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Proposed Damage Index for Seismic Evaluation of RC Bridge Shear keys

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ABSTRACT: Shear keys are bridge components that support the superstructure in transverse direction and may experience large displacements and extensive damages during earthquakes. Shear keys are designed to limit damage to abutment walls and piles by restraining the transverse movements. The shear force transferred to the abutments is controlled by design and detailing of the shear keys. Damage to shear keys during earthquakes may affect significantly on seismic behavior of the abutments and consequently, the bridge system. In this paper, a damage index is proposed for damage assessment of the bridge shear keys. The proposed damage index is defined based on the friction behavior and the ratio of the energy dissipation capacity to input energy. To evaluate the reliability of the damage index in damage assessment of the shear keys, finite element models of shear keys units, previously tested under cyclic loadings, are developed and the proposed damage index is calculated. Also, seismic response of shear key specimens are obtained under seven earthquake records using incremental dynamic analysis and the damage index is calculated for the shear keys in different PGA values of earthquakes. The results indicate that the proposed damage index can predict the damage progression in shear keys throughout loading histories and can provide reliable values for damage levels of shear keys with respect to the experimental observations.

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1. INTRODUCTION

Shear keys are bridge components that support the superstructure in transverse direction and may experience large displacements and damage during earthquakes. Shear keys are designed to limit damage to abutment walls and piles by restraining the transverse movement. The shear force transferred to the abutments is controlled by design and detailing of the shear keys [1]. Shear keys are regarded as secondary components of bridge but damage to shear keys may cause large relative displacement between the shear keys and girder in transverse direction that result in pounding between these components and affect the seismic response of the overall bridge [2]. Damage to shear keys during past earthquakes lead to change their design philosophy. In accordance with current design criteria, the ultimate capacity of shear keys is restricted to 75% of the total shear capacity of the adjacent bent [3]. There is little research available in damage assessment of shear keys [1-5]. The existing works have focused on the qualitative damage levels of shear keys in terms of cracking mechanisms, spalling of concrete and yielding of steel bars. However, none of the above-mentioned studies investigated the quantitative damage to bearings in their main failure modes and there is a lack of studies on quantification of seismic damage to bridge shear keys concerning their behavior under earthquake excitements.

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Therefore, it is required to propose a damage index to predict the intensity of damage during the earthquake to ass the seismic performance of bridge shear keys. In this paper, a damage index is proposed for damage assessment of the bridge shear keys. The proposed damage index is defined based on the friction behavior and the ratio of the energy dissipation capacity to input energy. To evaluate the reliability of the damage index in damage assessment of the shear keys, finite element models of shear keys units, previously tested under cyclic loadings, are developed and the proposed damage index is calculated. In addition, seismic response of shear key specimens are obtained under seven earthquake records using incremental dynamic analysis and the damage index is calculated for the shear keys in different PGA values of earthquakes.

2. DAMAGE INDEX

The proposed damage index is defined as:

$$DI = \frac{E_{hd}}{E_i} \quad (1)$$

where, E_{hd} is the energy dissipated by inherent damping (E_d) and the hysteretic behavior (E_h) of the system. E_i is the input energy. E_{hd} is calculated using the difference among the input energy and kinetic energy (E_k) and strain

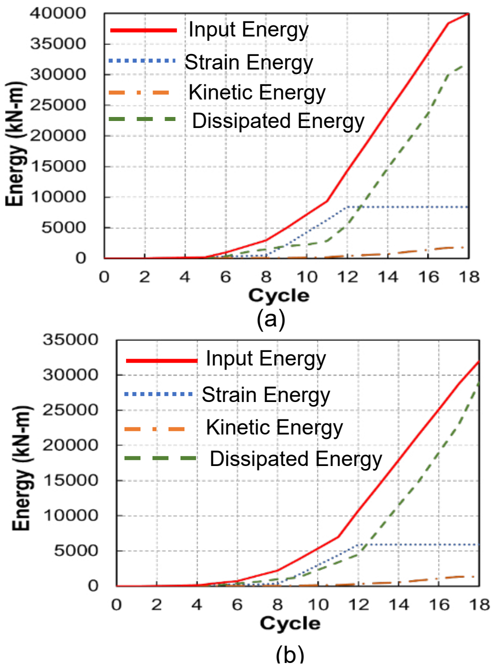

Fig. 1. Cumulative energy plots a) Unit 3A b) Unit 3B

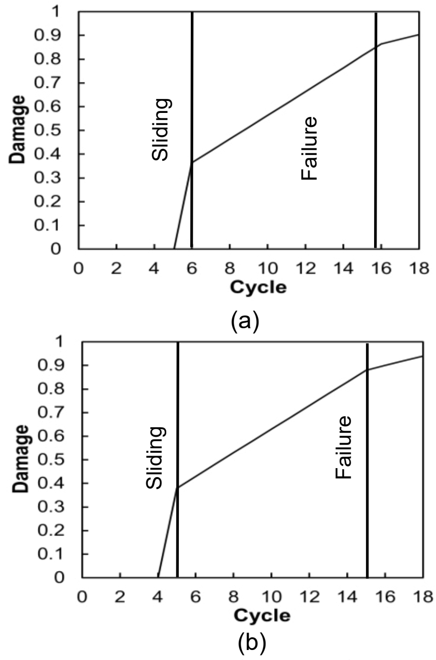

Fig. 2. Damage curves a) Unit 3A b) Unit 3B

energy (E_s) as presented below:

$$E_{hd} = E_i - E_k - E_s \tag{2}$$

The energy components used for damage analysis can be estimated with different methods. In this paper, the energy components are calculated with the direct integration method. The bearing is considered a single degree of freedom (SDOF) system.

The force-displacement behavior of shear keys are commonly defined with respect to the model presented by Borgzadeh et al. [2], Megally et al. [3] and Silva et al. [4, 5]. The model can be described by a combination of two spring representing the steel and concrete components, connected in parallel, and a gap element, connected in series.

3. DISCUSSION AND RESULTS

Finite element models of two shear key units tested by Megally et al. [3] are developed in OpenSees using a zero-length element characterized by the nonlinear force-displacement response of shear keys. The cumulative energy plots used for calculating the damage index are presented in Fig. 1. The proposed damage index is calculated for shear key units, as shown in Fig. 2.

To estimate the proposed damage index for the shear key units subjected to seismic loading, ground motion records of seven earthquakes are scaled and increased from 0.1g to 1g with increment of 0.05g and nonlinear time-history analysis is performed at each step. Damage index versus PGA for San Fernando record is shown in Fig.3.

4. CONCLUSIONS

The results are summarized below:

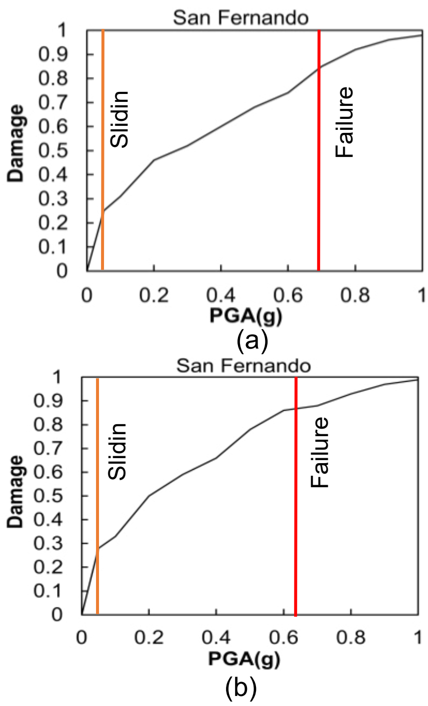

Fig. 3. Damage curves a) Unit 3A b) Unit 3B

- The damage index uses the cumulative energy components during the loading cycles and can consider the cumulative effects of loading cycles and strength degradation, and inelastic behavior.

- The damage model utilizes the earthquake input energy. The earthquake input energy can reflect the characteristics of the earthquake-like amplitude, duration and frequency at each time throughout the earthquake.

- The damage index provides a simple and practical approach for damage assessment of the shear keys. Calculating the dissipated energy using the difference among the earthquake input energy and other energy components ensures that no parts of energy is lost.

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