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The effect of degradation on seismic damage of RC buildings

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Abstract

The severity of seismic damage of reinforced concrete buildings depends on the tectonic characteristics of area, seismic features of ground motion, quality and quantity of buildings. One of the most important factor's, affecting the seismic damage, is the degrading rate of building. Degradation of stiffness and strength are the parameters, which their effect on the seismic damage of buildings are investigated, using an inelastic dynamic analysis. The buildings which are studied are moment resisting RC frames. In order to study the inelastic dynamic behavior of these buildings, IDARC software is used. Based on the obtained results, 40% degradation of strength or 50% degradation of stiffness will cause severe structural damage in the buildings.

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The effect of degradation on seismic damage of RC buildings

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Ali Khoshraftar, Reza Abbasnia, Farhad Fakheri Raof: The effect of degradation on seismic damage of RC buildings

ABSTRACT

The severity of seismic damage of reinforced concrete buildings depends on the tectonic characteristics of area, seismic features of ground motion, quality and quantity of buildings. One of the most important factor's, affecting the seismic damage, is the degrading rate of building. Degradation of stiffness and strength are the parameters, which their effect on the seismic damage of buildings are investigated, using an inelastic dynamic analysis. The buildings which are studied are moment resisting RC frames. In order to study the inelastic dynamic behavior of these buildings, IDARC software is used. Based on the obtained results, 40% degradation of strength or 50% degradation of stiffness will cause severe structural damage in the buildings.

Key words: RC buildings; stiffness degradation; strength degradation; seismic damage

Introduction

With Iran's history of strong earthquakes and other disasters that unfortunately have caused many life and financial losses, the determination of the Seismic Damage of Buildings is essential before an appropriate repair or upgrade system can be designed. Damage may be quantified by using any of several damage indices defined as functions whose values can be related to particular structural damage states. There are quite a few different methods of classifying damage indices, rather detailed discussion of the damage indices proposed in the literature can be found in state-of-the-art reports [1, 2, 3, 4].

Since the late 1970s several methods for assessment of damage in RC-frames have been suggested. Culver *et al*. [5], Toussi and Yao [6], and Sozen [7] all suggested different kind of damage indices based on measured interstorey drifts. Banon *et al*. [8] considered different indices such as flexural damage ratio, normalized cumulative rotations and normalized cumulative energy. Yao and Munze [9] and Stephens and Yao [10] formulated damage indices based on low-cycle fatigue. Though several models have been proposed in the recent past to provide a quantitative measure of the structural damage, the model proposed by Park and Ang [11] has been most widely used and calibrated against a significant amount of observed seismic damage states. According to this model, a damage index calculated as a combination of a maximum displacement term and a cumulative dissipated energy term.

The severity of seismic damage of RC Buildings depends on different factors that studying all at once is not possible. In this paper, Degradation of Stiffness and Strength are investigated. The concept applied to concrete structures of Moment Resisting systems. A number of four and five-storey residential reinforced concrete frame buildings are used to illustrate the effect of the Degradation.

Damage Evaluation Method:

The best-known and most widely used of all the damage indices is that of Park and Ang (1984). The Park and Ang damage model is incorporated in IDARK since the original release of the program. According to this model, structural damage consists of linear combination of the maximum displacement and the dissipated energy, in the form of a damage index D_i as follows:

$$D_i = \frac{\delta_m}{\delta_u} + \left[\frac{\beta}{\delta_u P_y}\right]\int dE_h$$

Where δ_m is the maximum experienced deformation; δ_u is the ultimate deformation of the element; P_y is the yield strength of the element;

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$\int dE_h$ is the hysteretic energy absorbed (dissipated) by the element during the response history (excluding the stored potential energy) and β is a model constant parameter.

The local damage index D_i, corresponds to an element. The damage index for a storey and the structure as a whole is obtained by summing component contributions, that is, $D = \sum \lambda_i D_i$, where λ_i is the weighting factor defined as the ratio of total energy absorbed (including the stored potential energy) by element i to total energy absorbed in the storey or the structure.

The advantages of this model are its simplicity, and the fact that it has been calibrated against a significant number of observed seismic damage, including cases of shears and bond failures. Park, Ang and Wen (1985) suggested $D_i = 0.4$ as a threshold value between repairable and irreparable damage, while the same authors in 1987 suggested the following more detailed classification [4]:

$D < 0.1$ No damage or localized minor cracking

$0.1 \le D < 0.25$ Minor damage-light cracking throughout

$0.25 \le D < 0.4$ Moderate damage-severe cracking, localized spalling

$0.4 \le D < 1.0$ Severe damage-crushing of concrete, reinforcement exposed

$D \ge 1.0$ Collapsed

The MRF Buildings:

The damage analysis is performed for ten medium-rise four and five-storey Moment Resisting Frame RC Buildings in Tehran. The buildings are designed according to the Iranian Code of Practice for Seismic Resistant Design of Buildings [12] and Iranian Concrete Code (ABA) [13]. The seismic behavior was studied using scaled ground motion records. The selected ground motions are the 1978 Tabas earthquake and the 1990 Manjil earthquake. The plans of the buildings are given in figure.1. Tables 1, 2 and 3 present the material properties, dimensions for different structural frame members. It is to be noted that the four-storey buildings with plans N1 to N5 are similar to five-storey buildings with plans N6 to N10.

Table 1: Material properties for different structural

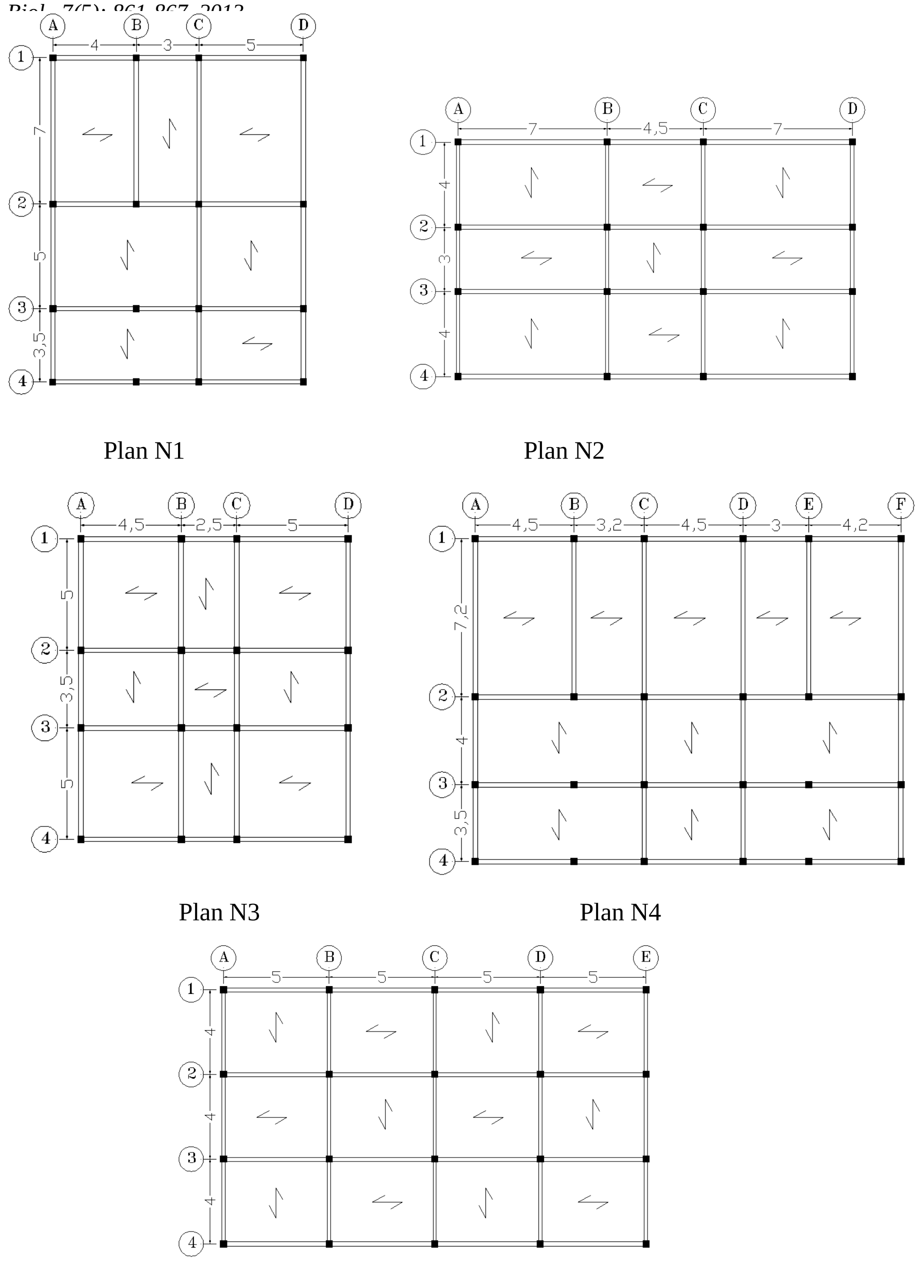
Characteristic compressive strength of concrete (MPa)	Specified yield strength of reinforcement (MPa)	Ratio of tension reinforcement in columns	Ratio of tension reinforcement in beams
30	400	2.5%	$0.3\rho_b$

Table 2: Dimensions of beams and columns of the four-storey buildings

Case	Floor	(cm) Beam Size	(cm) Column Size
N1	2-1	35 * 35	35 * 35
	4-3	30 * 30	30 * 30
N2	2-1	40 * 40	40 * 40
	4-3	30 * 30	30 * 30
N3	2-1	35 * 35	35 * 35
	4-3	30 * 30	30 * 30
N4	2-1	40 * 40	40 * 40
	4-3	30 * 30	30 * 30
N5	2-1	40 * 40	40 * 40
	4-3	30 * 30	30 * 30

Table 3: Dimensions of beams and columns of the five-storey buildings

Case	Floor	(cm) Beam Size	(cm) Column Size
N6	2-1	40 * 40	40 * 40
	5-4-3	35 * 35	35 * 35
N7	2-1	50 * 50	50 * 50
	5-4-3	40 * 40	40 * 40
N8	2-1	40 * 40	40 * 40
	5-4-3	35 * 35	35 * 35
N9	2-1	50 * 50	50 * 50
	5-4-3	40 * 40	40 * 40
N10	2-1	50 * 50	50 * 50
	5-4-3	40 * 40	40 * 40



Plan N1 Plan N2

Plan N3 Plan N4

Plan N5

Fig. 1: Floor plans of the MRF buildings (Dimensions are in meter).

Effect of Degradation on Damage Index:

Structures subjected to strong earthquake excitation are designed to dissipate energy by inelastic material behavior, interface friction, etc. However, under repeated cyclic deformation, there is invariably deterioration in the characteristics of hysteretic behavior. Such deterioration must be taken into account in the modeling and design of seismic resistant structural systems. Often structures that undergo inelastic deformations and cyclic behavior weaken and lose some of their stiffness and strength. Several hysteresis models have been proposed to predict the response of reinforced concrete members subjected to cyclic loading [14, 15, 16]. The Park's "trilinear model" (Park *et al*., 1987) has been shown to be capable of describing the behavior of degradation in stiffness and strength with a large number of laboratory models (Kunnath *et al*., 1989, 1990, 1991; Stone and Taylor, 1993). The IDARC Software used a trilinear moment-curvature relationship as shown in figure 2.

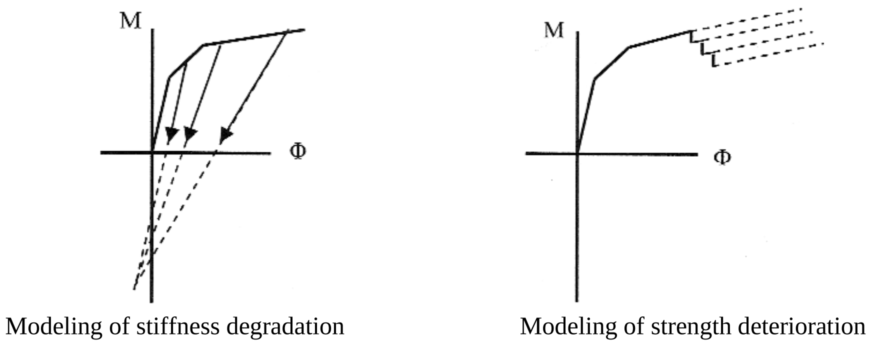


Fig. 2: stiffness and strength degradation.

Reduction in stiffness and deterioration in strength are two important parameters, which their effect on four and five-storey MRF buildings are investigated in the following manners:

- Reduction in stiffness under Manjil earthquake
- Reduction in stiffness under Tabas earthquake
- Deterioration in strength under Manjil earthquake
- Deterioration in strength under Tabas earthquake

The influence of mentioned parameters is illustrated in figures 3 to 10.

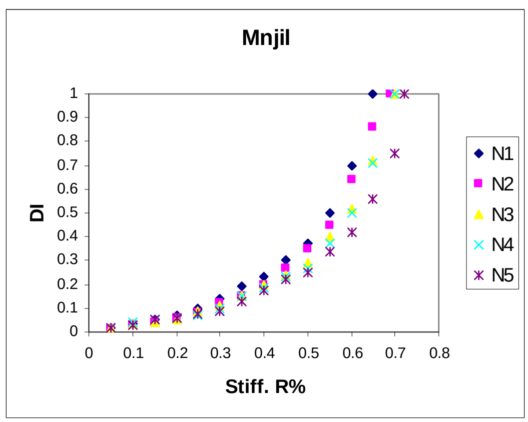


Fig. 3: Relationship between the Stiffness and the Damage Index for the Manjil EQ. 4-storey bldgs.

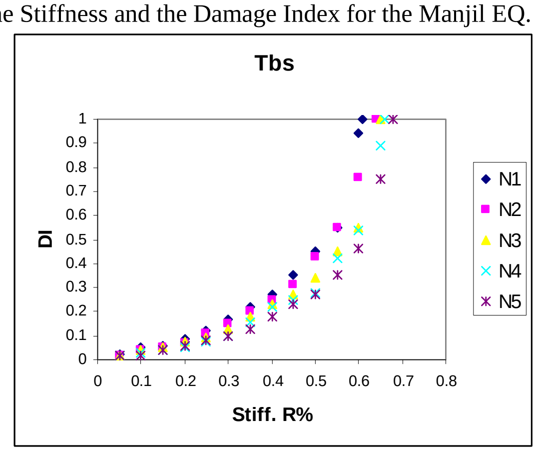


Fig. 4: Relationship between the Stiffness and the Damage Index for the Tabas EQ. 4-storey bldgs.

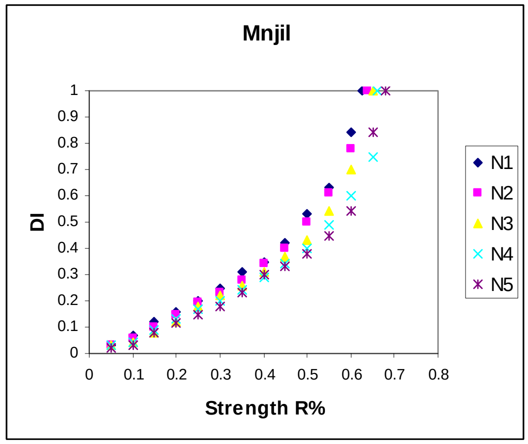


Fig. 5: Relationship between the Strength and the Damage Index for the Manjil EQ. 4-storey bldgs.

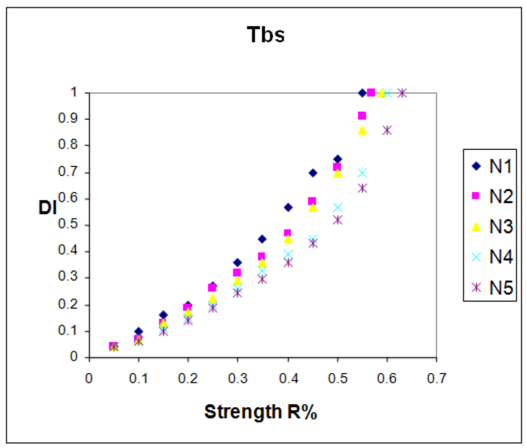


Fig. 6: Relationship between the Strength and the Damage Index for the Tabas EQ. 4-storey bldgs.

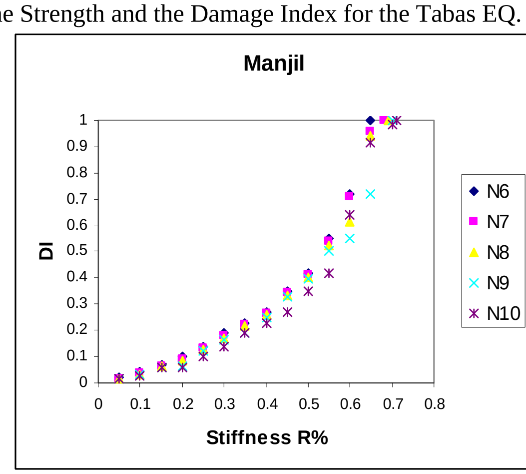


Fig.7: Relationship between the Stiffness and the Damage Index for the Manjil EQ. 5-storey bldgs.

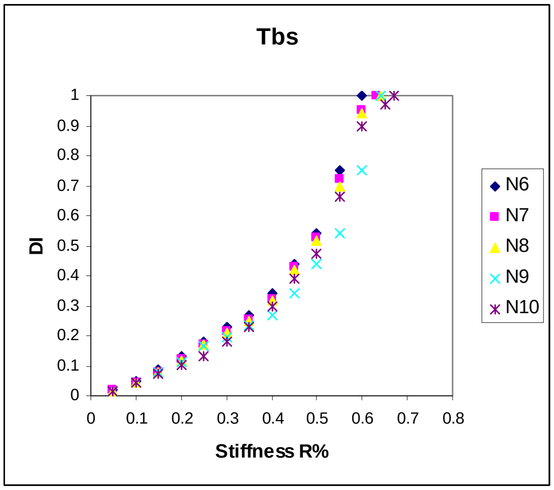


Fig.8 Relationship between the Stiffness and the Damage Index for the Tabas EQ. 5-storey bldgs.

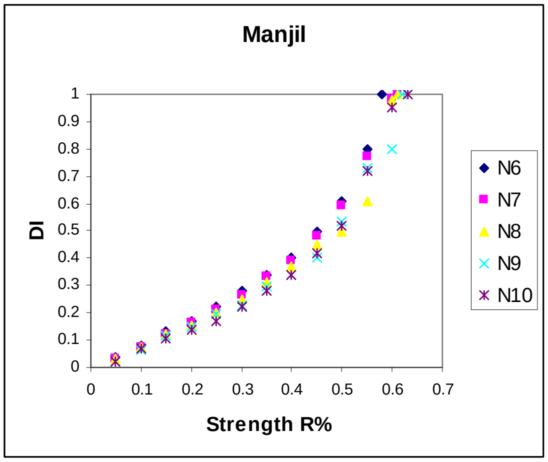


Fig. 9: Relationship between the Strength and the Damage Index for the Manjil EQ. 5-storey bldgs

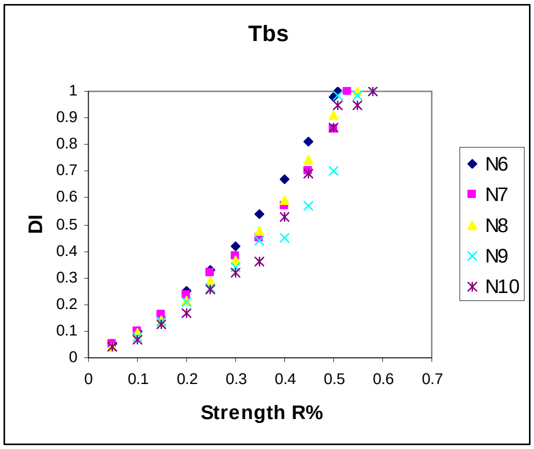


Fig. 10: Relationship between the Strength and the Damage Index for the Tabas EQ. 5-storey bldgs According to these figures,

-In MRF building subjected to Tabas earthquake,

Reduction in stiffness less than 30% indicates minor damage. A stiffness degradation between 30% and 50% indicates moderate damage but repairable, and between 50% and 65% indicates severe damage beyond repair. The building can be considered partially or totally collapsed for stiffness degradation greater than 65%.

Deterioration in strength less than 20% indicates minor damage. A strength degradation between 20% and 40% indicates moderate damage but repairable, and between 40% and 60% indicates severe damage beyond repair. The building can be considered partially or totally collapsed for strength degradation greater than 60%.

-In MRF building subjected to Manjil earthquake,

Degradation in stiffness less than 35% indicates minor damage. A stiffness degradation between 35% and 55% indicates moderate damage but repairable, and between 55% and 70% indicates severe damage beyond repair. The building can be considered partially or totally collapsed for stiffness degradation greater than 70%.

Degradation in strength less than 30% indicates minor damage. A strength degradation between 30% and 45% indicates moderate damage but repairable, and between 45% and 65% indicates severe damage beyond repair. The building can be considered partially or totally collapsed for strength degradation greater than 65%.

Conclusions:

Based on the results, degradation parameters have important effect on seismic damage for RC buildings so that stiffness degradation greater than 40% or strength degradation greater than 50% will cause Unsafe MRF Building with severe and irreparable structural damage. It was found by the present investigation that strength degradation have more influence on increasing the damage index in comparison with stiffness degradation.

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