A PROBABILISTIC MODEL FOR STRENGTH REDUCTION FACTOR FOR DAMAGE ASSESSMENT

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ABSTRACT:

This study presents a probabilistic approach for strength reduction factor (R) to be used in estimating maximum interstory drift ratio (MIDR) demands. MIDR is estimated using (Eroglu 2013) prediction equation, which is derived for typical reinforced concrete moment-resisting frame structures in Turkey. The above mentioned predictive model uses magnitude and distance as ground motion estimators whereas R is structural estimator. Single-degree-of-freedom (SDOF) analyses are conducted to derive a relationship on R that is based on Pseudo-Spectral Acceleration at the fundamental period (PSa (T_1)) and yield base shear coefficient (C_y). The probabilistic distribution of R at any specified target hazard level is then computed through the record selection and scaling procedure proposed by (Ay and Akkar 2011). MIDR demand with any specific annual mean exceedance rate may be subsequently combined with the structural capacity leading to the probabilistic damage assessment of frame type structural systems.

KEYWORDS: Maximum interstory drift ratio (MIDR), strength reduction factor (R), target hazard.

1. INTRODUCTION

Significance of lateral displacement demand has been investigated by several researchers. (Moehle 1992) studies the earthquake induced displacement as the design parameter for RC structures. Displacement-based earthquake loss assessment (DBELA) is a new concept introduced by (Silva, Crowley et al.) to derive fragility curves. (Ruiz-García and Miranda 2007) develop a prediction equation for inelastic displacement ratio of single-degree-of-freedom (SDOF) system leading to estimation of inelastic displacement from elastic spectral displacement. The model is basically dependent upon period and lateral strength of the oscillator, however, it has been observed some minor effects of magnitude and distance to site. Thus it may be more convenient to predict displacement demands considering ground motion parameters such as magnitude and distance as in the case of (Tothong and Cornell 2006). The authors of both researches extend their study to probabilistic seismic hazard analysis (PSHA).

SDOF analysis is a simple way to have a crude perception of the whole structure behavior. It is more rational of course to derive the structural response parameters by considering multi-degree-of-freedom (MDOF) systems. Lateral displacement of structures is generally normalized by height producing drift ratio. Residual drift ratio and maximum interstory drift ratio (MIDR) are the most common drift measures addressed in literature. Residual drift ratio plays an important role in seismic damage of buildings whose probabilistic evaluation is investigated by (Ruiz-Garcia and Miranda 2010) and (Yazgan and Dazio 2011). MIDR demand however has become a more common issue for researchers as it is a crucial parameter in estimating structural seismic performance, hence, empirical relations of MIDR and as a consequence MIDR hazard have been given a great effort. (Miranda 1999) presents a predictive model of MIDR based on ductility, fundamental period, modal shapes and building height with a main drawback of requiring a priori knowledge of nonlinear response. Another model is introduced by

(Medina and Krawinkler 2005) taking into account the frequency content, first mode participation factor and fundamental period. (Akkar, Yazgan et al. 2005) modify ground story drift ratio (GSDR) predicted by (Gulkan and Akkar 2002) to estimate MIDR as a function of spectral displacement at fundamental period and Blume's beam-column stiffness ratio. None of the above-mentioned relationships consider magnitude and distance as estimators so implementing any of these relations into conventional PSHA is not possible. Mean annual frequency (MAF) of engineering demand parameter (EDP) such as MIDR exceeding a specified value is computed through integrating hazard curve related to ground motion intensity measure (IM) and probability of EDP conditioned on IM. (Krawinkler, Medina et al. 2003) implement the aforementioned procedure on drift ratio using numerical and analytical integration representing consistency between two solutions. The intensity measure used in the study above is strength reduction factor which is proved to be independent of magnitude and distance. Using the same framework, (Luco and Cornell 1998) derive drift hazard curves with the goal of comparing ductile and brittle connections in steel moment frames. (Baker and Cornell 2005) peruse the effect of epsilon together with spectral acceleration (called as vector-valued IM) on the probabilistic estimation of drift ratio.

As a more recent study Eroglu (2013) creates a new predictive model of MIDR for typical moment resisting frames in Turkey which makes use of magnitude (M) and distance (D) as ground motion estimators together with strength reduction factor (R) as structural parameter. This model enables direct computation of hazard whose significance is highlighted by (Luco and Cornell 2007). The authors try to seek a sufficient and efficient intensity measure concluding that the most appropriate IM is the structural demand itself called as structure-specific intensity measure. As a result (Eroglu 2013) relation is applied for calculating MIDR annual exceedance rate since it eliminates the need of combining ground motion hazard curve with probability of MIDR conditioned on ground motion level.

The proposed approach may be then extended to probabilistic damage assessment of structures as confirmed by (Luco and Cornell 2007) and (Cornell, Jalayer et al. 2002), ultimately resulting in risk-targeted design approach described thoroughly by (Luco, Ellingwood et al. 2007). This research is a joint project among USGS, FEMA and BSSC to modify uniform ground motion hazard maps (2% probability of exceedance in 50 years) to uniform risk maps (2% probability of collapse in 50 years). (Luco and Cornell 1998) also computes design spectral acceleration for a target annual failure probability which is the outcome of comparison between drift hazard and drift capacity.

2. PROBABILISTIC DISTRIBUTION OF R

As mentioned previously, (Eroglu 2013) predictive equation is applied in this study. The hazard is then calculated by integrating the model and the uncertainties present in each estimator. The MIDR hazard is formulated as Equation 1.

$$\upsilon(MIDR \geq midr) = \iiint f(R) f(M) f(D) f(\varepsilon) P(MIDR \geq midr \mid M, D, R) d\varepsilon dD dM dR \qquad (1)$$

Where f is the probability density function related to each parameter and ε is the number of standard deviations below or above median. The only difference between well-known ground motion hazard formulation and Equation 1 is the presence of R.

There are several approaches to handle R in hazard formulation. (Ruiz-García and Miranda 2007) include the effect of R by proposing structure-specific hazard curves for fictitious C_y and T values which necessitates computing structural period and yielding strength. (Krawinkler, Medina et al. 2003) normalizes the intensity measure to base shear strength of the building so there is no need to evaluate the distribution of R independently. This is not the case in this paper as R is an independent estimator in predictive model. (Tothong and Cornell

2006) predicts R based on well-known attenuation models and yield displacement. It is noted that the mentioned method introduces extra uncertainty in the calculations. Strength reduction factor can also be considered as a constant value for design purposes as (Eroglu 2013). This approach is not applicable to probabilistic assessment of structures as the solely goal is displacement-based design.

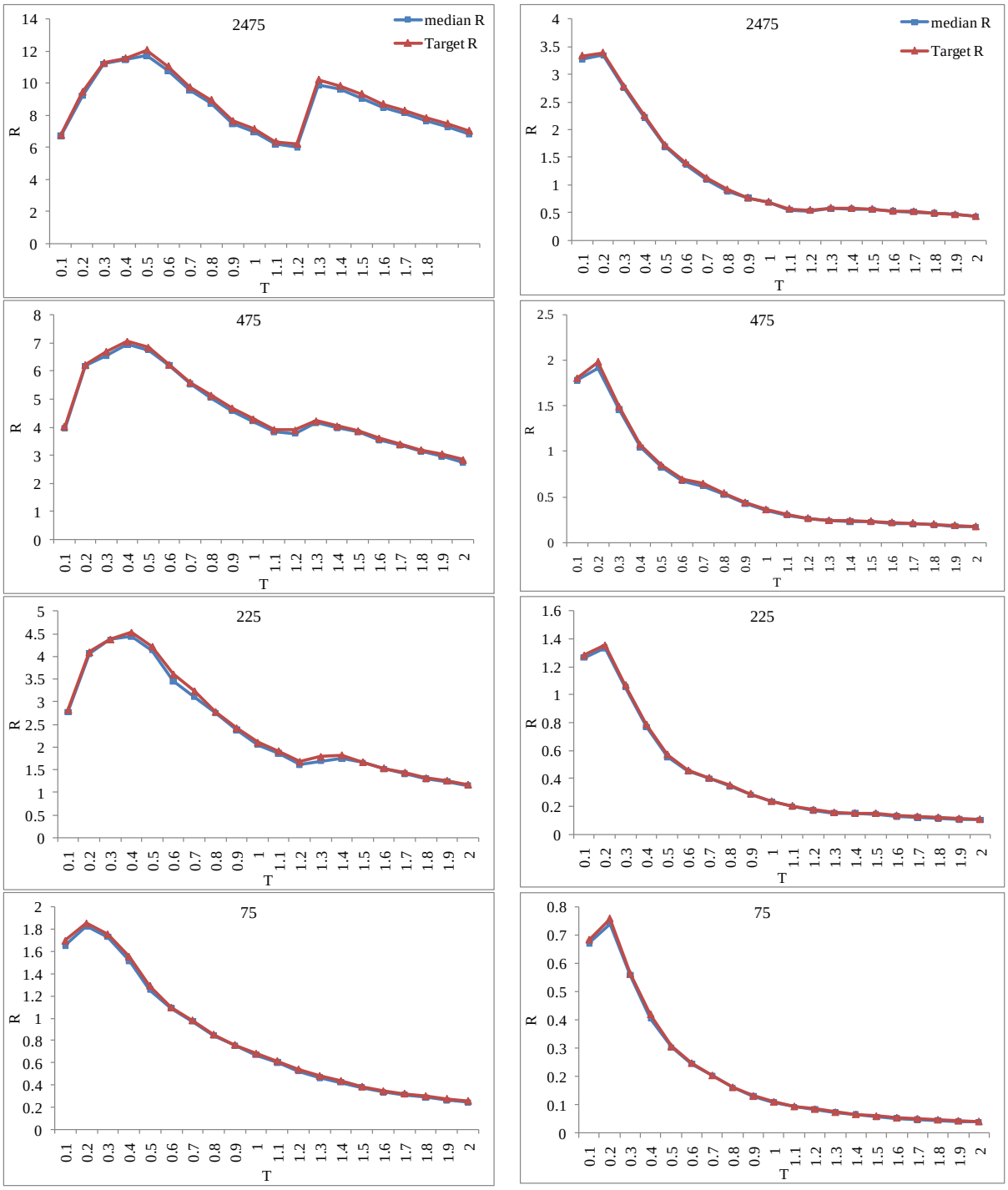
A new procedure is proposed in this study to generate the probabilistic distribution of R based on target hazard level and dominant ground motion scenarios. (Akkar and Bommer 2010) prediction equation is utilized for hazard calculations since it is appropriate for ground motion characteristics in Turkey. The hazard curves are derived for two high-seismic regions, an intermediate-seismic region and a low-seismic region located in Duzce, Sarkoy, Kastamonu and Ankara, respectively in order to observe the effect of regional seismicity.

Deaggregation of hazard curves is performed according to (Bazzurro and Cornell 1999) for four hazard levels with 72, 225, 475 and 2475 return periods. These are the most commonly used hazard levels in building codes for assessment of structural performance.

The ground motion recordings are selected from PEER NGA database and scaled with respect to the target spectral displacement using (Ay and Akkar 2011) method. The approach introduces a median and dispersion for the target intensity in contrary with other scaling procedures that suppress artificially the inherent variability in ground motion intensity level. The median and target R are determined through corresponding values of spectral ordinate divided by yielding base shear coefficient (C_y) that is obtained from static pushover analysis of the structure.

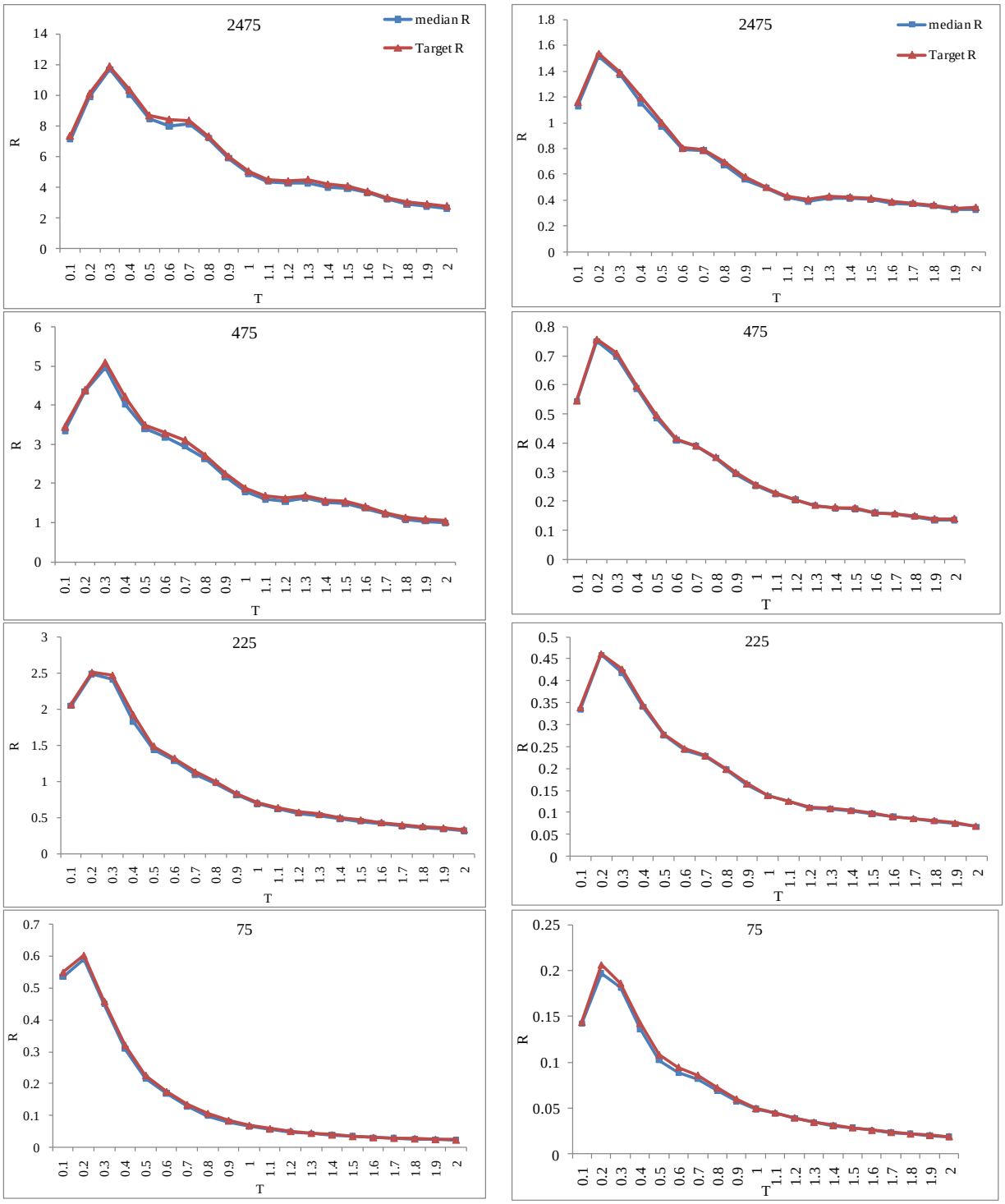
$$R = \frac{PSa(T_1)}{C_y \cdot g} \tag{2}$$

The dispersion of R is the same as spectral acceleration as C_y is a structure specific constant value. The median, target and logarithmic standard deviation of R are shown in Figure 1,2 and Figure 3, respectively for fictitious periods, C_y= 0.2 and aforementioned return periods.



(a) (b)

Figure 1. Median and target values of R for four hazard levels a) Sarkoy seismic region and b) Kastamonu seismic region



(a) (b)

Figure 2. Median and target values of R for four hazard levels a) Duzce seismic region and b) Ankara seismic region

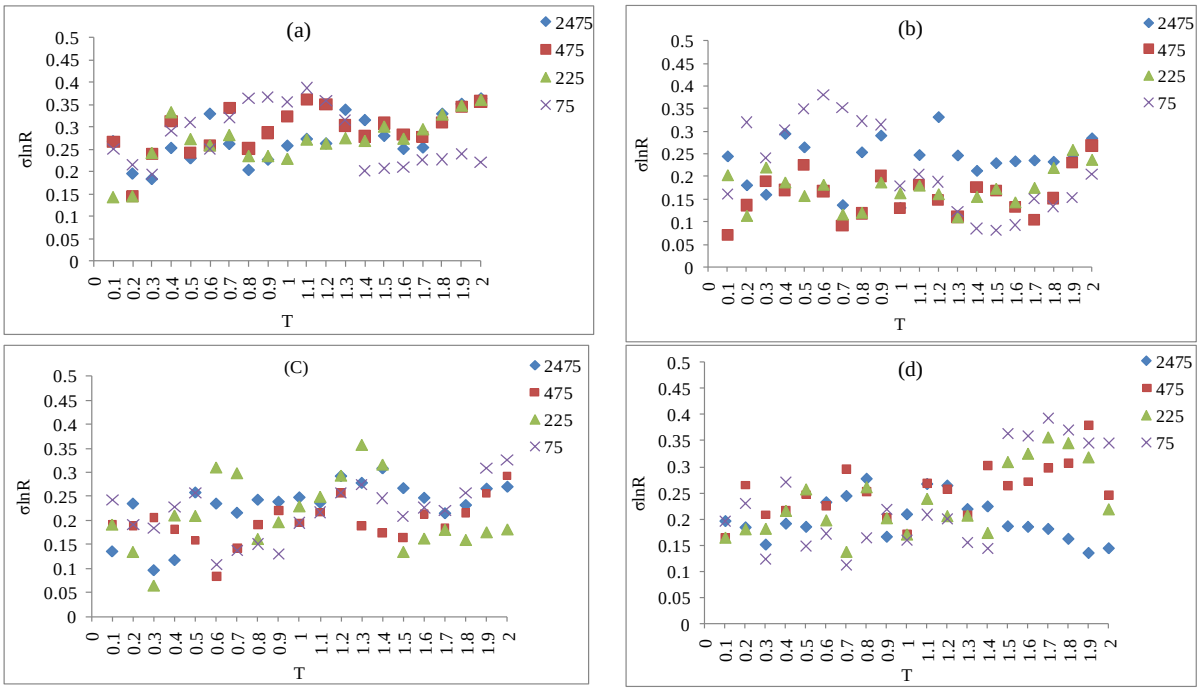


Figure 3. Dispersion of R for four hazard levels a) Duzce b)Ankara c) Sarkoy and d) Kastamonu

It is obvious from Figure 1 and 2 that median and target values of R are in good agreement for all periods and seismic regions. Hence central tendency of R used in Equation 1 can be taken as the specified target R. The dispersion represented in Figure 3 reveals approximately a narrower band for Duzce and Sarkoy known as high-seismic regions. For these regions R values are generally larger than unity indicating inelasticity.

3. EFFECT OF PERIOD

The median and dispersion of R including the whole seismic regions and hazard levels are figured out to investigate the effect of period. Both of the parameters can be proved to be lognormally distributed by conducting 5% confidence interval Kolmogorov-Smirnov test. Assuming lognormal distribution, the effect of period on R_{med} and σ_{lnR} is witnessed easily by calculating their median for each period. Figure 4 is indicative of strong dependency of R_{med} on period. As mentioned previously R_{med} has been selected as a priori according to R_{target} so this is not an unfavorable observation. Unlike R_{med} , σ_{lnR} constitutes a neglegible dependency on period. These findings allow one to use dispersion of R in Equation 1, irrespective of structural period.

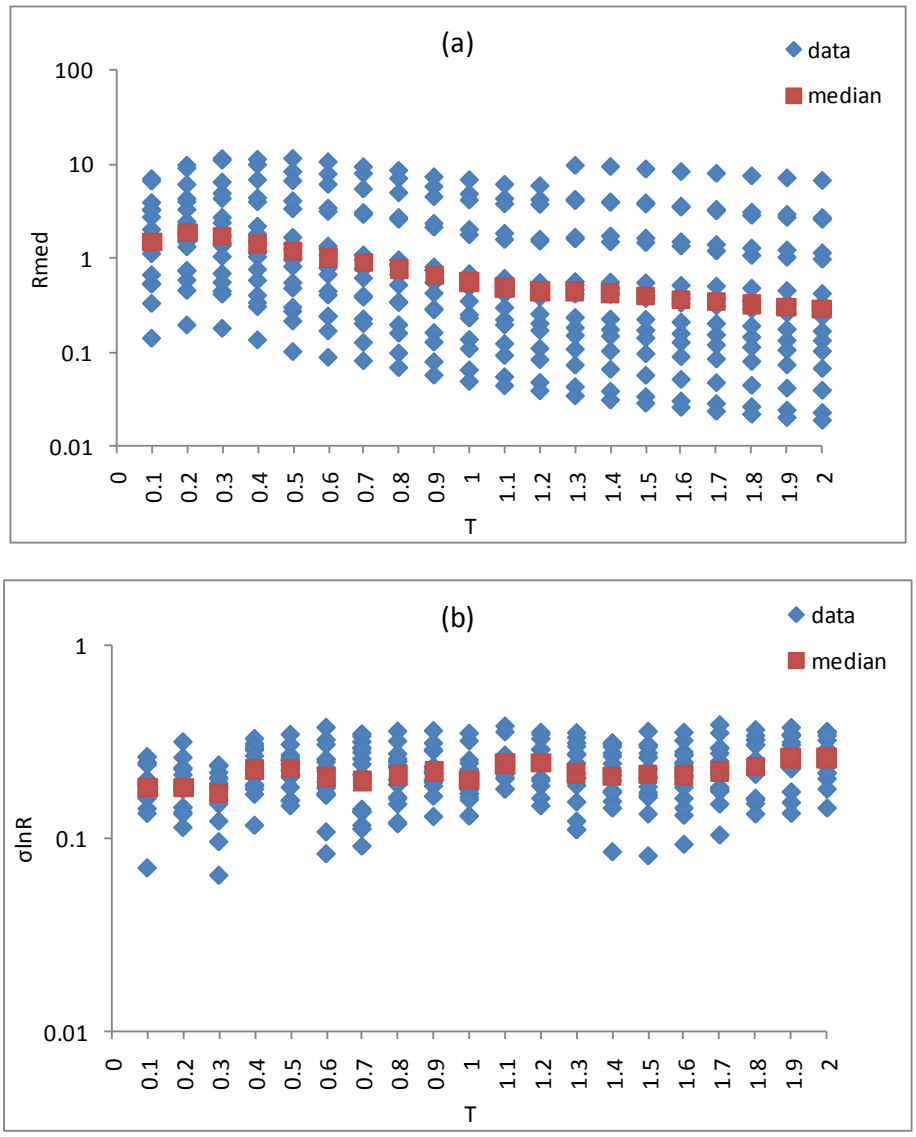


Figure 4. The scatter of a) median R b) dispersion of R versus period

4. EFFECT OF INELASTICITY

In the previous sections it was noted that the dispersion of R is a little bit narrower in case of inelasticity. This leads us to study the effect of inelasticity on R distribution more accurately. This is done by separating the data to elastic (R<1) and inelastic (R>=1) categories. The observations of figure 1, 2 and 3 are generalized to C_y=0.1, 0.3, 0.4 and 0.5 which are demonstrated in Figure 5 as the scatter of σ_{lnR} with respect to R_{med}.

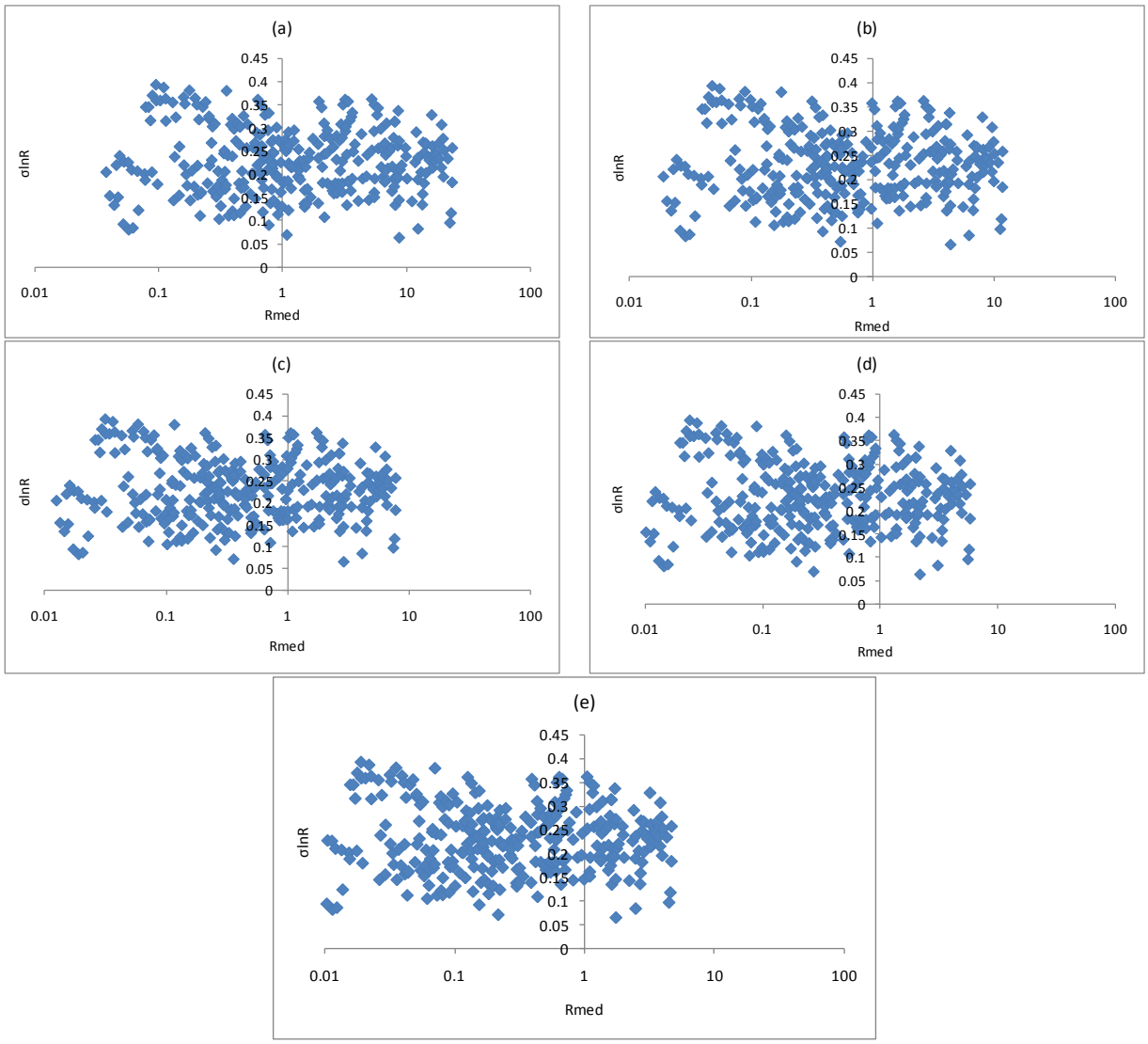


Figure 5. The scatter of σ_{lnR} versus R_{med} for a) C_y=0.1 b) C_y=0.2 c) C_y=0.3 d) C_y=0.4 e) C_y=0.5

It is straightforward to realize the larger dispersion of σ_{lnR} to the left of R=1 axis (elastic case) for all of C_y values. This observation verifies the previous comments on larger dispersion for low- and intermediate- seismic zones. The median and logarithmic standard deviation of σ_{lnR} are calculated in Table 1.

Table 1. Median and dispersion of σ_{lnR} for elastic and inelastic systems

Median of σ_{lnR}					
C_y	0.1	0.2	0.3	0.4	0.5
elastic	0.215652	0.213996	0.214889	0.217279	0.216725
inelastic	0.218944	0.222537	0.222639	0.217824	0.219578
Dispersion of σ_{lnR}					
C_y	0.1	0.2	0.3	0.4	0.5
elastic	0.366431	0.352108	0.344524	0.342654	0.340422
inelastic	0.304681	0.305484	0.311941	0.311191	0.315529

Table 1 is again a confirmation of higher dispersion of σ_{lnR} for elastic case than inelastic one. In contrary with dispersion, the median of σ_{lnR} demonstrates independency of elasticity. Both of the aforementioned observations seem to be applicable for all C_y values meaning that the probabilistic distribution of R existed in Equation 1 is independent of yielding base shear coefficient of the structural system.

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