Accuracy of Empirical Equations Predicting Sliding-Block Displacement

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ABSTRACT

The sliding-block model forms the basis of simple models predicting permanent co-seismic shear displacements of soils. For excitations consisting of actual accelerograms, different parameters of the applied motion have been used and different expressions have been proposed by researchers. Recently, many accelerograms have been recorded and these accelerograms are available in internet sites. These accelerograms allow the investigation of the accuracy of the expressions described above, some of which were based in a small number of accelerograms. In the present work the accuracy of empirical equations predicting sliding-block displacement is studied thru the application of 101 accelerograms covering a wide range of magnitudes, maximum accelerations, maximum velocities and dominant periods. The analysis illustrated that the accuracy of the methods vary. The Whitman and Liao (1984) method was found to produce the best predictions.

INTRODUCTION

Newmark's sliding-block model (Newmark, 1965) forms the basis of simple models predicting permanent co-seismic shear displacements of soils (Kramer, 1996). In this model, as shown in Fig. 1, a block rests in an inclined plane. In the general case, frictional and cohesional components of resistance exist in the interface between the block and the inclined plane. Critical acceleration is defined as the horizontal acceleration that causes the shear stress to become equal to the shear strength at the base of the block. When the applied acceleration is larger than the critical acceleration, the block slides. The total displacement is obtained by the addition of the slips where relative motion develops.

This model has been used for the estimation of permanent seismic deformations of natural slopes without considerable earthquake-induced loss of strength, of earth dams, of rockfill dams, and of gravity walls retaining dry soil (Makdisi and Seed, 1978, Richard, and Elms, 1979, Gazetas and Dakoulas, 1992, Whitman, 1993, Sarma, 1999). The solutions giving the distance moved by the sliding-block are used for the prediction of permanent seismic movement of these problems by replacing the maximum applied acceleration and critical acceleration of the block with those of the potential sliding mass under consideration.

For excitations of given analytical functions, analytical expressions giving the seismic displacement of the sliding-block model can be obtained and have been proposed (Kramer, 1996). For excitations consisting of actual accelerograms, different parameters of the applied motion have been used and different expressions have been proposed by researchers (Ambraseys and Menu, 1988, Richard and Elms, 1979, Whitman and Liao, 1984, Sarma, 1999, Ambraseys and Srbulov, 1993, Yegian et al, 1991).

Recently, many accelerograms have been recorded and these accelerograms are available in internet sites. These accelerograms allow the investigation of the accuracy of the expressions described above, some of which were based in a small number of accelerograms. In the present work the accuracy of empirical equations predicting sliding-block displacement is studied thru the application of more than 100 accelerograms covering a wide range of magnitudes, maximum accelerations, maximum velocities, dominant periods and time durations.

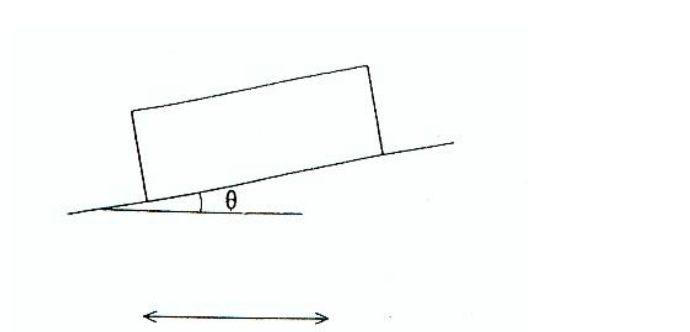

Fig. 1. Newmark's sliding-block model

THE SLIDING-BLOCK MODEL

The equation that describes the motion of the sliding-block model described above and shown in Fig. 1 (e.g. Stamatopoulos, 2003) is:

$$d^2u/dt^2 = A*g*[k(t)-k_c] \quad \text{for } du/dt > 0 \qquad (1)$$

where

$$A = cos(\varphi-\theta)*cos\theta / cos\varphi$$

$$k_c = [m*g*sin(\varphi-\theta)+c*L*cos\varphi]/[m*g*cos(\varphi-\theta)]$$

In the above equations, u is the relative downward displacement of the block, g is the acceleration of gravity, k(t) is the applied acceleration history normalized by the acceleration of gravity, k_c is the critical acceleration defined above normalized by the acceleration of gravity, m is the mass of the block (per unit length), θ is the angle of the block with the horizontal, , φ and c is the friction angle and the cohesion at the interface between the block and the inclined plane and L is the length of the slip surface. The inequality du/dt >0 indicates that displacement accumulates only when the applied horizontal acceleration exceeds the critical acceleration at one direction (the downward).

Equation (1) is usually solved in the bibliography with the assumption A=1.0, or

$$d^2u/dt^2 = g*[k(t)- k_c] \text{ for } du/dt > 0 \qquad (2)$$

Two consecutive intergrations of equation (2) give the velocity du/dt and the displacement u in terms of time.

In real slopes the typical values of the angles θ and φ are such that the factor A does not differ considerably from unity. Thus, equation (2) is a reasonable approximation of equation (1).

SOLUTIONS THAT HAVE BEEN PROPOSED

For excitations of given analytical functions, analytical expressions giving the seismic displacement of equation (2) can be obtained and have been proposed (Kramer, 1996). Usually, the final seismic displacement predicted by the sliding-block model (uf) is expressed as the dimensionless factor ($uf/[g\ k_{max}T^2N]$), where u is the displacement, k_{max} is the maximum acceleration of the applied accelerogram normalized by the acceleration of gravity and T and N are the period and number of cycles of the excitation respectively, in terms of the ratio of the critical by the maximum acceleration (k_c/k_{max}).

For excitations consisting of actual accelerograms, different parameters of the applied motion have been used and different expressions have been proposed by researchers. In particular, all expressions that have been proposed depend on the ratio (k_c/k_{max}). Ambraseys and Menu (1988) propose a relationship that gives uf in terms of only the ratio k_c/k_{max}:

$$\log (uf) = 0.90 + \log (1 - k_c/k_{max})^{2.53} (k_c/k_{max})^{-1.09}) \qquad (3a)$$

where the displacement uf is in cm.

Richard and Elms (1979) give an upper limit on the displacement for earthquakes of magnitude M=7.5, in a relationship that in addition to the ratio k_c/k_{max} includes the value of the maximum acceleration (k_{max} g) and the maximum velocity V_{max} of the applied excitation:

$$uf < 0.09 [V_{max}^2 /(g\ k_{max})] (k_c/k_{max})^{-4} \qquad (3b).$$

Whitman and Liao (1984), similarly, using the 14 ground motions, propose a relationship that in addition to the ratio k_c /k_{max} includes the value of the maximum acceleration and the maximum velocity of the applied excitation:

$$uf = 37*[V_{max}^2/ (g\ k_{max})]*e^{(-9.4kc/kmax)} \qquad (3c)$$

Expressions (3b) and (3c) were derived for the design of gravity walls, but also apply for any structure designed by the predictions of the sliding-block model.

As described by Sarma (1999), Sarma in 1988 proposes a relationship that predicts uf in terms of the ratio k_c/k_{max}, the critical period T_κ, and the maximum value of the acceleration of the applied exchitation:

$$\log (4uf /(g\ k_{max}T_\kappa^2)) = 1.07 - 3.83\ k_c/k_{max} \qquad (3d)$$

Ambraseys and Srbulov (1993) give the seismic displacement uf in terms of the ratio k_c/k_{max} and of seismological parameters of (a) the magnitude M_s and (b) the distance r of the fault of the earthquake :

$$\log (uf) = -2.41 + 0.47\ M_s - 0.010\ r + \log [(1- k_c/k_{max})^{2.64} (k_c/k_{max})^{-1.02}] \qquad (3e)$$

where the displacement uf is in cm and the distance r is in Km The relationship has the advantage of using directly seismological parameters of a given location, that can be estimated from seismological studies.

Finally, Yegian et al. (1991), propose a relationship that in addition to the ratio k_c/k_{max} includes the value of the maximum acceleration, the significant number of cycles Neq and the dominant period:

$$\log (uf/(g\ k_{max}N_{eq}\ T_\kappa^2)) = 0.22 - 10.12\ k_c/k_{max} + 16.38\ (k_c /k_{max})^2 - 11.48\ (k_c /k_{max})^3 \qquad (3f)$$

At this point it should be noted that, as described by Seed and Idriss (1982), Neq can be related to the Earthquake Magnitude (M). This is illustrated graphically in Fig. 2. Fig. 2 also gives an empirical expression predicting the data:

$$Neq= 0.07 \exp(0.70\ M) \qquad (4)$$

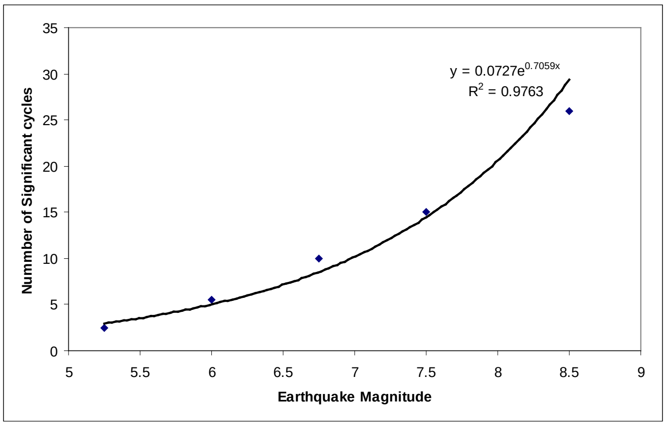

Fig. 2. Representative number of cycles in terms of Earthquake Magnitude (Seed and Idriss, 1982) and empirical expression predicting the data

DATA BASE OF ACCELEROGRAMS

During the present study, one hundered and one (101) accelerograms were collected from earthquakes with magnitudes 5 to 7.9 from the internet. The accelerograms were retrieved primarily from the sites
[http://peer.berkeley.edu/nga/ earthquakes.html],
[http://peer.berkeley.edu/smcat/search.html],
[http://www .isesd.cv.ic.ac.uk/ESD/frameset.htm] ,
[http://web.ics.purdue.edu/ ~braile/edumod/seisres/] ,
[http://www.pnsn.org/ seismosurfing.html] ,
[http://nsmp.wr.usgs.gov/].

The accelerograms were convered to fomat readable by the program seismograph, used to evaluate the dominant period of the accelerogram, and the program multi-block (Stamatopoulos and Mavromihalis, 2009), that was used to apply the sliding-block model.

The accelerograms that are included in the data base are given in the Appendix. For each accelerogram, the following parameters were recorded or estimated: maximum acceleration, maximum velocity, critical period, average period, earthquake magnitude, earthquake distance, earthquake energy, Arias earthquake intensity. In Fig. 3 characteristics of the data base are given. In particular, the maximum acceleration (a_{max}), the maximum velocity (V_{max}), the dominant period (T_k), the average period (T_{mean}) and the earthquake magnitude of the earthquake records is presented. It can be observed that the accelerograms cover a wide range of magnitudes, maximum accelerations, maximum velocities and dominant periods

The possible relationship between the maximum horizontal acceleration and the earthquake magnitude and distance is investigated for the accelerograms of the data base collected in Fig. 4. It is observed that as theory predicts (Kramer, 1996), the maximum horizontal acceleration decreases as the earthquake distance increases and increases as the magnitude of the earthquake increases. The coefficient of correlation is very small for the earthquake distance and reasonable for the earthquake magnitude.

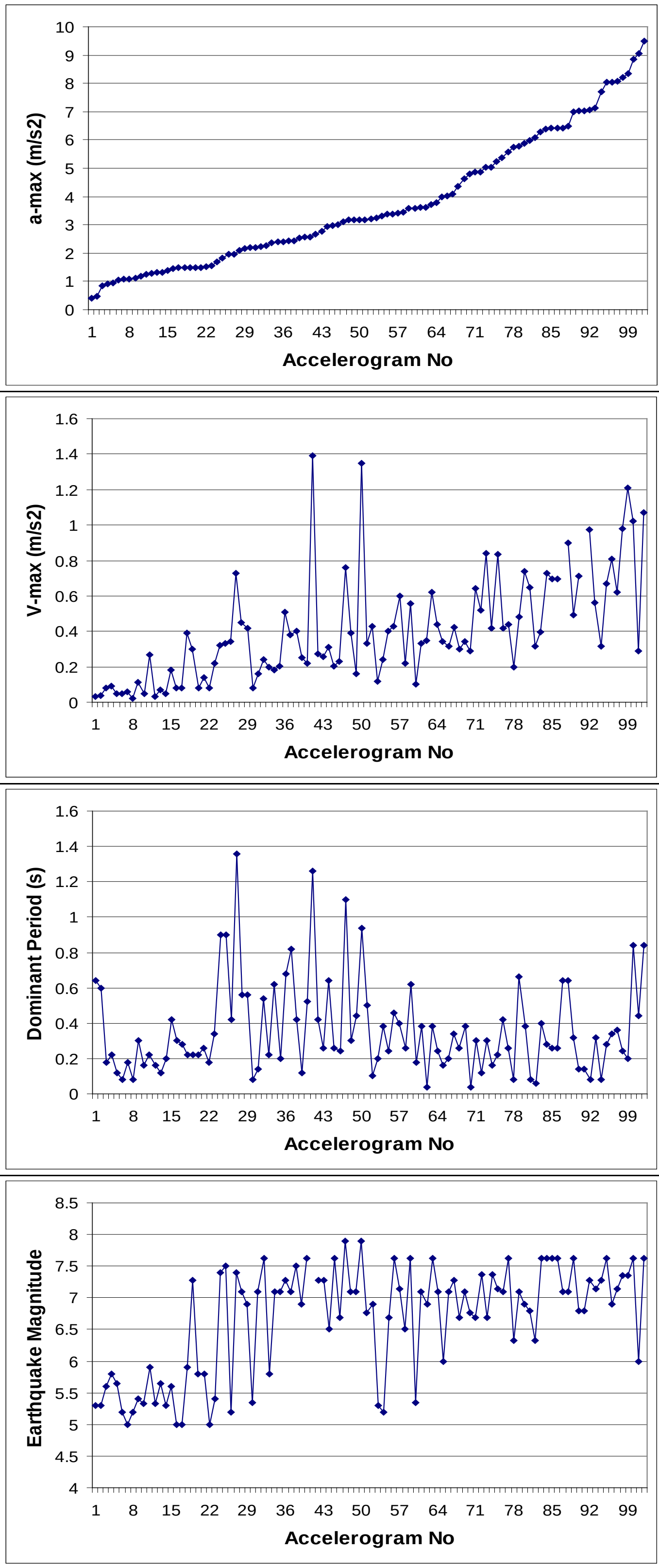

Fig. 3. The maximum acceleration, maximum velocity, dominant period and earthquake magnitudre of the data base of the earthquake records

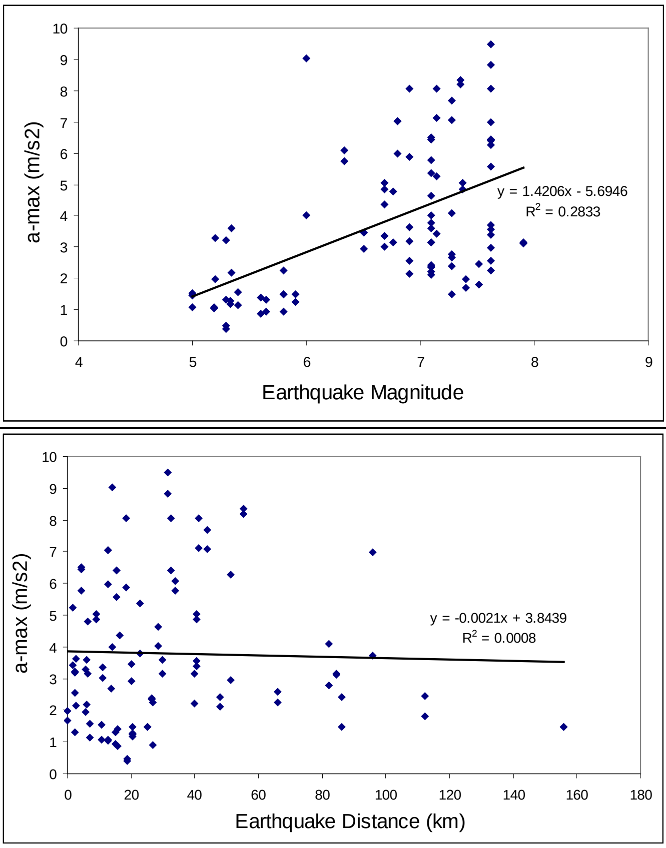

Fig. 4. The maximum horizontal acceleration in terms of the earthquake magnitude and distance.

ESTIMATION OF THE SEISMIC DISPLACEMENT

The seismic displacement of the sliding-block model was estimated by the multi-block program that has been developed by Stamatopoulos and described by Stamatopoulos and Mavromihalis (2009). A block having an inclination of appoximately 10^o was considered. By varying the frictional strength at the interface between the block and the inclined plane, the cases of critical acceleration coefficient of kc=0.03, 0.13 and 0.18 were considered. All accelerograms of the data base described above were applied for each case of kc.

CHARACTERISTICS OF THE APPLIED ACCELEROGRAM THAT AFFECT THE SEISMIC DISPLACEMENT

The correlation of the seismic displacement of the sliding-block model (uf) with parameters of the applied excitation is first studied. The maximum acceleration, the maximum velocity, the dominant period and the average period of the applied accelerogram are considered. In addition, the effect of seismological parameters of the earthquake that caused the accelerogram such as the Earthquake magnitude, the distance, the Energy, the Arias Intensity (T_{Arias}) is also considered.

It is assumed that

$$uf\ (m) = A1\ Z + A2 \tag{5}$$

where Z is a quantity of the applied excitation correlated to the displacement (uf) and A1 and A2 are best-fit parameters. Figs 5, 6, 7 give the obtained correlations for the cases of kc=0.03, 0.13, 0.18. Table 1 gives the best-fit parameters A1 and A2 of equation (5). Table 2 summarizes the coefficient of correlation [R^2] for all cases.

It is observed that, as theory (Kramer, 1996) predicts, as the maximum acceleration, the maximum velocity, the dominant period and the average period of the applied accelerogram increase, the seismic displacement increases. In addition, as the earthquake magnitude, energy and Arias intensity increase, the seismic displacement increases. Table 1 illustrates that the parameters of the linear expression A1 and A2 change with kc in a consistent manner. Furthermore, from table 2 it is observed that the best correlation exists between the seismic displacement and the maximum velocity and the maximum applied acceleration. On the other hand, T_k and T_{mean} of the applied accelerogram and the Arias Intensity, the magnitude, the distance and the energy of the earthquake that caused the excitation do not correlate well the computed displacement.

Table 1. Best-fit parameters A1 and A2 of equation (5) of the relationship between the seismic displacement and parameters of the applied excitation

PARAMETER	A1			A2		
kc	0.03	0.13	0.18	0.03	0.13	0.18
Maximum acceleration (m/s2)	0.29	0.09	0.04	-0.22	-0.16	-0.10
Maximum velocity (m/s)	3.27	0.61	0.32	-0.45	-0.10	-0.06
Critical Period (s)	0.14	0.22	0.09	0.36	0.06	0.04
Average Period (s)	1.64	0.21	0.07	-0.06	0.02	0.03
Earthquake magnitude (Ms)	0.61	0.11	0.06	-3.30	-0.62	-0.33
Earthquake distance (km)	0.001	-0.002	-0.002	0.77	0.23	0.08
Earthquake Energy (erg)	$2*10^{-28}$	$2*10^{-29}$	$8*10^{-30}$	0.71	0.13	0.06
Arias Intensity (s)	0.04	0.005	0.002	0.35	0.07	0.04

Table 2. Comparison of the correlation between the seismic displacement and parameters of the applied excitation

PARAMETER	R^2		
	kc=0.03	kc=0.13	kc=0.18
Maximum acceleration	0.34	0.56	0.52
Maximum velocity	0.73	0.51	0.45
Critical Period	0.11	0.05	0.03
Average Period	0.20	0.07	0.02
Earthquake magnitude	0.31	0.17	0.13
Earthquake distance	0.001	0.04	0.002
Earthquake Energy	0.07	0.008	0.006
Arias Intensity	0.13	0.005	0.002

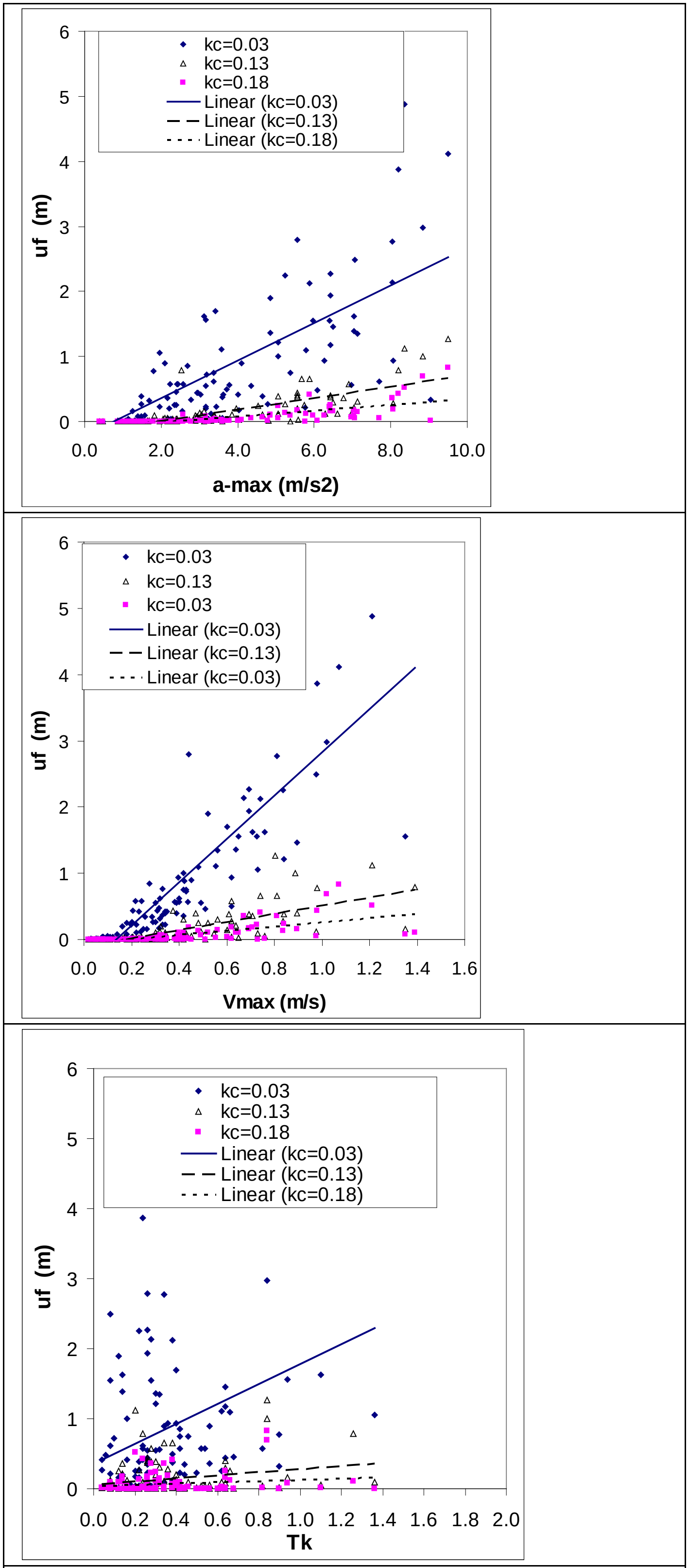

Fig. 5. The effect of the maximum acceleration, maximum velocity and dominant period of the applied accelerogram on the computed sliding-block seismic displacement.

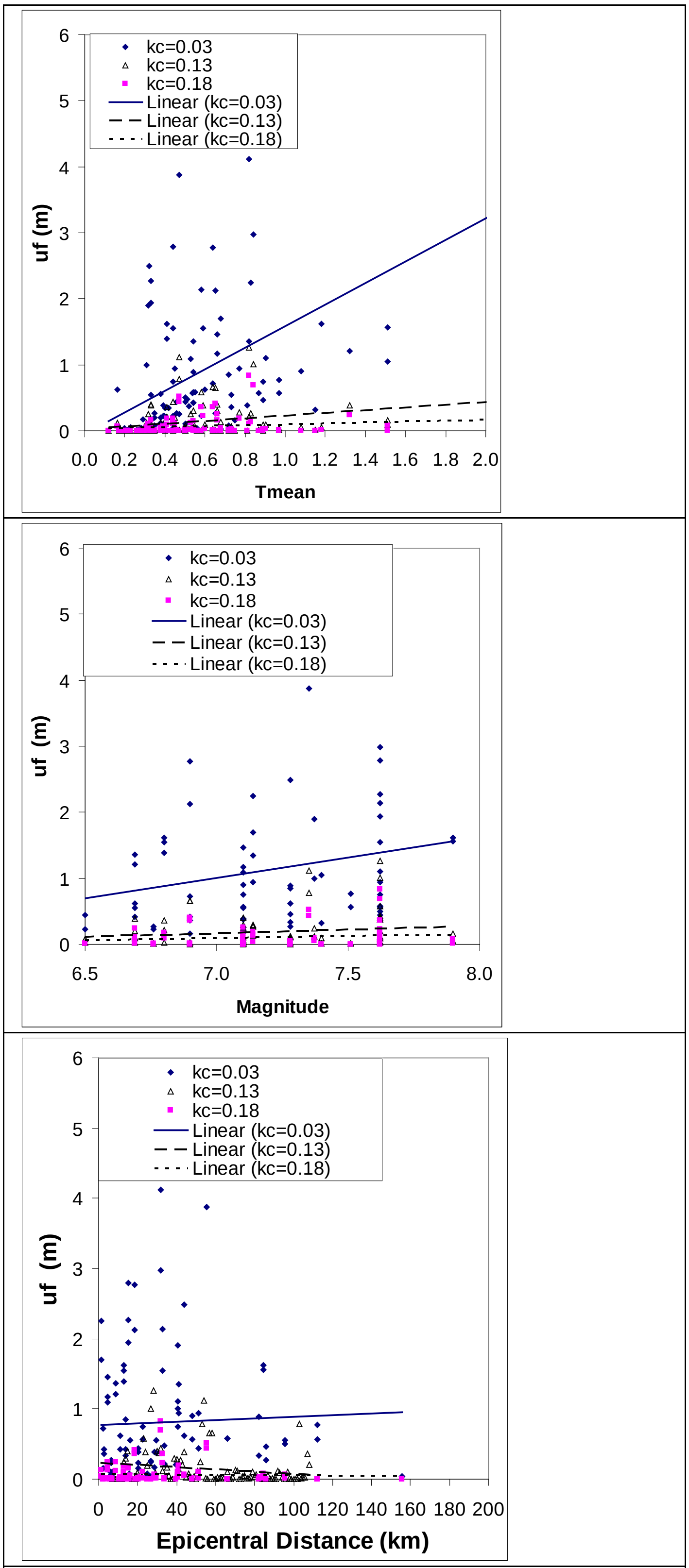

Fig. 6. The effect of the mean period, earthquake magnitude and earthquake distance on the computed sliding-block seismic displacement.

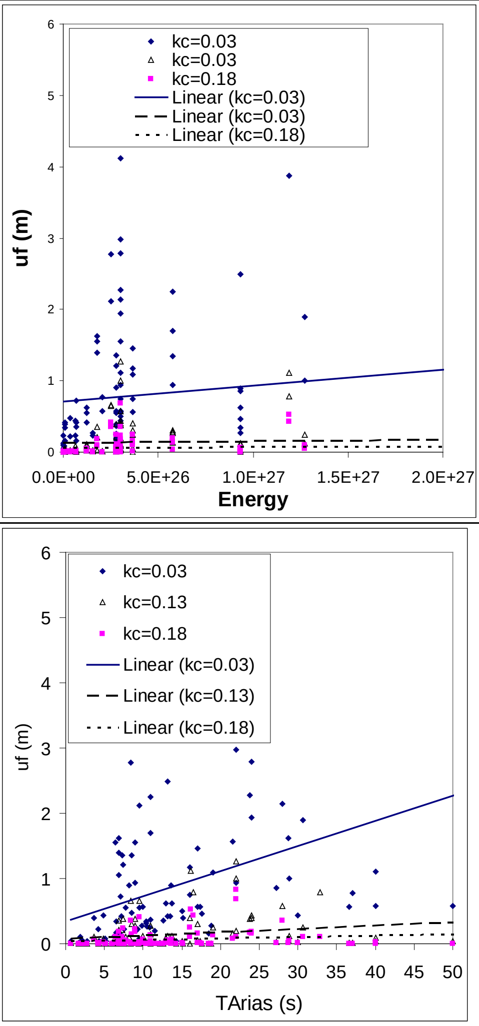

Fig.7. The effect of the earthquake energy and TArias on the computed sliding-block seismic displacement.

INVESTIGATION OF THE ACCURACY OF EMPIRICAL RELATIONSHIPS OF THE BIBLIOGRAPHY

The data base of accelerograms that was created was used to investigate the accuracy of the empirical equations that have been proposed in the bibliography and are given in the section "Solutions that have been proposed" predicting the seismic displacement of the sliding-block model (uf). In the method of Yegian et al, the equivalent number of cycles was obtained from the earthquake magnitude using equation (4).

The predicted by the various methods versus the computed seismic displacement is given in Figs 8 and 9. In addition, the predicted (P) versus actual (X) values of seismic displacement are compared assuming linear relationship:

$$P = A\ X \qquad (5)$$

where A is a factor. The factor A, as well as the coefficient of correlation (R^2) must be close to unity for good prediction. Table 3 gives the factor A, as well as the coefficient of correlation (R^2) for all methods for kc=0.03, 0.13 and 0.18. It can by observed that the accuracy of the predictions depends on the method and the critical acceleration value.

Referring to equation (5), satisfactory prediction is defined in the present work as the cases where (a) 1.4>A>0.7 and (b) R^2>0.4. Table 4 gives the satisfactory predictions for each case. It can be observed that the Whitman and Liao method is satisfactory for all values of kc. The Ambraseys and Menu and Yegian methods give satisfactory predictions for kc=0.03, but not for kc=0.13 and 0.18. The Ambraseys and Srbulov and Sarma methods do not give satisfactory predictions for kc=0.03, 0.13 and 0.18. It can be noted that the above are consistent with the observations of table 1 indicating that the seismic displacement is related better with the maximum velocity and maximum acceleration than to other factors of the applied accelerogram such as the dominant period, the earthquake magnitude and the earthquake distance.

As the Richard and Elms method provides an upper limit, and not the average displacement, the above comparison is not relevant. Yet, Fig. 8 illustrates that the upper limit predicted by the Richard and Elms method is a reasonable approximation for uf<0.1m , but not for uf>0.1m, where it is over-conservative.

Table 3. Comparison of the accuracy of the methods

	kc=0.03		kc=0.13		kc=0.18	
METHOD	A	R^2	A	R^2	A	R^2
Ambraseys and Menu	0.84	0.41	0.45	0.46	0.46	0.36
Richard and Elms	930	0.60	14.0	0.69	6.72	0.72
Whitman and Liao	0.94	0.44	0.88	0.68	0.82	0.69
Ambraseys and Srbulov	0.43	0.54	0.26	0.56	0.28	0.69
Sarma	1.13	0.25	2.00	0.43	2.48	0.57
Yegian et al	0.87	0.42	0.54	0.55	0.52	0.71

Table 4. Satisfactory prediction (1.4>A>0.7 and R^2>0.4 of equation (5)), in terms of the method and the kc value

METHOD	kc=0.03	kc=0.13	kc=0.18
Ambraseys and Menu	yes	no	no
Whitman and Liao	yes	yes	yes
Ambraseys and Srbulov	no	no	no
Sarma	no	no	no
Yegian et al	yes	no	no

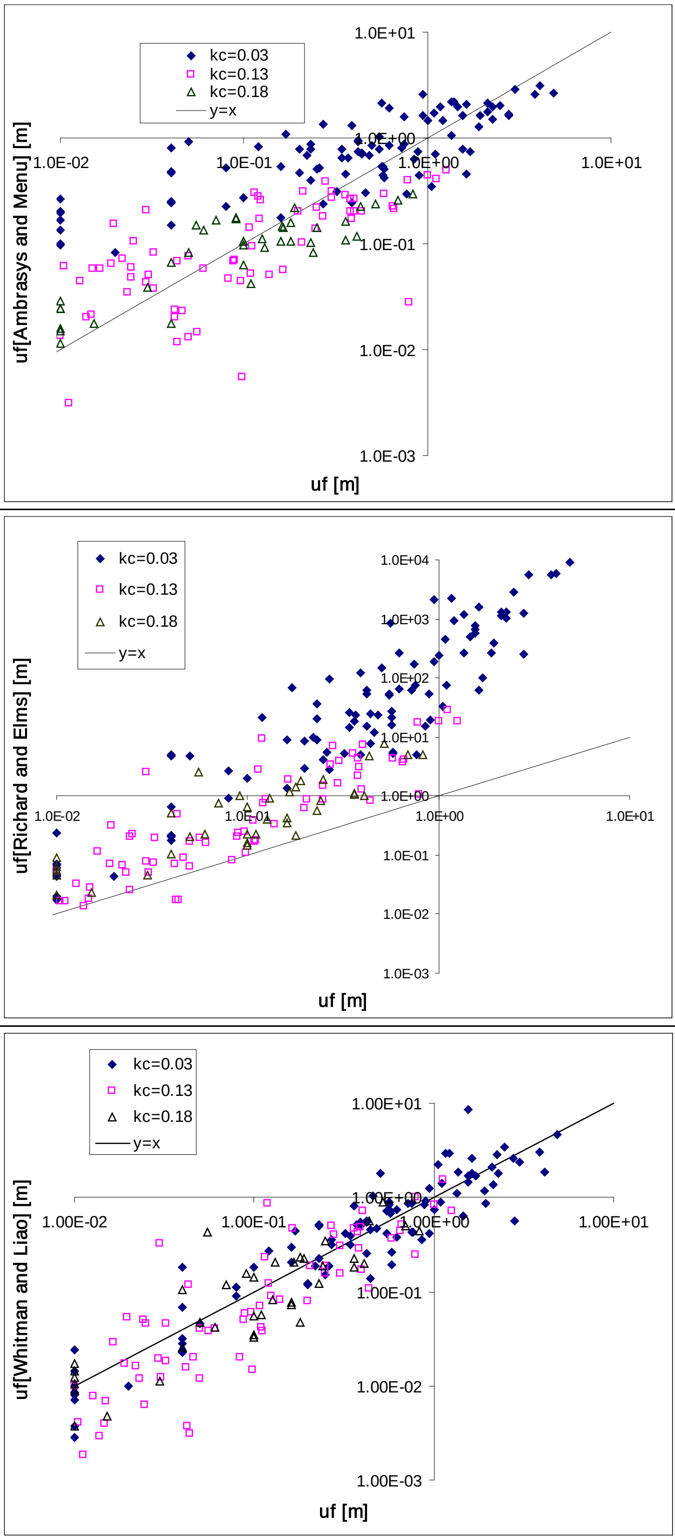

Fig. 8. Comparison of the predictions of the Ambraseys and Menu (1988, Richard and Elms (1979), Whitman and Liao (1984) empirical methods with the computed sliding-block seismic displacement.

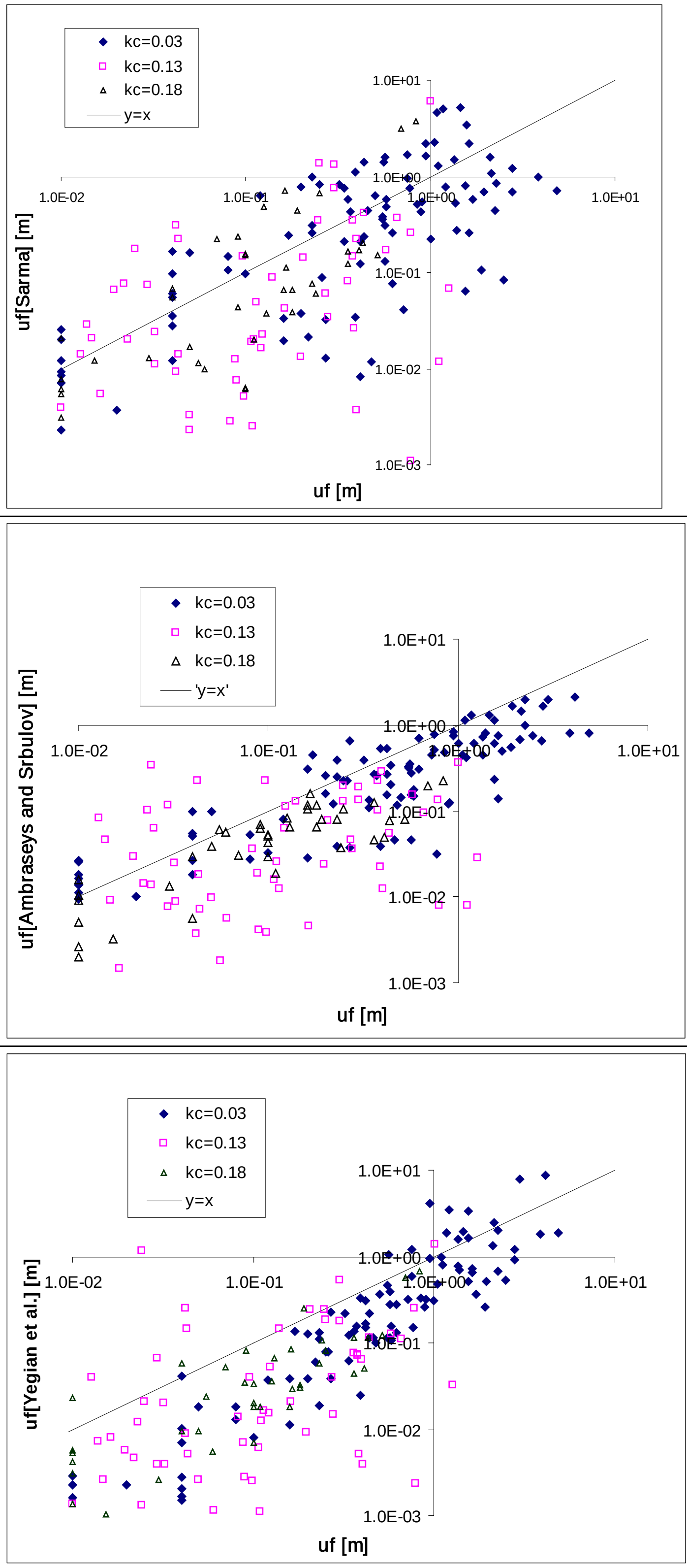

Fig. 9. Comparison of the predictions of the Sarma (1999), Ambraseys and Srbulov (1993) and Yegian et. al. (1991), with the computed sliding-block seismic displacement.

CONCLUSIONS

One hundered and one (101) accelerograms of earthquakes of magnitudes 5 to 7.9 were collected from the internet. This data base of accelerograms was first used to investigate the correlation of the sliding-block seismic displacement with characteristics of the applied accelerogram and the earthquake that produced it. It was observed that best correlation exists between the seismic displacement and the maximum velocity and the maximum acceleration. On the other hand, the dominant and average periods of the applied accelerogram and the Arias Intensity, the magnitude, the distance and the energy of the earthquake that caused the excitation do not correlate well the computed displacement.

Then, the data base was used to investigate the accuracy of the empirical equations that have been proposed in the bibliography and predict the seismic displacement of the sliding-block model. It was observed that the accuracy of the predictions depends on the critical acceleration value (kc). Referring to equation (5), satisfactory prediction was defined as the cases that both (a) 1.4>A>0.7 and (b) R^2>0.4. As illustrated in tables 3 and 4, the Whitman and Liao method is satisfactory for all values of kc. The Ambraseys and Menu and Yegian methods give satisfactory predictions for kc=0.03, but not for kc=0.13 and 0.18. The Ambraseys and Srbulov and Sarma methods do not give satisfactory predictions for either kc=0.03, 0.13 or 0.18. It can be noted that the above are consistent with the observations of table 1 indicating that the seismic displacement is related better with the maximum velocity and maximum acceleration than to other factors of the applied accelerogram such as the dominant period, the earthquake magnitude and the earthquake distance.

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APPENDIX. DATA BASE OF ACCELEROGRAMS CONSIDERED

	REGION	DATE	MA GN	STATION	DIRECT.
1	VERIA GR	9/7/84	5.30	99999ITS	NS
2	VERIA GR	9/7/84	5.30	99999ITS	WE
3	MT.LUIS	31/3/86	5.60	CDMG571 91	0.00
4	LIVERMOVE	24/1/80	5.80	CDWR126 5	156.00
5	CHALFANT VALLEY	21/7/86	5.65	CDMG544 28	360.00
6	ANZA HORSE CAN	25/2/80	5.19	USGS5044	135.00
7	YOUNTVILLE	3/9/00	5.00	STUSGS1 761	180.00
8	ANZA HORSE CAN	25/2/80	5.19	USGS5044	45.00
9	KALAMATA GR	15/9/86	5.40	99999ITS	NS
10	LYTLE CREEK	12/9/70	5.33	CDWR620	180.00
11	WESTMORLA ND	26/4/81	5.90	USGS5051	315.00
12	LYTLE CREEK	12/9/70	5.33	CDWR620	90.00
13	CHALFANT VALLEY	21/7/86	5.65	CDMG544 28	270.00
14	ISMIR TURKEY	16/12/7 7	5.30	ERD99999	T
15	MT.LUIS	31/3/86	5.60	CDMG571 91	90.00
16	PELECANADA GR	10/10/8 4	5.00	99999ITS	WE
17	PELECANADA GR	10/10/8 4	5.00	99999ITS	NS
18	WESTMORLA ND	26/4/81	5.90	USGS5051	225.00
19	LANDERS	28/6/92	7.28	22074Y	360.00
20	NORTHWEST CHINA	15/4/97	5.80	19001JIA	0.00
21	NORTHWEST CHINA	15/4/97	5.80	19001JIA	270.00
22	YOUNTVILLE	3/9/00	5.00	STUSGS1 761	270.00
23	KALAMATA GR	15/9/86	5.40	99999ITS	WE
24	ROUMANIE	4/3/77	7.40		E-W
25	KOCAELI	17/8/99	7.51	AMBARLI	90.00
26	MANAGUA NICAR	23/12/7 2	5.20	3501E550	90.00
27	ROUMANIE	4/3/77	7.40		N-S
28	LOMA PRIETA	18/10/8 9	7.10	1028HOL	180.00
29	IMPERIAL VALLEY	15/10/7 9	6.90	6618	273.00
30	DURSUNBEY TURK	18/7/79	5.34	99999ERD	L
31	LOMA PRIETA	18/10/8 9	7.10	57425G	0.00
32	CHICHI	20/9/99	7.62	CHY014	E
33	LIVERMOVE	24/1/80	5.80	CDWR126 5	246.00
34	LOMA PRIETA	18/10/8 9	7.10	1652AND	360.00
35	LOMA PRIETA	18/10/8 9	7.10	1652AND	270.00
36	LANDERS	28/6/92	7.28	22074Y	270.00

	REGION	DATE	MA GN	STATION	DIREC T.
37	LOMA PRIETA	18/10/89	7.10	1028HOL	90.00
38	KOCAELI	17/8/99	7.51	AMBARLI	0.00
39	IMPERIAL VALLEY	15/10/79	6.90	6616UN	315
40	CHICHI *[TP-02]	20/9/99	7.62	CHY014	N
41	LANDERS	28/6/92	7.28	22170J	0.00
42	LANDERS	28/6/92	7.28	23COOL	N
43	FRIULI ITALY	6/5/76	6.50	8012TOL	270.00
44	CHICHI	20/9/99	7.62	CHY041	W
45	NORTHRIDGE	17/1/94	6.69	24087	360.00
46	DENALI ALASKA	3/11/02	7.90	ALY510	317.00
47	LOMA PRIETA	18/10/89	7.10	47380GIL	90.00
48	LOMA PRIETA	18/10/89	7.10	57425G	90.00
49	DENALI ALASKA	3/11/02	7.90	ALY510	47.00
50	CANADA_NAHA NNI	23/12/85	6.76	609851	360.00
51	IMPERIAL VALLEY	15/10/79	6.90	6616UN	45.00
52	ISMIR TURKEY	16/12/77	5.30	ERD99999	0.00
53	MANAGUA NICAR	26656	5.2	3501E550	3
54	NORTHRIDGE	34351	6.69	24087	W
55	CHICHI *[TP-01]	36423	7.62	CHY006	270
56	DUZCE	36476	7.14	DUZCE	90
57	FRIULI ITALY	27886	6.5	8012TOL	0
58	CHICHI	36423	7.62	CHY006	TR
59	DURSUNBEY TURK	29054	5.34	99999ERD	125
60	LOMA PRIETA	32799	7.1	47380GIL	90
61	IMPERIAL VALLEY	29143	6.9	6618	240
62	CHICHI	36423	7.62	TCU095	EW
63	CAPE MENDOCINO	33719	7.1	89324	T
64	MAMMOTH LAKES	29368	6	54214	NS
65	LOMA PRIETA	32799	7.1	47379GI	L
66	LANDERS	33783	7.28	23COOL	270
67	NORTHRIDGE	34351	6.69	90014	360
68	LOMA PRIETA	32799	7.1	47379GI	W
69	CANADA_NAHAN NI	31404	6.76	609851	315
70	ERZICAN	33676	6.69	95ERZIC	0
71	IRAN MANJIL	33044	7.37	BHRCAB	90
72	ERZICAN	33676	6.69	95ERZIC	0
73	IRAN MANJIL	33044	7.37	BHRCAB	45
74	DUZCE	36476	7.14	DUZCE	N
75	CAPE MENDOCINO	33719	7.1	89324	W
76	CHICHI	36423	7.62	TCU071	N
77	VICTORIA MEXICO	29381	6.33	UN6604	N-NEG
78	CAPE MENDOCINO	33719	7.1	89156	0
79	JAPAN KOBE	34715	6.9	JMAKJMA	90
80	USSR GAZLI	27897	6.8	9201KAR	0
81	VICTORIA MEXICO	29381	6.33	UN6604	45
82	CHICHI	36423	7.62	CHY041	N
83	CHICHI	36423	7.62	CHY028	W
84	CHICHI	36423	7.62	TCU071	N

	REGION	DATE	MAGN	STATION	DIRECT.
85	CHICHI	36423	7.62	TCU071	N-NEG
86	CAPE MENDOCINO	33719	7.1	89156	90-NEG
87	CAPE MENDOCINO	33719	7.1	89156	90
88	CHICHI	36423	7.62	TCU095	N
89	USSR GAZLI	27897	6.8	9201KAR	90
90	USSR GAZLI	27897	6.8	9201KAR	90
91	LANDERS	33783	7.28	SCE24	270
92	DUZCE	36476	7.14	BOLU	0
93	LANDERS	33783	7.28	SCE24	0
94	CHICHI	36423	7.62	CHY028	N
95	JAPAN KOBE	34715	6.9	JMAKJMA	0
96	DUZCE	36476	7.14	BOLU	90
97	IRAN TABAS	28749	7.35	9101TAB	LN
98	IRAN TABAS	28749	7.35	9101TAB	TR
99	CHICHI	36423	7.62	CHY080	N
100	MAMMOTH LAKES	29368	6	54214	0
101	CHICHI	36423	7.62	CHY080	W