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SYNOPSIS The evaluation method of the man-made ground vibration and its formula are reviewed in the paper. The author's formula presented the possibility to solve the vibration in near source due to the body wave from varied sources. The ground vibration sources, such as traffic, pile driving etc. and the effects of the embeded source are involved as well. The paramenters of the soil energy attenuation and the geometrical attenuation presented have been examined by National Standard Committee of CHINA in 1994. The case histories on varied testing site and vibrating effects are described.

REVIEWS OF THE STATE-OF-THE ART. GROUND VIBRATION ANALYSIS

In the present, analysis of the wave propagation of ground vibration are susally considerd as the practical effect both the rule of wave propagation within the ideal elastic medium and the soil as a medium with unelastic property.

The existent practical analysis of the man-made ground vibration attenuation relative to distance are frequently calculated by Bornitz's formula in 1931 (Richart, Woods, Hall, 1970) as follow

$$W = W_1 \sqrt{\frac{r_1}{r}} \exp\left[-\alpha(r - r_1)\right] \qquad (1)$$

Where W_1 --amplitude of vertical component of the R-waves at distance r_1 from the source

W -- amplitude of vertical component of the R-waves at distance "r" from the source

r_1 --distance from the source to the point of known amplitude

r -- distance from the source to the point of unknown amplitude

α --coefficient of attenuation, 1/m.

It may be seen that formula(l) is a precipitous exponential curve, therefore, where the r_1 is not a wide distance, the amplitude measured near the source is smaller and that measured far from the source is greater than predicted by Bornitz's formula. This is especially true for ground vibrations caused by powerful source. It is observed that the curve of the attenuation of ground vibration calculated by using the formula(l) are generally intersected at one point only with the observed one, and the values of the calculating one over this point causing deviation are usually engenderd in whole curve. Since the Bornitz's formula is a surface wave attenuation formula, providing no information about groud vibration induced in near source due to the body waves.

In the last decades of years, ground vibration are generally considered by suface wave (R-wave). For instance, a vertically oscillating circular source on an elastic half space, Miller and Pursey (1955) determined that the distribution of total input energy among the three elastic waves was 67 percent for the R-wave, 26 percent for the S-wave, and 7 percent for the P-wave, and indicated that the R-wave is of primary concern for ground vibration and so calculated it by formula Bornitz. However, an additional and often overlooked fact in above conclusive result, that is the two-thirds of R-wave energy on elastic half space, is from far source (Miller 1955). This far source is equal or larger than $2.5\lambda_R$ (prakash and Vijy 1988, and Richart, 1970), in which λ_R -wave length of R-wave. For instance, the distances for ground vibration induced by machine, are for common soil from 20m to 150m; for rock base 50m to 400m; and for saturated silt clay 10m to 100m. The conclusive results indicated the Bornitz's formula suitable for the range where the distance is equal or larger than $2.5\lambda_R$ (Viz, $r_1 > 2.5\lambda_R$), and the distance where primarily needed for designer is less than $2.5\lambda_R$ (Viz, $r_1 < 2.5\lambda_R$) in the unsuitable range.

On the other hand, only little if any progress has been made in reliably estimating distance from the source to the point of known amplitude (Viz, r_1). Although the r_1 in Bornitz's formule may at first glance seem logical, it is in fact an obsolete one since it ignores the effect on the wave propagation of all other variables of the problem (e.g.energy,radius of sources, geometrical attenuation of suppoting soil and so on), and the r_1 is a variable quantity and a random quantity. For example, the r_1 measured on the same soil is as follows, Table 1.

It may be seen that in Table 1 the r_1 is against physical and mechanical rule that the r_1 is proportional to the source energy, and the α varies largely to the same soil.

Apparently, the Bornitz's formula used in practice may mislead the designer and it is well-known that the frequency and area of the source have important effects on the amplitude of the attenuation of ground vibration.

TABLE 1. Measured r_1 and α of Bornitz's Formula

Soil	Sources energy		r_1 (m)	α (1/m)
1. Miscellaneous fill. dense, Slight wetness	forging hammer (ton)	< 1.0	18.8	0.07
		2.0	8.6	0.09
2. Siltes clay, median dense, Slight wetness		3.0	8.3	0.12
	fall hammer (ton−m)	60.0	31.3	0.06
		120.0	31.3	0.07
(After Song 1990)		180.0	31.3	0.05

GROUND VIBRATION INDUCED BY DYNAMICAL AREA SOURCE

Due to the complexity of the mechanics of energy dissipation of dynamic area sourec in soil, in the paper the dynamical area source, which is man−made, the approximate relationships of the attenuation of ground vibration are presented as a function of distance from the source " r ", effect coefficient of energy attenuation of soil "α_0". It may be a practical method for solving this problem. The energy of a dynamic area source is transmitted through the ground by composition of body (P,S) and surface (R) wave. By neglecting the phase difference between the body and R waves, then Yang (1981) obtained formula(2). The related parameters of the foumula (2) have been examined by National Standard Committee of CHINA in 1994. Then the formula (2) as follow

$$A_r = A_0 \sqrt{\frac{r_0}{r}\left[1-\zeta_0\left(1-\frac{r_0}{r}\right)\right]}\ \exp\left[-\alpha_0 f_0 (r-r_0)\right] \qquad (2)$$

in which A_r −−amplitude on free surface of soil at a distance r from dynamic area source center

A_0 −−amplitude at exciting source

ζ_0 −−coefficient of geometrical attenuation in relation to an area source, as given in Table 2

r_0 −− radius of exciting source, for a rectangular or square area, the equivalent radius is

$$r_0 = \mu_1 \sqrt{F/\pi}$$

F −− exciting source area

μ_1 −−coefficient for dynamic effects

For $F < 10m^2$ $\mu_1 = 1.0$

$F = 15m^2$ $\mu_1 = 0.9$

$F > 20m^2$ $\mu_1 = 0.8$

f_0 −− exciting frequency of source

α_0 −− coefficient of energy attenuation of soil, as given in Table 3.

It is clear that in formula(2), the radical expressions indicate the energy density for waves decrease as the distance from the source is increased, namely the geometrical attenmation and the amplitude of the body waves decreases as $1/r$, the R−wave decrease as $1/\sqrt{r}$, and the part other than the exponential item indicates consumption of energy by soil material damping. For $\zeta_0=0$, $f_0=1$ and $r_0=r_1$, Eq(2) becomes idential with the Bornitz's formula.

TABLE 2. Coefficients of Geometrical Attenuation, ζ_0

Soil Group	Radius of Exciting Foundtion, r_0(m)							
	≤0.5	1	2	3	4	5	6	≥7
Clayey Soil and Sands	0.85 ~ 0.99	0.70	0.60	0.55	0.45	0.40	0.35	0.15 ~ 0.25
Saturated Soft Soil	0.85 ~ 0.99	0.65 ~ 0.70	0.50 ~ 0.55	0.45 ~ 0.50	0.35 ~ 0.40	0.30 ~ 0.35	0.25 ~ 0.30	0.10 ~ 0.20
Rocks	0.90 ~ 0.99	0.85 ~ 0.90	0.80 ~ 0.85	0.75 ~ 0.80	0.70 ~ 0.75	0.65 ~ 0.70	0.60 ~ 0.65	0.40 ~ 0.50

NOTE: 1.For intermediate values of r_0 is calculated by means of the method insertion .

2.For saturated soft soil, when the depth of under ground water is equal to or less than 1m, smaller ζ_0 value is used, and when it is more than 2.5m, the ζ_0 value for common soil is used.

3.For rocks, when the thickness of covering layer is within 2.5m, larger value is uesd, and when it is over 2.5m, smaller ζ_0 value is used, and when it is over 6m, the ζ_0 value for common soil is used.

TABLE 3. Coefficent of Energy Attenuation of Soils α_0

SOil Group		α_0 S/m
Rocks(Coverins layer Within 1.5 ~ 2.0m)	Shale,limestone	$(0.385 \sim 0.485)10^{-3}$
	Sandstone	$(0.580 \sim 0.775)10^{-3}$
Hard Plastic Clays		$(0.385 \sim 0.525)10^{-3}$
Broke Stones of Medium Density Cobbles		$(0.850 \sim 1.100)10^{-3}$
Plastic Clays,Coarse Sands and Gravels of Medium Density		$(0.965 \sim 1.200)10^{-3}$
Soft Plastic Clays,Siltes,Sliphty Dense,Medium or Coarse Sands		$(1.255 \sim 1.450)10^{-3}$
Silty Clays,Siltes,and Saturated Fine Sands		$(1.200 \sim 1.300)10^{-3}$
Recently Deposited Clays and Unsaturated Loose Sands		$(1.800 \sim 2.050)10^{-3}$

NOTE: For the some condition, when the void ratio of soil is larger, larger α_0 valne is used and when it is smaller, smaller α_0 valne is used.

SOME ESPECIAL DYNAMIC AREA SOURCE

For Some especial dynamical area as mentioned in formula(2)−−Yang(1981),the related parameters may be considered as following.

Highway and Railway

Radius of Source. The highway for flexible pavement $r_0 = 3.25$m; the highway for stiff pavement and the railway $r_0 = 3.0$m.

Coefficients of geometrical attenuation. The highway $\zeta_0=0.30$; the railway $\zeta_0 = 0.35$, coefficients of energy attenuation of soil. silty clays $\alpha_0=0.25\times10^{-3}$ s/m; silty sands and gravels $\alpha_0 = 0.85\times10^{-3}$; unsaturated loosesands $\alpha_0 = (1.40 \sim 1.45)10^{-3}$.

Subway−−Embeded Source

Radius of Source (when $H > 2.5r_m$). When $r < H$, $r_0 = r_m$; when $r > H$, $r_0 = \delta r_m$. where r −−distamce in terms of formula(2); r_m −−radius of embeded source; H — —depth of embeded sources; δ — — coefficients of embeded source, when $\rho_f/\rho_b = 0.75$ (in which ρ_f — —mass density of fille soil beside the foundation, ρ_b — — mass density of soil below the founda tion) and when $H/r_m=0.5$, $\delta = 1.3$, when $H/rm = 0.7$, $\delta = 1.4$, when $H/r_m = 1.0$, $\delta = 1.5$

Coefficients of geometrical attenuation. When $r < H$, the ξ_0 value is in Table2 multiplication by increasing coefficient 1.5; when $r > H$ the ξ_0 value can be obtained from Table2.

Piling

Radius of the source. For the soft clays and saturated fine sands $r_0 = 4 r_p$; for the hard clays $r_0 = 5r_p$; for the medium sands $r_0 = 6r_p$. where r_p — -radius of a pile.

Coefficients of geometrial attenuation ξ_0 and energy attenuation of soil α_0 can be obtained from Table 2 and 3.

Piling Vibration Source

$$V_0 = \frac{\sigma}{\sqrt{\rho E}} \qquad (3)$$

$$A_0 = \frac{1}{2\pi f_0} \frac{\sigma}{\sqrt{\rho E}} \qquad (4)$$

where $\sigma = \varepsilon_e E_e$; $\varepsilon_e = V_e/V_s$.

ρ — — mass density of soil layer below the tip of pile

Ee — — compression modulus of soil layer below the tip of pile (kPa)

$E = (3 \sim 10)E_e$ — — elestic modulus of soil layer below the tip of pile(kpa)

Vs — — velocity of shear wave of soil layer below the tip of pile (m/s)

Ve — — velocity of particle extruded soil below the tip of pile(m/s).

For soft clays and saturated fine sands Ve = (0.4 ~ 0.6)m/s, for hard clays Ve = (0.8 ~ 1.2) m/s, and for medium sands Ve = (1.2 ~ 2.0) m/s.

Basic Frequency of Piling Source. In the field, the soil layers are composet of plastic clays, silty clays and silts, the frequency determined by piling as follow

Radius(r_p) mm	length(l) m	fo HZ
170 ~ 200	12 ~ 13	fo = 2 + 0.0265[R]
170 ~ 200	7 ~ 8	fo = 0.855 + 0.059[R]

in which, [R] — — the bearing values of subsoil having to be corrected in the light of the depth(kPa).

Example: a soft clay site, the driving hammer was model 25, the concrete pile was a 350 × 350mm in section and 13m long, Ee = 6400KPa, Vs = 198m/s and Ve = 0.4m/s, calculating the piling source velocity from Eq, (3), then, $V_0 = 41.93$mm/s, the velocity tested in site was $V_0 = 33.47$mm/s. In comparison with the result by Eq (3) is a approach value.

CASE HISTORIES

The case histories in evaluation of man — —made ground vibration have been conducted in the varied testing site as following.

Evaluation of Environment Vibration. The biggest forging hammer in a site was to set work, the falling weight was about 21 tonnes. The environment vibration having an effect on reseptors such as precise machines etc. must be properly evaluated before its construction, or the constructive site must be far distant the original work, if not, there is a large amount of precision machines harmed du to the ground vibration.

The comparative resultes both evaluated by formula (2) and measured in site after the hammer foundation and its workshop was constructed in the original site were presented in Table 4.

As a result of the hammer foundation and its workshop const ructed in the original site, the work is both a good environment and a economical site power pipeline process flow and cost of productions. It has been properly operated for 15 years and great economic benefit has been made.

Evaluation of Ground Vibration

The comparative resultes determined from varied soil surface and different source, both calculated by formula(2) and measured in site, as follow in Fig.1, Fig.2. The soil and scurce propertyare listed in Table 5.

CONCLUSIONS AND DISCUSSION

Although the r_1 in Bornitz formula may at first glance seem logical, but it is a variable quantity and a random quantity, and the distance where is primarily needed for designer $r_1 < 2.5\lambda_R$ is in the unsuitable range.

The formula(2) propounded by Yang(1981) shows that the calclated values almost identical with that of the measured ones for vavied soil surface and different source.

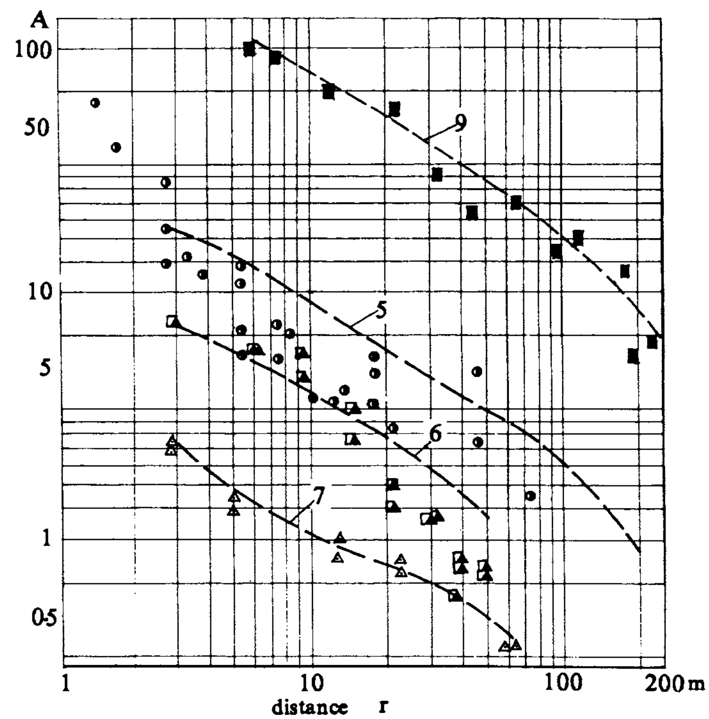

Fig.1 Comparative resultes of amplituedes attenuation with distance from the truckes and Compressor.

TABLE 4 Evaluation Environment Vibration by Heavyduty Forging Hammer

Source	Distance m	Evaluational Receptors						Remarks
		Receptor	Velocity of Ground Vibration V mm/s			Frequencyin site by Hammer Hz		
			Permitting Value	Caculated by Eq.(2)	Measured	Designed	Measured	
Heavyduty Forging Hammer	100.0	Precision Machine Tool	4.00	3.60	2.74	10.0	11.5	* Permitting imput Velocity
	300.0	Generating Plant	1.26*	0.94	0.73**	10.0	11.5	** Measuredby the same site

TABLE 5 Soil and Source Property

№	Source	Soil	№	Source	Soil
1	⊙–Loading train, V=60km/h	Silts	6	◪–5ts truck, V=30km/h, rigid pavement	Silty loam
2	△–Loading train, V=20~30km/h	Silt loam and Coarse sand	7	◬–Bus, V=30km/h, rigid pavement.	Silty loam
3	◭–Do.horizontal, radial	Silt loam and Coarse sand	8	□–Heavyduty forging hammer	Hard Silts
4	▲–Do.horizontal, Tangent	Silt loam and Coarse sand	9	■–Heavy compressor.	Saturated silt Clay
5	◑–4ts truck, V=50km/h, flexibl Pavement	Silts		------ Calculatad by formula(2)	

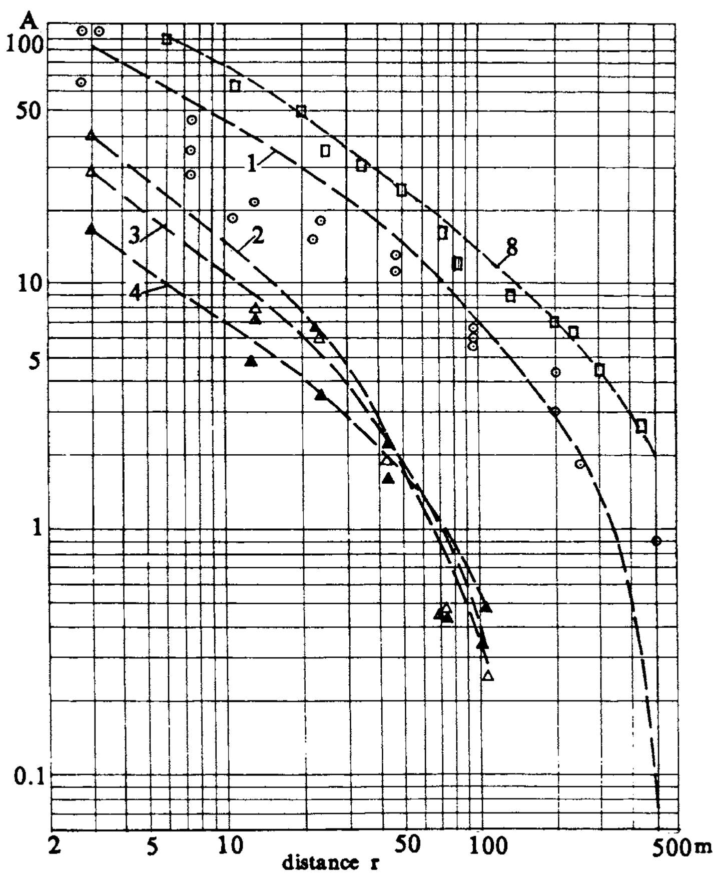

Fig.2 Comparative resultes of amplituedes attenuation with distance from the traines and forging hammer.

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