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Estimation of newmark displacement according to critical acceleration categories

Kritik ivme siniflarina göre newmark deplasmaninin tahmin edilmesi

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Abstract

Newmark Method is a useful approximation for the prediction of the amount of earthquake-induced ground movement. According to equations produced depending on this Model, critical acceleration is one of the most significant parameters. In literature, the critical acceleration values of 0.02g, 0.05g, 0.1g, 0.2g, 0.3g and 0.4g have been used to calculate the Newmark Displacement. The equations used as general solutions to calculate ground displacement are independent of these acceleration categories. However, it has been obtaained that the regression fits of the analyses have changed according to these categories. In practice, to obtain the Newmark Displacement of any slope, the critical acceleration of this ground should be firstly calculated. Therefore, because the critical acceleration is known, the displacement can be calculated more accurately using the equation with the most appropriate regression fit in that category. Using 2519 records belonging to 35 significant worldwide earthquakes, the new equations with suitable results in terms of the regression parameters have been acquired and the new and previous regression formulas have been re-obtained according to the acceleration categories and the regression results have been compared. In addition, it has been determined that Newmark approximation gives less suitable regression results when the ground is stronger.[†].

Keywords: Landslide, Strong Ground Motion, Slope Displacement, Newmark Method, Critical Acceleration

Öz

Deprem kaynaklı zemin deplasman miktarının tahmini için Newmark Yöntemi kullanışlı bir yaklaşımdır. Kritik ivme değeri bu yönteme bağlı üretilen denklemler için en önemli parametrelerden biridir. Literatürde kritik ivmenin 0,02g; 0,05g; 0,1g; 0,2g; 0,3g ve 0,4g değerleri kullanılarak Newmark Deplasmanı hesaplanmaktadır. Zemin deplasmanının hesabında genel çözüm olarak kullanılan denklemler bu ivme sınıflandırmasından bağımsızdır. Ancak bu sınıflandırmaya bağlı olarak analizlerin regresyon uyumlarının değiştiği tespit edilmiştir. Pratikte herhangi bir şevin Newmark deplasmanını elde etmek için bu zeminin öncelikle kritik ivmesi hesaplanmalıdır. Bu nedenle, kritik ivme bilindiğinden, o kategorideki en uygun regresyon uyumuna sahip denklem kullanılarak yer değiştirme daha doğru hesaplanabilir. Dünya çapındaki 35 önemli depreme ait 2519 kayıt kullanılarak regresyon parametreleri açısından uygun sonuçlara sahip yeni denklemler elde edilmiş, ivme kategorilerine göre yeni ve önceki regresyon formülleri yeniden elde edilerek regresyon sonuçları karşılaştırılmıştır. Ayrıca zeminin daha sağlam olduğu durumlarda Newmark yaklaşımının daha düşük regresyon sonuçları verdiği tespit edilmiştir

Anahtar kelimeler: Heyelan, Kuvvetli Yer Hareketi, Şev Deplasmanı, Newmark Yöntemi, Kritik İvme

1 Introduction

Permanent ground deformation or displacement (PGD) is very significant effect of an earthquake. Estimation or calculation of the amount and effects of this movement is significant for engineering structures [1-22]. Newmark suggested the sliding block model (Fig. 1a) to estimate the slope displacement [23]. According to this approximation earthquake-induced slope displacement can be calculated depending on strong ground motion records (Fig. 1b).

In this method, ground is described as a block (Fig. 1a) that slides and this block has a critical acceleration level that triggers it. Considering Fig.1, previous acceleration values of the X point, block has no motion for a_c=0.2g because the acceleration rates are below this critic level of acceleration (a_c=0.2g). After the X point the velocity diagram can be plotted by integrating the acceleration-time graph which above the a_c value. The velocity rises to top point called as Y point.

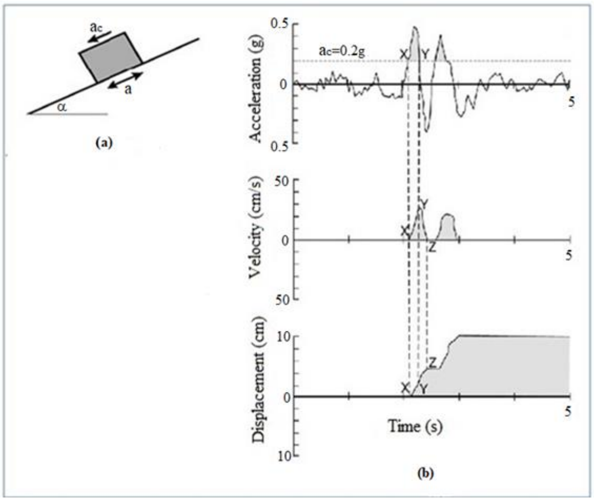

Figure 1. Newmark approximation [23].

The sliding block maintains to move because of its inertia, while the acceleration record falls below the critical acceleration

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value. Because of the friction force and reverse movement of the slope, the movement of the block stops at Z point. When the similar process continuous at other points where the acceleration record above the critical acceleration value, the total movement of the sliding block is obtained in consequence. According to this method, in addition to accepting that the soil slides in blocks, it is assumed that the static and dynamic soil shear strength is homogeneous, the dynamic pore water pressure is neglected, the critical acceleration remains constant throughout the analysis, and the reverse movement of the sliding block is prevented. For this reason, it is not appropriate to use this model in situations outside the acceptance limits of the method, such as cohesionless soil, which do not slip in blocks, increase in pore water pressure and liquefaction.
Critical acceleration has been described as Equ.1 [24].

$$a_c = g\left[\frac{c}{\gamma h} + \cos\alpha \,.\, \tan\emptyset - \sin\alpha\right] \qquad (1)$$

While a_c is the critic value of acceleration, g refers to gravitational acceleration. α is the angle of the sliding block with horizontal. The friction angle of soil is Ø. c, γ and h are soil cohesion, material unit weight and slope thickness respectively.
The following regression formula (to be mentioned to as Ambraseys & Menu Equ.) has been developed to calculate Newmark Displacement by Ambraseys and Menu [25];

$$log\delta = 0.90 + log\left[\left(1 - \frac{a_c}{a_{max}}\right)^{2.53}\left(\frac{a_c}{a_{max}}\right)^{-1.09}\right] \qquad (2)$$

Jibson has modified this equation (to be mentioned to as Modified Ambraseys & Menu Equ.) as follows [26];

$$log\delta = 0.215 + log\left[\left(1 - \frac{a_c}{a_{max}}\right)^{2.341}\left(\frac{a_c}{a_{max}}\right)^{-1.438}\right] \qquad (3)$$

Where a_c is the critical acceleration and amax is the maximum acceleration of an earthquake.
Jibson has suggested another formula (Equ.4) to estimate the slope movement (to be mentioned to as Jibson93 Equ.). The critical acceleration (a_c) values of 0.02g, 0.05g, 0.1g, 0.2g, 0.3g and 0.4g have been used for developing the new regression equation [27].

$$log\delta = 1.460logI_a - 6.642a_c + 1.546 \qquad (4)$$

Where; δ is displacement in cm, ac is critical acceleration in g and Ia (m/s) is Arias intensity expressed as follows [28]:

$$I_a = \frac{\pi}{2g}\int_0^{T_d}[a(t)]^2\,dt \qquad (5)$$

Wilson and Keefer have proposed Equ.6 to predict Arias Intensity (m/s). In this equation M is the earthquake moment magnitude and R is the earthquake source distance (km) [29].

$$logI_a = M - 2logR - 4.1 \qquad (6)$$

Jibson et. al. have recommended Equ.7 (to be mentioned to as Jibson98 Equ.) as below [30];

$$log\delta = 1.521logI_a - 1.993loga_c - 1.546 \qquad (7)$$

Equation 8 has been offered by Jibson (2007) as folllows (to be mentioned to as Jibson2007/1 Equ.)

$$log\delta = -2.71 + log\left[\left(1 - \frac{a_c}{a_{max}}\right)^{2.335}\left(\frac{a_c}{a_{max}}\right)^{-1.478}\right] + 0.424M \qquad (8)$$

In this same paper, Jibson has proposed Equ.9 (to be mentioned as Jibson2007/2 Equ.)

$$log\delta = 0.561\,log\,I_a - 3.8331\,log\left(\frac{a_c}{a_{max}}\right) - 1.474 \qquad (9)$$

Hsieh et.al. have been produced another regression formula (to be mentioned to as Hsieh Equ.) as follows [31];

$$log\,\delta = 0.847logI_a - 10.62a_c + 6.587a_clogI_a + 1.84 \qquad (10)$$

Yigit has suggested a new regression formula (to be mentioned to as Yigit 2020/1 Equ.) as below [32];

$$Log\,\delta = 1.2185logI_a - 1.3669loga_c + 1.5811log\left(1 - \frac{a_c}{a_{max}}\right) - 0.5532 \qquad (11)$$

Another study has been developed by Yigit as Equ.11 (to be referred to as Yigit 2020/2 Form) [33];

$$Log\,\delta = 1.37logI_a - 1.62loga_c + 0.46log\left(\frac{a_c}{a_{max}}\right) + 1.93log\left(1 - \frac{a_c}{a_{max}}\right) - 0.493 \qquad (12)$$

The regression parameters of all of these equations have been gathered in Table-1. According to this table it can be said that Hsieh Equ. is the most suitable equation with respect to the regression factors (R^2 & standard deviation, σ). However, with respect to data used in this manuscript, these results have changed as shown in Table-3.

Table 1. The regression parameters of the regression analyses

Equation	R^2	σ (cm)
Modified Ambraseys&Menu	0.84	0.510
Jibson-93	0.87	0.409
Jibson-98	0.83	0.375
Hesieh	0.89	0.295
Jibson2007/1	0.87	0.454
Jibson2007/2	0.75	0.616
Yigit 2020/1	0.86	0.337
Yigit 2020/2	0.87	0.333

2 Analyzes

Earthquake acceleration-time data used in the paper have been obtained from the Republic of Turkiye Disaster & Emergency

Management Authority Presidential of Earthquake Department and Pacific Earthquake Research Center (PEER) websites [34, 35]. Depending on this data, previous regression equations have been re-analyzed. These examinations have been carried out considering the a_c values of 0.02g, 0.05g, 0.1g, 0.2g, 0.3g and 0.4g. With in this framework, two new regression formulas have been developed. For these analyses, 2519 strong ground motion records ($M_W > 6.0$) of 35 significant earthquakes have been used (Table 2). Compared to previous studies, more seismic records and earthquake data have been used in these analyzes. (For Ambraseys & Menu 50 records of 11 earthquake, for Jibson93 11 earthquakes's data, for Jibson98 555 records of 13 earthquakes, for Jibson2007 2270 records of 30 earthquake and for Yigit2020 2307 records of 26 earthquake had been used in previous studies).

On the other hand, estimation properties of new and previous formulas according to soil strength have been investigated. That means the regression fits of all equations obtained in the scope of this paper have been investigated according to critical acceleration categories.

2.1 General equations

Using the significant earthquake data in Table 2 former regression formulas have been re-acquired as following equations:

Ambraseys & Menu Form;

$$log\delta = -0.13223 + log\left[\left(1-\frac{a_c}{a_{max}}\right)^{1.3268}\left(\frac{a_c}{a_{max}}\right)^{-1.5653}\right] \quad (13)$$

When the previous and the new forms of Ambraseys & Menu have been compared (Fig.2), it can be said that the original form gives bigger results than the others do. The modified and the new regression equation outcomes are closer each other than the original results but the new form (this study) has the smallest displacement values. According to the data used in this study (dots), the original form line is located far from the cloud center (Fig.2).

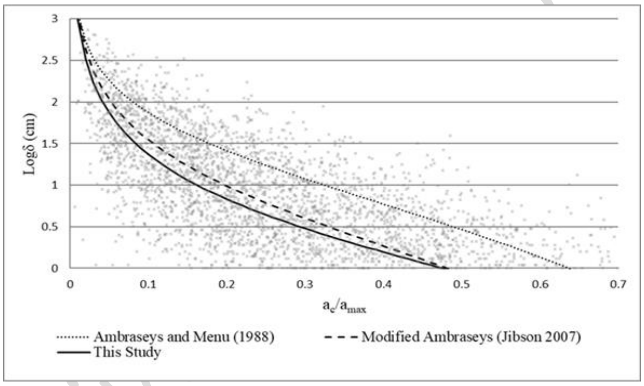

Figure 2. Ambraseys & Menu forms

Table 2. Acceleration-time records [34, 35]

	Time	Earthquakes	M_w	Total Records
1	1952	Kern County-USA	7,4	12
2	1971	San Fernando-USA	6,6	130
3	1976	Denizli-Turkiye	6,1	3
4	1976	Friuli-Italy	6,5	15
5	1978	Tabas-Iran	7,4	21
6	1979	Imperial Valley-USA	6,5	96
7	1980	Mammoth Lakes-USA	6,1	9
8	1983	Erzurum-Turkiye	6,6	3
9	1983	Canakkale-Turkiye	6,1	4
10	1983	Coalinga-USA	6,4	290
11	1984	Morgan Hill-USA	6,1	71
12	1985	Nahanni-Canada	6,8	8
13	1986	Malatya-Turkiye	6,0	3
14	1986	North Palm Springs-USA	6,1	96
15	1987	Superstition Hills-USA	6,5	28
16	1988	Adana-Turkiye	6,2	5
17	1989	Loma Prieta-USA	6,9	248
18	1992	Erzincan-Turkiye	6,6	3
19	1992	Izmir-Turkiye	6,0	2
20	1992	Cape Mendocino-USA	7,0	39
21	1992	Landers-USA	7,3	231
22	1994	Northridge-USA	6,7	302
23	1995	Afyon-Turkiye	6,4	3
24	1995	Kobe-Japan	6,9	66
25	1999	Duzce-Turkiye	7,1	9
26	1999	Kocaeli-Turkiye	7,6	14
27	1999	Chi-Chi-Taiwan	7,6	300
28	2000	Cankırı-Turkiye	6,0	3
29	2002	Afyon-Turkiye	6,5	2
30	2003	Bingol-Turkiye	6,3	3
31	2004	Niigata Ken Chuetsu-Japan	6,6	303
32	2011	Van-Turkiye	7,0	5
33	2014	Aegean Sea - Turkiye	6,5	87
34	2017	Aegean Sea - Turkiye	6,2	48
35	2017	Bodrum - Turkiye	6,5	57

Jibson93 Form;

$$log\,\delta = 1.3877logI_a - 8.22137a_c + 1.5775 \quad (14)$$

Figure 3 shows the comparison of the original and the obtained Jibson93 forms for I_a=3 m/s. The harmony of these two equations is good at low and large values of a_c. However, the original form generally gives higher results than the new form. Besides, for the other values of I_a, these results have not changed.

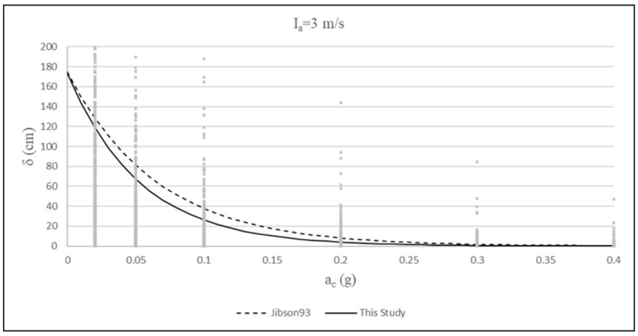

Figure 3. Jibson93 forms

Jibson98 Form;

$$log\,\delta = 1.5168logI_a - 2.023loga_c - 1.6648 \quad (15)$$

To compare the new and the original forms of Jibson98, Fig.4 has been plotted for I_a=3 m/s. According to this comparison, the original form of Jibson98 gives higher displacement values than the new form. This case has not changed for other investigated Arias Intensity (I_a) values. On the other hand, the accordance of original and obtained equations decreases for small values of critical acceleration (a_c).

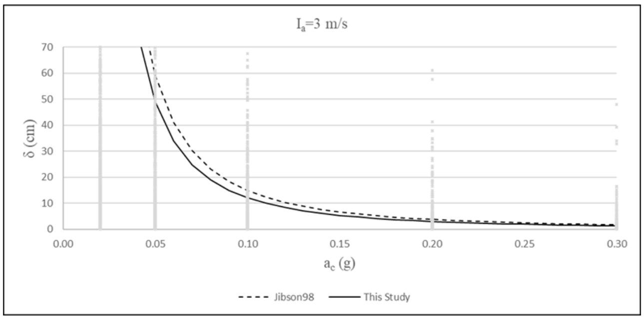

Figure 4. Jibson98 forms

Jibson2007/1 Form;

$$\log\delta = -3.0372 + \log\left[\left(1-\frac{a_c}{a_{max}}\right)^{1.3593}\left(\frac{a_c}{a_{max}}\right)^{-1.5863}\right] + 0.4288M \quad (16)$$

The comparison between the original and the new equations of Jibson2007/1 Form has been observed in Fig.5. As shown in the figure, original form results are bigger than the obtained form results. Moreover, it has been determined that this case is valid for all M values, as well.

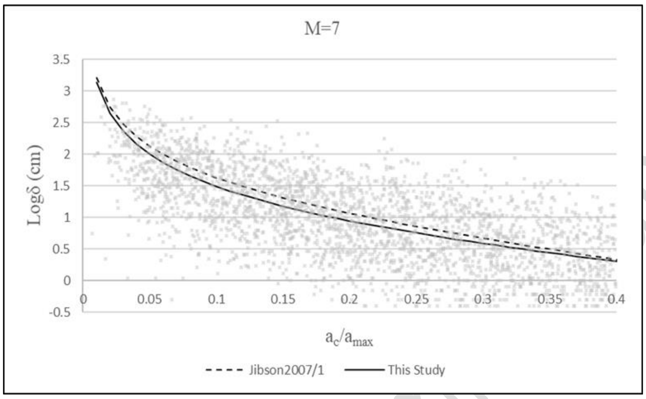

Figure 5. Jibson2007/1 forms

Jibson2007/2 Form;

$$\log\delta = 0.4642\log I_a - 1.8579\log\left(\frac{a_c}{a_{max}}\right) - 0.411 \quad (17)$$

It is seen in Fig.6 that the original and re-obtained regression equations of Jibson2007/2 Form have not good fit. Two equations overlap at a_c/a_{max} =0.3g. For other values of Arias Intensity, the same results have been obtained.

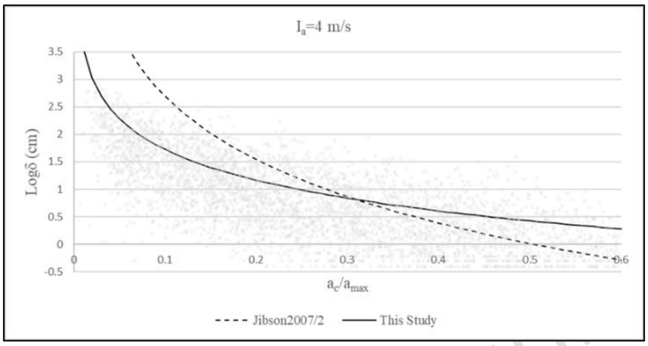

Figure 6. Jibson2007/2 forms

Hsieh Form;

$$\log\delta = 1.1791\log I_a - 9.8863a_c + 5.2351a_c\log I_a + 1.6246 \quad (18)$$

Obtained and the original Hesieh equations overlap at I_a=4.5 m/s (Fig.7). It has been observed from the investigation that when I_a less than 4.5 m/s and a_c<approximately 0.15g, the New Hsieh Equ. gives low displacement values. Besides, when I_a bigger than 4.5 m/s and a_c<approximately 0.15g, the New Hsieh Equ. has grater displacement values than the original form. Apart from these cases, the two equations overlap.

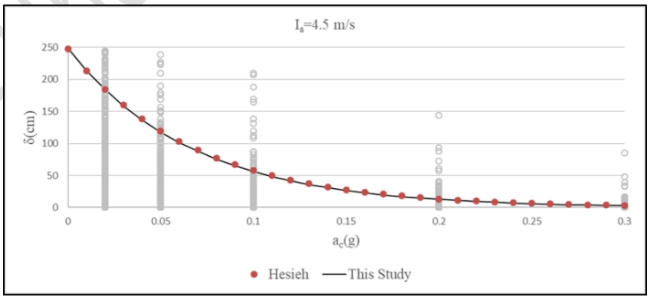

Figure 7. Hsieh forms

Yigit 2020/1 Form;

$$\log\delta = 1.2085\log I_a - 1.3575\log a_c + 1.59\log\left(1-\frac{a_c}{a_{max}}\right) - 0.5417 \quad (19)$$

Yigit 2020/2 Form;

$$\log\delta = 1.3697\log I_a - 1.6168\log a_c + 0.4616\log\left(\frac{a_c}{a_{max}}\right) + 1.9265\log\left(1-\frac{a_c}{a_{max}}\right) - 0.4926 \quad (20)$$

Previous and the new Yigit 2020 Forms approximately have the same results though 212 strong ground motion records have been added to the original studies. Therefore, the comparisons between the new and original Yigit forms have not been needed. Using the same data in Table 2, two new regression formulas have been developed for ac values of 0.02g, 0.05g, 0.1g, 0.2g, 0.3g and 0.4g as follows (to be mentioned to as New-1 Equ and New-2 Equ., respectively);

New-1 Form;

Depending on Arias Intensity (I_a, m/s), critical acceleration (a_c, g) and maximum acceleration (a_{max}, g), New Form-1 regression formula has been offered as Eq.21;

$$\log\delta = 1.3163\log I_a - 2.077\log a_c + 0.4087\log a_{max} - 1.4977 \quad (21)$$

New-2 Form;

The New Form-2 has been obtained by adding the LogM parameter to the Yigit2020/1 Form as follows;

$$\log\delta = 1.1818\log I_a - 1.31\log a_c + 1.6671\log\left(1 - \frac{a_c}{a_{max}}\right) + 1.3369\log M - 1.5804 \quad (22)$$

To be able to compare the regression parameters of these analyses, Table 3 has been prepared. According to this table it can be said that Jibson98, Yigit2020/1, Yigit2020/2, New Form-1 and New Form-2 have more suitable regression results than the others. Thus, useful two new regression equations have been obtained in scope of this study. Depending on this finding more suitable regression equations (Jibson98, Yigit2020/1, Yigit2020/2, New Form-1 and New Form-2) have been compared in Fig.8 using Chi Chi - Taiwan (Rsn1244_Chichi_Chy101-N) record's values (M=7.6, I_a=2.998, a_{max}=0.398g). With respect to this figure, in general, while New Form-1 has the least displacement values, New Form-2 gives the highest results. However, this situation is not constant and may change with variation of parameters on which the regression equations depend. For instance, among these equations, the only equation dependent on M is New Form-2, so this equation is more sensitive to changes in M than the others.

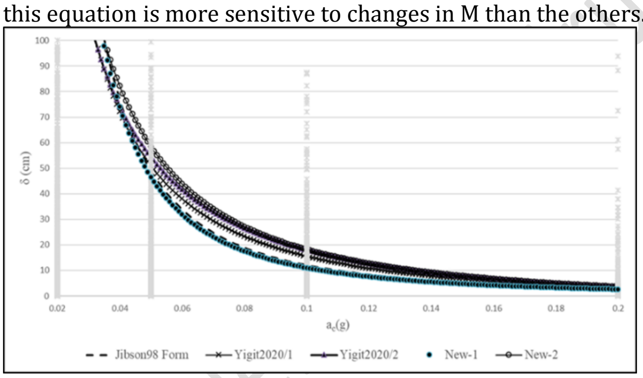

Figure 8. The comparison of suitable forms

Table 3. The regression parameters of the new analyses

Equation	R^2	σ (cm)
Ambraseys&Menu	0.67	0.523
Jibson-93	0.71	0.489
Jibson-98	0.82	0.392
Jibson2007/1	0.71	0.492
Jibson2007/2	0.74	0.468
Hsieh	0.76	0.447
Yigit 2020/1	0.86	0.338
Yigit 2020/2	0.87	0.333
New-1	0.82	0.386
New-2	0.87	0.336

2.2 2.2. Analyses Depending on Critical Acceleration Categories

Some previous studies have shown that regression behaviors of the Forms have changed depending on critical acceleration according to each other as shown in Fig. 9. For example, while Jibson98 Form has a larger displacement than Hsieh Form at a_c= 0.02g; Hsieh Form gives a greater displacement at a_c= 0.1g than Jibson98 Form, according to Fig.9. Therefore, in this section, it is aimed to investigate which formula outputs more convenient results in terms of the regression results at the same critical acceleration value. Thus, when the critical acceleration value that triggers the movement of the examined slope during shaking is known (can be calculated from Equ.1), earthquake-induced displacement can be obtained more properly, selecting the more appropriate regression equation at that critical acceleration value.

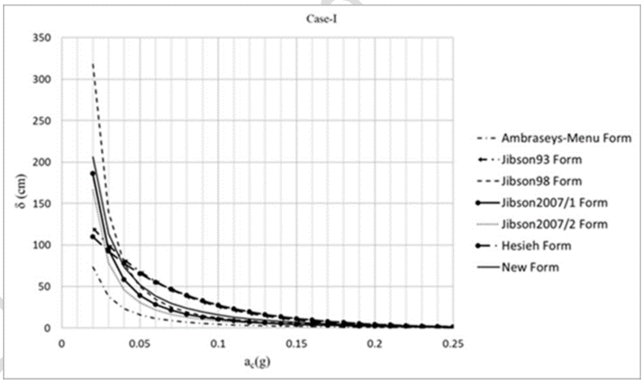

Figure 9. a_c –Displacement relation according to the forms [32]

Considering the a_c values of 0.02g, 0.05g, 0.1g, 0.2g, 0.3g and 0.4g, the forms mentioned above (Table 3) have been re-obtained separately. For these constant values of the critical acceleration, the templates of these forms have been produced as below;

For Ambraseys & Menu Form;

$$\log\delta = C + \log\left[\left(1 - \frac{a_c}{a_{max}}\right)^D \left(\frac{a_c}{a_{max}}\right)^E\right] \quad (23)$$

For Jibson93, Jibson98 and Hsieh Forms;

$$\log\delta = A\log I_a + C \quad (24)$$

For Jibson2007/1 Form;

$$\log\delta = C + \log\left[\left(1 - \frac{a_c}{a_{max}}\right)^D \left(\frac{a_c}{a_{max}}\right)^E\right] + GM \quad (25)$$

For Jibson2007/2 Form;

$$\log\delta = A\log I_a + E\log\left(\frac{a_c}{a_{max}}\right) + C \quad (26)$$

For Yigit 2020/1 Form;

$$Log\,\delta = A log I_a + D log\left(1 - \frac{a_c}{a_{max}}\right) + C \quad (27)$$

For Yigit 2020/2 Form;

$$Log\,\delta = A log I_a + E log\left(\frac{a_c}{a_{max}}\right) + D log\left(1 - \frac{a_c}{a_{max}}\right) + C \quad (28)$$

For New-1 Form;

$$log\,\delta = A\,log\,I_a + B log\,a_{max} + C \quad (29)$$

For New-2 Form;

$$log\,\delta = A\,log\,I_a + D\,log\left(1 - \frac{a_c}{a_{max}}\right) + F\,log\,M + C \quad (30)$$

The regression parameters of the analyses are as in the Table 4 and the coefficients belonging to these equations have been calculated as in the Table 5 according to a_c values;

Table 1. The regression parameters of the analyses according to critical acceleration categories.

Form	a_c=0.02g	a_c=0.05g	a_c=0.1g	a_c=0.2g	a_c=0.3g	a_c=0.4g
Ambraseys & Menu Form	R^2=0.70 σ=0.501	R^2=0.71 σ=0.487	R^2=0.66 σ=0.495	R^2=0.53 σ=0.525	R^2=0.53 σ=0.516	R^2=0.46 σ=0.519
Jıbson93, Jıbson98 and Hesieh Forms	R^2=0.86 σ=0.344	R^2=0.83 σ=0.373	R^2=0.75 σ=0.421	R^2=0.66 σ=0.445	R^2=0.53 σ=0.512	R^2=0.45 σ=0.518
Jıbson 2007/1 Form	R^2=0.77 σ=0.473	R^2=0.74 σ=0.457	R^2=0.69 σ=0.474	R^2=0.57 σ=0.505	R^2=0.55 σ=0.502	R^2=0.47 σ=0.515
Jıbson 2007/2 Form	R^2=0.86 σ=0.344	R^2=0.84 σ=0.359	R^2=0.80 σ=0.380	R^2=0.73 σ=0.400	R^2=0.65 σ=0.442	R^2=0.60 σ=0.443
Yigit 2015 Form	R^2=0.89 σ=0.299	R^2=0.87 σ=0.325	R^2=0.84 σ=0.344	R^2=0.75 σ=0.382	R^2=0.71 σ=0.408	R^2=0.65 σ=0.423
Yigit 2020/1 Form	R^2=0.88 σ=0.321	R^2=0.87 σ=0.327	R^2=0.84 σ=0.344	R^2=0.75 σ=0.381	R^2=0.71 σ=0.406	R^2=0.64 σ=0.422
Yigit 2020/2 Form	R^2=0.89 σ=0.301	R^2=0.87 σ=0.325	R^2=0.84 σ=0.344	R^2=0.75 σ=0.381	R^2=0.71 σ=0.407	R^2=0.64 σ=0.422
New Form-1	R^2=0.86 σ=0.344	R^2=0.84 σ=0.359	R^2=0.80 σ=0.380	R^2=0.73 σ=0.400	R^2=0.65 σ=0.442	R^2=0.60 σ=0.443
New Form-2	R^2=0.88 σ=0.311	R^2=0.87 σ=0.327	R^2=0.84 σ=0.344	R^2=0.75 σ=0.382	R^2=0.71 σ=0.407	R^2=0.64 σ=0.422

Table 5. The coefficients of the templates.

Form	a_c=0.02g	a_c=0.05g	a_c=0.1g	a_c=0.2g	a_c=0.3g	a_c=0.4g
Ambraseys & Menu Form	C= -0.0284 D= 2.3297 E= -1.4453	C= -0.1589 D= 1.6681 E= -1.7735	C= -0.0814 D= 1.4400 E= -1.8516	C= -0.1401 D= 1.0925 E= -1.9909	C= 0.7498 D= 2.2184 E= -0.5864	C= 0.6006 D= 1.6468 E= -0.3762
Jıbson93, Jıbson98 and Hesieh Forms	A= 1.4062 C= 1.6805	A= 1.6461 C= 1.0364	A= 1.7465 C= 0.4244	A= 1.8059 C= -0.3230	A= 1.5538 C= -0.6806	A= 1.4394 C= -0.9290
Jıbson 2007/1 Form	C= -3.8497 D= 2.5097 E= -1.4778 G= 0.5635	C= -2.9290 D= 1.8314 E= -1.7598 G= 0.4160	C= -2.5432 D= 1.5693 E= -1.8150 G= 0.3730	C= -2.7110 D= 1.3475 E= -1.7705 G= 0.4066	C= -1.7303 D= 2.1655 E= -0.5934 G= 0.3654	C= -1.0392 D= 1.4974 E= -0.5601 G= 0.2259
Jıbson 2007/2 Form	A= 1.4533 C= 0.0895 E= 1.7783	A= 1.3268 C= 0.5702 E= -0.6572	A= 1.2524 C= -0.1107 E= -1.1942	A= 1.3414 C= -0.6513 E= -1.4229	A= 1.1308 C= -0.9732 E= -1.8294	A= 1.1455 C= -1.1698 E= -1.7911
Yigit 2020/1 Form	A= 1.1750 C= 1.7350 D= 1.5526	A= 1.2727 C= 1.2445 D= 1.5833	A= 1.2745 C= 0.8440 D= 1.6018	A= 1.3856 C= 0.2765 D= 1.3529	A= 1.0529 C= 0.2827 D= 1.7519	A= 1.0172 C= -0.0477 D= 1.3104
Yigit 2020/2 Form	A= 1.4768 C= 2.7107 D= 2.5659 E= 0.8599	A= 1.3537 C= 1.5039 D= 1.8796 E= 0.3107	A= 1.2847 C= 0.8795 D= 1.6439 E= 0.0546	A= 1.3551 C= 0.1510 D= 1.1960 E= -0.2430	A= 1.0554 C= 0.3152 D= 1.7930 E= 0.0617	A= 1.0213 C= -0.2838 D= 1.0548 E= -0.4769

New Form-1	A= 1.4533 B= -0.0895 C= 1.6264	A= 1.3268 B= 0.6572 C= 1.4252	A= 1.2524 B= 1.1942 C= 1.0836	A= 1.3414 B= 1.4229 C= 0.3433	A= 1.1308 B= 1.8294 C= -0.0166	A= 1.1455 B= 1.7911 C= -0.4571
New Form-2	A= 1.1042 C= -0.7572 D= 1.9006 F= 2.9989	A= 1.2724 C= 1.2377 D= 1.5840 F= 0.0083	A= 1.2924 C= 1.3306 D= 1.5683 F= -0.5974	A= 1.3917 C= 0.4168 D= 1.3451 F= -0.1747	A= 1.0655 C= 0.6147 D= 1.7447 F= -0.4113	A= 1.0840 C= 1.7176 D= 1.3059 F= -2.1781

3 Results

When compare the original equations (Table 1) with the general equations obtained in this study (Table 3), it can be determined that the regression fits of Ambraseys-Menu Equ., Jibson93 Equ., Jibson2007/1 Equ. and Hsieh Equ. have decreased. On the other hand, Jibson 2007/2 and Jibson98 Forms have approximately the same results for both cases based on the regression parameters. Yigit 2020/1 and Yigit2020/2 Forms have not been compared in terms of the original and the obtained equations because data used in both cases are almost the same. Thus, the results are nearly equal.
In this study, two new equations (New Form-1 and New Form-2) have been suggested. These equations have great regression fits, as can be seen in Table 3. With regard to regression parameters (goodness of fit, R^2 and standard deviation, σ), two proposed equations are among the useful equations with the best results as shown in Table 3.
To compare the goodness of fits of the general solutions (Table 3) with the equations' R^2 values obtained according to critical acceleration categories, Table 6 has been prepared. In this table, shaded areas refer to regions that the R^2 values obtained according to critical acceleration categories bigger than the R^2 values obtained from general solutions. For instance, shaded R^2 value of Jibson98 for a_c=0.02g (R^2=0.86) and a_c=0.05g (R^2=0.83) bigger than the R^2 value of Jibson98 according to general solution (R^2= 0.82). It can be seen from the table that the category-based fits are better than the general fits at low critical acceleration values.

Table 6. Comparison of the R^2 values

Critical Acceleration Categories	0.02g	0.05g	0.1g	0.2g	0.3g	0.4g
Ambraseys-Menu Equ.	0.70	0.71	0.66	0.53	0.53	0.46
Jıbson-93 Equ.	0.86	0.83	0.75	0.66	0.53	0.45
Jıbson-98 Equ.	0.86	0.83	0.75	0.66	0.53	0.45
Hesieh Equ.	0.86	0.83	0.75	0.66	0.53	0.45
Jıbson 2007/1 Equ.	0.77	0.74	0.69	0.57	0.55	0.47
Jıbson 2007/2 Equ.	0.86	0.84	0.80	0.73	0.65	0.60
Yigit 2020/1 Equ.	0.88	0.87	0.84	0.75	0.71	0.64
Yigit 2020/2 Equ.	0.89	0.87	0.84	0.75	0.71	0.64
New-1 Equ.	0.86	0.84	0.80	0.73	0.65	0.60
New-2 Equ.	0.88	0.87	0.84	0.75	0.71	0.64

As shown in Table 4 and Fig.10 the regression equation fits decrease when critical acceleration increases. It means that if an investigated slope has relatively greater critical acceleration, the proper estimation of the movement of this slope due to an earthquake is getting difficult in this approach.

According to Fig.10, Ambraseys & Menu Form has the least regression fits for all critical acceleration categories. Jıbson 2007/2 Form and New Form-1 are in the same group and give the same regression parameters according to critical acceleration categories. Therefore, using the new equation simplifies the calculation of the displacement.
Besides, Jibson93, Jibson98 and Hsieh Forms have the most severe change in terms of the regression fit. For these forms, while ac changes from 0.02g to 0.4g, regression goodness varies from 0.86 to 0.45.

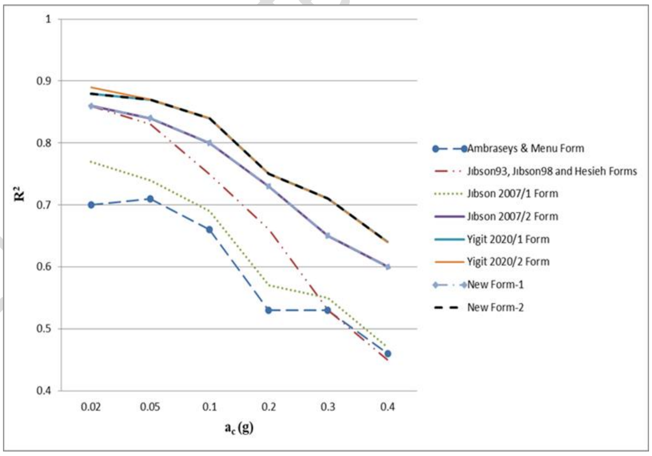

Figure 10. R^2 - a_c relations for the forms

On the other hand, Yigit 2020/1 Form, Yigit 2020/2 Form and New Form-2 have the same and most appropriate regression fits except for $a_c \leq 0.05$g. When $a_c \leq 0.05$g, the goodness of fit of Yigit 2020/2 Form becomes more suitable than the others do.
Although there is a bit of a difference between Yigit 2020/1 Form and New Form-2 in Table 3, when both equations are compared it can be said that moment magnitude has not changed the regression results according to Table 6. This consequence may have been obtained since moment magnitude is effective in Equ.6 that Arias Intensity, which is the parameter of both equations, is calculated.

4 Conclusions

Newmark Method is a considerable analysis to predict the earthquake-induced slope displacement. Depending on Newmark approximation, some significant and useful regression equations have been obtained. In general, these formulas depend on critical acceleration (a_c, g), maximum acceleration (amax, g), Aria Intensity (I_a, m/s), moment magnitude (M_w). In practice, after the calculation of critical acceleration of investigated region, the ground displacement is estimated. Therefore, instead of the general solution, the equations prepared according to critical acceleration categories should be used. In this study, it is determined that Yigit 2020/2 Form is the most convenient equation in terms of the critical acceleration category. Besides, Yigit 2020/1 Form

and New Form-2 have approximately the same regression results as the Yigit 2020/2 Form. On the other hand, it can be seen from the results of this study that two new suitable regression formulas have been obtained.
For stronger grounds, regression equations obtained according to Newmark Method have less suitable regression outcomes. In other words, if the critical acceleration of any slope increases, the degree of the estimation accuracy of Newmark Displacement decreases. Therefore, it can be said that Newmark Method can predict the earthquake-induced displacement of the weaker slopes more suitable.

5 Author contribution statement

The author solely contributed to the formation of the idea, literature review, performing of the method in a systematic way examining of obtained results, writing and supervision of the article in terms of content.

6 Ethics committee approval and conflict of

interest statement

Ethics committee approval is not required for the article prepared.
There is no conflict of interest with any person/institution in the article prepared.

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