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ON TWO SEISMIC LOADING INPUTS TO BUILDING FOR ASEISMIC DESIGN, TAKEN ACCOUNT OF SOIL-STRUCTURE INTERACTION

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SUMMARY

In this paper the authors clarify that two seismic inputs, stress and displacement, must be specified for the buildings resting on soil strata and the soil-building interaction have to be taken into consideration, instead of only one acceleration in the current routine design, which is suitable only for rigid ground, i.e. very hard rock whose strain may be neglected, and is based on the force- method. Then, it is shown that given acceleration input to building foundation is equivalently given stress input to it, for one-dimensional wave propagation problems, to some extent of approximation. Therefore, additional inputs of displacements have to be specified for a complete aseismic design. It is also pointed out that seismic loading is closely related with the earthquake mechanism and the wave propagation paths. Based on the earthquake focus model presented earlier by the first author, which should be more suitable to some big earthquakes most occurred in intact rock strata, the stresses and velocities at focus have big jump value and have jump also elsewhere so that the displacements cannot be obtained via direct integration of accelerations and must be measured in-situ instead. The jump stresses and jump velocities on the fault plane of focus are roughly estimated for a quake of shallow focus. At last, to see the influence of overlooking the displacement input, some comparative calculations for two design methods of a simplified building are given and the results showed that the influence could be quite great and the displacement and stress (now replaced by acceleration) inputs will play different roles to the building's damage extent, so without considering the seismic displacement input the aseismic design cannot be reasonable and reliable. Thus, the two inputs must be specified in design and simultaneous observations of both acceleration and velocity (or displacement) at same sites of near field and far field should be conducted from now on.

INTRODUCTION

It is evident that in order to get a reasonable, reliable and economic aseismic design of buildings in strong earthquake prone zone the first important step is correctly determining the seismic loading to building. Up to the present, the routine approach is based on the peak accelerations and response spectra specified in aseismic design codes or selected acceleration recordings as base inputs for FEM computations.

As is well known, since decades ago, at the first stage of aseismic design, the soil-structure interaction was not taken into consideration and one acceleration input seems good enough for the design based on a so-called force-method. However, in recent decades the soil-structure interaction has been widely accepted in most design whereas the seismic input is still chosen acceleration one only. This fact seemed evidently to deviate from the principles of dynamics of continuous media, but so far nobody has paid attention to this important fundamental problem.

It has been shown only firstly in the paper Men [1, 2] that two seismic inputs to buildings, i.e. the two quantities, displacement (or velocity) and stress, should be specified at the base of the foundation of buildings when response analyses must be conducted for aseismic design, according to either the continuity conditions of solid dynamics or the new model of earthquake focus, presented by the first author Men [1,3,4]. The routine approach used only of one acceleration seems to deviate from the above principle and, strictly speaking, is suitable either only for the condition of rigid base ground and the design based on force-method because the rigid ground can only move as a whole horizontally and vertically without strains and shear deformations, or for those buildings whose foundation base are posed directly on the ground surface of a deformable stratum since there will be not seismic stresses inputted on the base of foundation since the stresses become zero on the free ground surface. However, the rocks and soils are really deformable so that they can transmit various types of wave (stress- , displacement- , and shear waves) to buildings and interact with the buildings during earthquakes and almost all building foundations are always located some depths below the ground surface. Therefore, two types of seismic inputs should be specified in a general case for aseismic design. It seems that given only the acceleration input means given the stress input, without the displacement input, and consequently this may endanger those displacement sensitive buildings, as roughly estimated in a previous paper Men [2] and this paper.

This paper deals with, in more detail, the problem of evaluation of the two inputs to the foundation base of buildings in aseismic design, based on the earthquake mechanism presented by the first author, as well as the dynamics of continuous media. It is shown that only in certain one-dimensional wave propagation problems the two stresses inputs can approximately be deduced from the routinely used accelerations of ground surface, in an explicit way, while for multi-dimensional problems this is impossible, or in other words, for multi-dimensional problems such direct approximate explicit relations between the accelerations and stresses are not available. While the displacement input should be provided by the use of the direct recording data of velocity graph or displacement graph recorded near the site of the building for the focus model Men [1,3,4] and for the routine method a displacement input is needed also even obtained via integrations.

To make a clear account in mind, some quantitative order of seismic stress input corresponding to the routinely used acceleration are given. A rough estimation is also given to an earthquake of shallow focus, including the shear and tensile stresses as well as the two velocities, which are quite greater than those shocked on the ground surface of an air atomic explosion. Then, some main features of the theoretical seismograms nearby the focus are roughly estimated and some suggestions on in-situ recording velocity and acceleration are also presented shortly.

At last, to see the influence of overlooking the displacement input, some comparative calculations for the two design methods of a simplified buildings are given and it is shown that no matter what the focus model will be the displacement input plays a quite important role and must be added in any aseismic design.

TWO SEISMIC INPUTS TO FOUNDATION BASE OF BUILDING

Why we must take two seismic inputs to the foundation base of buildings, instead of only one acceleration as so far used to do, when soil-structure interaction have to be taken into account, is come from two reasons, i.e.,

3. According to the elastic theory of dynamics of continuous media, two continuity conditions, stress continuity and displacement continuity, between the soil and structure, must be always satisfied. So it is clear that two such inputs, stress and displacement, propagating from earthquake focus through rocks and soils to building foundations, must be required to make a dynamic response analysis of buildings under seismic actions.

However, the routine approach so far used only of one acceleration seems to deviate from the above principle and, strictly speaking, is suitable either only for the condition of rigid base ground because the rigid ground can only move as a whole horizontally and vertically (i.e. motion of a rigid body), without normal and shear strains but in reality such rigid ground is not existed; or for those buildings whose foundation base are posed directly on the ground surface of a deformable stratum since there will be not seismic stresses inputted on the base of foundation, because the stresses become zero on the free ground surface., but this latter case are almost not exist in regions with soil deposits, except those very hard rocks, especially in cold and heavy rainy regions.

(2) Based on the new model of earthquake focus, presented by the first author, Men [1,3,4], there are two pairs of unloading jump stress and two pairs of loading jump velocity at the focus when a great earthquake due to excessive compression forces led fault break suddenly occur. So there will be two pairs of P and S waves due to stress and velocity propagated from the focus to far fields, and, therefore, also to building foundations. In other words, there must be two types of seismic input, stress and velocity, applied on the building foundations.

We have to point out that even based on the fault focus model of Haskell [5], representing a fault fracture caused by pure shearing action, well accepted until now in seismology, in fact there are also two types of excitation at focus, shear stress and fault displacement, and their effects must propagate to everywhere, including building foundations. Unfortunately, the model overlooked the role of propagation of the fault displacement excitation occurred at the focus and for the far field it gave out only the displacement input derived from the shear stresses on the fault plane. We must point out that, in reality, at any fault focus two types of excitation must be existed because almost all shallow earthquakes` focus is fault fracture evolving rapid stress and displacement changes.

Thus we suggest confidently that two seismic inputs, stress and displacement or stress and velocity, should be accepted in aseismic design in the future to overcome the shortage available so far in the current design practice. While since the stress input will be more difficult to be defined so we try to find its relation with the acceleration input in the next section. in order to be able to use again the abundant observational data of acceleration obtained as well as the numerous accelerographs up to now.

As to why so far the acceleration has been widely accepted as the seismic input but not the displacement or velocity, not to say two of them, we think it may be due to the fact that the inertial forces of lumped mass is easy to calculate especially in the dominant period of pseudostatic design; i.e. the so-called force-method design and the acceleration observation is easier to realize since the principle of accelerograph of mass-spring type is more simple.

ON RELATION BETWEEN STRESS INPUT AND ACCELERATION INPUT

When the building sites are located in far field and the baserock is relatively even with upper thicker soil deposits, the wave propagation path may be taken as usually the same as currently used, i.e. from the baserock up toward the foundation of building and ground surface Men [3, 4],. In this one-dimensional wave propagation case, the dynamic equations of homogeneous, isotropic overburden soil (or weak rock, shortly represented by soil from now on) layer may be written as follows, in the x – z coordinate system where z indicates vertical direction. Note, in derivation of the equations we only assume that the material damping terms are very small and not taken into consideration and the deformations are infinitesimal. It is also evident that the equations are always valid, no matter how the stress versus strain relationships will be.

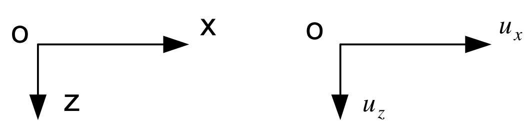

Fig.1. The coordinate system

$$\frac{\partial \tau}{\partial z} = \rho \frac{\partial^2 u_x}{\partial t^2} \qquad (1)$$

$$\frac{\partial \sigma_z}{\partial z} = \rho \frac{\partial^2 u_z}{\partial t^2} \qquad (2)$$

where, τ = shear stress in soil; σ_z = vertical stress in soil: u_x = horizontal displacement component; u_z = vertical displacement component; a_x = horizontal acceleration; a_z = vertical acceleration; ρ = mass density of soil; t = time.

Replacing the terms in right hand of equations (1) and (2) by a_x and a_z, we get

$$\frac{\partial \tau}{\partial z} = \rho a_x \tag{3}$$

$$\frac{\partial \sigma_z}{\partial z} = \rho a_z \tag{4}$$

Now, letting τ (z ,t) and a_x (z, t) be

$$\tau(z,t) = \tau(z) T_1(t) \tag{5}$$

and

$$a_x(z, t) = a_x(z) T_2(t) \tag{6}$$

respectively, and substituting them into Eq. (3) and Eq .(4), we get

.

$$\frac{T_2}{T_1} = \frac{d\tau(z)}{dz} / \rho a_x(z) = C \tag{7}$$

$$\therefore \ \frac{d\tau(z)}{dz} = C\rho a_x(z), \quad T_1 = CT_2 \tag{8}$$

Since T_1 and T_2 are arbitrary functions of time so the constant C must equal one, and thus leads

$$T_1(t) = T_2(t)$$

Therefore, the solution of Eq.(8) becomes

$$\tau(z) = \int_0^z \rho a_x(z) dz \tag{9}$$

which means that the shear stress is a integral function of the accelerations with respect to depth.

Similarly, from Eq. (4) and taking account of that like Eq. (5) and Eq. (6) but for σ_z and a_z instead, we can obtain the vertical stress in terms of vertical accelerations, i.e.

$$\sigma_z(z) = \int_0^z \rho a_z(z) dz \tag{10}$$

It is evident that in one- dimensional problems the stress input at depth z can be evaluated by the acceleration distribution along the depth, and vice versa. In reality, in aseismic design, only one acceleration measured (or specified) at ground surface is known. So one can get only an approximate stress from Esq. (9) and Esq. (10) by the use of numerical integration method, or as a first approximation, nearly we take them as follows,

$$\tau(z) \cong \frac{1}{2}\rho(a_x(z) + a_x(0))z \tag{11}$$

$$\delta_z(z) \cong \frac{1}{2}\rho(a_z(z) + a_z(0))z \tag{12}$$

Since only the accelerations of ground surface can be easily recorded during earthquakes, so for the shallow foundations we may take a (z) to equal a (0) and obtain, as a rough approximation,

$$\tau(z) \cong \rho a_x(0) z, \quad \sigma_z(z) \cong \rho a_z(0) z \tag{13}$$

Now let us see some numerical relations between the horizontal accelerations and the shear stresses based on Eq.(13), which leads

$$\tau = \rho \, a_x z = w \, z \, a_x / g$$

where, ρ = mass density of soil; w = unit weight of soil; g = gravity acceleration.

For example, taking w = 1.6 tone/m^3, a_x/g = 0.2, 0.3, 0.4 and 0.5; respectively, the shear stresses on the foundation base buried at depth z = 1, 2, and 3 m are listed below (Table 1)

Table 1. Shear stress (tone/m^2)

	z=0	z =1m	z = 2m	z = 3m
a_x/g = 0.2	0.0	0.32	0.64	0.96
a_x/g = 0.3	0.0	0.48	0.96	1.44
a_x/g = 0.4	0.0	0.64	1.28	1.92
a_x/g = 0.5	0.0	0.80	1.60	2.40

It seems that a 0.2 g acceleration of ground surface would be nearly equivalent to apply 0.64 tone/m^2 of shear stress to a foundation base at depth of 2 m below the ground surface, while 0.4 g acceleration would be near 1.44 tone/m^2 one. As a consequence, the foundation of larger base area will transmit larger total force to its upper building.

In two-dimensional problems the dynamical equations are

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau}{\partial z} = \rho a_x \qquad (14)$$

$$\frac{\partial \sigma_z}{\partial z} + \frac{\partial \tau}{\partial x} = \rho a_z \qquad (15)$$

There are three stress components and two acceleration ones in these two equations. It is evident that these three stresses cannot be determined directly from the two known accelerations. The third compatibility equation must be considered, which relates to the strains and the stress ~ strain relationships of soil. Therefore, in this case the use of accelerations cannot means to give the stresses easily provided that either the horizontal normal stresses are assumed known a priori or the three equations must be solved simultaneously. However, the solution will be rather difficult to get even under elastic soil assumption, due to the high order partial differential equations and relevant to displacements` functions.

$$\frac{\partial^2 \varepsilon_x}{\partial z^2} + \frac{\partial^2 \varepsilon_z}{\partial x^2} = \frac{\partial^2 \gamma}{\partial x \partial z} \qquad (16)$$

Similarly, for the three-dimensional problems, given only three accelerations we cannot obtain directly the six stress components.

To sum up the above statements, it appears that only in one-dimensional wave propagation problems the two kinds of accelerations, horizontal and vertical, can directly provide the two stress inputs in a proximate way. Whereas for multi-dimensional problems the stresses can never be obtained directly from the given accelerations or, in other words, the two acceleration inputs cannot be equivalent to the stress inputs.

ON RELATION BETWEEN ACCELERATION AND VELOCITY

In the sense of mathematics, velocity can be obtained simply by means of integration of acceleration with respect to the time variable. Until now, the routine method of getting velocity is integration of acceleration records over time with assumption that the velocity at t = 0 is zero. However, since the theoretical velocity records should have a jump value, different from zero, as explained in the paper Men [1,3,4] on the earthquake mechanism model, so the integration constant cannot be zero, but an unknown jump value at the location. This fact makes it clear that the velocity must be measured directly in-situ by velocity graphs and cannot be obtained by integration of the acceleration records.

It must be pointed out that the above statements, on relation of velocity versus acceleration, related to the earthquake focus in this paper are based on the focus mechanism mode presented by the first author, which is suitable to the conditions that the fault break is caused by shear fracture under excessive compression pressure in intact rock strata and the fault break propagation speed must be very great and at least greater than the wave propagation speed of the rock around the focus. Due to the fact that earthquakes may be caused also by other force conditions (e.g. pure shearing, folding, and so on) and thus will lead to other focus mechanism and some different statements. But, as we will clarify later by some simple comparative calculations, even for the conventional usage of displacement obtained via direct integration of acceleration the use of two seismic inputs are still necessary.

ON RELATION BETWEEN VELOCITY AND DISPLACEMENT

Now the displacement can be obtained directly by integrating the velocity with respect to time

$$u = \int_0^t v dt \qquad (17)$$

Since displacements have not jump at the focus so u will equal zero at $t = 0$, therefore, the displacement inputs can be obtained in such a way..

HOW TO DEFINE THE SEISMIC INPUTS TO THE BUILDING FOUNDATION

Based on the foregoing relations it appears that only when we treat the seismic waves as so far usually used to, as an one – dimensional and without damping, can the acceleration be used to replace approximately the function of stress by Eq. (11) and Eq. (12). Moreover, the displacement inputs should be added, in addition. To this end, it is necessary to conduct in-situ recording of displacement (or velocity) at the depth at which the foundation will be set up. From the velocity record we can get the displacement by integration over time.

However, to measure the velocity of ground at different depths would be very difficult, if not impossible, in comparison with the conventional measurement by velocity graphs fixed on ground surface. As a first approximation, the velocity at depth z may be derived for a purely elastic ground from the following wave equations,

$$G \frac{\partial^2 v_x}{\partial x^2} = \rho \frac{\partial^2 v_x}{\partial t^2} \qquad (18)$$

$$E_z \frac{\partial^2 v_z}{\partial z^2} = \rho \frac{\partial^2 v_z}{\partial t^2} \qquad (19)$$

For multi-dimensional problems it has been explained that only given the two accelerations cannot enable us to get the stress inputs in an explicit way. So it seems that, at present stage, the routinely used one – dimensional wave propagation scheme, from baserock up to ground surface, have to be used again, before more comprehensive approaches will be found in the future.

ON WAVE PHASES IN SEISMOGRAMS

Besides the simplified approach for determination of seismic inputs stated above, there is also an analytical method on the basis of shock waves originating from the fault plane of quake focus, by integration, similar to that Haskell (1964) and others have used. However, due to the fact that the wave propagation paths are difficult to be rigorously defined and the mechanical properties of the ground media, responding velocity loading and damping, etc. are not clear enough, this method also cannot be expected to give reliable results at present stages.

In what follows we want only make some rough estimation of the possible wave phases in the seismograms at locations near the focus. To this end, let us first make a rough estimation of the shock loading at the focus of a shallow focus earthquake, for an example. Of course, it must be recognized that this estimation would be much rough because we lack the exact mechanical properties of the focus rocks under high pressure and high temperature environment.

Let the focus depth be 10 km, with rock overburden of unit weight 2.4 tone/m^3, in average. The shear strength of the rock at focus is contributed by friction, $\tan\phi$ ¡×1.0 and cohesion c = 10000 kpa, which are estimated from the test data of shallow rock strata Editorial Board [6] with some modifications based on physical reasoning.

From the Eq. (5) and Eq. (6) of the previous paper Men [1,3,4], we can get

$$\tau_s = 2.4\times10^4\times1.0 + 10000$$
$$= 2.5\times10^5\text{kpa}$$

$$v_s = \frac{\tau_s}{\rho c_s} \cong \frac{25\times10^4}{\frac{24}{9.81}\times2\times10^3} \cong 50\text{m/s}$$

$$\sigma_s \cong \gamma h + (1 \text{ to } 2)\,\tau_s$$
$$\cong 5.0 \leftrightarrow 7.0\times10^5\text{kpa}$$

$$v_\rho = \frac{\sigma_s}{\rho c_\rho} \cong 70 \leftrightarrow 90\text{m/s}$$

It could be seen that the unloading shear stress and unloading tensile stress have about an order of 10^6 kpa , while the corresponding loading velocities have an order of 10^2 m/s at the focus. If the focus depth of an earthquake were 20 km, then the stresses and velocities would be at least about double what are estimated above. Clearly, such great stresses and velocities are quite higher than those applied to the ground surface induced by an air atomic explosion Ginsberg [7], Men [8]. Fortunately, they are applied first on quite deep ground and thus could not directly hit human bodies and buildings.

A key problem that we should study further would be how these quantities attenuate along the propagation path to far fields. To solve, more correctly, this problem, many deep studies have to be undertaken. At present, the authors can only roughly predict the main phases in the theoretical seismograms of near field, in which the influences of wave reflection, refraction, diffraction, scattering, attenuation and other interaction have not yet occurred.

According to the earthquake mechanism model presented by the first author, the seismograms nearby the focus should represent the effects originated from the two pairs of jump stress and velocity at the focus. Especially, for accelerograms we should make some discrimination. They are mainly consisted of four parts too. The two parts correspond to the unloading shear and tensile stresses and other two parts correspond to the loading shear and compression velocities. The ones due to stresses have more complex relations with the stresses, while the ones due to velocity would have more simple relations. Because there are two velocity jumps at the focus, so their differentials with respect to time, being the accelerations, must be existed also. However, at the jump points these derivatives would equal a quite great value of Delta function of time. Therefore, it can be imagined that a quite great acceleration jump (for the example stated above it is about 5g to 10g) will appear at the time when the two jump velocities arrive at the location of accelerograph. Theoretically speaking, such jumps should occur in far field also, but diminishing somehow, probably, due to geometrical and earth material damping and other influencing factors.. Whereas in the many real recordings of acceleration these jump values have not been found. The authors are not sure what is the reason and think it may be caused by the fact that up to date the commonly used strong motion accelerographs have lower frequency response range while the Delta function has very high frequency spectrum..

COMPARATIVE CALCULATIONS

In order to see how the results will be different between the two types of seismic loading inputs we make some simplified comparative calculations for a mass-spring structure of one- degree of freedom, resting on soil deposits overlaid a bedrock stratum. The wave propagation in free fields is regarded as the one-dimensional one from the bedrock up to the ground surface.

Firstly, let us evaluate the response of the upper structure of a single lumped mass – spring system fixed on a massless rigid footing as shown in Fig.2 without damping, under the horizontal shear stress, acceleration, and displacement inputs. The equations of motion are respectively,

$$m\frac{d^2x}{dt^2}+kx=-A\tau \qquad (20)$$

$$m\frac{d^2x}{dt^2}+kx=-m\frac{d^2u}{dt^2} \qquad (21)$$

$$m\frac{d^2x}{dt^2}+kx=-ma \qquad (22)$$

where $m=$ mass of the structure; $k=$ stiffness of spring to lateral movement; A = area of the footing of building; τ, $u=$ input shear stress and horizontal displacement to the footing base; respectively; $a=$ input horizontal acceleration of ground, $x=$ horizontal displacement of the lumped mass; $\omega=\sqrt{k/m}$,natural frequency of the system.

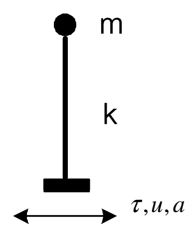

Fig. 2 Three types of seismic input

We can get the solutions of Eqs (20-22) as follows.

For shear stress inputs

Assuming the shear stress input to be $\tau=\tau_0\cos\omega_p t$, the general solution of Eq. (20) can be obtained as follows,

$$x=x_0(\cos\omega t+\sin\omega t)+x_1\frac{\sin\omega t}{\omega}-\frac{A\tau_0}{m\omega}\int_0^t\sin\omega(t-\theta)\cos\omega_p\theta d\theta \qquad (23)$$

When $x_0=x_1=0$ the solution becomes

$$x=-\frac{A\tau_0}{m\omega}\int_0^t\sin\omega(t-\theta)\cos\omega_p\theta d\theta \qquad (24)$$

While for the shear stress input of the form $\tau=\tau_0\delta(t)$

we obtain the solution to be

$$x=-\frac{A\tau_0}{m\omega}\int_0^t\sin\omega(t-\theta)\delta(\theta)d\theta \qquad (25)$$

or

$$x=-\frac{A\tau_0}{m\omega}\sin\omega t \qquad (26)$$

For horizontal displacement inputs

Similarly, when

$$u=u_0\cos\omega_p t$$

we get the solution of Eq.(21) to be

$$x=-\frac{u_0\omega_p^2}{\omega}\int_0^t\sin\omega(t-\theta)\cos\omega_p\theta d\theta \qquad (27)$$

which shows that the response is also strongly related to the frequency of input, in addition to the natural frequency of the structure.

and when $u=u_0\delta(t)$

we get

$$x = -\frac{u_0}{\omega}\int_0^t \sin\omega(t-\theta)\delta''(\theta)d\theta \qquad (28)$$

and its solution is not easy to get because the present of $\delta''(t)$ in the integral.

For horizontal acceleration input $a = a_0 \cos\omega_p t$
the solution is

$$x = -\frac{a_0}{\omega}\int_0^t \sin\omega(t-\theta)\cos\omega_p\theta d\theta \qquad (29)$$

and when $a = a_0\delta(t)$
we get

$$x = -\frac{a_0}{\omega}\sin\omega t \qquad (30\ )$$

Concrete examples
To see the real differences we made a comparative calculation in what follows.

(1) The structure `s foundation is located on the surface of soil layer (Fig.3)

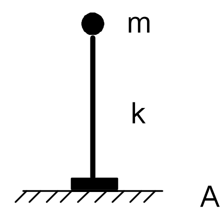

Fig. 3 Foundation on ground surface

By the routine method in which only horizontal acceleration of ground surface is given as a cosine function of time with amplitude of a_0 i.e. $a = a_0 \cos\omega_p t$ and then we can obtain the following results.

For the case 1 where only one acceleration input is impacted to the base

we get

$$x = -\frac{a_0}{\omega}\int_0^t \sin\omega(t-\theta)\cos\omega_p\theta d\theta \qquad (31)$$

For the case 2 where two seismic inputs, displacement and stress, impact to the base

Since the stress input is zero on the ground surface so we can get the solution only from the displacement input which must be determined by the in-situ observational data for the earthquakes model that the authors of present paper based on, and it could be different from that of Case 1.

Now let us see what result will be when we take the displacement input from the acceleration via integration by assuming the two integration constants to be zero, as routinely done up to date. Thus we get

$$u = -\frac{a_0}{\omega_p^2}\cos\omega_p t \qquad (32)$$

while the response x under this input will be

$$x = -\frac{a_0}{\omega}\int_0^t \sin\omega(t-\theta)\cos\omega_p\theta d\theta \qquad (33)$$

In comparison with that solution for acceleration input Eq.(31), they are equal.

(2) The structure’s foundation base is buried below the ground surface at depth, h (Fig.4)

For the case 1 where only one acceleration input is impacted to the base as the routine method assumed.

As usually done in the current design, for shallow foundations the acceleration on the base may assume again equal to that on the ground surface, so the solution is nearly equal Eq. (31).

For the case2 where two inputs are necessary. Obviously, under such structure conditions two inputs, stress and displacement, must be given. Now we can use the equivalent stress input to replace the acceleration input and a displacement input must be added, in addition, to satisfy the two continuity conditions between the foundation base and the soil deposit.

The responses should be more complicated if taken account of the lateral confine effect of buried soils, which may have yet different response to these two types of input. If we can neglect this effect then the routine design should be changed to as follows, under the acceleration $a_x = a_0 \cos \omega_p t$ of ground surface,

3. According to the routine design method
Under acceleration input $a_x = a_0 \cos \omega_p t$
we can get same as Eq.(31) as

$$x = -\frac{a_0}{\omega} \int_0^t \sin \omega(t-\theta) \cos \omega_p \theta d\theta \qquad (34)$$

and under displacement input $u = -a_0 \int \int_0^t \cos \omega_p t dt^2$

From Eq.(27) we can get

$$x = -\frac{a_0}{\omega} \int_0^t \sin \omega(t-\theta) \cos \omega_p \theta d\theta \qquad (35)$$

And the total solution should be the sum of the two, i.e.

$$x = -\left(\frac{a_0}{\omega} + \frac{a_0}{\omega}\right) \int_0^t \sin \omega(t-\theta) \cos \omega_p \theta d\theta \qquad (36)$$

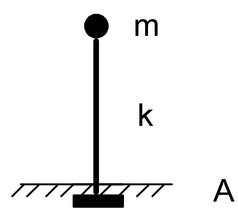

Fig. 4 Buried Foundation

it is two times of that result when only acceleration input is applied.

b) According to the author's method based on the focus model Men [1,3,4], the stress input $\tau = \rho h a_x \cos \omega_p t$, instead of the acceleration, induces

$$x = -\frac{A \rho h a_0}{m\omega} \int_0^t \sin \omega(t-\theta) \cos \omega_p \theta d\theta \qquad (37)$$

and the total solution would be

$$x = \text{Eq.(37)} + U_x \text{ induced term} \qquad (38)$$

where U_x = displacement input specified from real observational data in-situ.

It can be seen that only for those simplest structures rested on the ground surface under same a simple harmonic input in terms of acceleration or displacement can the routine design method give out same response. While for structures buried some depths below the ground surface the calculation results for the two design approaches are quite different. Neglecting the displacement input may result in underestimation of the response of the structure particularly for those displacement-sensitive structures and those harmonics of high frequencies because the response of displacement inputs relates not only to the natural frequency of the structure but also to the frequency of the harmonic input as can be seen from Eq.(27).

As to the influence of rigidity of soil deposits to the response of structure, following these two design approaches we will give some comparative calculations elsewhere.

CONCLUTIONS AND DISCUSSIONS

From the foregoing statements the authors are inclined to point out that

3. In aseismic designs of engineering structures two seismic inputs, stress and displacement to their foundations must be specified and taken into account, regardlees what the focus model (Men or Haskell) will be. It is shown that the commonly used acceleration inputs may be only equivalent, approximately, to the stress inputs in the given way when the problems can be treated as one-dimensional. So the displacement inputs must be given otherwise. On the contrary, when the problem must be regarded as multi-dimensional, such a direct equivalency will not exist. In other words, given only two accelerations we cannot find out explicit relations between the accelerations and the stress components.

2. Even in one-dimensional problems, attention should be paid on that the stresses are transmitted via foundations up to upper structures and the total seismic force loading is directly proportional to the total base area of foundations, as can be seen also from Eq.(20). While the acceleration inputs are independent of the foundation area. Therefore, only for those buildings with raft foundation can the acceleration inputs be equivalent to the stress inputs, as evaluated above, while for those with single and/or strip foundations the total force inputs are smaller than the normal ones, see Fig.5 (where building 1 subjects the total seismic load smaller than building 2), or in other words, the acceleration inputs are overestimated the stress inputs in such cases. This conclusion can also be seen from the Eq.(25) and Eq.(29), or the Eq.(20) and Eq.(22), in the comparative calculation.

Building 1 Building 2

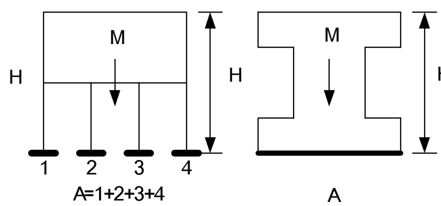

Fig.5 Buildings of different area of foundations, per unit area

3. For the great earthquakes following the focus model of Men [1,3,4] besides the stress inputs or acceleration inputs, the velocity or displacement inputs have to be added, which must be determined by the data of direct recordings in the field. Although from viewpoint of mathematics it is easy to get these two quantities from acceleration via integration, but, as he has clarified, this method cannot be valid because the velocity has a jump at t = 0. While even for the current routine method that uses integration, the displacement inputs must be added too because the displacement input plays a quite different role in comparison with the stress input, as indicated by Eq.(27) where the amplitude of response is directly proportional to the square of frequency of the harmonic displacement input, whereas the amplitude of response to stress or acceleration, see Eq.(25) and Eq.(29), is independent of that input frequency.

Moreover, the routine design method based on one acceleration input seems to be reasonable only when the structure` foundation is located on the ground surface. Otherwise, for buried foundation this method may underestimate even about a half of the actual response, as indicated from the concrete example, Eq.(36). For more complex types of structure as well as under seismic inputs of more complicated time functions we could expect that the deviations between the two design methods should be more evident and complex.

4.. From the focus mechanism of Men [1,3,4] we can forecast that a record of accelerogram recorded in near field should be consisted of four parts, i.e., those due to the unloading shear stress and tensile stress, and the loading shear velocity and compression velocity. The former two may be uneasy to obtain their solutions at present, and the latter two can be observed directly from the velocitygram by differentiation with respect to time. It is evident that the accelerations due to velocities should have a quite great value of Delta function of time. However, it seems that whether this jump value can be recorded would be dependent on many factors, particularly the pick up instruments` frequency response range.

5. To gain more reliable and complete data, regular simultaneous observations of acceleration and displacement (or velocity) at same sites, of near and far fields, would be desirable from now on. It is well known that because the locations of coming earthquake focuses would be very difficult to know a priori, so up to now there have not been many strong motion records obtained right on or nearby the focuses, not to say both complete acceleration and velocity records at the same locations. Only use of these records can we do their mutual check and to testify the authors` prediction of the theoretical seismogram and the mechanism mode. While in far fields over the years since the 1970`s after the 1971 San Fernando Earthquakes there have been many strong motion records of acceleration recorded by analog and digital instruments Trifunac [9-12] in which no initial jumps have been observed and it appears that those obtained by digital instruments have overcome the trigger delay problem. About why no jumps have been observed the authors of this paper are inclined to believe that even so far the jumps have not been observed it does not mean that the jumps are definitely not existed. In reality, up to date, using the pick up of elastic pendulum type (mass-spring system), commonly with frequency band of 0 to 50 Hz, acceleration and velocity recording may be more suitable for the signals of low frequency range, and not for those signals evolving very high frequencies content such as the Delta and Heaviside function of time. Therefore, further achievements in seismometry to overcome these difficulties are urgently desired to get more actual and complete seismic recordings. It seems that new types of strong motion instrument other than the pendulum types (e.g. piezoelectric, laser, etc) should be devised to this goal. Without such advanced strong motion seismographs of very broad frequency response band and abundant simultaneous recording data of velocity and acceleration the aseismic design seems to be unable to have a sound basis.

6. The current methods of aseismic design based on given acceleration inputs only is actually based on stress inputs to some approximate extent, and lack the displacement inputs. This fact might lead some unsafe consequences when soil- structure interactions must be taken into consideration and the structures locate not on the ground surface, as roughly shown in the comparative calculations, especially for those displacement sensitive structures and buildings. So an updated method based on both acceleration- and displacement inputs should be started to preparation in combined with the improvement of observation technique and seismometers for acceleration and velocity recording without missing the largest amplitude of acceleration and the jump velocity.

Of course, since there are still many uncertainties and unknowns in earthquake origin, seismology, wave propagation path, dynamic properties of earth materials, seismic loading inputs to buildings, building behavior under stress and displacement inputs, seismometry, etc. so, up to date, it appears that earthquake engineering could not be a very rigorous science and much effort of professionals in all related fields should be done in the future, and any reasonable novel contributions should be encouraged so as to improve it gradually becoming more rigorous. .

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