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General Report — Session XI: Engineering Vibrations and Solutions

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General Report - Session XI
Engineering Vibrations and Solutions

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INTRODUCTION

The topic of this session "Engineering vibrations and solutions" is closely related to other sessions, and in particular to Session X, "Wave propagation in soils" and Session V, "Soil structure interaction", where several interesting papers have been presented. Ten papers have been submitted to this session, covering a wide range of topics. Different types of investigation methods have been used, including analytical studies, laboratory and field tests as well as case histories. The papers address the following topics, table 1.

Table 1. Topics of papers

Topics	**Papers**
Vibration problems at source	11.06, 11.12, 11.23
Wave propagation/ground response	11.06, 11.11, 11.24
Effects of vibrations on soil and structures	11.01, 11.09, 11.23, 11.24
Vibration isolation/screening	11.09, 11.10, 11.17, 11.18

The investigation methods used are summarised in table 2.

Table 2. Methods of investigation

Investigation method	**Papers**
Laboratory tests	11.01, 11.09, 11.24
Analytical investigations	11.06, 11.10, 11.17
Model tests in laboratory/field	11.06, 11.09, 11.17, 11.23
Case histories	11.11, 11.12, 11.23, 11.24

GENERAL

Engineering vibrations cover a wide range of problems, such as vibrations caused by:

- construction activities (blasting, pile driving, soil compaction or excavation),
- industrial processes (vibrating machines, hammers, shredders, saws, weaving machines etc.),
- traffic (railway, cars, trucks, military vehicles) and
- military activities.

The diagram in figure 1 shows the typical range of predominant vibration frequencies at the respective strain level for different vibration sources. It is interesting to note the almost linear relationship and the wide range these vibration problems cover.

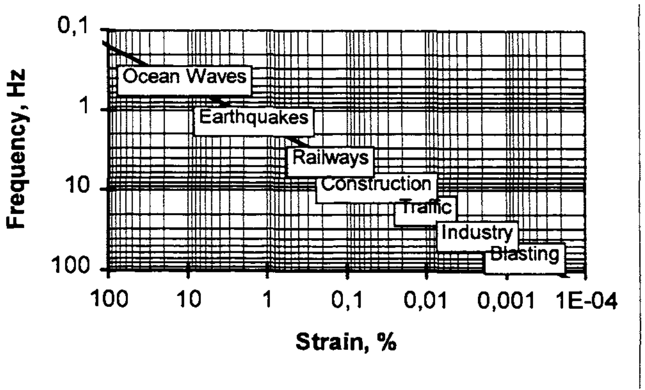

Figure 1. Frequency range and typical strain levels for different vibration sources, Massarsch (1993)

Another important aspect is that vibration problems are affected by a large number of factors, which may not always be apparent. In order to fully understand the effects that vibrations can have on structures in or above the ground, it is important to consider the propagation of vibrations from the source, through the ground and into the affected structure.

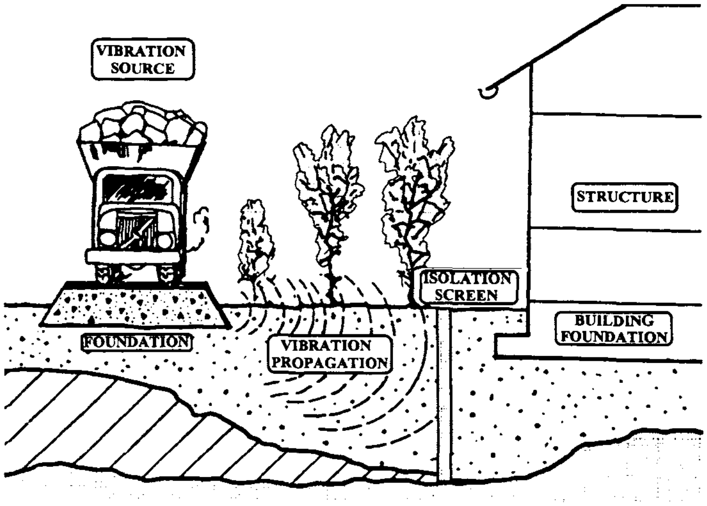

Figure 2. Wave propagation from the source through the ground and into the affected structure, Massarsch (1993)

Paper No. 11.01: E. Pardilla

"The Effect of the Produced Vibrations by the Urban Electric Train on the Fillings of Pumiceous Soils"

The paper presents a study on the damage produced by the vibrations from urban electric train operation. Settlements, which caused damage to buildings, were investigated by extensive field measurements and laboratory tests. The soil deposit consisted of a very loose fill and partially saturated silty sand with very low SPT values, ranging between 1- 4. The ground water level was located about 5 m below the ground surface.

Vibrations originated from a train tunnel which was located 6,5 m below the ground surface. Measurements showed that the vibration velocity was significantly higher (1,5 mm/s) at 5 m depth than at the ground surface (0,5 mm/s). No information is given regarding dominant vibration frequencies, which would allow assessment of deformation amplitudes. In very loose soils it can be assumed that settlements are governed by strain amplitude rather than velocity amplitude. Assuming that the wave propagation velocity for shear waves and Rayleigh waves in the very loose silty sand are on the order of 50 m/s or lower, a vibration velocity of 1,5 mm/s corresponds to a shear strain level of at least $0{,}5.10^{-3}$ %, which is at the threshold of soil degradation and could explain gradual increase of settlements.

Shake table tests were performed on samples with a relative density as low as 10 - 14 % (!) at accelerations of 0,02, 0,06 and 0,25 g and resulted in vertical strain on the order of 2,5 to 5,5 %, figure 3.

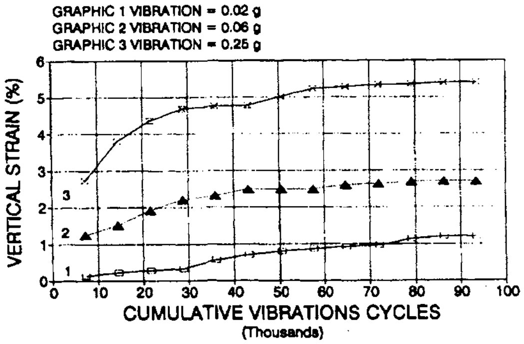

Figure 3. Results of shake table tests on very loose silty sand, E. Pardilla (1995)

It would have been interesting to know the excitation frequency (and thus the strain amplitude) of the shake table tests, which probably was significantly lower than the vibration frequencies in the field. Thus the strain level at the shake table tests was probably higher than the strain level in the field.

Paper No. 11.06: P. J. Moor, J. R. Styles and Wing-Hing Ho

"Vibrations Caused by Pile Driving"

A very interesting paper was presented by Moor et al. Ground vibrations caused by impact were measured at two sites, one consisting of sand and the other of clay. Measurements were made at various radial distances from the impact at the ground surface. The impact was produced by a weight falling either on a plate or onto a short rod driven into the ground. Interestingly, the authors report some errors in the widely used expressions published by Attwell and Farmer (1985) and propose corrected relationships for wave attenuation of body and surface (Rayleigh) waves.

High-quality field measurements are reported for two sites with different soil conditions (sand and clay, respectively), which lend themselves to detailed analysis of wave propagation in the near and far field. However, the posts used to simulate an embedded source (depth of embedment 0,62 m and 0,82 m, respectively) does not represent the case of pile driving, but rather a surface source as well.

An example of wave attenuation is given in the below figure 4 which suggests significantly higher peak particle velocities than theoretically predicted.

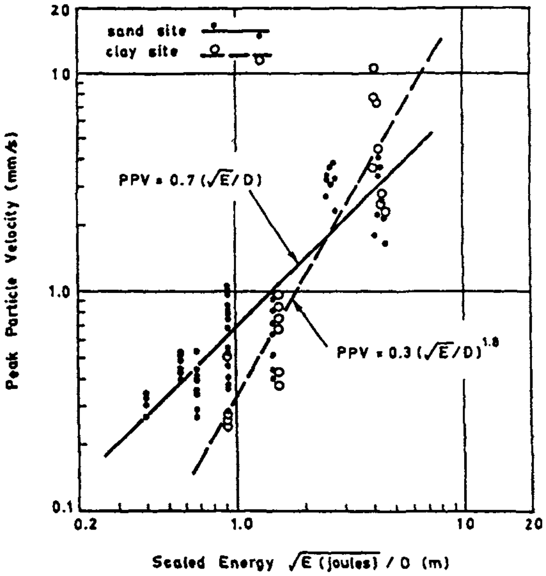

Figure 4. Ground motions - impact from an embedded source, Moore et al. (1995)

The authors also report measurements of the change of principal frequencies with increasing distance from the impact source, which shows a decreasing trend from about 80 Hz at 5 m from the source to about 40 Hz at 50 m distance.

In the below diagram, Figure 5, the variation of vibration velocity for the sand and the clay site is plotted in a log-log diagram. In spite of some scatter, the attenuation of vibration amplitude agrees is in reasonable agreement with the attenuation of surface waves, giving values with the coefficient of attenuation α between 0,03 and 0,07. The decreasing α-values with increasing distance can be explained by the gradual decrease of the predominant vibration frequency with increasing distance from the impact source.

Theoretical predictions of the peak particle velocity were not successful and generally yielded values significantly higher than those observed. This can be explained by the fact that energy loss, which occurs at the source of impact is not properly accounted for in the theoretical approach.

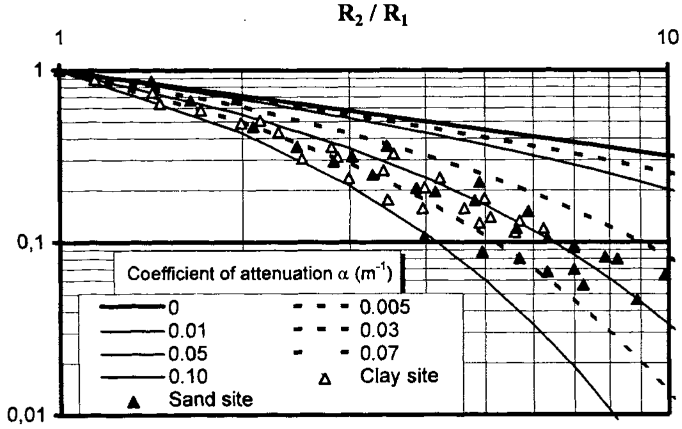

Figure 5. Attenuation of vibration amplitude for surface (Rayleigh waves)

Paper No. 11.09: M. Tehranizadeh

"Sliding base isolation system for unreinforced buildings"

The author presents a concept of base isolation for low-cost buildings, using a sliding layer. Results of model tests are reported with different isolation materials, such as sand-clay mortar, silt and puzzolana. The layer thickness and material properties were varied.

The test results indicate that non-cohesive materials (silt and puzzolana) are more suitable than sand-clay mortar. Design recommendations are presented for base isolation of a masonry building using a thin sliding layer.

Paper No. 11.10: S. Ahmad and T. M. Al-Hussaini

"Simple model for active isolation of machine foundations by open trenches"

The paper addresses the problem of active (near-field) vibration isolation of machine foundations. A three-dimensional boundary element algorithm was used to perform an extensive parametric study. The vibration isolation effect was calculated using the ratio of an integrated vertical displacement amplitude. The results are in reasonable agreement with previously published data. However, the authors point out the importance of the footing size in the assessment of the vibration isolation effect, Figure 6.

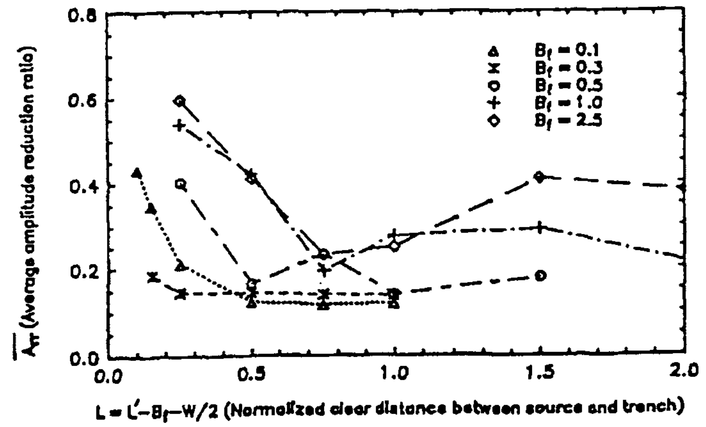

Figure 6. Influence of normalised footing radius for different barrier locations for a trench with a depth of one wave length, S. Ahmad and T. M. Al-Hussaini (1995).

Based on the detailed theoretical analysis the authors also propose a simplified model which can be used for design purposes.

Paper No. 11.11: XianJian Yang

"Evaluation of man-made ground vibrations"

The author presented a modified solution to the problem of vibration attenuation from the vibration source. The discussion of the problem of wave propagation appears to neglect the frequency-dependence of the coefficient of attenuation, Massarsch (1993). The paper addressed dynamic problems with surprisingly large wave length (20 - 150 m), which would correspond to very low vibration frequencies (around 1 Hz in soil with a surface wave velocity of say 100 m/s). This is in contrast to most problems caused by engineering vibrations.

The Bornitz-solution as used by the author is strictly valid only for Rayleigh waves, but could be readily modified to apply to the case of body waves (compression waves and shear waves), Massarsch (1993). Instead, the author modified the Bornitz-equation, introducing empirical factors in order to account for different wave types (P, S or R wave) and the effect of frequency variation.

Interestingly, the effect of the geometry of the vibration source and the dependence of the attenuation coefficient on soil type are introduced in the proposed wave attenuation formula.

Several case histories are presented which show the practical usefulness of the method.

Paper No. 11.12: J. Bencat

"Assessment of ground vibration from passing train"

The paper addresses vibration problems caused by the passing of high speed trains. Various factors affecting the transmission of vibrations from the train vehicle via the rails, sleepers and the embankment to the surrounding are discussed. The paper presents some results of field tests, which are part of an extensive test programme. Vibration measurements are reported from a test site with an embankment on a 10 m deep deposit of sandy gravel. The ground water level was 10 m below the ground surface. Power Spectral Densities (PSD) of the vibration acceleration are presented in different points for a train (100t bulk carrier) passing at a speed of 70 km/h.

The measurements show a clear change of the predominant vibration frequency at different locations of the test section. High frequencies (at 120 Hz) show significant damping. PSDs on the ground show peaks in the range of 20 Hz. The author also suggests that three kinds of vibrations are caused by train traffic: a) stationary vibrations with a constant amplitude and a fundamental frequency, b) the sum of waves which propagate along the rail, with a frequency range larger than the fundamental one, and c) the sum of waves which propagates in the downward direction, with a wide range of frequencies.

Unfortunately, the paper does not present more details of the very interesting test programme and the hypotheses presented are substantiated.

Paper No. 11.17: S. Ahmand, J. Baker and J. Li

"Experimental and numerical investigation on vibration screening by in-filled trenches"

The screening effect of infilled concrete and soil bentonite trenches has been investigated by field model tests. The trench extended about 0,5 m into an about 1 m thick layer of brown silty clay, which was on top of a layer of very stiff grey clay. The wave propagation velocity of the silty clay are not given but can be estimated to about 75 m/s. The ratio of the width, W to the depth D of the trenches was about W/D = 0,4, which is rather large considering full-scale applications (say a trench depth of 10 m would require a width of 4 m).

The vibration source consisted of an electromagnetic vibrator which generated harmonic ground vibrations. The vibrator generated vibrations with a frequency of 300 Hz. The wave length of the surface wave can be estimated to about 0,35, which thus is significantly shorter than the trench depth.

The "soft barrier" consisted of a soil-bentonite mixture with a Rayleigh wave velocity of about 30 m/s, which was only about 50 % lower than the surface wave velocity of the soil layer. The stiff barrier consisted of quick-setting concrete.

Surface vibrations were measured by accelerometers at a spacing of about 0,10 m. Four test series were carried out, two with near field isolation (active isolation), and two with far field isolation (passive isolation). At each site, the effect of a stiff barrier (concrete infill) and a soft barrier (soil-bentonite infill) was studied.

The isolation effect was determined by comparing the surface displacement with a trench to the value without a trench. Contours of amplitude reduction ratio for the case of passive isolation using a the "soft" soil-bentonite trench are shown in Figure 7.

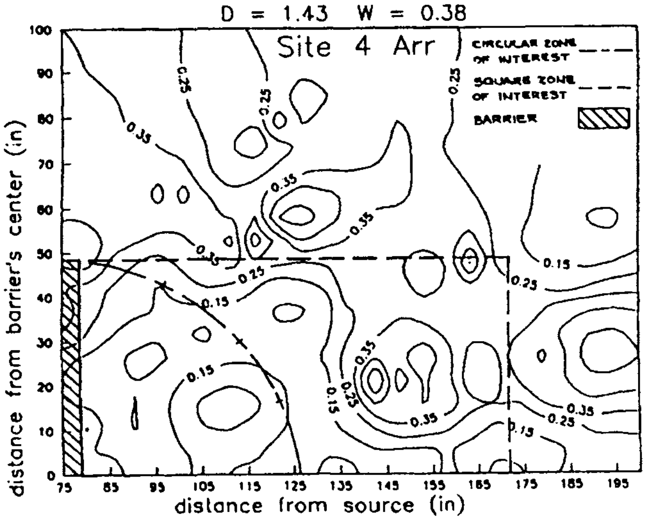

Figure 7. Contours of amplitude reduction ratio for the case of passive isolation using soft (bentonite-soil) trench, Ahmend et al. (1995).

The reported amplitude reduction values for the stiff concrete trench are surprisingly high, on the order of 70 % for a trench depth of one wave length. The reduction values are even more surprising for the relatively stiff, "soft" soil-bentonite trench, cf. figure 7.

Although the study presents interesting results of field tests with wide (W/D = 0,4) shallow trenches, the quantitative results should be treated with caution, awaiting verification by large-scale field tests.

Paper No. 11.18: E. Conte and G. Dente
"Screening of Rayleigh waves by open trenches"

A numerical study of the effectiveness of open trenches in reducing the ground vibrations caused by propagating Rayleigh waves is presented. The scattering of Rayleigh waves was studied under plain strain conditions, using the Boundary Element Method. The isolation efficiency of the trench is expressed in terms of an energy reduction, defined as the ratio of energy computed in the presence of the trench and that without the trench.
A parameter study of different trench configurations confirms the results presented elsewhere. The width and shape of the trench has little effect on vibration isolation efficiency. The optimum isolation effect is achieved when the trench depth corresponds to the Rayleigh wave length. Figure 8.

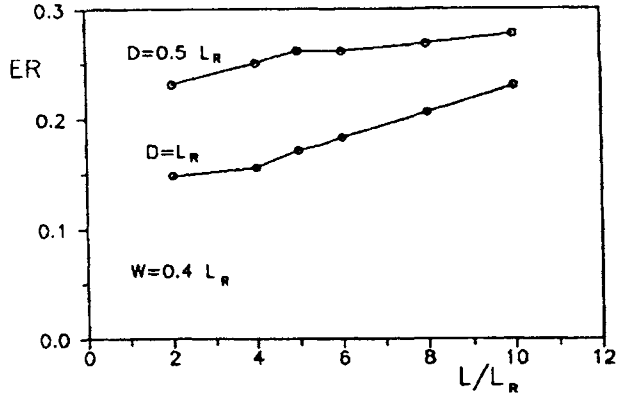

Figure 8. Effect of trench depth D on energy reduction ratio, Conte and Dente (1995)

It is interesting to consider the practical application of open trenches for the case of wave length which normally are on the order of 5 - 15 m. In soft clays and loose sands with a high ground water level, it is practically impossible to maintain the stability of long trenches with a depth exceeding 4 m. Massarsch (1993) proposed a ground vibration isolation method using gas-inflated cushions, which can be installed in a self-hardening cement-bentonite suspension, figure 9. The flexible cushions are inflated to a pressure lower than the ambient pressure in the ground. A trench is excavated using the slurry trench method. In this way, trench depth in excess of 15 m have been achieved. Thereafter, the screen, consisting of horizontally arranged, overlapping cells is anchored to the bottom of the trench. The self-hardening cement-bentonite suspension becomes an impermeable and flexible layer, protecting the gas cushion screen. The material properties of the protection layer are similar to that used for ground water isolation.

The isolation effect of the gas cushion screen has been evaluated by full-scale tests and on real applications and is in good agreement with the findings by Conte and Dente (1995).

Paper No. 11.23: V. K. Lekarkin, A. G: Wilfand, D. D. Akhmedov, F. F. Zekhniev and B. B. Zukhurdinov
"Dynamic test of foundation with explosives"

Problems regarding the stability of foundations on loess soil subjected to dynamic loads from earthquakes or other dynamic effects are solved using compaction by falling weight. Full-scale investigations of the

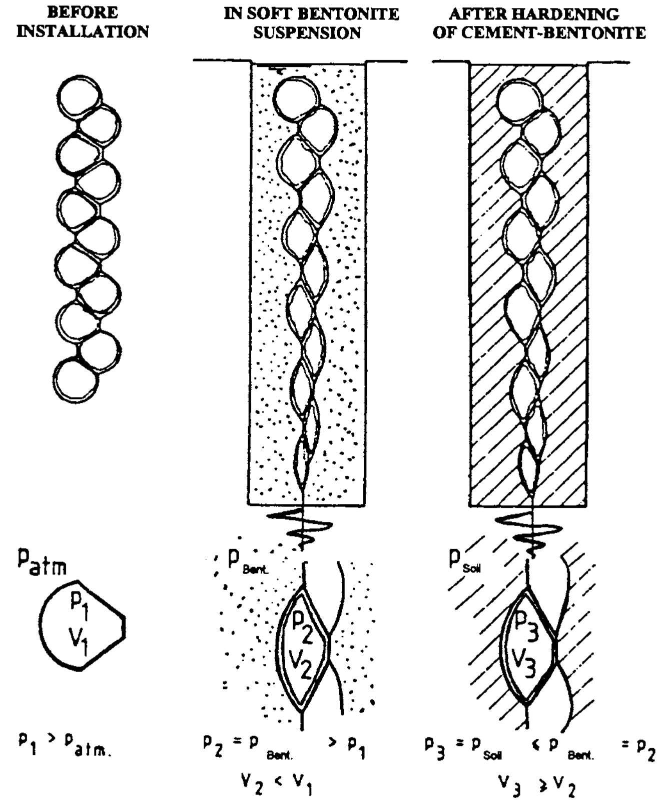

Figure 9. Ground vibration isolation method using gas-inflated cushions, Massarsch (1993)

static and dynamic bearing capacity of these foundations are reported, using a novel, sophisticated testing device. The detonation of a series of explosive charges, arranged in a semi-circle around the foundation to be tested, is initiated by an electronic device. The generated ground excitation (vibration amplitude) is recorded by seismic sensors, placed in the vicinity of the foundation to be tested.

The response of a foundation to static and dynamic loading is described, using a semi-empirical relationship.

The paper presents an interesting approach to full-scale testing of foundations. However, the reviewer has found it difficult in the abbreviated paper to fully appreciate the theoretical background of the testing method and of the data evaluation. Detailed results of further tests would help to enlighten the profession about a potentially very useful testing technique.

Paper No. 11.24: C. S. Pan, D. Li and F. Gao

"Dynamic behaviour of Beijing sandy clay and dynamic response of Beijing subway to traffic vibrations"

The construction of a new subway line has necessitated comprehensive investigations in the laboratory, theoretical analyses and field investigations in order to predict vibration levels above the subway tunnel. Extensive laboratory tests were used to determine the static and dynamic soil properties of sandy clay with great accuracy, figure 10. Surprisingly high damping values (12 - 20 %) were measured at strain levels of 10^{-4} to 10^{-3} %.

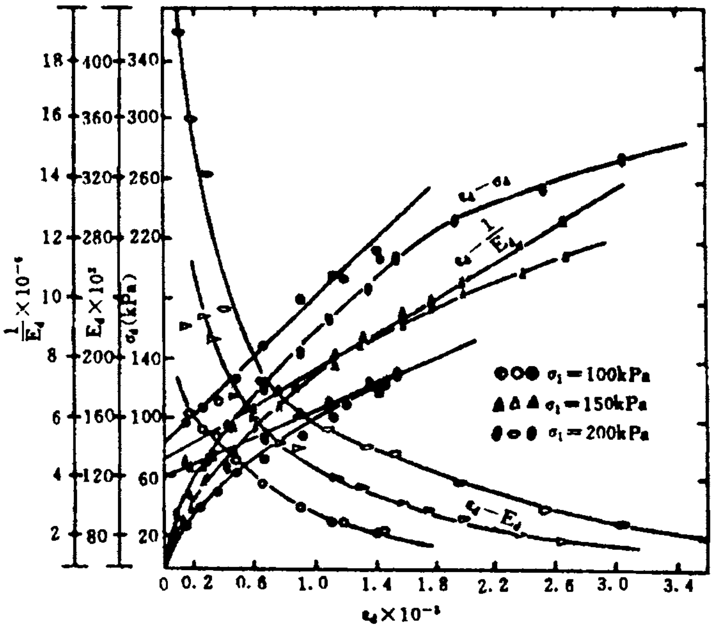

Figure 10. Results of servo-controlled triaxial tests on sandy clay, Pan et al. (1995)

Vibration measurements at the site were used as input data for a comprehensive finite/infinite element analysis of a tunnel section. Based on the analysis, settlements on the order of 0,5 mm were predicted.

The short paper can only superficially describe all aspects of the study. Therefore, many potentially interesting results could not be fully comprehended.

CONCLUDING REMARKS

The papers submitted to the session cover a wide range of problems, related to engineering vibrations. The problem of vibration excitation by different sources is discussed in several papers and detailed, high-quality field data are becoming available. These are needed to verify the abundance of analytical methods reported in the literature.

A particular interest existed for the solution of wave propagation in the ground and measures to reduce vibrations. Different screening methods have been investigated analytically and by small-scale field tests. The analytical results are encouraging but full-scale verification of the analytical results is needed. Also the prediction of wave propagation in the ground and the effect of vibrations on structures on the ground have been.

REFERENCES

Massarsch, K. R., 1993. "Man-made Vibrations and Solutions", State-of-the-Art Lecture, Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1 - 6, 1993, Vol. II, pp. 1393 - 1405.