Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Pseudostatic testing related to damage potential of earthquakes

M. Rodríguez
Instituto de Ingeniería, Universidad Nacional Autónoma de México, Mexico

ABSTRACT: Pseudostatic method of testing has been used by many researchers for studying in laboratory the capacity of structures to resist earthquakes. However it has been criticized because it is not related to a specific earthquake. In this investigation the seismic response of simple structures during strong earthquakes is analyzed and a methodology is proposed to relate pseudostatic testing to damage potential of earthquakes. For a given ductility factor, the damage indexes calculated for a group of pseudostatic loading histories vary over a large range. In some cases they are unconservative when compared with the damage indexes demanded by strong earthquakes.

1 INTRODUCTION

Shaking table and pseudostatic tests have been commonly used by researchers for studying in laboratory the capacity of structures to resist earthquakes. Several shortcomings of the shaking table have limited its use. Among these are the high experimental costs, limitations in the maximum weight and dimensions of experimental models, as well as difficulties in observing the performance of specimens during the short duration of testing. Pseudostatic testing overcomes these shortcomings, however it has been criticized because it does not relate to the strength, deformation and energy dissipation demanded by a specific earthquake.

In this paper the seismic response of simple structures during two strong earthquakes is analyzed and a methodology is proposed to relate a pseudostatic method of testing to damage potential of earthquakes. An energy approach is employed for defining a damage index of earthquakes and pseudostatic testing.

2 PSEUDOSTATIC TESTING

In pseudostatic testing a structure is subjected to displacement controlled lateral loading cycles in which the displacement history is not related to a specific earthquake. Because of the slow rate of applying loads, the strain rate and velocity-dependent damping are considered negligible. Limited experimental studies have been performed for relating pseudostatic and dynamic tests. Oliva et al (1990) have tested large panel precast walls to compare both types of testing procedures. A satisfactory agreement of results from the pseudostatic and shaking table tests was found, particularly in the overall strength vs. deformation envelopes.

A review of the literature shows that a wide range of different displacement histories for pseudostatic testing has been used in experimental research. This has caused difficulties when comparing the structural response of similar specimens tested by different researchers using pseudostatic testing. A sample of various displacement histories which have been used by researchers in pseudostatic testing is illustrated in Figure 1. These are:

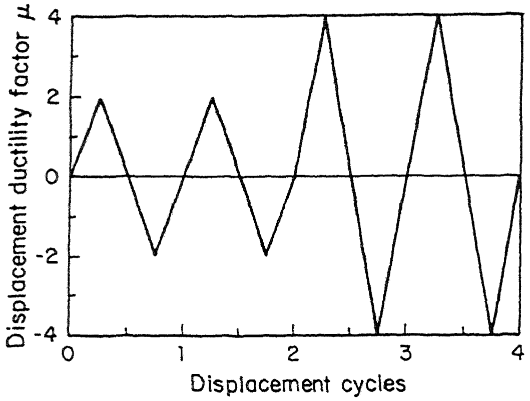
Fig. 1a: Displacement history used in the University of Michigan, USA, Abdel-Fattah and Wight (1987).

Fig. 1b: Displacement history used in the Portland Cement Association, USA, Fiorato and Corley (1978).

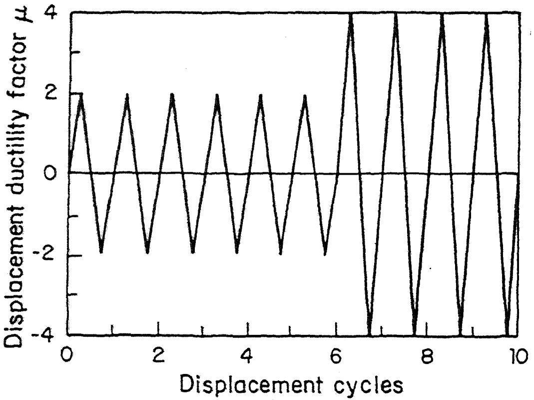
Fig. 1c: Displacement history used in the University of Canterbury, New Zealand, Park (1989).

3 ANALYTICAL METHOD

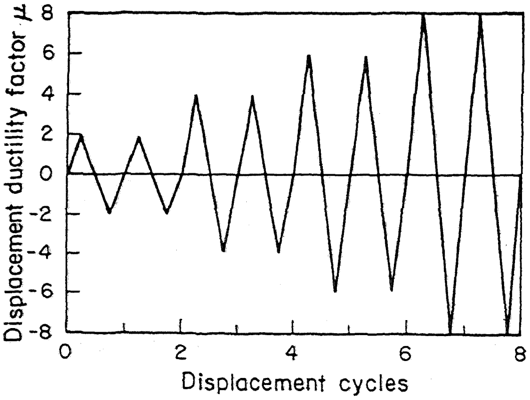
The structure displacement ductility factor is commonly used in earthquake-resistant design of buildings. Although using this factor appears to be a simple way to evaluate or to limit damage, it alone does not account for cumulative damage associated to an earthquake excitation. It has been suggested that an



a) University of Michigan



b) PCA



c) University of Canterbury

Figure 1. Examples of displacement histories employed in pseudostatic testing.

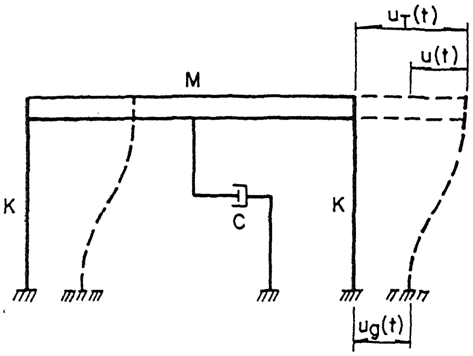


Figure 2. SDOF system subjected to an earthquake ground motion.

earthquake damage criterion should include not only the maximum response but also the hysteretic energy associated to the effect of repeated cyclic loading (Zahrah and Hall 1984). This energy approach is employed in this paper. With this approach an adequate seismic design implies that the energy supply of a structure should be larger than the energy demand.

4 ENERGY EQUATIONS FOR SIMPLE STRUCTURES

The equation of motion for a single-degree-of-freedom structure, Figure 2, subjected to a horizontal earthquake ground motion can be written as

$$\ddot{u}(t) + 2\,\xi\,\omega\,\dot{u}(t) + R(u) = -\,\ddot{u}_g(t) \qquad (1)$$

in which $\omega = 2\pi/T$ where T is the natural period of the structure, ξ = fraction of critical damping, R(u)=resistance per unit mass. Note that R(u) is equal to $\omega^2 u$ for a linear elastic model.

Integrating equation (1) with respect to u yields

$$\int \ddot{u}(t)\,du + \int 2\xi\omega\dot{u}(t)\,du + \int R(u)\,du = -\int \ddot{u}_g(t)\,du \qquad (2)$$

The first and second term on the left-hand side of equation (2) represent the kinetic and damping energies respectively. The third term is the absorbed energy, E_R

$$E_R = \int R(u)\,du = E_S + E_H \qquad (3)$$

E_R represents the sum of elastic strain energy, E_S , and hysteretic energy, E_H .

A computer nonlinear program using a step by step numerical integration was elaborated for solving the above equations. Only the elastoplastic material model was considered.

5 DAMAGE MEASURES

5.1 *Damage potential of pseudostatic testing*

Figure 3 shows a complete loading cycle with displacement ductility factors $+\mu$ and $-\mu$ obtained in a pseudostatic testing. The hysteretic energy, E_H, dissipated by this cycle is the area enclosed by the hysteresis loop, which can be evaluated as

$$E_H = 4\alpha\omega^2 u_y^2(\mu-1) \tag{4}$$

where ω^2 and u_y are the elastic stiffness per unit mass and yielding displacement respectively of the elastoplastic cycle showed in Figure 3, and α is the ratio of the hysteretic energy dissipated in the laboratory loading cycle to the hysteretic energy dissipated in the complete elastoplastic loading cycle. Values for α of about 0.5 have been found in pseudostatic testing conducted by Priestley and Park (1987) on reinforced concrete columns with good confinement and flexural behaviour.

By using equation (4), the total dimensionless hysteretic energy dissipated during an arbitrary pseudostatic loading history is defined as follows.

$$\frac{E_H}{(R_yT)^2} = \frac{\alpha}{\pi^2}\sum_{i=1}^{m} n_i(\mu_i-1) \tag{5}$$

where n_i is the number of full loading cycles at a displacement ductility factor μ_i. μ_m is the maximum displacement ductility factor that the structure experiences during pseudostatic testing. For the sake of simplicity α and the cycles'strengths have been assumed constants for the complete loading history.

5.2 *Damage potential of earthquakes*

A definition of index of damage potential of earthquakes is that due to Zahrah and Hall (1984):

$$N = \frac{E_H}{\omega^2 u_y^2(\mu_m-1)} \tag{6}$$

By modifying equation (6) an alternative index of earthquake damage is defined as follows.

$$N_0 = \frac{E_H}{(R_yT)^2} \tag{7}$$

From equations (6) and (7) it can be shown that

$$N_0 = N\frac{(\mu_m-1)}{4\pi^2} \tag{8}$$

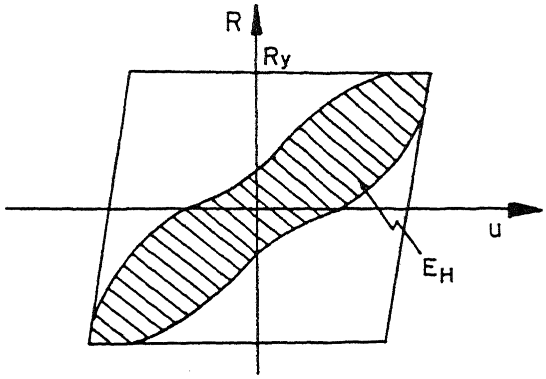


Figure 3. Resistance-displacement curves

Equation (8) shows that N_0 is numerically equal to a fraction of the cumulative displacement ductility factor $N(\mu_m-1)$.

6 COMPARISON OF DAMAGE POTENTIAL OF EARTHQUAKES AND PSEUDOSTATIC TESTING

The above equations suggest a methodology for relating pseudostatic testing and damage potential of earthquakes. It is proposed to evaluate with equation (5) the index N_0 associated to a pseudostatic testing pattern with a specific μ_m value. This index must be compared with the index N_0 evaluated with equation (7) and the energy equations (2) and (3) which must be solved for the same μ_m value of the pseudostatic testing. Using this procedure, damage index N_0 for typical earthquakes and pseudostatic testing patterns are evaluated and discussed in the following.

Two earthquake ground motions are used in this study. One is the well known El Centro record obtained in the Imperial Valley in May 18,1940, and the other is the SCT record, N90E component, recorded in the bed lake of Mexico City during the Earthquake of September 19, 1985. Variation of damage index N_0 of both earthquakes for displacement ductility factor μ_m of 4 and damping ratio of 0.05 is shown in Figure 4. It can be observed that the peaks of the damage index spectrum shape for both earthquakes correspond to different period ranges.

The pseudostatic testing histories used in the University of Michigan (UM) and PCA (both illustrated in Figure 1) were evaluated. In addition, a pseudostatic testing history that would result of using the Commentary of the current New Zealand Code, SANZ Code 1984, was also considered. It suggests that a structure should sustain 4 loading cycles to a displacement ductility factor of 4 in each direction without the horizontal load carrying capacity reducing by more than 20% (Park 1989). This loading history is later referred

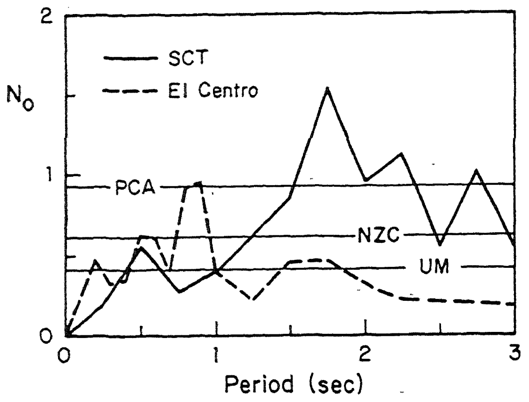


Figure 4. Comparison of damage indexes for pseudostatic testing and elastoplastic systems with μ=4 and ξ=0.05 when subjected to El Centro and SCT motions.

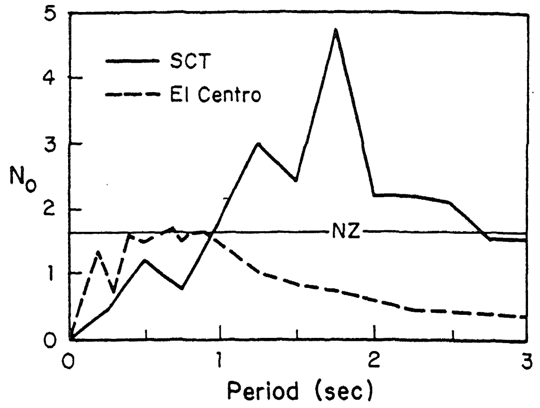


Figure 5. Comparison of damage indexes for pseudostatic testing and elastoplastic systems with μ=8 and ξ=0.05 when subjected to El Centro and SCT motions.

as NZC.

The calculated damage index N_0 for the three loading histories using a α value of 0.5 is shown in Figure 4. It can be observed that these loading histories are related to damage potential that vary over a large range. Figure 4 also shows that the UM loading history is unconservative for the El Centro and SCT ground motions in a wide period range, and the PCA loading history would be unconservative for the SCT ground motion in a some cases of the period range larger than about 1.5 sec. The NZC loading history falls between the UM and PCA loading histories.

The calculated damage potential of the analyzed earthquake ground motions with a ductility factor μ_m of 8 and damping ratio of 0.05 is shown in Figure 5, along with the calculated damage potential for the New Zealand (NZ) loading history (illustrated in Figure 1) with a α value of 0.5. Figure 5 shows that the NZ loading history would be conservative for the El Centro ground motion in a wide period range. However a significant increase in the number of cycles of this loading history would be necessary to adequately represent the damage potential of the SCT ground motion in the period range of about 1 to 2 sec.

7 CONCLUSIONS

1) The pseudostatic method of testing has been criticized because is not related to a specific earthquake. A methodology is proposed to relate an earthquake damage index to a damage index defined for a pseudostatic testing.

2) A group of pseudostatic loading histories is evaluated in this paper. For a given ductility factor,the damage indexes calculated for these loading histories vary over a large range. This shows the need for using an unified and rational approach for defining a pseudostatic method of testing.

3) The damage indexes calculated for some pseudostatic loading histories were found unconservative when compared with the damage indexes demanded by typical strong earthquakes.

REFERENCES

Abdel-Fattah, B. and J. Wight 1987. Study of moving beam plastic hinging zones for earthquakes-resistant design of RC buildings. ACI struct journal,84,1:31-39

Fiorato, A. and W. Corley 1978. Laboratory tests of earthquake-resistant structural walls systems and elements. Workshop on Earthquake-Resistant RC Building Constr., UC, Berkeley.III: 1388-1429

Oliva, M., P. Gavrilovic and R. Clough 1990. Seismic testing of large panel precast walls: Comparison of pseudostatic and shaking table tests. Earthquake eng. struct. dyn. 19: 859-875

Park, R. 1989. Evaluation of ductility of structures and structural assemblages from laboratory testing. Bull of the New Zealand Nat Soc for Earth. Engr. 22:155-166

Priestley, N. and R. Park 1987. Strength and ductility of concrete bridge columns under seismic loading.ACI str journal, 84,1:61-75.

Zahrah, T. and W. Hall 1984. Earthquake energy absorption in *SDOF structures*. *Journal* struct. div. ASCE, 110, 8: 1757-1772