STUDY OF DANGEROUS ASPECTS OF NEAR-FIELD SEISMIC MOTIONS BASED ON DYNAMIC ELASTO-PLASTIC MODEL

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A nonlinear dynamic analysis of SDOF structure subjected to near field records were examined. Acceleration records were used as input to the structural system with bilinear (elasto-perfectly-plastic) stiffness hysteretic relationship. Time-history response, spectral values and energy content properties of the records were studied, revealing high damage potential due to long duration pulse of the records in the near field. The results showed the maximum displacement ductility is significantly big and corresponds with the time when the peak of long duration pulse happened. That big demand of ductility is usually accompanied by large amount of energy that should be dissipated by the system in a short time.

1. INTRODUCTION

The 1994 Northridge and the 1995 Hyogo-Ken Nanbu (Kobe) are the most important earthquakes recorded in the near field that left severe damage in engineering structures. These are the first large sets of strong motion data include the near field records from a crust (18 km depth) earthquake in Japan and the United States. This information will be very useful for evaluating the criteria that are currently used in the seismic resistant design of structures. The Northridge (Sylmar and Newhall) and Kobe (Kobe, Takatori, Kobe University) records show long-duration acceleration pulses giving large response spectral values, never before reached for any earthquake in the near field.

Because of insufficient and representative records available, different characteristics of the Ground Strong Motion in the near-field were not well studied. The damages cause by this type of shock seismic movements call for an urgent review of analysis with this kind of seismic waves.

Therefore the studies of the significance of long duration pulses, high peak acceleration, characteristics of near field records, in the time history response analysis and its spectral values, are very important for the evaluation of demand side and capacity side of structures and for the development of practical aseismic codes.

2. METHOD OF ANALYSIS

A single degree of freedom (SDOF) models with 5 percent of critical damping were considered and a bilinear structural model restoring force relationship with equal yielding point in the two directions of displacement.

The responses were calculated for different yielding strengths and ductility values. The yielding strengths Cy, defined as the quotients of the lateral force that causes yielding in the structure to the structure weight were set to 0.2, 0.4 and 0.6, to investigate the response of structures. Special focus was put to Cy=0.2 that was the yielding strength value of many severely damaged wood housing and another type of existent structures during the Kobe earthquake.

From the point of view of control ductility in the design of structures, the responses were found for the ductility values of 1(elastic case), 2, 4, 6 and 8 to check the yielding strength requirements.

The earthquake energy absorption in single degree of freedom are also investigated$^{1)}$. The range of time and amount of energy imparted in the structures and the amount of energy that should be dissipated for various mechanisms are focused in this study.

The range time-history of acceleration considered in the analysis was set to 15 sec, sufficiently time to consider the damage potential of the earthquake represented by the long duration acceleration pulses.

Key words: Strong ground motion, near field, long duration pulse, response spectra, directivity, energy.

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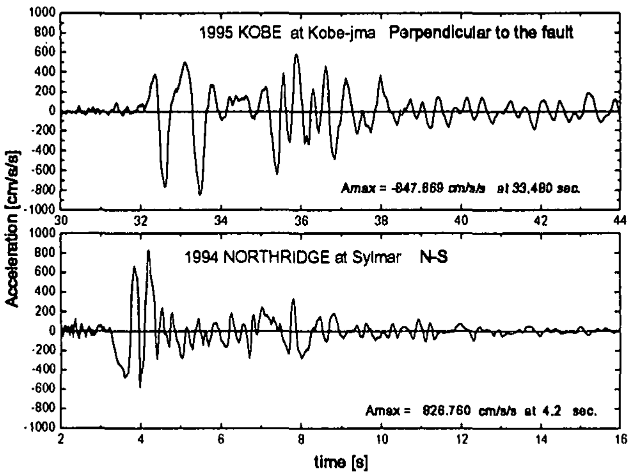


Fig.1 Ground Strong Motion with Long Duration Pulses in the Near-Field

Table1 Earthquakes In the Near-Field

STATION	E.DIST	COMP	PGA	PGV	PGD
	km		cm/s/s	cm/s	cm
1 TARZANA	5.00	E-W	1744.53	110.16	29.15
		N-S	970.73	77.18	28.17
2 ARLETA	9.90	E-W	337.32	40.36	8.80
		N-S	302.05	23.29	8.29
3 SYLMAR	15.80	E-W	592.64	76.94	15.22
		N-S	826.76	128.88	32.55
4 NEWHALL	19.80	E-W	571.62	74.84	17.59
		N-S	578.19	94.72	30.47
5 NISHI AKASHI	10.40	N-S	474.20	48.43	14.53
		E-W	455.34	38.03	18.07
6 TAKATORI	11.30	N-S	605.29	121.81	32.62
		E-W	656.64	123.63	32.36
7 KOBE-jma	18.47	N-S	617.23	91.48	20.22
		E-W	817.89	75.95	21.80
8 KOBE University	25.30	N-S	270.31	53.73	24.92
		E-W	301.03	32.33	16.30

The solution of the SDOF equation was calculated using non-linear integration time dependent numerical method step-by-step[2,3]

3. INPUT GROUND MOTION

Some of the earthquakes selected as input ground motions are those with shallow sources and large magnitude, ranged among 6.7 and 7.5, and epicentral distance ranged less than 25 km. All records have a high peak acceleration combined with long duration pulses, which can be considered sufficiently representatives of those dangerous earthquakes that happened in the near field in recently events.

Some of the characteristics of the regarded earthquakes such as components, maximum peak ground motion values are given in the Table1.

The selected records were intended to represent the type of motion of those earthquakes in the near field, with long duration pulses, high peak acceleration, and relatively short duration.

Theoretical studies and recently seismic events have revealed that records earthquakes with long duration pulses occur near fault rupture[4]. In the Fig.1 is possible observe one or two long pulses in the Kobe earthquake at Kobe(jma) and Northridge earthquake at Sylmar records.

El Centro earthquake and Taft earthquake, free field records, well studied and used as reference in many codes. They were also analyzed and compared with those in the near field.

4. DIRECTIVITY

The parameters that define the ground motion: acceleration, velocity, displacement, frequency content, and duration, are strongly influenced by the properties of the seismic source. The shear wave is polarized on the rupture progress direction, generating a long duration and big amplitude pulse.

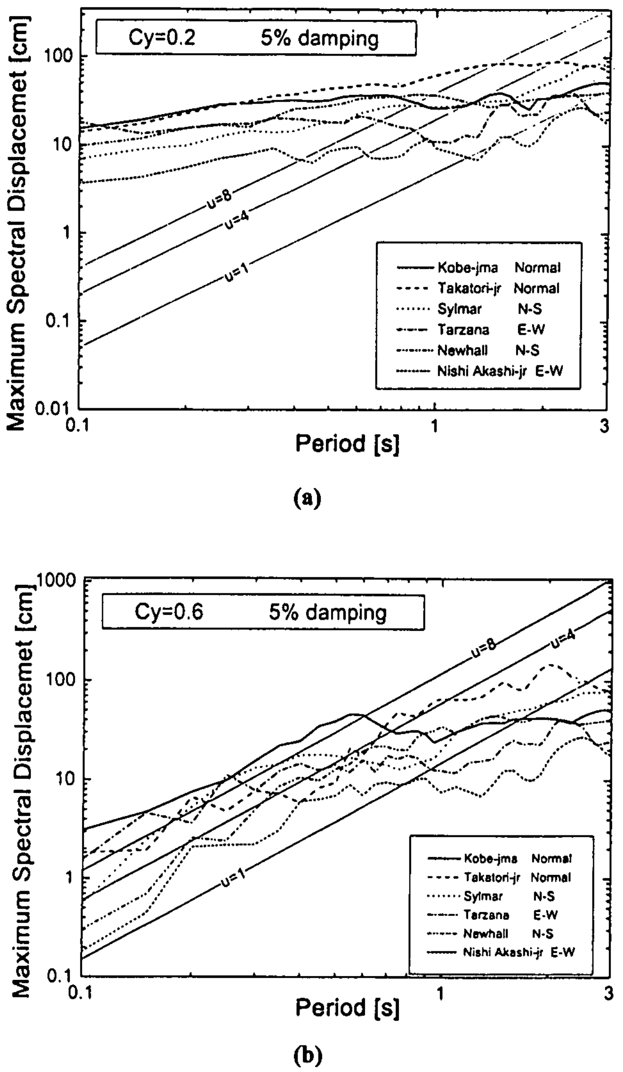
After making the respective rotation to the perpendicular and parallel direction to the fault, it is observed the main characteristic related with the frequency content, and the magnitude of their values. In the tension direction (perpendicular to the fault) the records are low frequency content and high frequency content those parallel.

The magnitude of the parameters, peak acceleration, peak velocity and peak displacement is important only in the case of Kobe earthquake records, but it is not in Northridge earthquake. The parameters of Kobe earthquake records in the direction perpendicular to the fault are almost twice the values of those in the parallel direction.

5. MAXIMUM DISPLACEMENT AND DUCTILITY DEMANDS

The maximum displacements for structures with yielding strength Cy=0.2 and 0.6 are shown in Figures 2 (a), (b). The ductility demands are also shown for reference like lines indicating displacement corresponding to the ductility 1(elastic case), 4 and 8.

For structures with Cy=0.2 and periods less than 1 seconds, the displacement demands are extremely big and exceed largely the allowable ductility levels. Above 1 seconds, except for Takatori-jr , all of them are under the ductility required by



(a)

(b)

Fig.2 Maximum Displacement Response Spectra

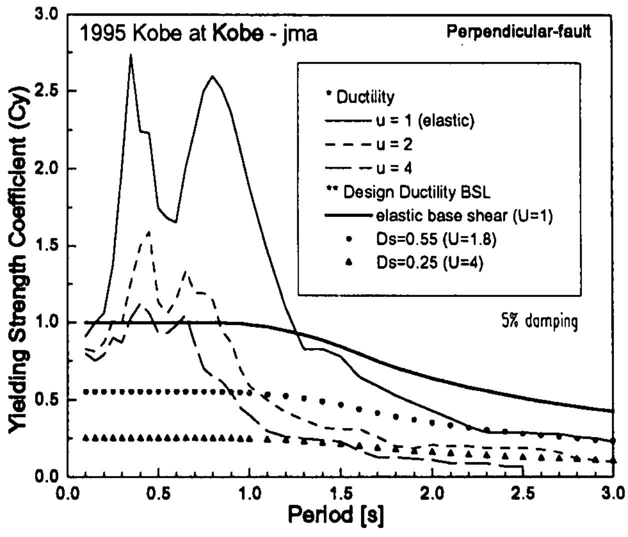


Fig.3 Inelastic Acceleration Response Spectra

codes, and by periods bigger than 3 seconds the displacements are in the elastic range. The large displacements for periods less than 1 seconds continue up to Cy<0.6 , where the displacement drooped close to normal levels of ductility used in design as it showed in the Figure 2 (b).

Up to Cy=0.6., it is seen that always the Kobe earthquake records at Kobe-jma and Takatori-jr (perpendicular to the fault direction) give the largest displacement demands.

The influence of the big area in the accelerogram represented by the long pulses on the inelastic displacement response is evident. At the same time of occurrence of pulses associated with large peak acceleration as it is showed in the Figure 1 (32-34 sec in Kobe-jma, and 3-5 sec in Sylmar), the maximum inelastic displacement response happened (see Figure 5(a), (b) upper part), which are characterized by one or two large yield excursions with permanent deformation[5,6]. Small and steady inelastic displacement with minor importance in the response of the structures is usually followed.

So the suddenly impact in a short-time of near field earthquakes with large impulses loading required big ductility demands[5]. For short and also middle period structures less than 1 second the demands are notable, it calls for an urgent code review, respect to the ductility levels by increasing yielding strength to control displacement.

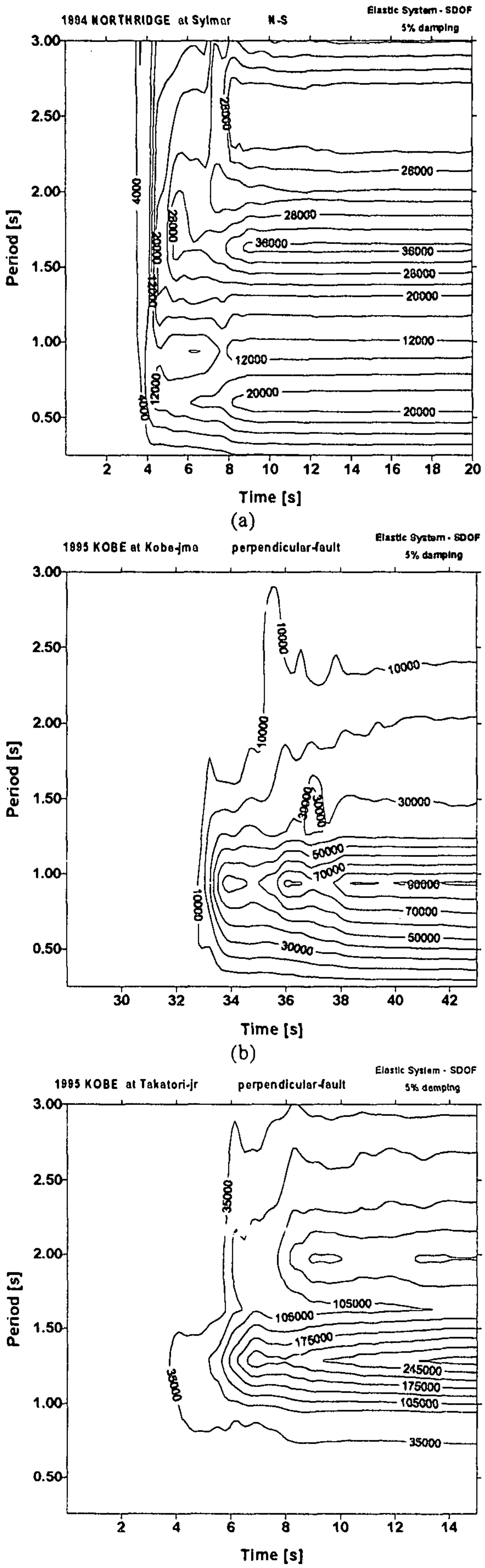
6. INELASTIC ACCELERATION RESPONSE SPECTRA

Current methods of design as well as analytical studies are based on linear elastic response spectra. Because most of the structures go into nonlinear behavior under a seismic event, this point of view is necessary to modify and move into inelastic analysis and use of inelastic response spectra as well as the control of energy dissipation time-history[6].

In figure 3 the inelastic acceleration response spectrum in function of displacement ductility is shown. This picture gives a better concept of the inelastic demands and capacities[8].

The ductility used are the lines identified by 1, corresponding to u=1, for the linearly elastic case, and those with 2 and 4. In the same picture are compared with the BSL Japanese code[9,10] for the elastic base shear and the range of ductility recommended Ds=0.55 (U=1.8) and Ds=0.25 (U=4).

It can be clearly seen from the Figure 3 that the strength levels demanded for ductility in the range 2-4 are more than twice the values of yielding strength recommended in this case by the Building Standard

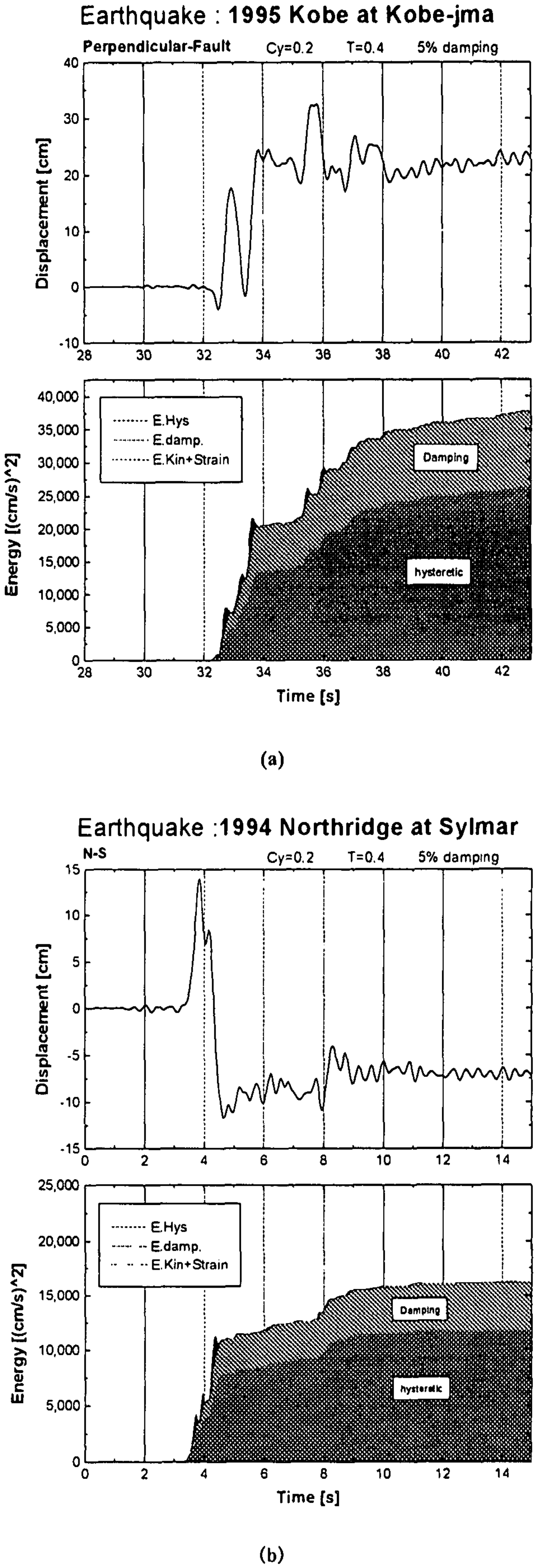


(a)

(b)

(c)

Fig.4 Elastic Energy Input per unit mass (cm/s)^2



(a)

(b)

Fig.5 Inelastic Time-history Displacement and Energy

Code with the ductility range equivalent 1.8-4. It means that the code specified spectra for design are inadequate for some earthquakes in the near-field, especially in low period range below 1 second. Some examples of the serious consequences for stiffness and low rise structures were clearly noted during Kobe and Northridge seismic events.

The strength demands of the near field record significantly exceeds values of code design standards.

7. ENERGY DEMANDS

A satisfactory design implies that the energy supply should be larger than the energy demand$^{12)}$, but are the amounts of energy demands well known and are the structures well built in the near field?. Those are question very important to be considered seriously to prevent of damages like another Kobe or Northridge seismic events.

The time-history elastic input energies of near field records for various natural periods of structures are shown in the Figures 4 (a), (b) and (c). It is evident those records contain in short and middle period range the highest levels of energy ever observed. Northridge at Sylmar had high levels of energy in short and middle period up to 1.25 seconds, giving maximum level of input energy in period around 0.75 seconds. The case of Takatori-jr is very important, this record gave the highest levels of input energy, especially in middle period range among 0.8 and 3.0 seconds, with maximum values concentrated around 1.25 seconds.

The most important characteristic is the short time-input energy. The input energy observed in the Figure 4 shows that more than 70-80% of the total is exerted on the system in less than 2 seconds. At Sylmar in around 1.0 seconds and Kobe 1.5 seconds. Takatori-jr on the contrary is exerted steadily.

In real cases, allowing the structure goes in the non-linear behavior, time-history of input kinetic, damping, hysteretic and recoverable energy subjected to the Kobe and Sylmar records are shown in the Figure 5. Note the impact of the Impulse Loading in the displacement response, therefore high levels of hysteretic energy dissipation in a few seconds.

This means that the structures did not have enough cyclic time vibrations to utilize structural damping efficiently, as a result the only way of dissipation of energy was for the hysteretic loops, it means by structural damage.

It is convenient to point out the great importance of the short time-history impact of energy dissipation in the analysis and design to be considered in future structures in the near field. The elastic and inelastic spectral based parameters do not account for the duration of the input ground motion, represented by shock loading pulses in a few seconds. This is a significant characteristic that can be addressed by reflecting the impact time on the possibility of high energy dissipation demands. Near-field impulse type ground motions, results in a sudden release of energy in the structure that must be dissipated immediately$^{12)}$.

8. CONCLUSIONS

The evaluation of time-history response SDOF under near-field earthquakes, showed high destructiveness potential due to the long duration pulses. The directivity, long-duration pulses earthquakes combined with large peak acceleration, large displacements and the short range-time of high dissipation of energy are principal issues to be considered to improve the current seismic codes in the near field.

The influence of directivity is evident, it showed low frequency accelerogram with high spectral values in the principal direction of the movement.

Near field earthquakes are characterized for causing big solicitation in stiffness structures. Among the solicitations are ductility demands and large amount of energy input. The ductility demands are enormous and characterized by one or two loops of large displacement.

The sudden shock of energy into the structures that should be dissipated immediately by hysteretic loops "structural damage" call us for a review to consider the short time-history on the possibility of high energy dissipation demands.

Design structures and/or urban areas' infrastructures near seismic sources with near-field strong ground motion are necessary.

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動力学的な弾性—塑性モデルに基づいた近地地震動の危険度に関する研究

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近地地震動記録に対するＳＤＯＦ構造の非線型動力学的解析を試みた。両線形（弾性且つ完全塑性）な剛性ヒステリシス関係を持つ構造物系への入力として加速度記録が用いれれた。加速度記録の時刻履歴反応、スペクトル値、エネルギー特性を調べ、近地においてはその長周期パルスによって被害の大きくなる可能性を示した。結果によると最大変位延性は有為に大きく、長周期パルスのピークが起きた時に一致している。このような大きな延性が起きるのは、大量のエネルギーの短時間における分散が通常伴うからである。