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

Artificial accelerograms consistent with the 1980 Irpinia earthquake

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ABSTRACT: Estimating ground motion at a given site where records of past events are not readily available is an aspect still far from being completely understood and solved. In this a procedure for reconstructing artificial acceleration time histories of bedrock motion consistent with records of past events is presented. The proposed procedure allows to determine the parameters considered most representative of an earthquake from an engineering point of view, such as the peak ground acceleration, the elastic response spectra and the envelope curve of the acceleration time history. Using the proposed procedure, artifical accelerograms were reconstructed for some sites where ground motion was recorded during the Irpinia Earthquake that struck Southern Italy in 1980. The artificial accelerograms generated in this study are in reasonable agreement with the real records in terms of damage potential of structures.

1 INTRODUCTION

Among the unsolved questions related to the design of earthquake resistant structures, one that certainly deserves further attention is the evaluation of the time dependent loading conditions likely to be induced by an earthquake at a given site selected for construction. In fact it is readily understood that, to obtain representative results from structural and soil-structure interaction dynamic analyses under seismic actions, time histories representing earthquake loads must be defined.

Due to the complex nature of the problem, studies and research carried out sofar have been focused mainly on the development of numerical techniques to perform seismic analyses under transient loading conditions while the prediction of ground motion at a site within a seismic region is still a matter of debate.

The first aspect has been extensively investigated, probably also due to the increased storage capacity of modern computers and the reduction of computational costs. Instead the development of reliable and efficient procedures to estimate earthquake induced loads within a seismic area still lags behind.

As a result numerical techniques to perform dynamic response analyses are today readily available for use in engineering practice; on the contrary the selection of representative time dependent loading conditions still involves a great deal of personal judgement.

This in fact involves a two stage analysis. Firstly the intensity and characteristics of ground shaking that can be reasonably expected to occur during the design life of the structure at the selected site must be estimated. Secondly appropriate acceleration, velocity or displacement time histories representative of the estimated ground motion must be selected to express numerically the transient loads that will act on the structure. Accordingly, to provide an improved basis for evaluating the seismic response of structures, the development of procedures that can be used in practice to estimate acceleration time histories representative of a given event is highly desirable.

The purpose here is to present the results of a research on the determination of artificial acceleration time histories consistent with a given event. On the basis of these results a procedure for reconstructing artificial records is thus suggested. The procedure, described in this paper, can be applied in principle to any seismic region for which records of past earthquakes are available and allows to determine bedrock motions for any given distance from the earthquake source. At this stage of the study the proposed method has been applied to obtain motions consistent with the 6.5 magnitude Irpinia Earthquake that struck Southern Italy in November 1980.

In order to check the reliability and quality of the artificial accelerograms, elastic and inelastic response spectra have been calculated using both the artificial and the recorded accelerograms. Some results expressing the damage potential to structures, calculated using the real and artificial motion at some sites where ground accelerations induced by the 1980 earthquake were recorded, are also presented and discussed.

2. CURRENT PRACTICE

Two different procedures are currently adopted to estimate acceleration time histories for use in dynamic analyses given the magnitude of the design event and the distance of the selected site from the earthquake source.

One procedure is based on the assumption that available records of past events may be readily used, provided some adjustments to account for the specific seismic case under examination are made (Seed 1982). Depending on availability, records are selected preferably from data of stations located on outcropping bedrock at a distance from source comparable to that of the design site being considered. When selecting records for use in dynamic analyses only the data obtained during events whose magnitude is close to that of the design earthquake should be considered.

Selected records are then adjusted, usually by scaling, in order to fit the particular case being examined. For example acceleration amplitudes and time intervals can be proportionally increased or reduced to obtain an accelerogram whose maximum acceleration and predominant period are equal to those expected at the site. Given the distance from the earthquake source, the values of the maximum accelerations and velocities as well as of the predominant periods typical of rock motions can be easily estimated using one of the many correlations presented in the literature (Krinitzsky 1987, Seed 1969).

It is readily apparent, however, that record selection and subsequent scaling is quite a subjective process. Also the number of available records increases with time as more instruments are installed in the ground throughout the world and data on new earthquakes are collected. As a result, selection of appropriate records of past events may be in some cases quite a cumbersome task.

In order to make this process simpler, a different approach has been suggested. With this second procedure elastic response spectra are first determined for a given site (Joyner 1985). This is accomplished using appropriate correlations on the basis of knowledge of earthquake magnitude, distance from source and soil profile. Soil types are usually divided schematically into three classes: outcropping bedrock, stiff soils and deep soft soils overlaying rock. Once the response spectra have been determined and plotted, a time history of ground motion can be selected choosing among those records whose spectrum more closely resembles the one previously obtained. Alternatively artificial accelerograms that fit the reconstructed response spectra are generated using suitable numerical procedures (Gasparini 1976).

While the methods just described provide a rather fast and simple way of estimating the load history due to an earthquake, they may lead to quite different results. In fact, in both cases, at some stage during the process the user has to make some choices that depend only on personal judgement. Also there are no standardized criteria for selecting among different records the one which would be most appropriate for a particular seismic area. Moreover the effectiveness of adjustments made with a simple scaling procedure may be highly questionable.

In this respect it should be emphasized that the results of studies carried out sofar are too meagre to establish in which cases the correlations presented in the literature can be extrapolated from one seismic region to another. It should surprise, therefore, if relationships to estimate ground motion parameters, such as peak acceleration, velocity, displacement and predominant period, determined for one area provided good estimate of earthquake motions for other areas.

Furthermore it should be mentioned that at present there is no way to assess the reliability of structural design when earthquake records obtained in a seismic area are used for a different one, though similar with respect to the geological and tectonical settings.

3. RECONSTRUCTION OF ARTIFICIAL ACCELEROGRAMS

For purpose of developping a procedure to reconstruct artificial accelerograms consistent with records of past events it was deemed of great importance to keep as much unaltered as possible the majority of information on the characteristics of the original earthquake. It was further believed that, to obtain artificial records representative of a real event, the fundamental characteristics of the real motion had first to be traced back, and then used to generate the artificial records.

In this study it was assumed that useful information on the characteristics of an earthquake could be derived from the acceleration time histories recorded during the event. Choice of this type of data seems logical considering that accelerograms are currently adopted when representing the loading conditions on a structure and that they bear the inherent characteristics of the event at a given point. Clearly this second condition holds if the modifications due to the process of recording, digitizing and correcting the raw data are minimal and can therefore be neglected.

The parameters used to characterize the 1980 Irpinia event were peak acceleration, response spectra and shape of the accelerogram record. In order to remove any bias due to surface propagation, the acceleration time histories selected for use in the study were transformed to obtain bedrock motions from the data recorded at ground surface. Clearly this analysis, that is usually referred to as deconvolution, was carried out only for those accelerograms that were not recorded on rock. The criteria followed in selecting the records for use in this study and the material properties to model soil behaviour under earthquake loading conditions are described elsewhere (Marino 1991, Viggiano 1991).

Given the acceleration time histories at top of bedrock, the parameters required to characterize the event could be readily determined. In order to define a procedure that could be used to obtain distance dependent acceleration time histories, attention was focused on establishing appropriate correlations to determine maximum ground acceleration, response spectra and accelerogram envelope curves as functions of distance from the earthquake source. The curve relating peak ground acceleration and distance from source for motions on outcropping rock, and for bedrock motions obtained after deconvolution of surface records on soil deposits, is shown in fig. 1. In the same figure an average curve taken from the literature for 6.5 magnitude earthquakes (Seed 1976) is also included for comparison. Though the two curves are similar in shape they are shifted and yield different values of peak ground acceleration.

With respect to the analysis of response spectra and shape of accelerograms, it is worth noting that curves cannot be uniquely represented by a single numerical value. To estabilish tentative correlations relating the curves of the response spectra and of the envelope of

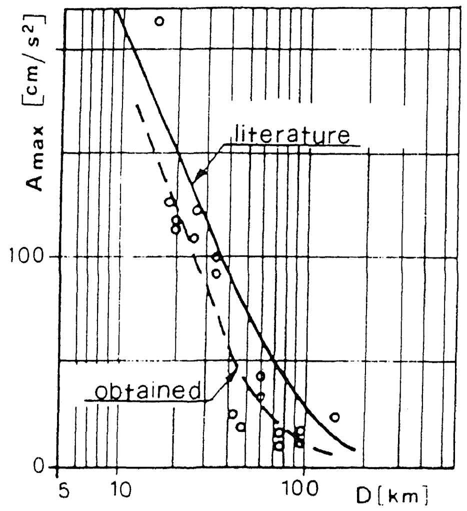

Figure 1. Peak acceleration, A_{max}, vs distance, D, from earthquake source for bedrock motions.

accelerograms with distance from the earthquake source, a procedure suitable for both types of curves was specifically developed. Curves were first discretized in several small intervals along the abscissa as shown schematically in fig. 2. Then a single numerical value was assigned to each interval in which the range of frequencies, for response spectra, or the duration, for acceleration time histories, were divided. Each numerical value was obtained as the area of the interval limited by the curve. The different values pertaining to each interval, obtained from the different records, were then plotted against distance from source. In fact each accelerogram and related spectra refer to a precise station, hence to a definite value of distance from the earthquake source. Accordingly a set of curves, each one referring to a particular frequency or time interval, was obtained. Fig. 3 shows the correlation between values of the area of the first interval, area 1, for the 20% damping pseudovelocity spectra and the distance from the earthquake source. Values of area 1 for envelope curves of accelerograms, obtained following the same criteria, are given in fig.4.

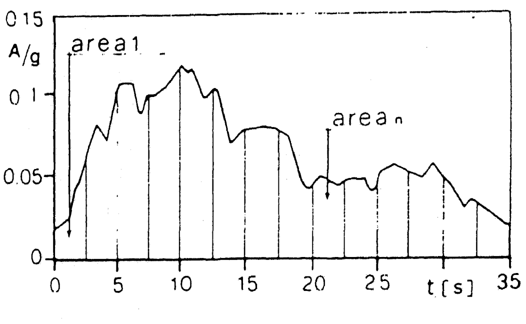

Figure 2. Scheme for discretizing curves to obtain correlations with distance from earthquake source.

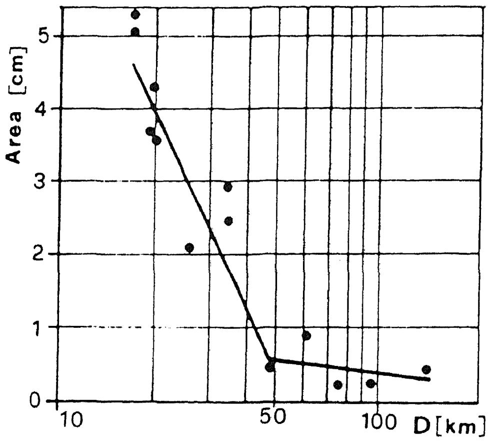

Figure 3. Values of area 1 relative to pseudovelocity response spectra vs distance from the earthquake source.

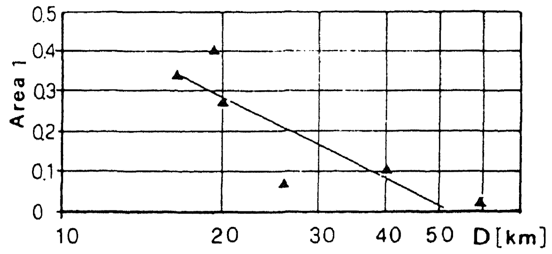

Figure 4. Values of area 1 relative to envelope curves vs distance from the earthquake source.

Once correlations as shown in figs. 3 and 4 have been established, these can be readily applied, together with fig. 1, to estimate the parameters needed for reconstructing the artificial records, given the distance from the earthquake source. To obtain the artificial acceleration time histories, a numerical procedure capable of generating synthetic quakes consistent with the above defined parameters was used (Gasparini 1976).

In order to check reliability and quality of the results, the artificial records were reconstructed for distances from the earthquake source equal to those of the stations where ground motion during the 1980 earthquake had been recorded. For each selected site 8 artificial accelerograms were recostructed. Response spectra and shape curves for the eight acceleration time histories were then calculated and averaged. A comparison between the averaged pseudovelocity elastic response spectra (20% damping) for the artificial and real motions relative to the station Bagnoli is presented in fig. 5. Similarly, envelope curves of the two motions for the station Calitri are compared in fig. 6.

4. COMPARISON OF DAMAGE POTENTIAL

In order to evaluate the effectiveness and reliability of the procedure developed in this study to reconstruct artificial

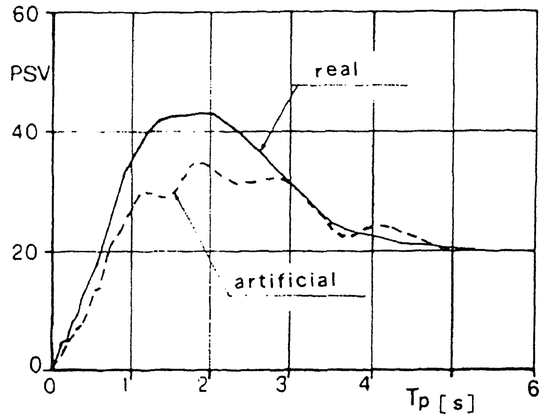

Figure 5. Comparison between pseudovelocity response spectra of real and artficially reconstructed motions for the recording station at Bagnoli.

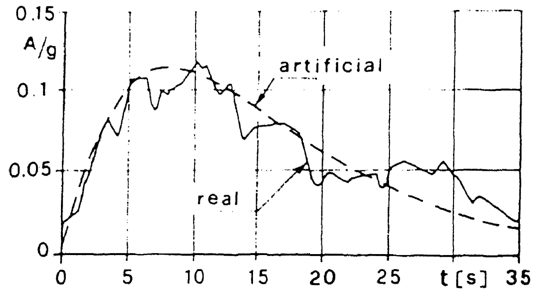

Figure 6. Comparison between envelope curves of real and reconstructed motions for the recording station at Calitri.

accelerograms consistent with a given earthquake, a comparison between the effects of real and artificial motions on the behaviour of structures is proposed. At this aim, besides comparing elastic response spectra, it is necessary to analyse the non linear behaviours of single degree of freedom systems. At this stage of the research the simple elastic perfectly plastic hysteresis law has been considered. The initial period has been varied in the range of interest for real structures, i.e. between 0.2 and 2.0 seconds.

To express the damage potential many different indicators have been proposed in the past (Powell 1988). For R/C structures many authors agree in proposing an index which is a function of a displacement ductility and of the normalized total energy dissipation (Banon 1982, Park 1985). However there is not a complete agreement on the type of function. For this reason in this paper the Cyclic Displacement Ductility CDD and the Normalized Dissipated Energy NDE are analysed separately.

They are defined as:

$$CDD = (u_{max} - u_{min}) / u_y$$
$$NDE = E_{dis} / E_y$$

where:

u_{max} = maximum displacement;
u_{min} = minimum displacement (negative);
u_y = yield displacement;
E_{dis} = total dissipated energy;
$E_y = F_y u_y$.

For each group of eight artificial accelerograms relevant to a given site and for the two components of the corresponding recorded ground motion, the two above defined indicators have been evaluated. The yielding strength F_y of the SDOF system has been taken equal to:

$F_y = \nu m a_g$.

Where ν is taken equal to 0.25 or 0.50, m is the mass of the SDOF system and a_g is the peak ground acceleration of the artificial accelerograms evaluated using the regression curve of fig. 1.

The damage indicators obtained for each group of eight artificial accelerograms have been averaged and divided by the indicators obtained for the corresponding real accelerograms (EW and NS components). These ratios have been further averaged for the different sites, to obtain the average ratios shown in figs.7, 8, 9, 10.

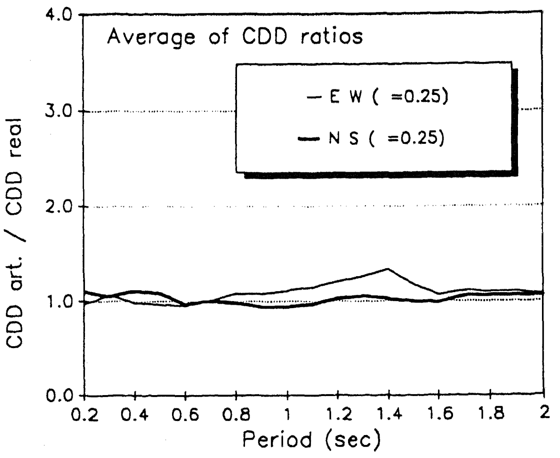

Figure 7. Average ratios of the Cyclic Displacement Ductility for $\nu = 0.25$.

As can be seen, the average ratios of the Cyclic Displacement Ductility for different periods oscillates around the unitary value with maximum errors of the order of 50%. The agreement is particularly good for $\nu = 0.25$ (see fig. 7), which represents the most interesting cases from a practical point of view. For the Normalized Dissipated Energy the values of the ratios are somewhat higher and vary generally between 1 and 2. The agreement is again better for $\nu = 0.25$ (see fig. 9).

CONCLUSION

The design of earthquake resistant structures in seismic areas requires an estimation of the time dependent loading

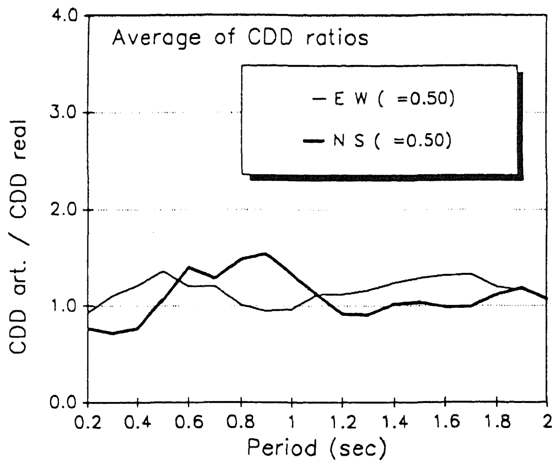

Figure 8. Average ratios of the Cyclic Displacement Ductility for v = 0.50.

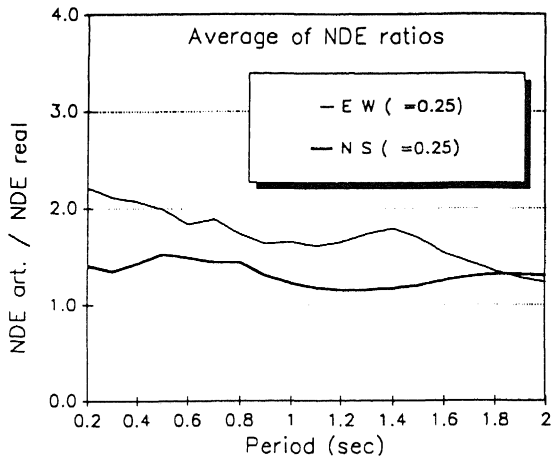

Figure 9. Average ratios of the Normalized Dissipated Energy for v = 0.25.

conditions that can reasonably be expected to occur during the design life at the site selected for construction. The results of studies and research completed sofar are still too meagre to assess if the procedures presently available for estimating ground motion parameters can be used indifferently in any seismic region.

The study decribed herein represents an attempt to define a procedure for reconstructing artificial acceleration time histories of bedrock motions consistent with available records of past events. For this purpose some correlations have been established to obtain the fundamental characteristics of the artificial motions, such as peak acceleration, response spectra and envelope curves of the acceleration time history, given the distance from the earthquake source. The quality and effectiveness of the artificial records in predicting earthquake effects on

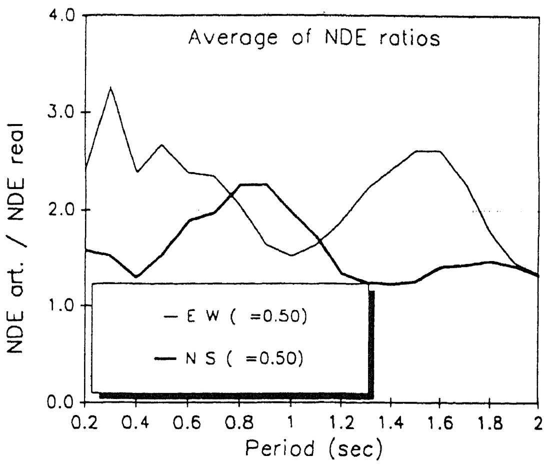

Figure 10. Average ratios of the Normalized Dissipated Energy for v = 0.50.

structures has been checked comparing elastic and inelastic response spectra obtained from both artificial and real motions for the same site. The reasonable agreement would seem to indicate the potential applicability of the procedure described for use in engineering practice and certainly encourages to pursue this line of research.

However, further analyses and investigations are needed to reach a full understanding of the obtained results and to improve the proposed procedure. In this respect some points should be stressed. First it should be observed that no distinction was made between the two horizontal components of the recorded motion. Secondly the dependence of the earthquake characteristics only on the distance from the earthquake source is a too simplified way to take into account all the aspects of the complex phenomena that take place in seismic wave propagation. Finally a better estimation of the soil profiles underneath the recording stations and relative mechanical properties would certainly lead to a better evaluation of the bedrock motions.

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