GEOSEA '98 Proceedings, Geol. Soc. Malaysia Bull. 43, December 1999; pp. 601-610

Ninth Regional Congress on Geology, Mineral and Energy Resources of Southeast Asia — GEOSEA '98
17 – 19 August 1998 • Shangri-La Hotel, Kuala Lumpur, Malaysia

The prediction of engineering properties of soils by geophysical exploration method: laboratory ultrasonic and field seismic refraction tests at Khon Kaen, Thailand

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Abstract: This research studied the wave velocities through compacted soils of SM group at different water contents. The soil samples were collected from Amphoe Muang Khon Kaen and adjacent areas, Khon Kaen Province, Thailand. The compression and shear wave velocities (Vp, Vs) were determined by an ultrasonic velocity test. The results indicate Vp and Vs decrease with increasing moisture and decreasing density. The uniaxial compressive strength (UCS), modulus of elasticity (Ed) and modulus of rigidity (G) could be predicted as follow: $UCS = 0.4Vp^{0.83} = 0.3Vs^{0.98}$ kPa, $Ed = 4.8Vp^{1.79} = 8.2Vs^{1.9}$ kPa and $G = 1.9Vp^{1.79} = 2.0Vs^{2.0}$ kPa. The seismic refraction method was used to check the laboratory test. The dynamic elastic constants determined from field investigation indicate a good fit to laboratory wave velocity curves.

INTRODUCTION

At present day, the conventional site investigation for soil foundation involves boring and field testing which are time consuming and costly. The authors intended to use the non-destructive methods to predict and evaluate the engineering properties of soils. Techniques of wave velocity measurement through soil media would have some significant relation to the soils properties (Youngme *et al.*, 1998). An ultrasonic velocity test and seismic refraction methods were used in the study (Sumatra, 1997). Amphoe Muang Khon Kaen and adjacent areas were selected as a pilot site. The soil deposits are silty sand classified as SM in Unified Soil Classification system. The study area is located between latitude 16°10' to 16°35'N and longitude 102°30' to 103°15'E (Fig. 1). The topography indicates undulating rolling terrains and flood plain, swamps and high mountain range in N-S trend at the west to North-West of the area.

LABORATORY TESTING

The collected samples were compacted at different moisture conditions using standard compaction method (Wannakao and Youngme, 1998). Figure 2 illustrates the moisture density condition of the soils. The sonic velocity of P and S waves of these compacted soils were determined using OYO Ultrasonic Viewer model 5217A. Each specimen was placed under P or S transmitter and receiver. When P or S wave was generated, then travel time through the specimen was determined. The P wave travel time (tp) was detected from first pulse of the wave form (Fig. 3a) but the S wave travel time (ts) was determined from phase different between the zero time and tested time curves (Fig. 3b). P and S wave velocities (Vp and Vs) were calculated from specimen length (L) divided by the travel time ($Vp = L/tp$; $Vs = L/ts$). Then, the specimen was uniaxially loaded till failure occurred. The uniaxial compressive strength (UCS) was then calculated.

FIELD SEISMIC REFRACTION EXPLORATION

A six-channel signal enhancement seismograph model Mcseis 150 was used in this study. The method of exploration was separated into two parts according to seismic wave sources, P and S waves generators.

A 12 lb hammer impacting on a metal plate of 0.5 inch thick was used as P-wave source. Six vertical geophones of 28 Hz were spread at 3 meters

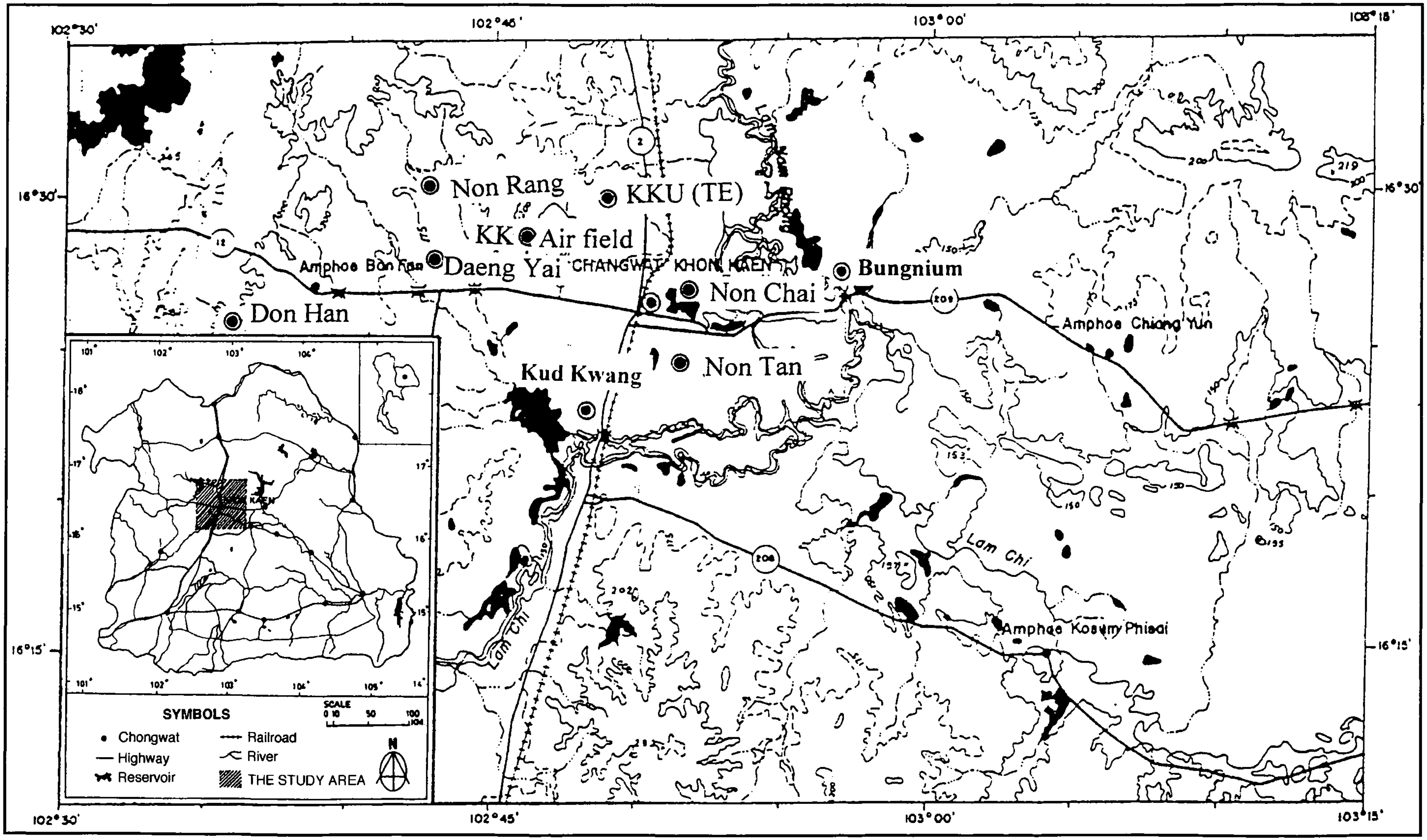

Figure 1. Map of study area and soil sampling locations in Khon Kaen and adjacent area.

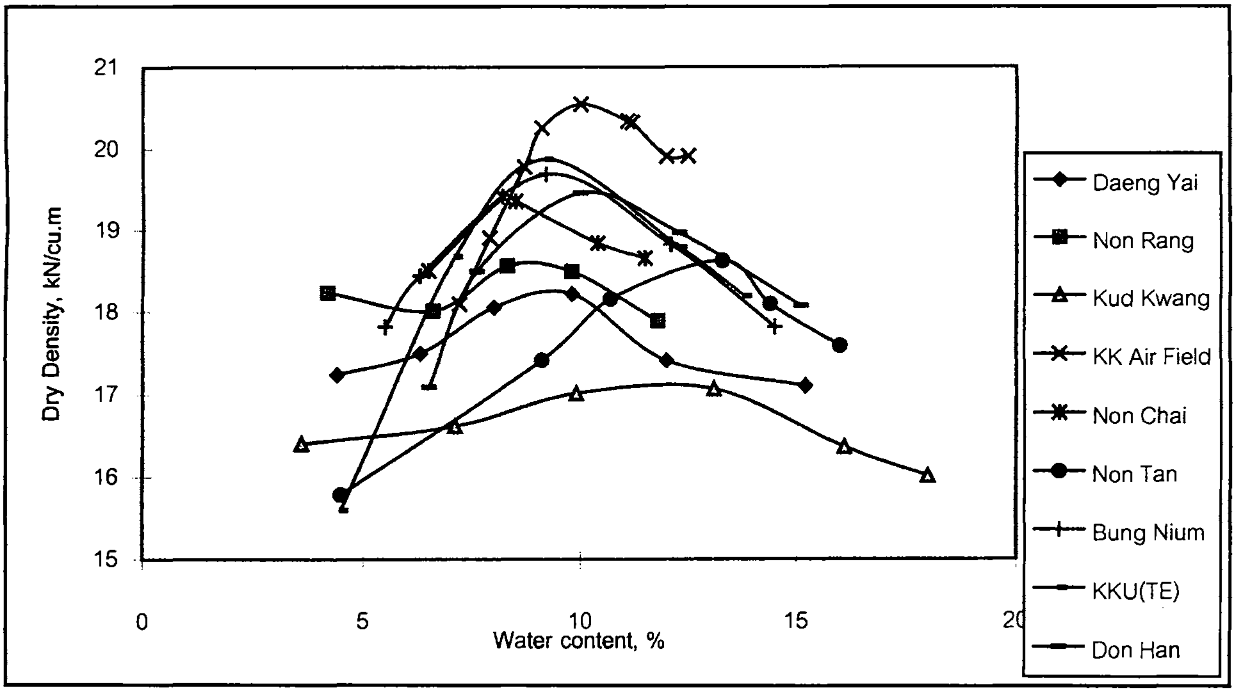

Figure 2. Moisture-Density of compacted soils (SM Type) from Khon Kaen, Thailand.

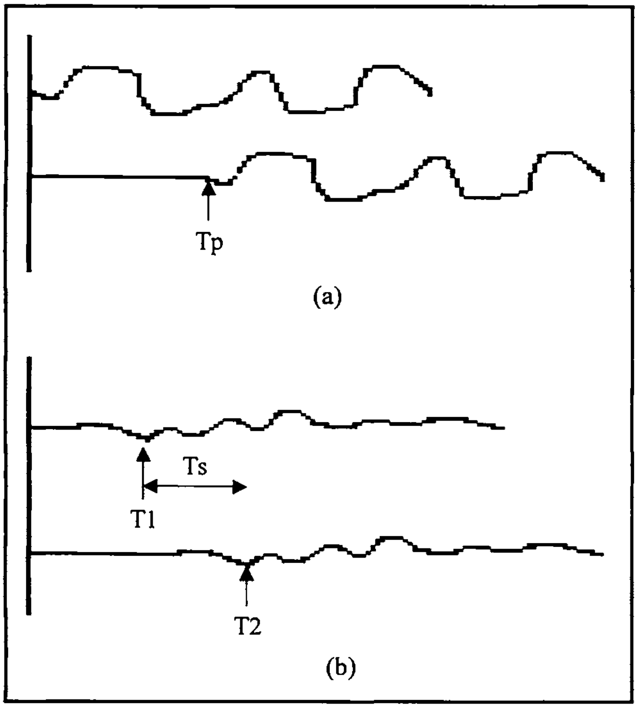

Figure 3. (a) Tp determined from first arrival; (b) Ts determined from phase difference (T2–T1).

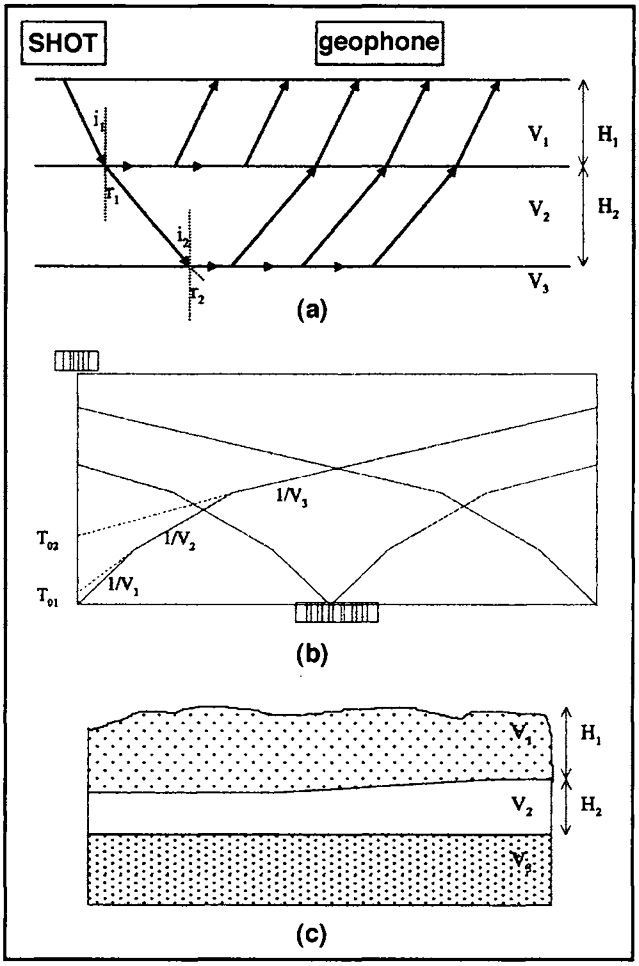

Figure 4. (a) geophone spreading and refraction theory, (b) T-X curve for Vp and thickness interpretation, (c) interpreted thickness of soil layers.

spacing for seismic wave detection. The time versus distance (T-X) curve could be plotted. The number of soil layers, thickness and P-wave velocity could be determined from the T-X curve (Fig. 4a, b, c).

S wave was generated by horizontal hitting at the end of a wooden plank of about 22 x 10 x 250 cm with a dead load on a jeep or truck (Fig. 5). The line of geophones was perpendicular to length of the wooden plank. In order to minimize the P-wave interference, the geophones were spiked in a horizontal position parallel to the hitting direction (Fig. 6). Youngme (1985) stated that a wooden plank, linear traction source, is most efficient for S wave source. The S wave travel time could be determined by reversing the hitting direction, then fitting the first and second hits seismogram to get the exact phase reversal for arrival time (Fig. 7).

RESULTS AND DISCUSSION

Wave Velocity-Moisture-Density

Figure 8 (a, b) and 9 (a, b) illustrate that the P and S wave velocities decrease with increasing moisture and decreasing density.

Wave velocity-UCS

Figure 10 (a, b) indicates a significant relationship between Vp-Vs and uniaxial compressive strength (UCS). The Vp-Vs increase with increasing strength. However, the relation is not exactly linear, but in a power relationship. The power cure fit could be used to predict soil strength from the Vp-Vs as follows:

$$UCS = 0.4Vp^{0.83}\ kPa$$
$$UCS = 0.3Vs^{0.98}\ kPa$$

Vp, Vs = P, S wave velocity, m/s

Wave Velocities-Dynamic Elastic Modulus

The dynamic elastic modulus could be calculated from elastic wave equations (Lama and Vutukuri, 1978) as:

$$Ed = \frac{\rho Vs^2 (3Vp^2 - 4Vs^2)}{Vp^2 - Vs^2}$$

$$G = \rho Vs^2$$

$$\nu = \frac{Vp^2 - 2Vs^2}{2(Vp^2 - Vs^2)}$$

where
Ed = dynamic elastic modulus, Pa
G = modulus of rigidity, Pa
ν = Poisson's ratio
ρ = density, kg/m^3

Figure 11 (a, b) show the power trend of Ed and Vp, Vs. Figures 12 (a, b) also show a good power trend fitting between G and Vp-Vs, especially with Vs. These modulus could be predicted as the following equations:

$$Ed = 4.8Vp^{1.79} = 8.2Vs^{1.9}\ kPa$$
$$G = 1.9Vp^{1.79} = 2.0Vs^{2.0}\ kPa$$

Sudirham (1986) stated that the Ed would be 10^2 greater than Es (static elastic modulus).

Field Interpretation

The seismic refraction exploration indicate 2 soil layers, silty sand and lateritic clay soil. The interpreted thickness, Vp and Vs of each layer from nine locations are listed in Table 1.

The Ed and G of 1st and 2nd layers were calculated as tabulated in Table 2.

The calculated field Ed of 1st and 2nd layers were plotted to the compacted soils curve (Fig. 13a-b). The plot indicates good fit especially the 1st layer soil of silty sand.

Vp/Vs Ratio

The Vp/Vs Ratio correspond to the Poisson's ratio. This implies packing or fracture in the soil grain. The Vp/Vs ratios increase with increasing Poisson's ratio or compressibility of soils. Figure 14 illustrates the Poisson's ratio of 1st and 2nd layers.

CONCLUSIONS AND SUGGESTIONS

The study indicates the effect of moisture and density on the wave velocities. Vp and Vs decrease with increasing moisture and decreasing density. The strength and dynamic elastic moduli could be predicted from Vp and Vs as power equations. However, most seismic refraction exploration could determine only Vp, as the S wave source is not quite common.

The field strength of the soil should be further determined by conventional standard penetration test (SPT). The static elastic modulus of 1st soil layer should be determined by either plate load test or dutch cone test. The measured static modulus should be compared to the dynamic modulus and wave velocities. More soil types should be studied. This method should be used together with conventional investigation i.e. boring or standard penetration test. It would make the method more efficient and reduce the number of borings and time of investigations.

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Figure 5. Wooden Plank, weighted by a truck (Youngme, 1985).

Figure 6. A Geophone, planted horizontally (Youngme, 1985).

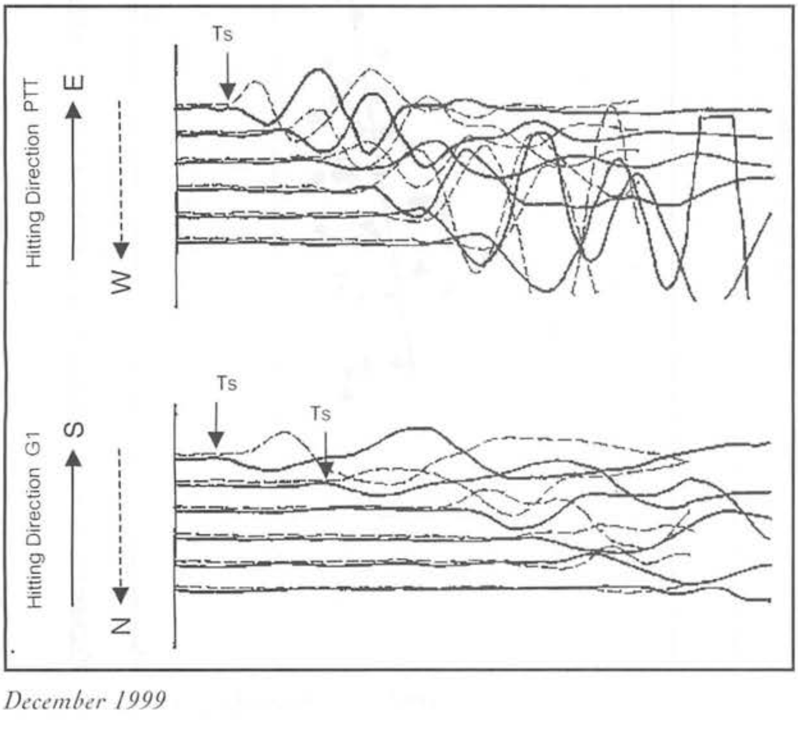

Figure 7. S wave travel time is determined from the difference in phase reversal between the first and second ends of wave sources.

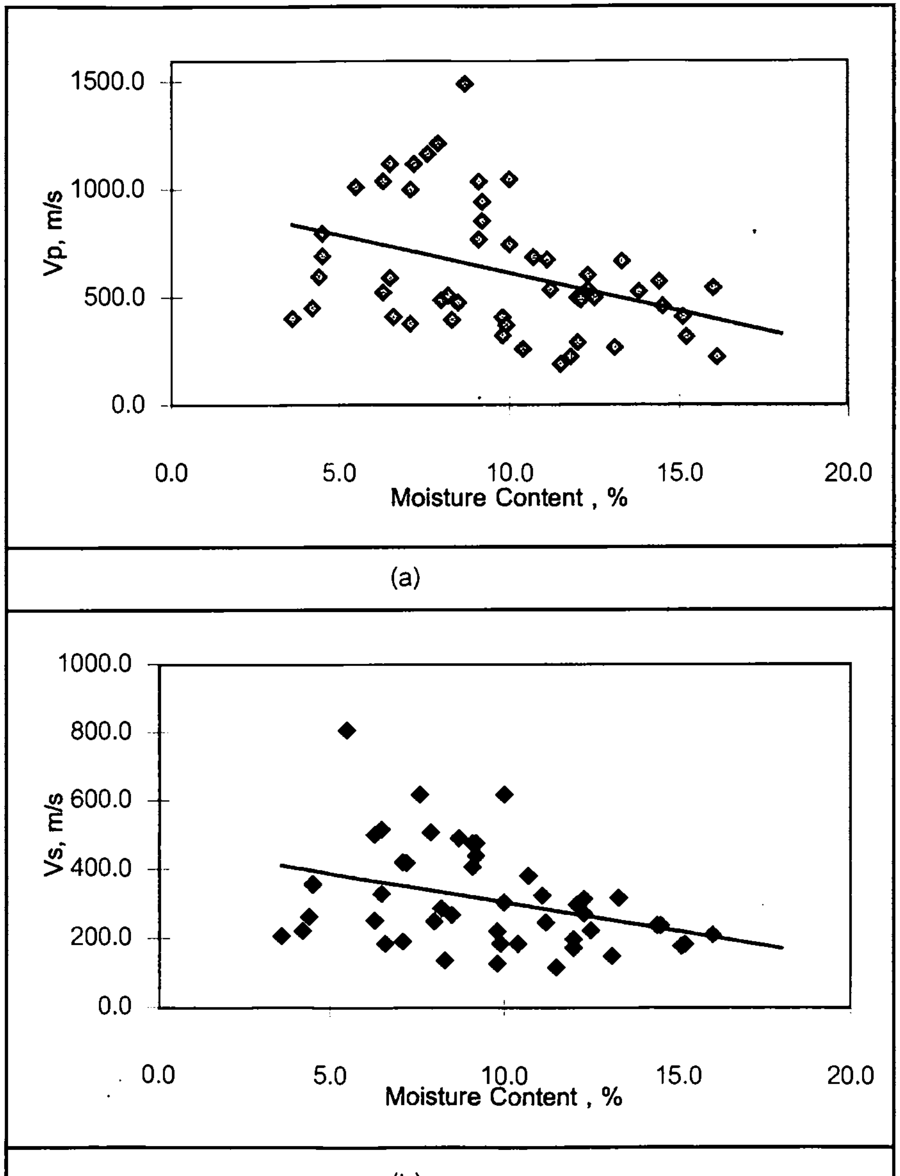

Figure 8a, b. P and S wave velocities decrease with increasing moisture contents.

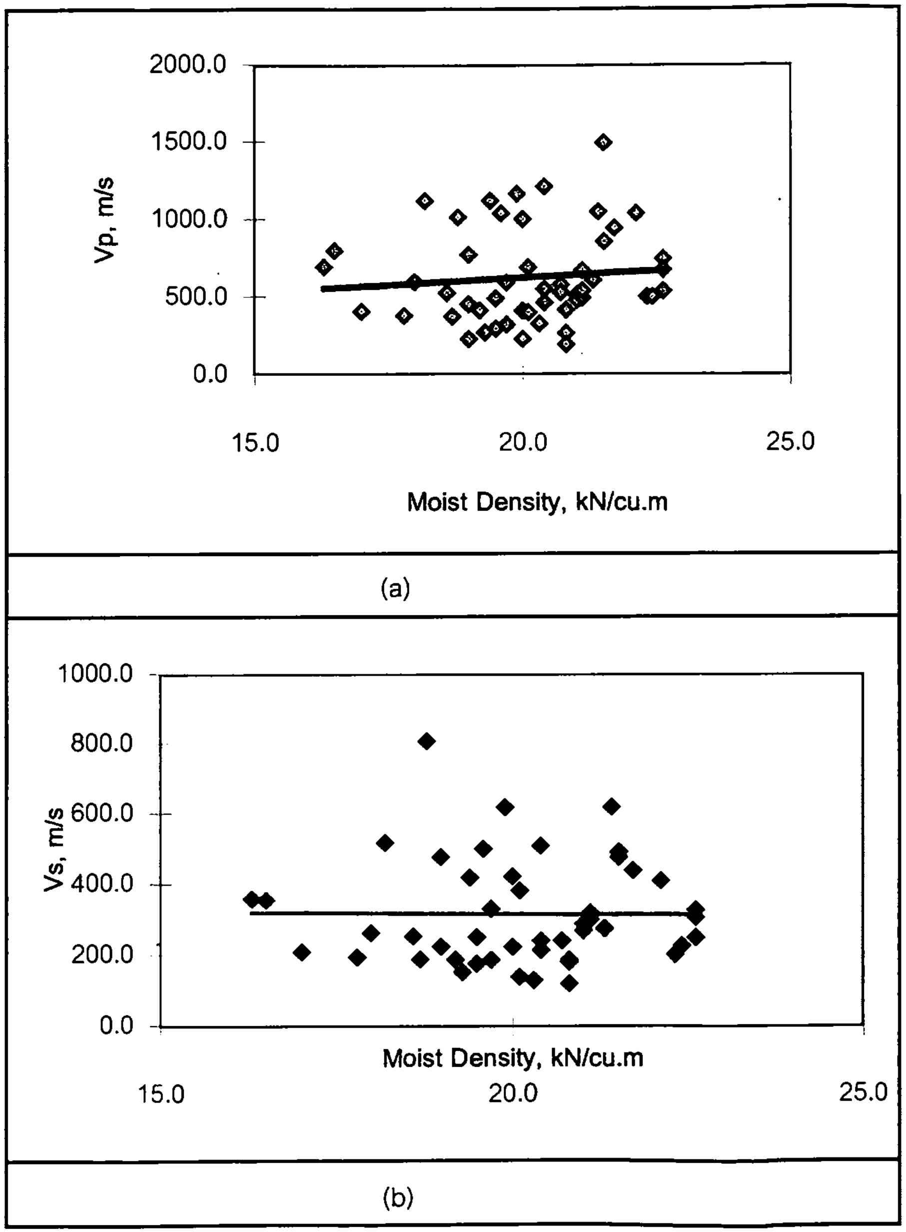

Figure 9a, b. P and S wave velocities decrease with decreasing density.

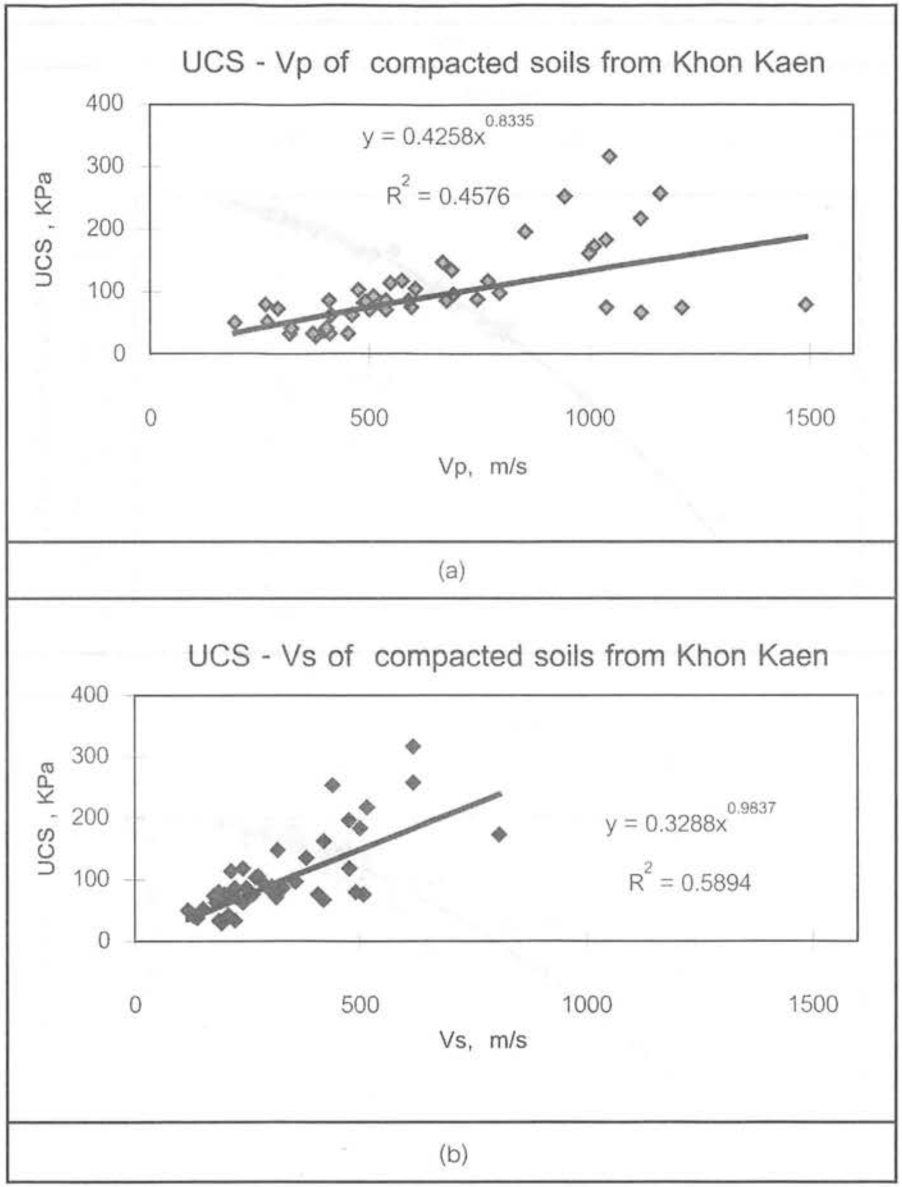

Figure 10a, b. Relationship between uniaxial compressive strength and wave velocities.

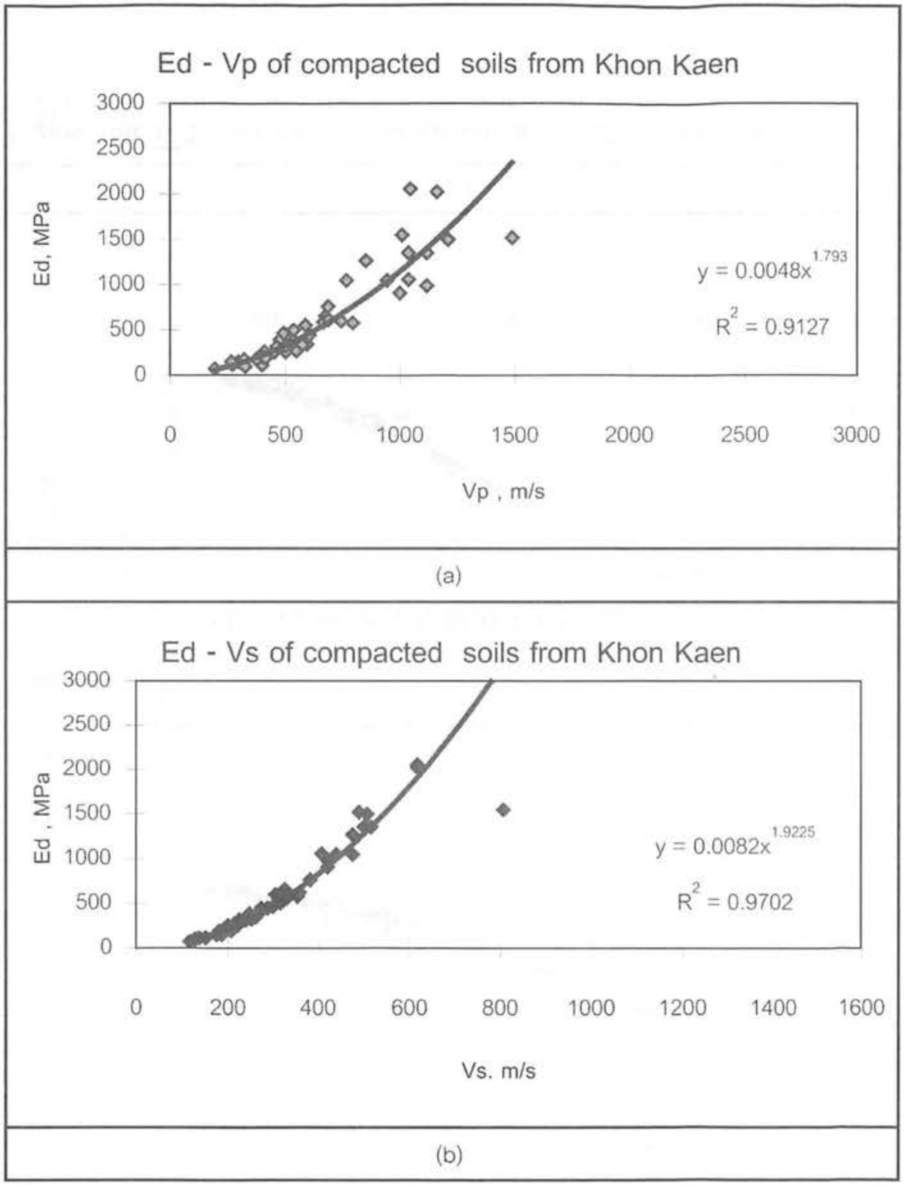

Figure 11a, b. Relationship between dynamic elastic modulus and wave velocities.

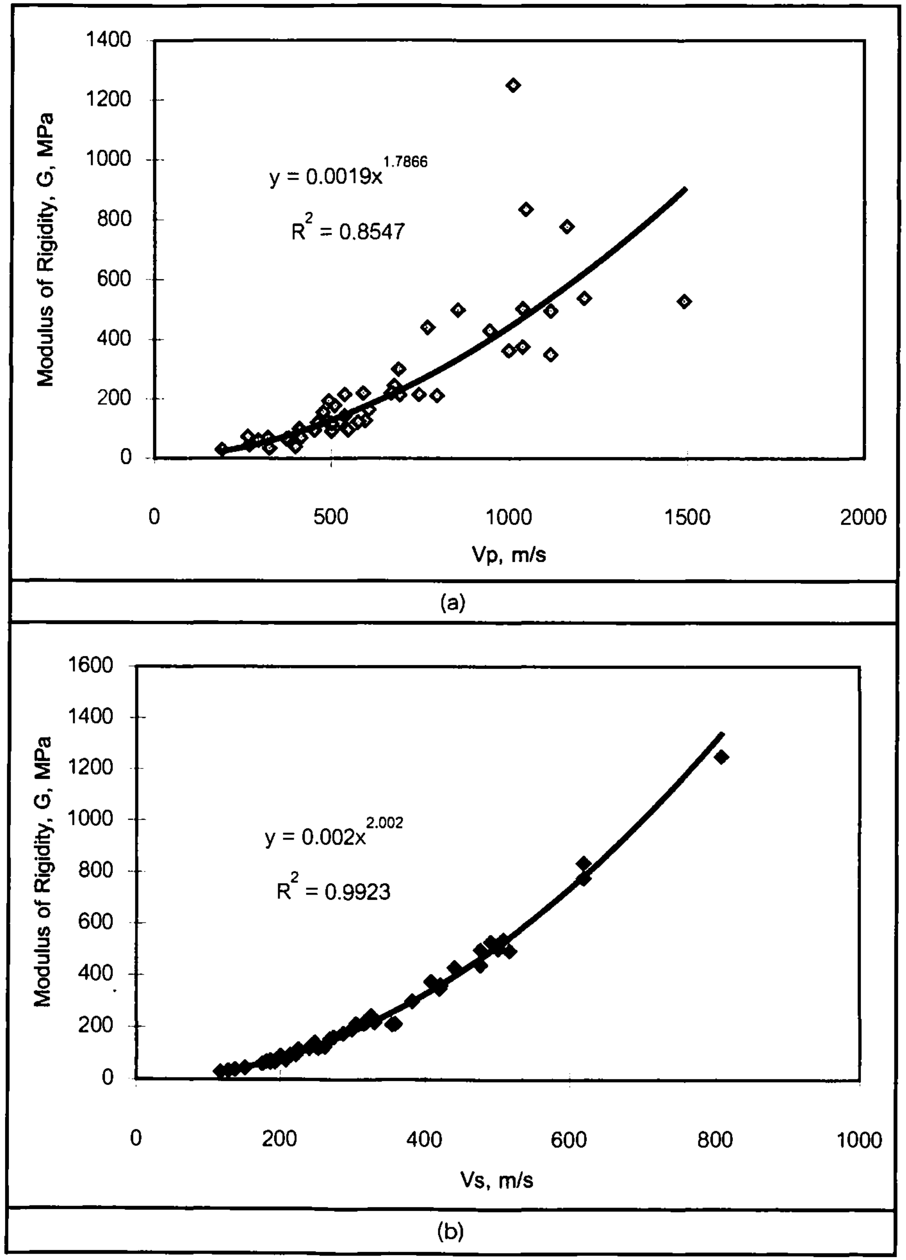

Figure 12a, b. Modulus of rigidity versus wave velocities.

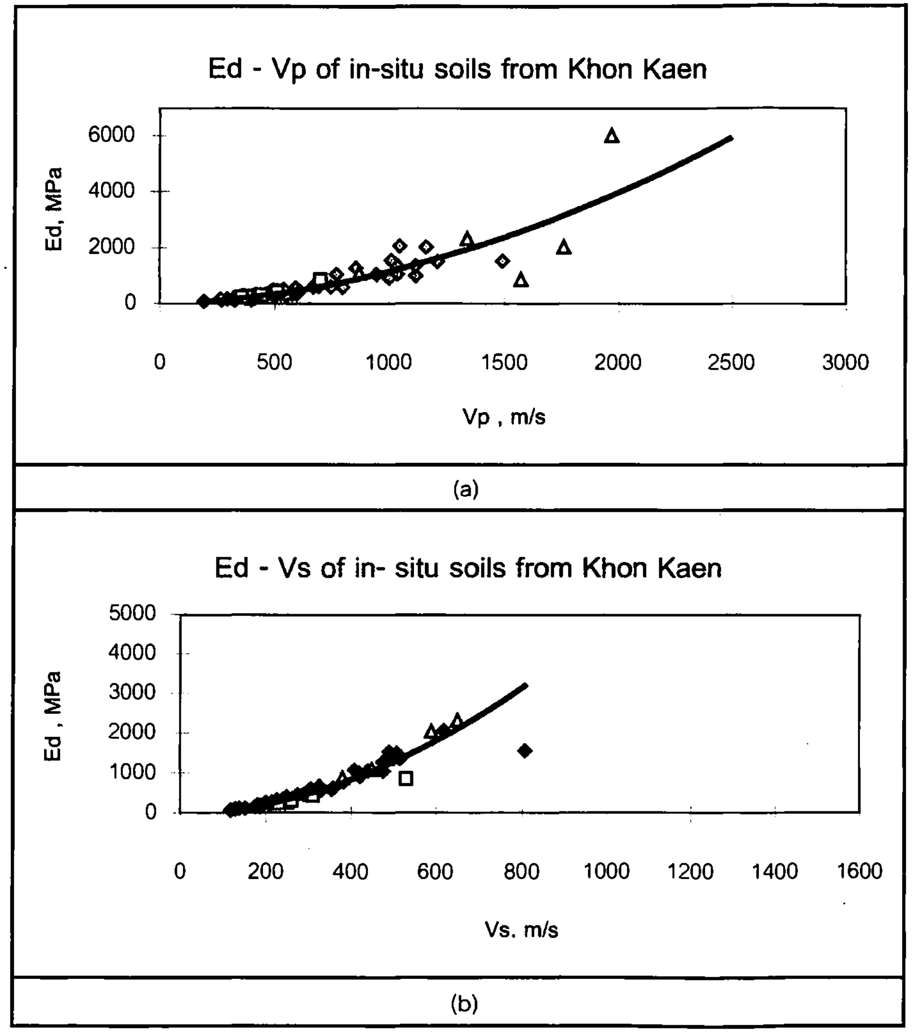

Figure 13a, b. Dynamic elastic modulus of silty sand layer (square) and lateritic soil layer (triangular) compared with compacted soil curve.

Table 1. Seismic refraction interpretation.

Location	Thickness 1st layer (m)	Moisture %		Vp (m/s)		Vs (m/s)	
		layer 1	layer 2	layer 1	layer 2	layer 1	layer 2
Non Rang	2.1	6.3	10.4	378	1,970	250	1,070
KK Air field	7.5	8.9	13.3	440	1,760	260	590
Non Tan	4.5	7.5	6.7	355	1,570	230	380
Non Chai	2.9	3.5	6.5	700	1,000	530	880
Don Han	5.4	5.8	3.5	375	1,340	340	650
Daeng Yai	3.1	6.5	4.0	510	870	310	450
KKU (TE)	3.3	7.0	11.5	310	580	270	520

Table 2. Seismic Elastic Moduli of silty sand and lateritic clay soils.

Location	Ed (MPa)		G (MPa)		Vp/Vs		ν	
	layer 1	layer 2	layer 1	layer 2	layer 1	layer 2	layer 1	layer 2
Non Rang	254.9	6,027.7	114.7	2,334.9	1.51	1.84	0.11	0.29
KK Air field	305.7	2,039.9	124.1	709.9	1.69	2.98	0.23	0.44
Non Tan	221.1	865.1	97.1	294.5	1.54	4.13	0.13	0.47
Non Chai	854.1	–	515.6	1,579.3	1.32	1.14	–	–
Don Han	–	2,319.8	212.2	861.7	1.10	2.06	–	0.35
Daeng Yai	425.8	1,088.1	176.4	413.0	1.65	1.93	0.21	0.32
KKU (TE)	–	–	133.8	551.5	1.15	1.12	–	–

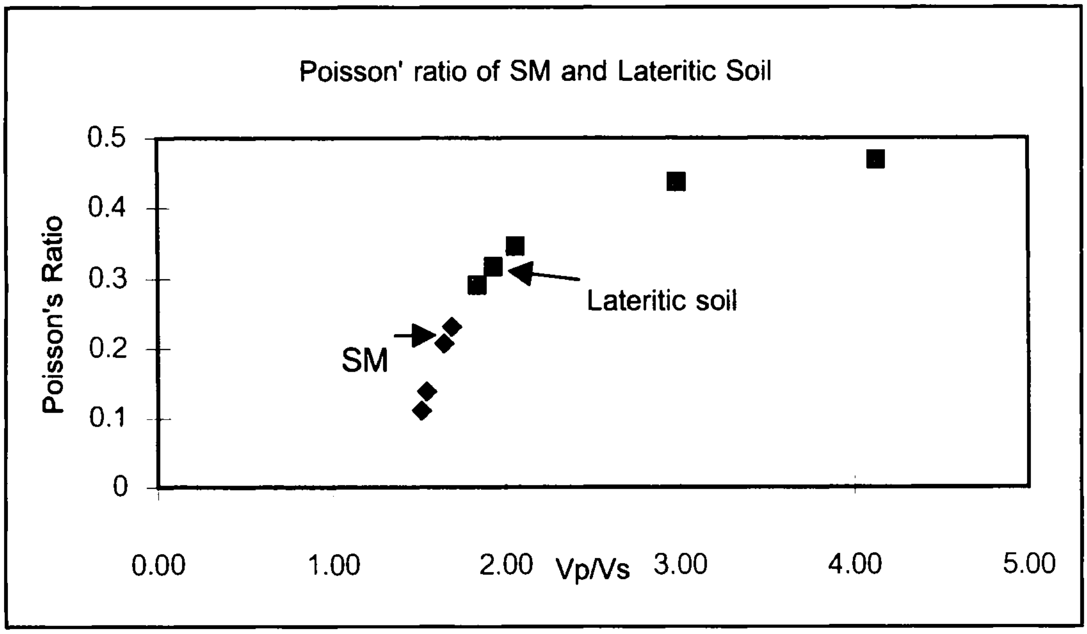

Figure 14. Poisson's Ratio of silty sand (SM) and lateritic soil layers to the Vp/Vs Ratio.

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Manuscript received 18 August 1998