DISPLACEMENTS ON SOFT SOILS SITES AT STRONG EARTHQUAKE AND IMPLEMENTATION OF SEISMIC JOINT

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At implementing of the macroseismic inspections of buildings in zones of strong earthquakes, not infrequently, it is noted that damages and destruction of buildings are caused by relative displacements of their constitutive parts. Typically, such damages take place in the buildings and structures located on soft grounds. Effects of surface grounds on intensity of seismic impacts is well-known and is considered in standards of anti-seismic construction design of all countries (FEMA P-750, 2009 and etc.). As a general rule, seismic loads on structures are dependent on ground acceleration and the influence of site conditions, for which corresponding design coefficients are used.

This factor used within the Seismic Code of Russian Federation (SNiP II-7-81*) may increase or decrease the seismicity by one point (by MSK64 scale) is considered. In the building codes of USA the site class coefficients Fa and Fv are used. These and other factors in different countries are used in determining a real seismic impacts on structures, by adjustment of the design accelerations. These approaches give a positive results for dense ground conditions (site categories A, B, and C).

However, unlike greater structure displacements caused by soft soils, seismic accelerations on different sites occur within a certain range. Therefore, application of the above - mentioned factors leads to some correction of design accelerations, but does not consider the impact of possible greater displacement resulting from soft soils.

This study is an attempt of comparative analysis of displacements, velocities and accelerations on soft soils resulting from strong earthquakes. As an initial material, our own database of numerous measured of shear wave velocities and the prevailing (dominant) periods on different sites were used, executed for seismic microzoning. The results of research in the well-studied area of the December-1988 Spitak earthquake by experts from different countries are used also (Atabekyan R.A,1998,2003, 2004, 2008, Borcherdt R.D 1989).

The velocities of particles oscillating movement (V) from the density of a stream of earthquake energy (Fo) with the following formula are defined (Aki K,1983)…

$F_0 = V^2 V_S \rho$, where *Vs* is the shear wave velocity, ρ is the density of soils. (1)

The energy generated by the Spitak earthquake with a magnitude up to 7.0 makes (*E* $=10^{22}$ erg $\approx 10^{15}$ N.m). It is connected with density of a stream of energy with following formula:

$$E = \int_S \int_T F_0 dS\, dT \qquad (2)$$

For the bounded territory is accepted $E = F_0 S T$. In the epicentre zone of the Spitak earthquake, by depth of the hipocenter 10km., for a semicircle surface, it has $S = 2\pi R^2 = 6{,}28 \cdot 10^2 km^2 = 6{,}28 \cdot 10^8\ m^2$. Duration of record of the basic impact in near zone is *T* = 24sec. (Recorded at seismic station of Ashotsq). On these data the density of a stream of energy is:

$F_0 = E/ST$ = $1 \cdot 10^{15}$ N.м. / ($6{,}28 \cdot 10^8 m^2 \cdot$ 24 sec) = $663 \cdot 10^2$ N/m.sec.

The portion of the seismic energy, directed on horizontal oscillating movement makes.

$\nu = 1/\sqrt{2} \approx 0{,}71$ and $F_0^{\nu} = 663 \cdot 10^2 \cdot 0{,}71$ N/m.sec.= $470{,}7 \cdot 10^2$ N/m.sec.

For superficial, rocky ground, we have average values of *Vs* = 2,7 km/sec. and ρ = 2400Kg/m3. From (1), for site of the first category (*class A*) the velocity of particles oscillating movement makes…

$V^2 = F_0^{\nu} / V_S \rho$ = 0,00726 m^2/sec^2, *V* = 0,085m/sec = 8,5 sm./sec.

The above values approximately corresponds to an earthquake of VII points on the MSK64 scale. The additional increase in intensity of concussions occurs within the limits of friable strata (Atabekyan R.A.2008,Yegian M.K... 1994). Here, it is necessary to note that in the city of Vanadzor (previously Kirovakan) the intensity of Spitak earthquake on analogous sites (*class A*) also is estimated as VII points (Atabekyan R.A.1998).

It is accepted, that the density of seismic energy does not vary in different soils, then a velocities of particles movement are similarly defined for a different sites. For the purpose of a more detailed differentiation of soils with respect to seismic properties, site grading according by BSSC (USA) is accepted per Table 1 below:

Table 1.

Average values *Vs* and particles' oscillating movement velocities *V* for various site classes:

Site Class	A	B	C	D	E
BSSC (m/sec)	V_S >1500	1500>V_S>760	760>V_S>360	360>V_S>180	V_S <180
$V_S^{av.}$ (m/sec)	V_S=2700	V_S= 980	V_S= 620	V_S= 210	V_S= 110
ρ (Kg/m^3)	2400	2150	1900	1650	1350
V (sm/sec)	8,5	14,9	20,0	36,9	56,3

The average values of shear waves velocities (on site class), which are received as a result of processing more than 100 measurement on different sites and archival records data, are given in Table 1. Presented here-also are the corresponding densities and the calculated values of velocities *V* of particles oscillating movement.

The displacements -D, acceleration -A and stress - τ during the passage of seismic waves are determined by known expressions for oscillations in an unbounded environment, with allowance the conditions on surface (3).

$$\frac{\partial^2 D}{\partial t^2} = V_S{}^2 \frac{\partial^2 D}{\partial x^2}, \quad \tau = V_S{}^2 \rho \frac{\partial D}{\partial x}. \qquad (3)$$

The function D is $D = D_0 \sin 2\pi\,(t/T_S - x/L_S)$, which with sufficient accuracy for a task describes seismic motion in the initial, the most intensive part of **S** waves.

For velocities, accelerations and stress is accordingly will had:

$$V = D_0(2\pi/T_S)\cos 2\pi(t/T_S - x/L_S)$$
$$A = -D_0(2\pi/T_S)^2 \sin 2\pi(t/T_S - x/L_S) \qquad (4)$$
$$\tau = -V_S^2 \rho D_0(2\pi/L_S)\cos 2\pi(t/T_S - x/L_S)$$

For the calculations the results of instrumental measurements of a prevailing periods T_0 in these sites are used. The Calculated displacements, accelerations and stress for average values of *To* are given in table 2.

Table 2. Values of displacements, accelerations and stress for various sites.

Site Class	A	B	C	D	E
V (sm/sec)	8,5	14,9	20,0	36,9	56,3
T_0^{av} (sec)	0,13	0,22	0,28	0,49	1,00
D_0 (sm.)	0,17	0,52	0,89	2,88	8,96
A (sm/sec^2)	397	424	448	473	353
τ (kN/m^2)	552	313	235	128	84

Through the results of all available data the curves of relative displacements, velocities and accelerations, depending on a ground conditions (by *Vs*) are plotted in fig.1.

Here the ordinate shows the ratio of the value of this parameter on the corresponding parameter for class B soils (V_S = 980 m/sec). For a comparison, the curved of relative velocities and accelerations plotted according to the soils coefficients - *Fv* and *Fa* (*FEMA P-750*) are also given.

According to the calculated results, the change of velocities and accelerations on soft soils basically are consistent with values in BSSC, but a displacements increase significantly more (up to several tens of times). The same results are obtained at natural measurements. The fig.2 shows seismograms and accelerograms, recorded in the stations Gyumri (Leninakan, site class E) and (Gogaran, site class B) at aftershock with magnitude 4,7 of Spitak earthquake 1988 [Borcherdt R.D. 1989). These stations are located on the same distance from the epicentre (24 and 23km.) and at practically identical accelerations (accordingly 15 and 18 sm/sec^2) the displacements on soft soils are ten times greater than on bedrock of a category B (accordingly 0,25 and 0,024см).

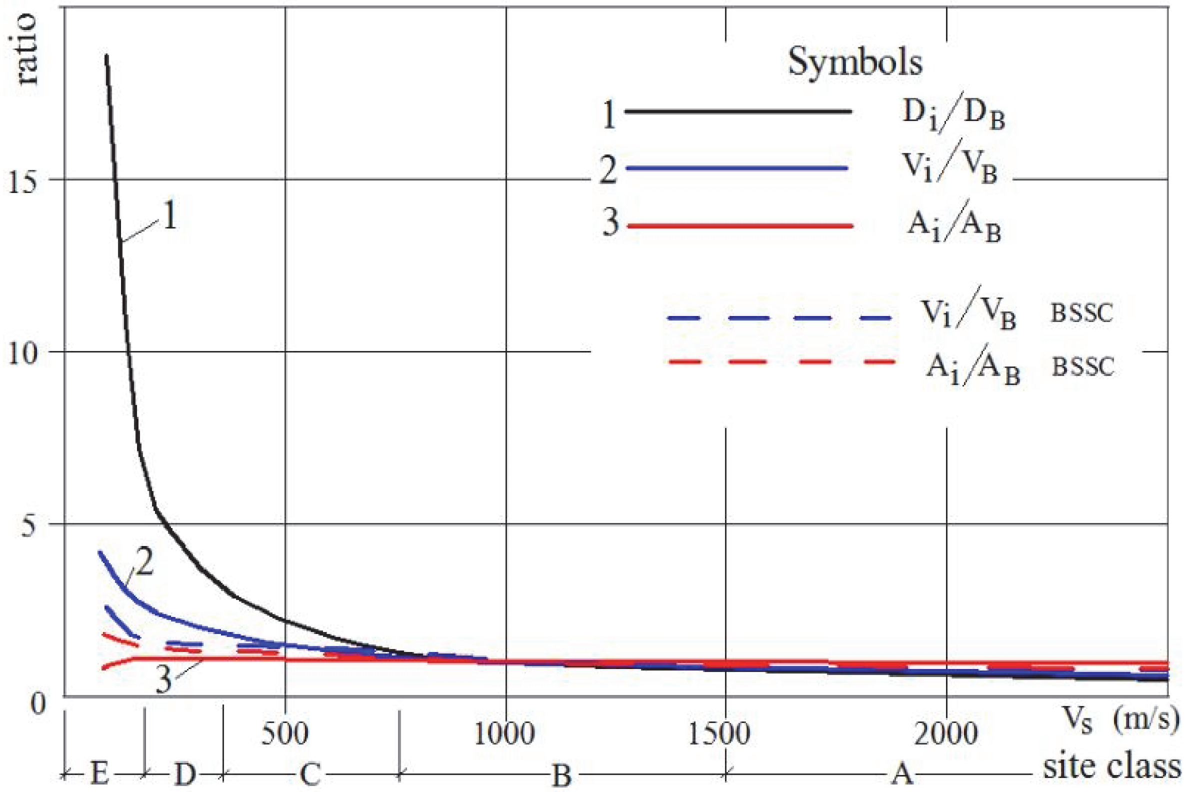

Fig.1. Changes of relative displacements –D_i / D_B, speeds –V_i / V_B, and accelerations – A_i /A_B depending on a class of surface soils

Thus, displacements on soft soils are increased repeatedly, whereas accelerations on different sites are changed at a smaller range (fig.1, fig.2).

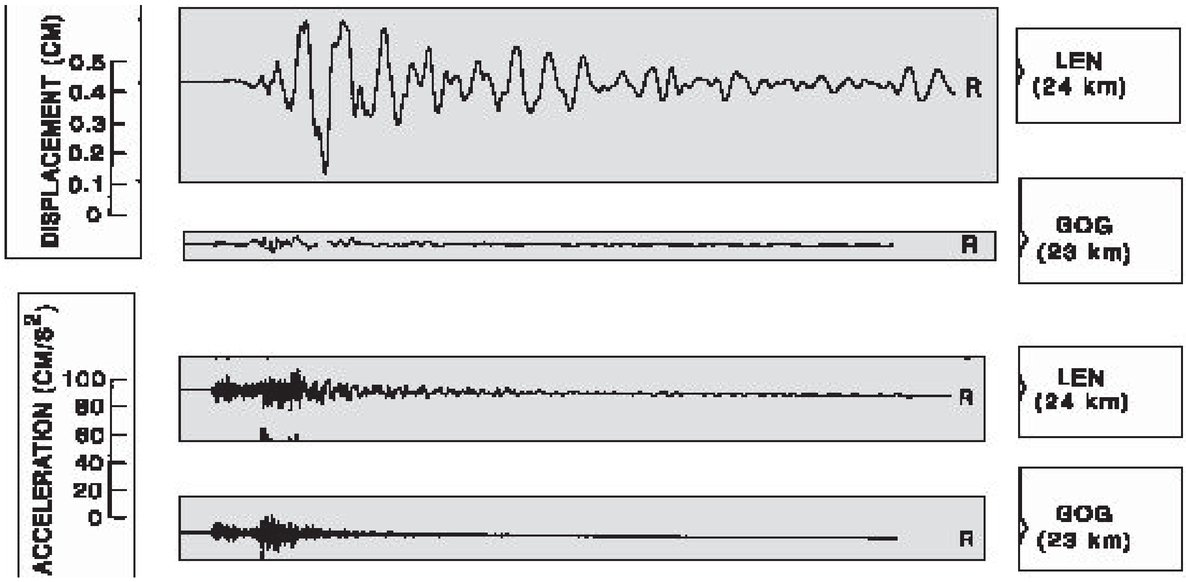

Fig.2 Seismograms and accelerograms, recording on stations *Len* and *Gog* at aftershock with magnitude 4,7

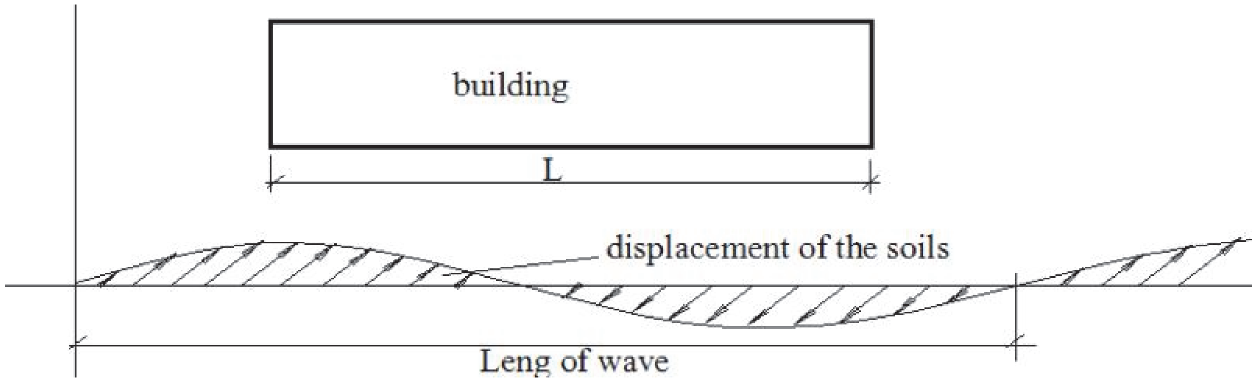

Fig.3 Displacement of the surface soils at passing of seismic waves

Hence, using of the site class factors, applied to correct of seismic impacts on structures, results only in adjustment of design acceleration values, but does not consider the true character of seismic impacts on constructions, located on the soft soils. As conclusion, it can be noted that the seismic events on sites with soft soils (category D, E), lead to greatest displacement of bases and foundations.

The obtained results indicate the need to take into account large displacements on weak soils, which is especially important for long structures (the long buildings, bridges, etc.) . Here, large displacements of the parts of the structure relative to each other can cause their considerable damage or destruction at the strong earthquakes.

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ПЕРЕМЕЩЕНИЯ НА СЛАБЫХ ГРУНТАХ ПРИ СИЛЬНЫХ ЗЕМЛЕТРЯСЕНИЯХ И УСТРОЙСТВО СЕЙСМИЧЕСКИХ ШВОВ

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Резюмэ

В работе сделана попытка сравнительной оценки смещений, скоростей и ускорений на слабых грунтах при прохождении сейсмических волн сильного землетрясения. В качестве исходного материала использованы как собственные данные многочисленных измерений скоростей прохождения волн и преобладающих периодов колебания грунтов, выполненные для микрорайонирования, так и результаты исследований специалистами из разных стран в зоне хорошо изученного Спитакского землетрясения 1988г. Для определения скоростей колебания частиц среды исходили из плотности потока энергии землетрясения.

Согласно полученным результатам изменение скоростей и ускорения на слабых грунтах в основном согласуется с принятыми в BSSC значениями, а смещения могут увеличиться во много раз (до нескольких десятков сантиметров). Поскольку сейсмические нагрузки на сооружения определяются по ускорениям, которые на разных грунтах изменяются в определенном диапазоне, то большие смещения слабых грунтов при проектирования практически не учитываются.

Полученные результаты свидетельствуют о необходимости учета больших смещений на слабых грунтах, что особенно важно для протяженных сооружений, мостов, и т.п., где большие смещения частей сооружения относительно друг друга могут стать причиной их значительных повреждений или разрушения при сильных землетрясениях. Рассматривается также целесообразность устройства сейсмических швов по всей высоте здания, включая разделения фундаментов.