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# SITE EFFECTS AND CONSIDERATIONS FOR SEISMIC CODE RENEWALS

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## ABSTRACT

Some recent studies have attempted to attract attention to the cases where the approach of linear spectrum, widely used in design practice, appears to be insufficient. Indeed, earthquake ground motion surges in several directions during a seismic event, which is reflected in yhe motion of oscillators on the quaked zone. Thus for each orientation of the oscillator there corresponds a linear response which occurs at a certain time. For a specific value of period, a least upper bound occurs at a specific orientation of the oscillator, at a specific instant. This situation specifies an envelope for the set of linear spectra referred as "planar spectrum" by the authors. The scope of the presented report extends to summarize the investigations based on the records of two recent heavy earthquakes, within the objective of determining envelopes of spectral values and formulating suggestions related to planar response concept for future codes.

## KEYWORDS

Planar response, planar spectrum, seismic code renewal.

## INTRODUCTION

More than half of the existing and future structures on the world are located on eathquake prone regions. Increasing sensitivity around the seicmic design is therefore logical. Seismic codes are on the way to become fundamental engineering documents an tools for the relevant design. Within this context, the attention is more and more focused on such contempory concepts as dynamic behaviour, spectral analysis, mode combinations etc... . Indeed, lot of progressive and new concepts have found place in modernized national codes & standards and international recommendation documents, which exhibit, on the other hand, weaknesses and uncertainties. Observations and studies on dynamic response of multistorey structural systems have led to adopt complex modal behaviour. But, handling this complexity by mathematical means is not a completely settled procedure, yet. Total response formed by modal components is generally based on the technique of square root of sum of squares (SRSS). Combined responses are functions of the ground motion characteristics as well of the structural features of the investigated load bearing system. Details on its formulation will be given in coming chapters.

Two major variables associated with responses, that could contribute to establish more realistic modal combinations, were introduced by the authors in their recent publications (Karaesmen and Erkay 1994). They are: "Orientation of the oscillator motion" and "Time of the ground motion as measured from the beginning of the quake".

Both variables are valuable operational factors which can be used to describe modal complexity in a visual way more completely. They both have, at the same time, intrinsic value of reflecting multidimensional aspects of an earthquake motion due to the nonuniform formation of the earth crest. Indeed, during few seconds of a strong quake, waves are released to the earth crest surging in several directions. The published findings of the authors' computations on records of the 1992 Erzincan Earthquake had exhibited this multidirectional character of the motion clearly. More recent investigations of on the October 1st 1995 Dinar (Turkey) Earthquake has yielded too, in results showing this multidirectional particularity.

These facts widely suggest that a strong motion surging in several directions as a natural site event could not be idealized in spectral diagrams resulting from a linear motion. Each investigation of seismic effect should deal with a set of linear spectrum diagrams and finally an envelope of them should be described as reflecting the most realistic spectral response. This spectrum is qualifiable as a "planar spectrum" since it translates the full planar responses during a strong quake. It should be noticed that planar response is reached in a specific orientation at a specific instant. Conjunct effect of these specific values of two parameters could be referred with qualification of planar spectral direction and time.

This report aimed to refresh newly developing concepts of planar response and planar spectrum, and to introduce comments on the site measurements obtained during the March 13th 1992 Erzincan Earthquake and the October 1st 1995 Dinar Earthquake, within this perspective. Suggestions are also developed for formats through which these realistic approaches could be included in Codes and Standards.

## THEORETICAL CONSIDERATIONS

Spectral analysis is a contemporary tool used to evaluate the seismic effect on structures, and multiple mode concept is widely adopted in design practice as well as in codes and standards. Orientation effects are taken into consideration using linear response spectra in two perpendicular directions The procedures already used are rather rough approximations leading sometimes to almost erronious results, as already pointed out by some investigators. (Singh and Chu, 1976; Wilson and Kiureghian et al, 1981).

### Description of Two New Major Parameters

In eigen analysis, which is the essential tool in determining the seismic effects on a structure, the bearing system is decomposed into uncoupled linear oscillators. But, each oscillator may be oriented in any direction on horizontal plane and therefore the response should be determined orienting the oscillator in the direction which yields the largest value. This response had been referred to as "planar response", by the authors. Critical importance of the oscillator orientation was also pointed out by some other observers. (Safak and Bendimerad, 1988). Althogh the orientation of the ocsillator constitutes an essential factor in description of a strong motion, it is not the sole effect on a seismic action. It is conjunctly interrelated with the spectral time. Oscillator orientation adopts a specific critical direction in which planar response occurs, at a specific instant. These two specific parametric values, associated with the planar response, could be referred a "planar spectral direction" and "planar spectral time". It is to be noted that the occurrence of a response need not be unique, while generally it occurs only once, in its positive value, during a ground motion.

To visualize the physical phenomenon, consider an oscillator generating horizontal displacements (u) in some direction $\Theta$ as shown in Fig.1. The ground accelerations are resolved into two perpendicular directions (1) and (2). In Fig.2, the displacement response, S, is sketched corresponding to each orientation, $\Theta$, of the oscillator, for a given period (T). The least upper bound of these responses is specified to be the "planar response", corresponding to the period under consideration, and the associated direction happens to be the planar spectral direction as defined above. The instants of the motion could be defined with times measured

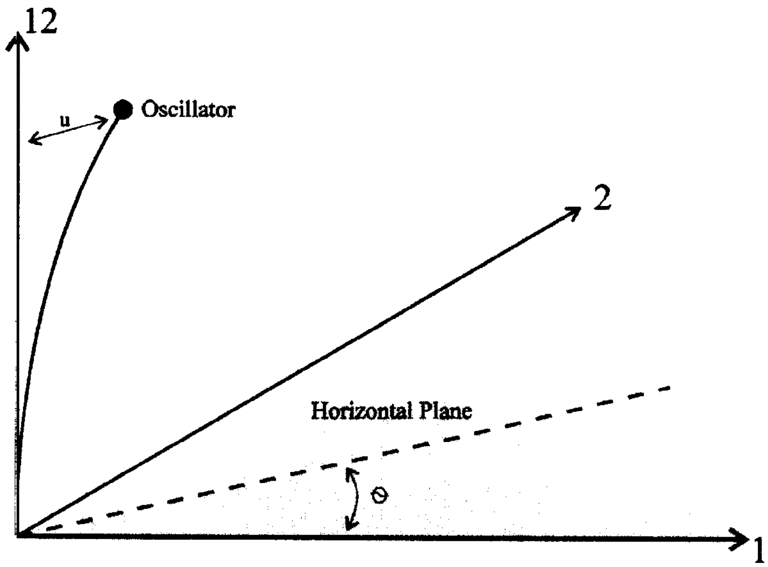


Fig.2. Oscillator orientation on horizontal plane

referring to the beginning of the earthquke. The very instant at which the displacement of the oscillator arrives to the least upper response value is defined to be the "planar spectral time" . Thus, three spectral quantities are associated with each value of the period.

It should be noticed that each linear spectrum diagram may be plotted over the line determined by the direction of the ocsillator, thus yielding a three dimensional representation of the set of linear responses, for a given period. The sketch given in Fig.3, shows such a representation, together with the planar response values. For each value of T, the planar response will be the least upper bound of the responses on the circle of radius T. This is a representative visualization of the situation referred by some authors as three dimensional spectral occurrence. (Penzien, 1975).

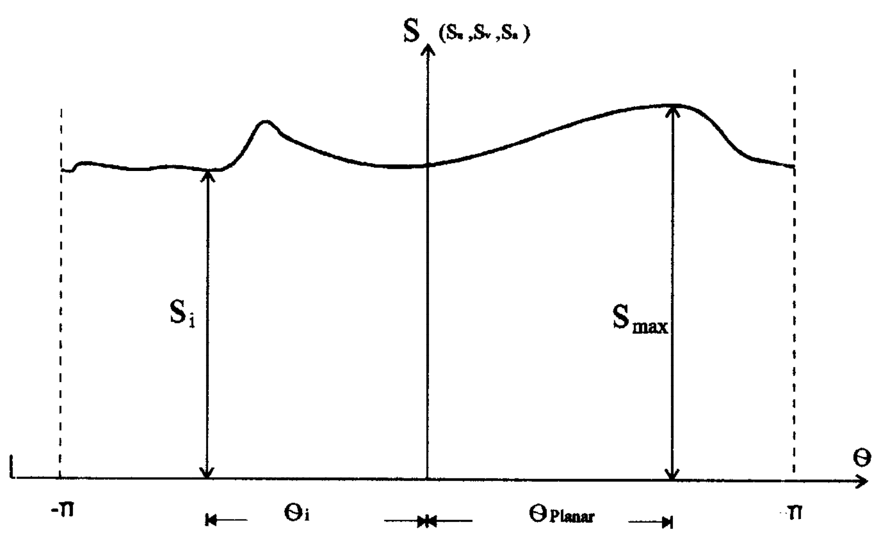


Fig. 2. Variation of S=f(θ) for a given period T

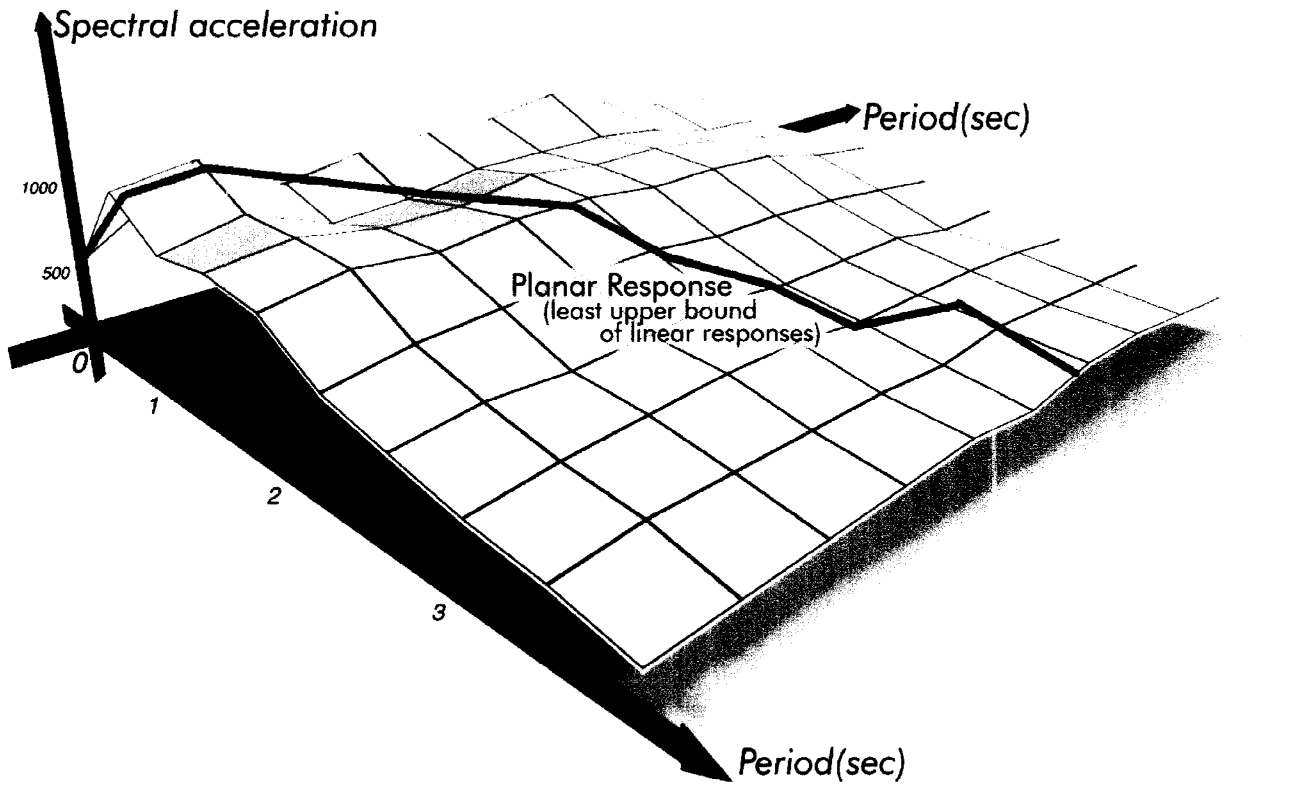


Fig. 3. Planar response versus linear responses : three dimensional representative diagram

Design Aspect

The design practice of ordinary structures may not necessitate detailed seismic evaluations. However, complex structures with unusual shapes and with large heights are increasingly more constructed in seismic zones. A more suitable and safe evaluation of seismic effect is appropriate for such structures, since earthquake effects may be prohibitive sometimes.

It is known that the widely accepted SRSS (square root of sum of squares) combination method may lead to almost erronious results deviating from the actual values considerably, especially in cases where the periods are close each other. There are attempts to establish a more realistic combination rule. Planar spectrum concept seems to provide a fundamental facility in this respect, by introducing two more parameters associated with each response.

More specifically, if a quadratic form for combination is adopted, the combined value (R) of a structural quantity (such as a force component or of a displacement component) may be expressed as

$$R = \sqrt{\mathbf{F}.\mathbf{C}.\mathbf{F}} = \sqrt{\Sigma F_i.C_{ij}.F_j}, \quad (1)$$

where (**F**) stands for the structural quantity vector whose components would correspond to the modes under consideration, and (**C**) is the combination matrix correlating the responses. Elements of (**C**) are functions of several variables, including response characteristics of the structure. It should be remembered that the two parameters, the planar spectral time and the planar spectral direction, associated with the planar response, may aid to establish a more realistic combination matrix (**C**).

Design aspect of the problem is closely related to the code formats. Codes and equivalent documents usually provide graphical information on spectra which is presented under idealized forms of bipartite or tripartite diagrams. (ATC, 1978; AASHTO, 1991). The planar spectrum or any procedure utilizing it is not included in the codes, yet. It should be hopefully expected that the future modifications and enlargements in the codes, would comprise the planar spectrum concept as a design tool.

## CASE STUDIES

Site measurements of two heavily damaging earthquakes which occurred in Turkey constituted valuable sources of numerical informations: The March 13th, 1992 Erzincan Earthquake and the October 1st, 1995 Dinar Earthquake.

### Summary of Findings for Erzincan:

The March 13th 1992 Erzincan Earthquake, evaluated as an event of magnitude 6.8 on Richter scale, has hazarded more than 5000 dwelling units and killed 600 people. A full set of accelerographical data had been obtained and following a long numerical process in accordance to the theoretical approach described above the planar spectral values had been determined. Computations of the planar acceleration with a damping ratio of 0.05 had yielded in a spectrum diagram. This diagram which differs from all linear spectral acceleration diagrams evaluated for this earthquake, in shape and in numerical values; since the responses of each period obtained by this process constitutes the least upper bound of the responses of the same oscillator for all directions on the plane. This spectrum which is qualified as planar spectrum has the fundamental feature of uniqueness, and is considered the only mathematical output of representative character for the earthquake.

### Dinar Earthquake: Overall Description

Dinar, a southwestern town of 35000 population of Anatolian Peninsula, experienced a medium size eathquake on October 1st, 1995. Geological deformations and structural hazards in the town and in its vicinities were revealed at a higher degree than that of the geophysical features (magnitude was 6.1 Richter, only) would lead to imagine. Responses were amplified especially at the urban zones of deposit soil, as seen in Fig.4. which also indicates unfortunate accumulation of conceptual errors and contructional mistakes. Around 100 were killed whose 90 in urban Dinar and altogether 8000 urban and rural dwelling units were touched at various severity. (TUBITAK, Turkish Council of Scientific and Technical Researches, 1995).

### Planar Spectral Accelerations for Dinar

Accelerogram records were made available for each interval of 0.005 seconds of the earthquake. Measurements came from the Dinar Meteorological Station installed at city center.

According to the above described theoretical considerations a full investigation of planar acceleration for Dinar Earthquake have been achieved. First, the ordinary linear response spectra are evaluated for North-South, East-West, and Vertical directions. The shapes of the two horizontal spectra differ from each other, as should be expected.

As for the planar spectra, the displacement responses along with the associated directions and the times of occurence, are evaluated first through time dependent oscillator motions, for each value of the period. The time dependent motion of an oscillator oriented in some direction, $\Theta$, may be obtained directly from time dependent solutions for +L (South) and +T (East), due to the linearity of the governing differential equations. This fact facilitates the computations greatly. The response velocity and acceleration spectra follows from the displacement spectrum.

Fig. 4. Structural hazard : 1995 Dinar Earthquake

The results are summarized in the form of diagrams reproduced consecutively in Fig.5. The diagram at the top is the planar acceleration spectrum, the following two are the diagrams of associated fundamental characteristics: planar spectral direction and planar spectral time. All three characteristics are plotted as functions of period of the same scale.

## Base Shear Coefficients for Dinar

The two essential seismic parameters used in design are the coefficient of Effective Peak Ground Acceleration ($A_a$), and the coefficient of Effective Peak Velocity-Related Accelleration ($A_v$). The maximum value of the magnitude of the ground acceleration vector is MGA=338.27 mG, as determined from records.. The site values of effective peak spectral velocity and effective peak spectral acceleration are EPSA=1070 mG and EPSV=136.9 mG.sec, respectively, as determined in correspondence with the tri-partite idealization of logarithmic spectral velocity graph. These results yield the site values of the design parameters as $A_a$=0.339 and $A_v$=0.860. As the peak value coefficient $A_p$, it is computed as 1.070.

If the Applied Technology Council (ATC) expression ($C_{sm}$) is used for the design value of spectral acceleration, then both $A_a$ and $A_v$ may be taken 0.428 for rock conditions, assuming a soil profile type S2 at the site.

## Some Significant Comparative Values

Numerical findings related to planar responses and base shear quantities for the two earthquakes investigated by the authors, yield in following results:
a) The March 13th 1992 Erzincan Earthquake had been evaluated as adopting a planar acceleration response with numerical values larger than computed equivalent values for the October 1st 1995 Dinar Earthquake. Peak values have been computed 1671 mG and 1317 mG, respectively, for Erzincan and Dinar. The acceleration values of the two diagrams happened 15-20% higher for Erzincan than that of the Dinar in the laps of period values between 1.0 and 2.5 seconds.
b) Planar spectral acceleration values of both earthquakes, were above the linear spectral diagrams evaluated by classical methods already in use, as should be. (Peak values of linear spectra in two main perpendicular directions computed as 1602 and 881 mG versus 1671 mG for planar response. Other values of linear spectrum had remained, respectively, 3-8% and around 40% lower than planar response values. For Dinar,

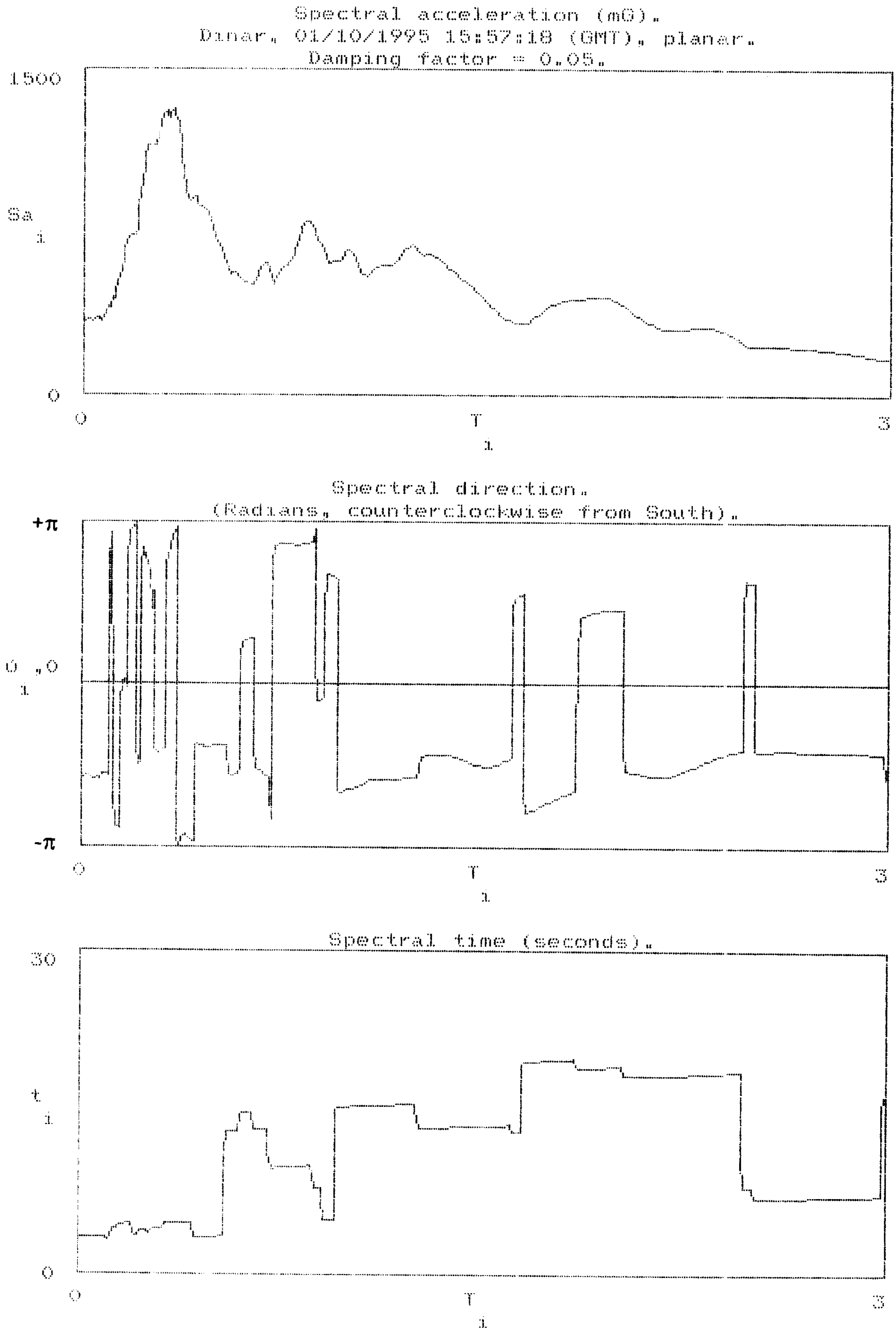


**Fig.5. Planar Spectral Characteristics for 1995 Dinar Earthquake**

peak values of linear spectral accelerations were 1268 and 1290 mG versus 1317 mG for planar response. All other planar response values corresponding to all other period values were also, naturally, larger than linear spectra values.).
c) As for the base shear aspect; the values of $A_a$ and $A_v$=0 for rocky soil conditions defined by coversion from S2 type of stiff clayey soil specified by ATC, have been evaluated as 0.582 and 0.630, respectively, for Erzincan. They remained around 0.428 for Dinar as converted to comparable soil conditions for the site.

It should be reminded that Dinar Earthquake was a smaller event than Erzincan Earthquake as above provided comparative information indicates, too. But the structural hazard was heavier than this comparative findings would lead to imagine. Necessity of establishing an extensive and efficient mechanism of construction of quality control in seismic zones of the country is once again strongly felt.

## CONCLUDING REMARKS

Present report stresses the critical importance of planar response of structures during a strong motion. No linear response corresponding, for a specific value of the period, to any direction may exceed the planar response which constitutes the least upper bound of them all.

Thus, planar spectral acceleration graph covers all the linear acceleration spectral diagrams since it happens to contitute an envelope for them. Within this context the authers tried to contribute to develop a systematic computational process for a safer seismic design. Indeed, in design engineering media, the attention is basically oriented to practicle methods provided by codes and equivalent official documents under well established and simplifed formats. To approach closer to the physical reality, while remaining at the safe side are the recommendable attitutes for serious professionals. Within this framework, the future codes should formulate clear requirements in view of including planar response parameters in evaluation of combination matrix, C, correlating modal responses.

Observations and investigations on planar response facts in all earthquake prone countries are hopefully expected to be compiled, soon, in order to generate more coherent and realistic code definitions. On the other hand, more extensive site measurements in seismic regions are wishfully expected, since more realistic and safer approaches as attempted by the authors are widely based on the outputs of site records.

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