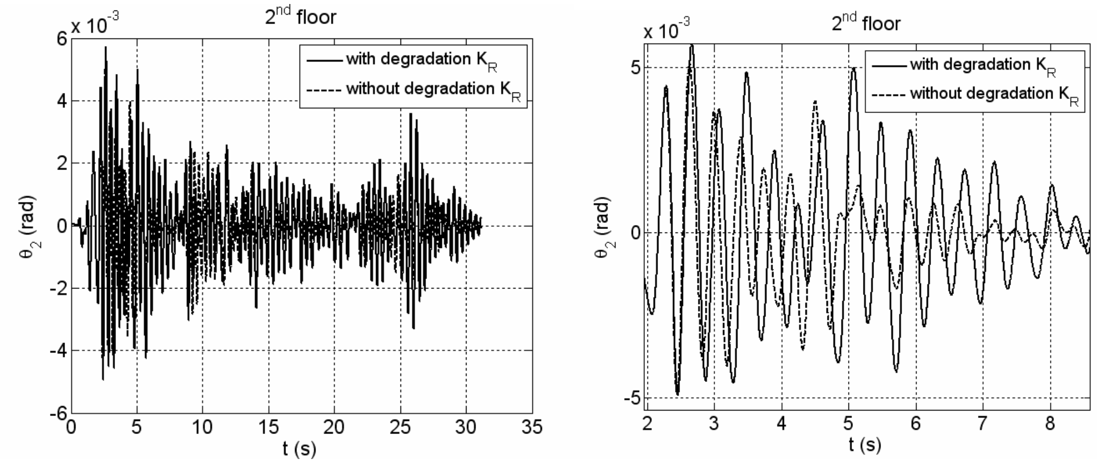

Figure 8. Response of rotation at 2nd floor

When a building structure is subjected to seismic excitations and begin to vibrate, its energy equilibrium equation based on structural dynamics is

$$E_K + E_D + E_A = E_I \tag{3}$$

where E_K is kinetic energy, E_D is damping energy, E_A is absorbed energy, and E_I is input energy of the structural system. The input energy total of the structure due to seismic excitation can be expressed (Cheng et al., 1996) as:

$$E_I = \int_0^t \left(\sum_{i=1}^{n} m_i \dot{u}_i \gamma \right) dt \tag{4}$$

where γ is base acceleration and m_i and $\dot{u}_i$ are mass and velocity relative to the base of i story, respectively.

And the result shows that the method integrating stiffness degradation affects more energy input than the classical method.

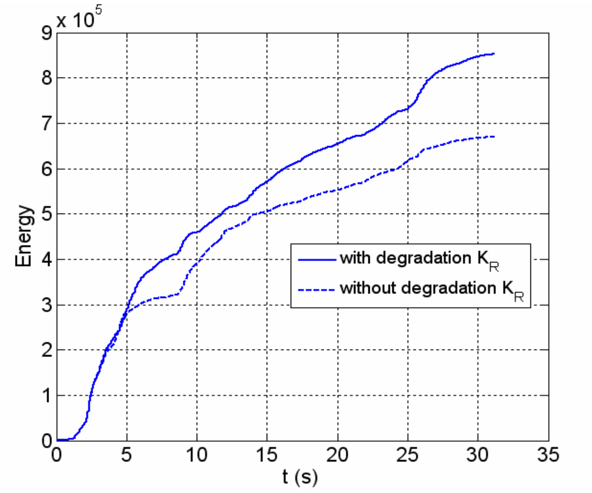

Figure 9.Total energy input

5. CONCLUSION

A global model based on the concept of coupling the decrease of the stiffness with a non cumulative damage indicator is employed to assess the damaging effect on structure caused by ground motion excitation. The relevance of damaging potential indicators used in earthquake engineering and proposed in the literature is investigated by correlating them with the damage as defined in this study.

It is interesting to compare this simplified model with global hysteretic models commonly used in earthquake engineering. In accordance with the design philosophy of plastic hinges, hysteretic models are concerned with predicting in the most realistic way the energy dissipation corresponding to hysteretic loops area. The model proposed in this work takes into account explicitly the changes in the fundamental frequency due to damage. In addition to its simplicity and ergonomics, the interest of this original model lies in evaluating the only influence of the joint stiffness decrease on the dynamic response of a structure. Finally, hysteretic models encounter instability problems when the stiffness becomes negative. In this proposed model, such instability problems are avoided, because the non linear behavior is handled by a simple curve representing the changes in joint stiffness as a function of damage.

Although this method can reduce the time consummation, one needs to verify experimentally in the next research. With this article, the authors wish to give some brief contributions for considering the damage of the structure into dynamics simulation.

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