SIGNIFICANT GUIDELINE FOR THE DAMAGE INDICES APPLIED TO REINFORCED CONCRETE STRUCTURES

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ABSTRACT

In this paper, based on a deep overview and literature study, the different formulas proposed for damage indices (DIs) applied to reinforced concrete structures under monotonic or cyclic loading are classified and presented. The DIs are applied to quantify the damages to structures, ranging from zero to one. Normally, they are applied to make a decision for repairing or demolition of the structures in the post-earthquake phases.

Keywords: Damage indices, reinforced concrete structures, damage state, decision for repairing or demolition of structures.

INTRODUCTION

Earthquake loads are the most sudden exerting on the building that can make damage or collapse of the building. In estimation of the damage to building in their lifetime, which is the probabilistic problem. To quantify the damage to the structures the existing different approaches are based on stress, strain, displacement, curvature, deformation, baseshear, strength, stiffness, absorbed and dissipated energies. Damage indices (DIs) predict the structure damage degree using DIs formula. The acceptable value of DIs compared to different levels of damage states, which observed based on seismic damage after an earthquake. These values give a tool to make decision for repairing or demolition of damaged structures (Saleemuddin and Sangle, 2016; Sadeghi and Angin, 2018; Sinha and Shiradhonkar, 2012).

In this paper, the existing DIs are reviewed and classified for different seismic damage states categories for the structural damage of the various building.

DAMAGE INDICES

The basic remark of damage and damage aptitude in the structure design is the critical necessity for buildings subjected to an earthquake for predicting the amount of seismic damage, likely deterministic indices approach. This probabilistic approach, structural or nonstructural induces and economical induces are used based on how the approaches are defined, While the probabilistic approaches involve the DIs using the analytical or models and practical for calculating the damage values (Powell and Allahabadi, 1988). The damage induces are categorized base on the deformation, stiffness, or energy:

a) *Local DIs*: as non-cumulative DI or cumulative involved displacement based cumulative induces, the force based cumulative, hysteretic energy based cumulative induces.

b) *Global damage induces* as strength based global damage induces, as weight average of local indicator or model indices. However, damage quantification in the literature are also categorized into empirical and analytical DIs (Saleemuddin and Sangle, 2016).

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Classifications of Damage Indices

To make decision regarding the building status of damage whether to be repaired, reinforced or demolition of the structures, the classification and application of the DIs are necessary. This classification expresses DIs as deterministic and probabilistic methods, as well as local and global DIs based on the strength parameter (Amziane and Dubé, 2008; Rodriguez-Gomez and Cakmak, 1990).

Nowadays, many DIs are developed for the reinforced concrete (RC) building such as Sadeghi, Pak and Ang, Colombo and Negro and others. They correlated to the state of a building to give thoughtful of a post-earthquake circumstance of the building and it summarized in Table 1.

Sadeghi has proposed different forms of DIs' formulas to simulate and quantifying the local and global behaviors of structures by proposing different models of numerical and experimental simulations for RC structures ((Sadeghi, 1994, 1995, 1998, 2001, 2002, 2011, 2014, 2015, 2017a, 2017b,), (Sadeghi and Nouban, 2010a, 2010b, 2013,2016, 2017a, 2017b, 2017c, 2018). Summary of the DIs formulas are reported in Tables 1 and 2. Some applications of the DIs applied to RC structures can be found in the papers listed in the Reference Section of this paper.

Table 1. Summary of existing formulas for DIs

Type	*DIs Proposed*	*Description*	*Formulas*	*Factor values*
1.0 Local DIs				
Noncumulative	Powell and Allahabadi (1988)	DI is based on plastic deformation and displacement ductility	$D = \frac{\mu m - 1}{\mu u - 1}$ (1)	
	Park (1986)	Based on a parameter of ductility expressed as a function of characteristic member displacements	$\mu_r(\delta) = \frac{\delta_m}{\delta_y} = 1 + \frac{\delta_m - \delta_y}{\delta_y}$ (2)	
	Banon *et al.* (1981)	Flexural damage ratio in terms of stiffness degradation	$DI = \frac{M_u \phi_m}{M_m \phi_u}$ (3)	
		Based on ductility expressed as a function of the curvature	$\mu_r(\phi) = \frac{\phi_m}{\phi_y} = 1 + \frac{\phi_m - \phi_y}{\phi_y}$ (4)	
	Newmark and Rosenblueth (1971)	Based on the ductility expressed as a function of rotation	$\mu_r(\theta) = \frac{\theta_m}{\theta_y} = 1 + \frac{\theta_m - \theta_y}{\theta_y}$ (5)	
	Roufaiel and Meyer (1987)	Based on flexural damage Ratio in terms of stiffness	$MFDR = \frac{\frac{\varnothing m}{Mm} - \frac{\varnothing y}{My}}{\frac{\varnothing u}{Mu} - \frac{\varnothing y}{My}}$ (6)	
	Lybas and Sonen (1977)	Based on the ratio of initial stiffness to maximum elastic stiffness	$DI = \frac{K_o}{K_m}$ (7)	

Cumulative	Mehanny and Deierlein (2001)	Based on the deformation of powered plastic primary and followed loads cycle to trace out the loading history effect	$D_\theta^+ = \frac{\left(\theta_p^+\vert_{current\ PHC}\right)^\alpha + \left(\sum_{i=1}^{n^+}\theta_p^+\vert_{FHC,i}\right)^\beta}{(\theta_{pu}^+)^\alpha + \left(\sum_{i=1}^{n^+}\theta_p^+\vert_{FHC,i}\right)^\beta}$, $D = \sqrt[\gamma]{(D_\theta^+)^\gamma + (D_\theta^-)^\gamma}$ (8)	$\alpha = 1$, $\beta = 1.5$, $\gamma = 6$
	Hwang and Scribner (1984)	Based on stiffness, maximum displacement, and energy distribution in the cycle with initial stiffness	$DI = \sum_{i=1}^{n} E_i \frac{K_i}{K_e}\left(\frac{\Delta_i}{\Delta_Y}\right)$ (9)	
	Jeang and Iwan (1988)	Based on force effect of combining cycle with an amplitude	$DI = \sum_{i=1}^{n}\left[\frac{n_i\mu_i^s}{C}\right]$ (10)	
	Wang and Shah (1987)	Based on an exponential function of cyclic inelastic deformation	$D = \frac{e^{\eta\beta}-1}{e^{\eta}-1}$, $\beta = C\sum_{i=1}^{N}\frac{\theta_i}{\theta_u}$ (11)	$C = 0.15$, $\eta = -3$ & -1
	Banon and Veneziano (1982)	Based on normalized cumulative rotation	$DI = \frac{\sum_{i=1}^{n}\phi_{im}-\phi_y}{\phi_u}$ (12)	
	Stephens and Yao (1987)	Based on cumulative displacement ductility	$DI = \sum_{i=1}^{n}\left[\frac{\Delta d}{\Delta d_f}\right]^{1-br}$ (13)	$b = 0.7$
Combined cumulative	Kunnah (1997)	Based on maximum displacement and disintegrated energy within observed damage as chronological order	$I_D = \frac{\varphi_m - \varphi_y}{\varphi_u - \varphi_y} + \beta_e \frac{\int dE}{M_y \varphi_u}$, (14)	
	Park and Ang (1985)	Based on a combination of maximum plastic displacement and plastic disintegrated energy	$I_D = \frac{d_m}{d_u} + \beta_e \frac{\int dE}{F_y d_u}$, (15)	$\beta = 0.4$
	Colombo and Negro (2005)	Based on an exponential and hyperbolic function of energy exerting	$D = 1 - f(\beta_1, \mu)\cdot f(\beta_2, \int dE_{duct})\cdot f(\beta_3, \int dE_{br})$ $f(\beta_1, \mu) = \left(1 - \frac{\theta_m}{\theta_u}\right)^{1/\beta_1}$ $f(\beta_2, \int dE_{duct}) = 0.5\left(1 - \tanh\left(\beta_2 \frac{\int dE}{E_u^*} - \pi\right)\right)$ $f(\beta_3, \int dE_{br}) = \exp\left(-\beta_3 \frac{\int dE}{E_u^*}\right)$ (16)	$\alpha = 1$, $\beta_1 = 0.1$, $\beta_2 = 2.4$, $\beta_3 = 0.1$, $\gamma = 0.8$
	Niu and Ren (1966)	Similar to a Park and Ang with different formula use of constant values	$D = \frac{\theta_m}{\theta_u} + \alpha\left(\frac{E}{E_u}\right)^\beta$ (17)	$\alpha = 0.1387$, $\beta = 0.0814$
	Mizuhata and Nishigaki (1983)	Based on a linear combination of plastic deformation within energy distributed	$DI = \frac{\vert\Delta_{max}\vert}{\Delta_u} + \sum_{i=1}^{k}\left(\frac{n_i}{N_{fi}}\right)^{0,91}\left(1 - \frac{\Delta_i}{\Delta_u}\right)$ (18)	
	Banon and Veneziano (1982)	Based on the linear combination of maximum displacement, failure displacement, and hysteretic energy dissipation	$DI = \sqrt{\left(\left[\frac{d_m}{d_y - 1}\right]^2 + \left[\frac{2E_h}{F_y d_y}\right]^{0.38}\right)^2}$ (19)	

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Local	Sadeghi (1994, 1995, 1998, 2001, 2002, 2011, 2014, 2015, 2017a and b) and Sadeghi and Nouban (2010a and b, 2013,2016, 2017a, b and c, 2018)	DI, implicit local version	$$DI^{+}=\frac{\sum_{i=1}^{i=i}\int_{\varphi_{p(i-1)}^{+}}^{\varphi_{pi}^{+}} M_{pi}^{+}.d\varphi_{pi}^{+}}{E_{mu}^{+}}\times\frac{(M_{max}^{+}\times\varphi_{max}^{+})_{monotonic}}{(M_{max}^{+}\times\varphi_{max}^{+})_{cyclic}};$$ $$DI^{-}=\frac{\sum_{i=1}^{i=i}\int_{\varphi_{p(i-1)}^{-}}^{\varphi_{pi}^{-}} M_{pi}^{-}.d\varphi_{pi}^{-}}{E_{mu}^{-}}\times\frac{(M_{max}^{-}\times\varphi_{max}^{-})_{monotonic}}{(M_{max}^{-}\times\varphi_{max}^{-})_{cyclic}}$$ (20)	
		DI, explicit local version	$$DI^{+}=\frac{\sum_{i=1}^{i=i}\int_{\varphi_{p(i-1)}}^{\varphi_{pi}} M_{pi}^{+}.d\varphi_{pi}^{+}+\sum_{j=1}^{j}\sum_{k=1}^{k}\int_{\varphi_{f(k-1)}}^{\varphi_{fk}}\lambda_{j}^{+}M_{fk}^{j+}.d\varphi_{fk}^{j+}}{E_{u}^{+}}$$ $$DI^{-}=\frac{\sum_{i=1}^{i=i}\int_{\varphi_{p(i-1)}}^{\varphi_{pi}} M_{pi}^{-}.d\varphi_{pi}^{-}+\sum_{j=1}^{j}\sum_{k=1}^{k}\int_{\varphi_{f(k-1)}}^{\varphi_{fk}}\lambda_{j}^{-}M_{fk}^{j-}.d\varphi_{fk}^{j-}}{E_{u}^{-}}$$ (21)	positive and negative directio n loading
		DI, simplified local version	$$DI^{+}=\frac{\sum_{i=1}^{i=i}\int_{\varphi_{p(i-1)}}^{\varphi_{pi}} M_{pi}^{+}.d\varphi_{pi}^{+}}{\sum_{i=1}^{i=n}\int_{\varphi_{p(i-1)}}^{\varphi_{pi}} M_{pi}^{+}.d\varphi_{pi}^{+}}$$ $$DI^{-}=\frac{\sum_{i=1}^{i=i}\int_{\varphi_{p(i-1)}}^{\varphi_{pi}} M_{pi}^{-}.d\varphi_{pi}^{-}}{\sum_{i=1}^{i=n}\int_{\varphi_{p(i-1)}}^{\varphi_{pi}} M_{pi}^{-}.d\varphi_{pi}^{-}}$$ (22)	
		Estimating of the number of cyclic failure due to fatigue	$$n_{j}^{+}=\frac{E_{mu}^{+}-\int_{0}^{\varphi_{p1}} M_{p}^{+}.d\varphi_{p}^{+}}{\lambda_{j}^{+}\int_{0}^{\varphi_{f1}} M_{f}^{j+}.d\varphi_{f}^{j+}}$$ If at failure: DI = DI^{+}, or DI^{+} > DI^{-} $$n_{j}^{-}=\frac{E_{mu}^{-}-\int_{0}^{\varphi_{p1}} M_{p}^{-}.d\varphi_{p}^{-}}{\lambda_{j}^{-}\int_{0}^{\varphi_{f1}} M_{f}^{j-}.d\varphi_{f}^{j-}}$$ If at failure: DI = DI^{-}, or DI^{+} < DI^{-} (23)	

<u>*2.0 Global DIs*</u>				
Hysteretic energy	Park, Ang, Wen (1985)	Based on hysteretic energy-weighted average	$$D_{storey}=\frac{\sum_{i=1}^{N}D_{i}E_{i}}{\sum_{i=1}^{N}E_{i}}$$ $$D_{global}=\frac{\sum_{storey,i=1}^{N}D_{storey,i}E_{storey,i}}{\sum_{storey,i=1}^{N}E_{storey,i}}$$ (24)	
	Gosain et al. (1977)	Based on energy disintegrated considering threshold value on structure until collapse.	$$I_{D}=I_{W}=\sum_{i=1}^{n}\frac{F_{i}d_{i}}{F_{y}d_{y}}$$ (25)	
	Rodrigueza and Padilla (2009)	Based on seismic damage Parameter which is the Level of admissible Seismic performance.	$$DI=\frac{E_{H}}{E_{\lambda}}$$ $$E_{\lambda}=k_{\theta}.\theta_{c}^{2}$$ (26)	
	Mahin and Bertero (1981)	Based on the potential of elastic and inelastic deformation within hysteretic energy	$$\mu_{h}=1+\frac{E_{h}}{F_{y}u_{y}}$$ $$DI=\frac{E_{h}}{E_{hu}}$$ (27)	
Strength, global	Roufaiel and Meyer (1987)	Based on strength energy for using structure capacity curve	$$I_{Dglobal}=\mathrm{GDP}\frac{d_{m}-d_{y}}{d_{u}-d_{y}},$$ (28)	

Gravity load	Bracci (1989)	Based on gravity load-weighted average	$D_{storey} = \frac{\sum_{i=1}^{N} W_i D_i^{b+1}}{\sum_{i=1}^{N} W_i D^b}$ $D_{global} = \frac{\sum_{storey,i=1}^{N} W_{storey,i} D_i^{b+1}}{\sum_{storey,i=1}^{N} W_{storey,i} D_{storey,i}^{b}}$ (29)	
Global	Sadeghi (1994, 1995, 1998, 2001, 2002, 2011, 2014, 2015, 2017a and b) and Sadeghi and Nouban (2010a and b, 2013,2016, 2017a, b and c, 2018)	DI, implicit global version	$DI^+ = \frac{\sum_{i=1}^{i=i} E_{pi}^+}{E_u^+} \times C^+ \quad C^+ = \frac{(F_{max}^+ \times \delta_{max}^+)_{Monotonic}}{(F_{max}^+ \times \delta_{max}^+)_{Cyclic}}$ $DI^- = \frac{\sum_{i=1}^{i=i} E_{pi}^-}{E_u^-} \times C^- \quad C^- = \frac{(F_{max}^- \times \delta_{max}^-)_{Monotonic}}{(F_{max}^- \times \delta_{max}^-)_{Cyclic}}$ $DI = Max[DI^+,\ DI^-]$ (30)	positive and negative directions loading
		DI, explicit global version for fatigue case	$DI^+ = \frac{\sum_{i=1}^{i=i} \int_{\delta_{p(i-1)}^+}^{\delta_{pi}^+} F_{pi}^+ . d\delta_{pi}^+ + \sum_{j=1}^{j} \sum_{k=1}^{k} \int_{\delta_{f(k-1)}^{j+}}^{\delta_{fk}^{j+}} \lambda_j^+ F_{fk}^{j+} . d\delta_{fk}^{j+}}{E_u^+}$ $DI^- = \frac{\sum_{i=1}^{i=i} \int_{\delta_{p(i-1)}^-}^{\delta_{pi}^-} F_{pi}^- . d\delta_{pi}^- + \sum_{j=1}^{j} \sum_{k=1}^{k} \int_{\delta_{f(k-1)}^{j-}}^{\delta_{fk}^{j-}} \lambda_j^- F_{fk}^{j-} . d\delta_{fk}^{j-}}{E_u^-}$ (31)	
		DI, simplified global version	$DI^+ = \frac{\sum_{i=1}^{i=i} \int_{\delta_{p(i-1)}}^{\delta_{pi}} F_{pi}^+ . d\delta_{pi}^+}{\sum_{i=1}^{i=n} \int_{\delta_{p(i-1)}}^{\delta_{pi}} F_{pi}^+ . d\delta_{pi}^+}$ $DI^- = \frac{\sum_{i=1}^{i=i} \int_{\delta_{p(i-1)}}^{\delta_{pi}} F_{pi}^- . d\delta_{pi}^-}{\sum_{i=1}^{i=n} \int_{\delta_{p(i-1)}}^{\delta_{pi}} F_{pi}^- . d\delta_{pi}^-}$ (32)	
		Estimating the number of cycles due to Fatigue, global version	$n_j^+ = \frac{E_u^+ - \int_0^{\delta_{p1}^+} F_p^+ . d\delta_p^+}{\lambda_j^+ \int_0^{\delta_{f1}^{j+}} F_f^{j+} . d\delta_f^{j+}}$ If at failure: $DI = DI^+$ or $DI^+ > DI^-$ $n_j^- = \frac{E_u^- - \int_0^{\delta_{p1}^-} F_p^- . d\delta_p^-}{\lambda_j^- \int_0^{\delta_{f1}^{j-}} F_f^{j-} . d\delta_f^{j-}}$ If failure: $DI = DI^-$ or $DI^+ < DI^-$ (33)	
	Dipasquale and Cakmak (1988)	Based on the fundamental period variation of structures	$I_{DmS} = 1 - \frac{T_a}{T_m}$, Maximum Softening DI $I_{DIs} = 1 - (\frac{T_a}{T_m})^2$, Plastic DI $I_{DFs} = 1 - (\frac{T_a}{T_d})^2$, Final Softening DI (34)	

STRUCTURAL DAMAGE LEVELS

In the lifetime of the structures correlated to damage, the Dis, quantifying the damage state should be defined based on the classification of the experiences on the RC structures as global or local. The physical damage of building, interpretation of DIs and structural damage categories are described in Tables 2, 3 and 4 (Mihaita Mihai, 2013; Sinha and Shiradhonkar,2012).

Table 2. Damage physical descriptions of the building (Mihaita Mihai, 2013)

Damage level	Damage physical description
Light	Minor, localized, crack.
Minor	Minor crack localized throughout the entry structure.

	Local crushing of concrete.
Moderate	Crack on a large surface. Failure of flexible RC element.
Sever	Failure of a RC element throughout the entire structure. Columns reinforced buckling.
Total	Partial or total collapse.

Table 3. Physical interpretation of DIs (Hadzima-Nyarko et al., 2014)

DI	Structural damage description	Technical and Economical Reparation	Code damage level (S) (1^0 to 6^0)
$0 \leq DI \leq 0.3$	Insignificant	Repairable	1^0 - 2^0
$0.3 \leq DI \leq 0.5$	Moderate	Repairable	3^0
$0.5 \leq DI \leq 0.8$	Severe	Repairable	4^0
$0.8 \leq DI \leq 1.0$	Heavy	Repairable	5^0
$1.0 \leq D$	High level or collapse	Non-repairable	6^0

Table 4. Structural damage category (Sinha and Shiradhonkar, 2012)

Damage State	Column	Beam
S5	Crushing of critical joint point movement of a slab with a column of concrete, where cracking is less than 3 mm.	Crushing at supporting and excessive deflection of concrete.
S4	Diagonal/torsion cracks in the core concrete (0.5 mm to 3 mm), a gap of tie bars, buckling of longitudinal bars.	It breaks reinforced and concrete bond, cracks in the core/critical concrete (0.5 to 3 mm), shear tie bars botched.
S3	The majority covers part of concrete spelled but critical is undamaged with expected very thin line crack (0.2 to 0.5 mm).	The majority covers part of concrete spelled but critical is undamaged with expected very thin line crack (0.2 to 0.5 mm).
S2	Visible cracks (0.1 to 0.2 mm)	Visible cracks around supports like shear cracks and at the bottom as tension cracks (0.1to 0.2 mm)
S1	Fine crack (<0.1 mm)	Fine crack (<0.1 mm)
S0	No observable damage	No observable damage

As these Tables indicate, depending on the peak acceleration of earthquake, the loads' effects are classified as weak, moderate, strong and disaster, that can be developed for the values of DIs using the spectral damage roles within the input parameter level of post-elastic stiffness, damping, and the yield baseshear. Thus, based on the developed values of DIs, one should propose the technical assessment of damage to buildings to give an appropriate safety level evaluation mechanism for the damaged building, considering the criteria: the size of the crack gap, beam, and column. Most modern damage state purpose is latest scale level used at the

European level, which described the details of explicit use of voluntarily seismic, used connecting with macroseismic criteria and voluntarily seismic to correlating in a good manner between assessment of analytical damage level and observed damage when performing damage analysis. One should take into account the descriptions of physical damage on non-structural and structural elements of a building, the damage risk for the residential buildings and the service average structures subjected to the earthquake. (Mihaita Mihai, 2013; Sinha and Shiradhonkar, 2012).

Filiatrault et al. (1998) experimentally studied the ductile RC building, which had regular two bays and two stories as an example to correlate the DIs and damage states in the analysis of nonlinear time-history spectrum applied to different buildings exposed to different actual earthquake ground motion, using IDAC-2D software, version 7.0, using N04W earthquake records of West Washington. For this analyses peak response collaborating with different accelerograms scale showed well response experiment using bilinear moment curvature as increasing the base of excitation to collapse the building. Lu (2002) experimentally studied the building's structure with a primary long story, which has the regular 3-bay, 6-story. For analysis of the considered structure, the EC8 (Euro code 8) using a procedure of capacity design for the strong-column-weak-beam design with scaling accelerograms in each excitation separated with a time-interval. A trilinear moment-curvature relationship was used to show the peak displacement response giving satisfactory values corresponding to the excitations. For these two examples of buildings, the values for DIs for different damage states are describe in Tables 5 and 6.

Table 5. Comparisons of DIs and damage states, Example 1 (Sinha and Shiradhonkar, 2012)

Damage State	**0.21 g**	**0.31 g**	**0.42 g**	**0.52 g**	**0.21 g**	**0.3g**	**0.42 g**	**0.52 g**
	2	3	4	5	2	3	4	5
	Light	**Moderate**	**Extensive**	**Collapse**	**Light**	**Moderate**	**Extensive**	**Collapse**
	Hysteretic global DI Hysterttic Global Damage Indtx				**Gravity load global DI**			
Powell and Allababadi	0	0.00	0.04	0.71	0	0.02	0.06	1.04
MFDR	0	0.07	0.28	0.77	0	0.10	0.28	0.73
Wang and Shah (ɳ=-3)	0	0.15	0.91	0.97	0	0.29	0.94	0.98
Wang and Shah (ɳ=-1)	0	0.08	1.01	1.15	0	0.16	1.05	1.11
Mehanny and Deierlein	0	0.00	0.06	0.28	0	0.01	0.13	0.22
Colombo and Negro	0	0.20	0.29	31.17	0	0.32	0.36	300.68
Park and Ang	0	0.03	0.13	0.85	0	0.05	0.14	0.96
Niu and Ren	0	0.05	0.12	0.77	0	0.08	0.12	1.96

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Table 6. Comparisons of DIs and damage states, Example 2 (Sinha and Shiradhonkar, 2012)

Damage States	**0.1 g**	**0.3 g**	**0.6 g**	**0.9 g**	**0.1 g**	**0.3g**	**0.6 g**	**0.9 g**
	1	2	3	4	1	2	3	4
	light	**Moderate**	**Extensive**	**Collapse**	**light**	**Moderate**	**Extensive**	**Collapse**
	Hysteretic global DI				**Gravity load global DI**			
Powell and Allababadi	0	0.00	0.36	1.13	0	0.00	2.60	3.31
MFDR	0	0.01	0.30	0.43	0	0.12	0.66	0.64
Wang and Shah (η=-3)	0	0.11	0.75	0.83	0	0.51	0.97	0.97
Wang and Shah (η=-1)	0	0.09	1.02	1.10	0	0.44	1.32	1.33
Mehanny and Deierlein	0	0.00	0.15	0.35	0	0.07	0.16	0.19
Colombo and Negro	0	0.02	4.4E05	8.6E06	0	0.33	1.1E07	3.03E08
Park and Ang	0	0.01	0.53	1.39	0	0.22	1.32	2.97
Niu and Ren	0	0.01	0.43	1.17	0	0.09	1.38	2.93

CONCLUSIONS

This paper presents an overview of DIs formulas to quantify and evaluate the damage to structures, using different classification for Dis, to predict damage state of the buildings. DIs can be used to assess the damage levels of light, intermediate and severe for the safety of buildings in the post-earthquake phases.

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