Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Dynamic characteristics of collapsing loess and its site seismic response

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ABSTRACT: Collapsing loess is a special soil, it is a important respect of site seismic response to research dynamic charcteristics of collapsing loess. Through the test and statistical analysis of the dynamic characteristics of collapsing loess, including the tests of shear wave velocity at site, and the dynamic triaxial tests of soil samples (dynamic shear modulus and dynamic damping ratio), and statistical analysis of the characterstics parameters, this paper proposes the law of the dynamic characteristics of collapsing loess.

1 INTRODUCTION

In northwest regions of china, such as Shaanxi, Gansu, Niengxia and Shanxi province etc, Collapsing loess that thickness is larger, is widely distributed. these regions are usually located seismic areas that intensity is high, historical record indicated, seismic disasters have caused cnormous losses to the people's life and property of these regions, now, lareg–scale constructions have been making in these regions, with the earthquake resistance in wiew, it has important significance to research the dynamic characteristics of collapsing loess and its site seismic response. since seventies, some research departments and institutions of higher learning have made many test research about dynamic characteristics of loess one after another. The authors participated these test research, meantime, collected many information of dynamic tests, combining some site tests, a lot of statistical analysis, are made, site seismic response, is calculated, the statistical results about dynamic characteristics, are used in actural site analysis of seismic response, some preliminary imagines are provided for reference of aseismic design and seismic response calculation of engineering construction in collapsing loess regions.

2 DYNAMIC CHARACTERISTICS OF COLLAPSING LOESS

To research dynamic characteristics of site soil (to discuss its dynamic parameters), is first to research dynamic shear modulus and damping ratio, these parameters have important significance for seismic response.

Loess is a saline colloidal clay, it has wide–aperture and multi–aperture structure. natural void ratio is usually 0.8 to 1.1, the intensity of loess is higher in natural state, the compressibility is lower, if its cohesive force of concretion is destoried, then, its initial state is destoried immediately, additional subsidence is produced. In dynamic characteristics respects, loess is different from other soil.

2.1 The relationship of collapsing loess between dynamic–stress and dynamic–strain

Research results indicated that, the relative curve between dynamic–stress and dynamic–strain of collapsing loess is relative to its initial water content, when water content is tower, the relative curve is usually straight line, when water content is higher, it is usually hyperbola, two relationship of stress–strain may be shown as follow:

$$\text{when water content is lower: } \sigma_d = C\varepsilon_d \qquad (1)$$

$$\text{when water content is higher: } \sigma_d = \frac{\varepsilon_d}{a + b\varepsilon_d} \qquad (2)$$

in which, a, b, c are respecdvely different test parameters, they are relative to loess properties and stress of concretion.

2.2 The analysis of dynamic parameters of collapsing loess

According to formula (1) and (2), the normalized equations about dynamic–modulus and dynamic–strain may be given conveniently as follow:

$$G = \frac{\tau}{\gamma} \qquad (3)$$

$$\frac{G}{G_0} = \frac{1}{1 + \gamma / \gamma_0} \qquad (4)$$

in which, G_0 is initial shear modulus;

Table 1 The statistical regression results of shear wave velocity

The classifications of site soil		Regression equation	Correlation coefficient
Loess tableland or loess that is located high terrace		$V_s = 126.415H^{0.325}$	0.91
Loess that is located I grade or II grade terrace	Q_4	$V_s = 146.3H^{0.196}$	0.77
	Q_3 and before Q_3	$V_s = 141.2H^{0.28}$	0.76
Saturation loess		$V_s = 120.77+46.07L_nH$	0.85
Farinaceous clay		$V_s = 136.149H^{0.394}$	0.87
Sand		$V_s = 155.72H^{0.261}$	0.87
Gravel		$V_s = 177.95H^{0.272}$	0.92
Silt soil		$V_s = 87.7H^{0.382}$	0.84

G is dynamic shear modulus;
τ is dynamic shear stress;
γ is dynamic shear strain;
γ_0 is max dynamic shear strain.

The dynamic shear modulus may be obtained by testing, of course, it may be also obtained by statistical analysis, as well know, in small strain, the dynamic shear modulus of loess may be determinded according to shar wave velocity V_s, as follow,

$$G = \frac{\gamma}{g} V_s^2 \qquad (5)$$

in which, G is dynamic shear modulus;
γ is apparent density of loess;
V_s is shear wave velocity;
g is gravity acceleration.

Now, to determind shear wave velocity have had some riper and perfect methods. The authors have made many times site tests about shear wave velcity in collapsing loess regions of China, meantime, multitudinous initial data about this respect, are collected and sorted out, statistical analysis of these results, is made. Research results indicated, shear wave velocity increase with buried depth of loess, on condition that environments are different, itsregular pattern of change is also different. Assuming that, the cause of formation of loess is the same or similar, the mechanical characteristics of loess is resemble, then, the dynamic characteristics of loess of the same type, that is located different places but indentical soillayer, are the same or similar. Thus, through statisitcal regression of many test data of shear wave velocity, the shear modulus of loess may be determinded. The results of statistical regression of shear wave velocity are shown in table 1.

The damping ratio of collapsing loess may be determinded by tests, but now, because of effect of its soil structure, test results are usually discreter, for this reason, further research would be made.

According to Hardin's research results [1] about dynamic nonlinear problem of soil, the damping ratio of loess usually accord with formula (6),

$$\frac{\lambda}{\lambda_0} = \frac{\gamma_h}{1+\gamma_h} \qquad (6)$$

in which: λ and λ_0 are respectively damping ratio and max damping ratio;

$$\gamma_h \text{ ishyperbolicstrain}, \gamma_h = \frac{\gamma}{\gamma_0};$$

Many research results indicate that, it is reasonable to express nonlinear character of soil using formula (6), $\gamma_h$changes with the classifications of soil only.

Formula (6)is also suitable for collapsing loess, but, because of effect of soil structure, the change of $\gamma_h$is greater, damping ratio increases with dynamic shear strain of loess, the relevant information indicate that, on condition that water content is higher, meantime, the dynamic shear strain range between $10^{-4}$and 10^{-2}, damping ratio may be calculated, according to formula (7), other hand, adding a corresponding coefficient.

$$\frac{\lambda}{\lambda_{max}} = 1 - \frac{G}{G_0} \qquad (7)$$

3 THE SITE SEISMIC RESPONSE ANALYSIS OF COLLAPSING LOESS

3.1 Dynamic characteristics of collapsing loess

Collapsing loess is generally distributed valley terrace and loess tableland regions, thus, its site property is influenced by valley terrace and loess tableland. The site landform of loess tableland is smooth and wide, the thickness of loess is about tens of meters, even over one hundred meters; valley terrace have two types, one is a wide terrace of accumulation, its terrace face is smooth and wide, another is narrow terrace of basal stump, its terrace face is quite narrow, the thickness of terrace loess is usually from a few meters to tens of meters. Many cities and towns in loess region, are situated in above—mentioned districts.

3.2 Calculation method of seismic response

To counter these particular characteristics of loess site, appropriate calculation model may be selected in researching its seismic response. as for valley terrace and locss tableland that relief is smooth and wide, site soil may be looked on as horizontal layer-medium, one-dimensional mathematical model may be used in calculating; but, as for terrace of basal stump that is narrow or loess ridge and loess hillock that are mutation of relief, two-dimensional mathematical model may be used in calculating.

Because that actural bedrock depth of loess site is usually hundreds of meters, even over one thousand meters, thus, an assumed bedrock is determinded in calculating seismic response of loess site, generally speaking, the depth where the shear wave velocity exceeds 500 meters / sec, may be taken as the computational basement depth, the shear wave velocity of all soillayer would be lower than 500 meters / sec. Research results indicated that, the assumed bedrock depth of loess site is about 80 ~ 100 meters.

3.3 The selection of acceleration time histories of bed rock (Inputting seismic wave)

In calculating seismic response, to determind acceleration time histories of bedrock is utmost importnnt, generally speaking, according to require of target spectrum determinded by seismic risk analysis, two methods may be used, one is to use synthetic seismic waves, another is to select some seismic records formerly and to make correction, some major works as follow:

1. According to regional in seismic geology, the distribution of fault zones which may affect this site and their activeness were studied;

2. Prediction and programing of the latent seismic focus were made and its activity parameters were calculated;

3. Using Der Kiureghian Ang's model, a seismic risk analysis was made; a ground intensity with different probability of transcendence in 50 years, was given; and, at the same time, a bedrock peak acceleration and bedrock acceleration response spectra (target spectra) were given;

4. Artificially synthesized seismic motion time histories in the bedrock were given.

Other hand, according to H.B.Seed's experience relationship among peak acceleration, dominant period, magnitude of earthquake and epicentral distance, then, peak acceleration and dominant period of acceleration time histories of bedrock may be determinded, through correction, seismic wave of acceleration time histories of bedrock may be determinded also.

3.4 The calculating of seismic response

Generally speaking, because of requires of engineering construction, there are a great deal of detection holes and site geologic sections, these information reflect distributive condition of site soillayer. According to above-mentioned statistical amalysis results of dynamic parameters of loess site, some parameters, such as dynamic shear modulus, may be given in different soillayer, then, site seismic response may be made conveniently.

The shear wave velocity of three typical sections are given in table2, in which, V_{sm} is average value of shear wave velocity, σ is its mean-square deviation,combining other parameters, the spectra of A, B and C section were calculated, theirs results were shown in fig.1. Other hand, in order to check statistical discrete influence, in section C, shear wave velocity values of $V_{sm\pm2\sigma}$ were calculated also. The results of section c results caused by straggling of shear wave velocity were given in fig.2.

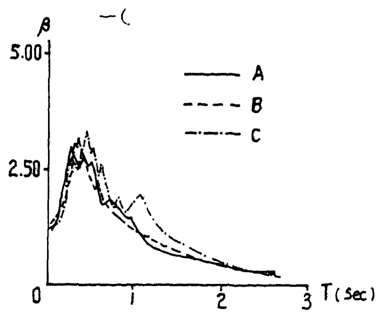

Fig 1. Calculating response spectra

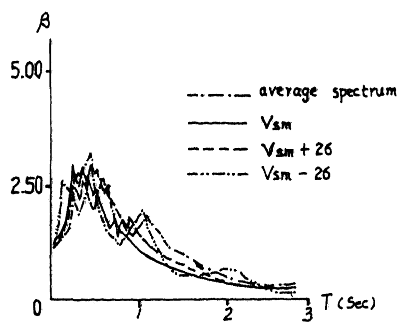

Fig 2. Calcuating response spectra of section c

4 THE ANALYSIS AND DISCUSSION OF SEISMIC RESPONSE

Using above-mentioned method, seismic response spectra of many sections in collapsing loess regions are calculated, meantime, through comparison, calculating results are discussed.

Table 2. The shear wave velocity of typical sections

Soillayer thickness(meter)		Shear wave velocity (meters / sec)				
Total thickness	Each layer thickness	Section A (V_{sm})	Section B (V_{sm})	Section C		
				C_1 (V_{sm})	C_2 ($V_{sm+2\sigma}$)	C_3 ($V_{sm-2\sigma}$)
2.5	2.5	194	137	203	269	137
5	2.5	194	203	203	269	137
7.5	2.5	266	218	280	330	230
10	2.5	266	218	312	330	230
12.5	2.5	307	222	312	386	238
15	2.5	307	266	312	396	236
20	5	351	258	342	396	288
25	5	419	345	358	424	292
30	5	450	362	360	430	286
35	5	495	433	373	439	307
40	5	504	433	436	516	338
45	5	523	425	494	584	404
50	5	478	380	523	621	425
55	5	481	404	514	574	454
60	5	494	424	514	574	454
65	5	514	424	468	522	414
70	5	509	439	514	614	414
75	5	530	442	530	600	460
80	5	538	486	538	590	486

4.1 Discrete influence of soil dynamic parameters

Response pactra are calculated using statistical regression, theirs comparison results are shown in table 3.

Response spactra parameters	ΔT_g(sec)	$\Delta\beta_m$
Comparing $V_{sm+2\sigma}$ with V_{sm}	0.02	0.065
Comparing $V_{sm-2\sigma}$ with V_{sm}	−0.066	0.007

In which, ΔT_g and $\Delta\beta_m$ are respectively average deviation values of dominate period and dynamic amplification coefficient between $V_{sm\pm2\sigma}$ and V_{sm}, negative sign indicate that, their results are greater than average value.

It may be made out, in table 3, when rigidity of soillayer increases, then, the dominate period of spectra will decreases; when rigidity of soillayer decreses, then, the dominate period of spectra will increases, it reflects this characteristics in fig.2. It may be made out, in table 3, the straggling caused by V_s is smaller.

4.2 The influence of soillayer depth

As for different depthes, the same section is calculated, other hand, different sections of soillayer distribution are also calculated, Research results indicate, when calculating depth is larger than 40 ~ 50 meters, its results have outstanding disparity, but, when calulationg depth is larger than 60 ~ 70 meters, the disparity of theirs results would decrease rapidly. In calculating, the rigidity of upper soillayer influences mainly short period components, when soillayer is over fixed depth, as for middle–long period components, its influence would be more obvious.

When soillayer exists soft interlayer, the groud seismic response would decrease, ground peak acceleration would decrease. But, if the depth of soft interlayer is the greatest, then, as for long–period components of spactra, it have amplification action.

4.3 The influence of seismic action

As for collapsing loess, under the action of common earthquake, the loess structure is not destoried, shear intensity is higher, rigidity is larger, dominate period of site response spectrum is shorter, it's value is about 2.5. Under the action of seldom seen earthquake, the loess structure is destoried, soillayer is plastic state, shear intensity decreases, dominate period is longer, it's value is about 2 ~ 2.25.

4.4 The influence of water content of site soil

The water content of loess influence directly it's shearing intensity and rigidity. The collapsing loess site that is located, on loess tableland and valley high terrace, because that its water table is lower, water content of loess is smaller, shear intensity is higher, dynamic amplification coefficient β_{max} is also higher. but, as for valley low terrace, its water table is higher, water content of loess is greater, shear intensity is lower, β_{max} is also lower, Inputting seismic in the same depth, the former dominate period of response spectrum is shorter than the latter.

5 CONCLUSION

5.1 The relationship between dynamic stress and dynamic strain of collapsing loess is relative to its initial water content, when water content is lower, the relative curve is usually straight line, when water content is higher, it is usually hyperbola.

5.2 The dynamic shear modulus of collapsing loess may be obtained by regressing analysis of shrar wave velocity, a convenient and feasible method was given, for calculating and discussing seismic response of collapsing loess site.

5.3 Using statistical regression method, seismic response spectra of collapsing loess site were calculated, the straggling influence of dynamic parameters is smaller, but, as for particular site soil, multiple seismic waves would be selected and calculated, average sults of calculation is given.

5.4 Under the action of common and seldom seen earthquakes, calculating results of seismic response spectra of loess site have the same characteristics. The water content of site soil would influence directly calculatring results of response spectra.

5.5 Dynamic characteristic and seismic response of collapsing loess site, are being researched now, because that it's soil structure is specialer, many problems, such as dynamic damping ratio etc, need be inquired further still.

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