ATRANS
ASIAN TRANSPORTATION RESEARCH SOCIETY

Final presentation
Development of a falling weight deflectometer (FWD) for evaluating the pavement conditions

21 August 2009

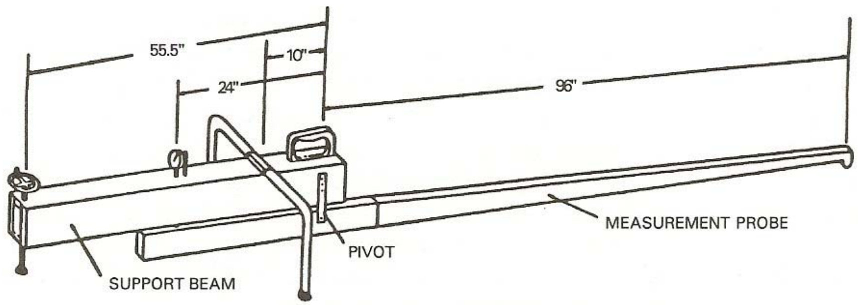
to

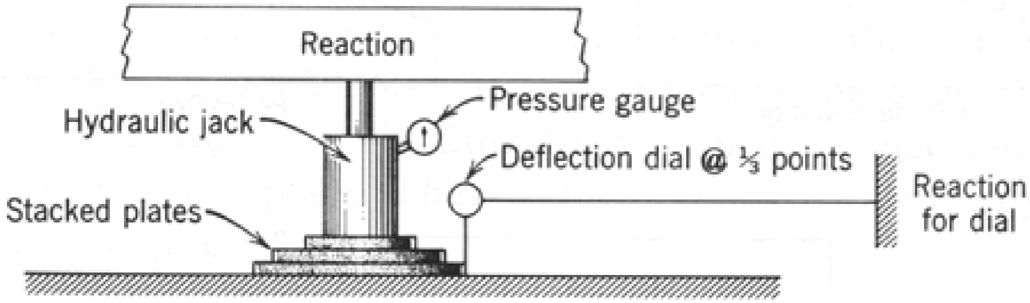
Asian Transportation Research Society (ATRANS)

by

Department of Rural Roads, Thailand

Introduction



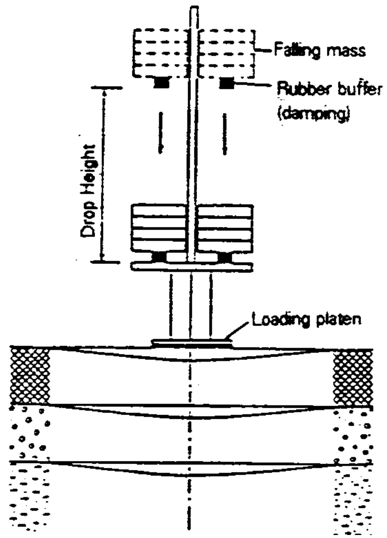


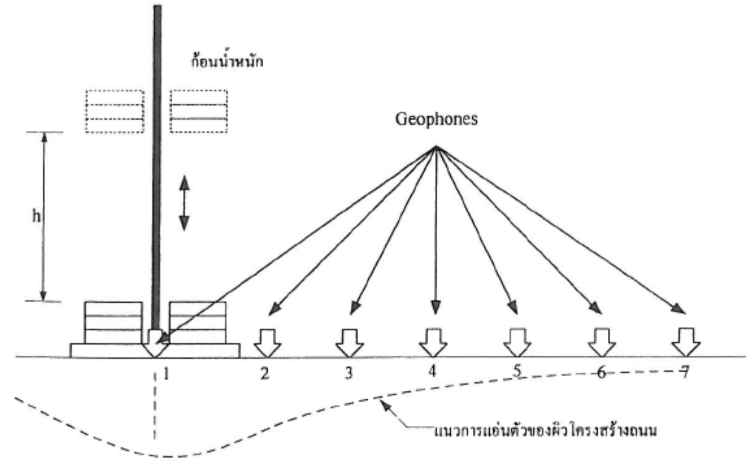
Both methods provide reliable test results; however, the test procedures are time-consumed.

Conventional test methods

ATRANS

Introduction

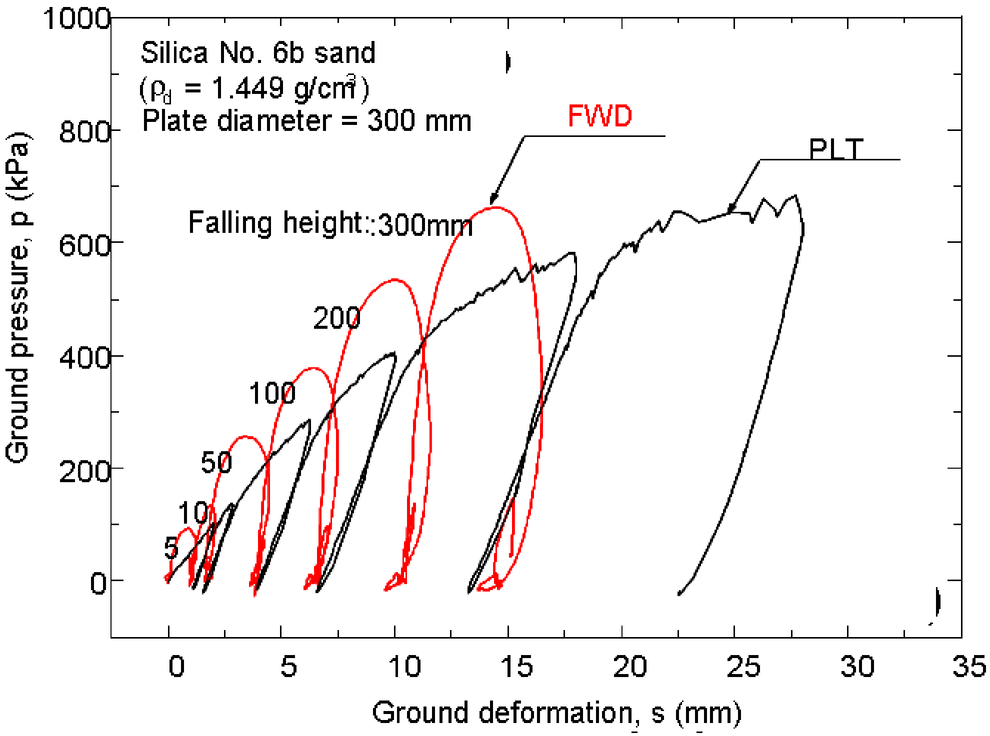




FWD has been commercially developed.
Test procedures are very fast.

Commercially available FWD apparatus

State of problem



Why the test results obtained from FWD are different from the convention method?

How to adjust the FWD test results to be close to the ones from the conventional method?

Commercially available FWD apparatus

Objectives

FWD Result

How?

Conventional Method Result

To investigate the rate-effect and dynamic-effect from FWD that affect to the pavement stiffness value.

FWD Device

Analysis Framework

Evaluate Stiffness Value

To develop an analysis framework taking into account the rate-effect and dynamic-effect for evaluating to the real pavement stiffness value.

Schedule/Timeframe of the Project

Activities	2008			2009									
	10	11	12	1	2	3	4	5	6	7	8	9	10
Productions of FWD and supporting apparatuses													
Preparation of materials for laboratory test													
Preparation for test measuring instruments													
Inception report													
FWD tests on pavement in laboratory and in field													
PLT tests on pavement in laboratory and in field													
Five-month report													
FWD tests on ground base in laboratory and in field													
PLT tests on ground base in laboratory and in field													
Analysis of test results													
Final presentation													
Preparation for a paper for ATRANS Journal													
Preparation for final report													
Final report due													

We are here.

Project members

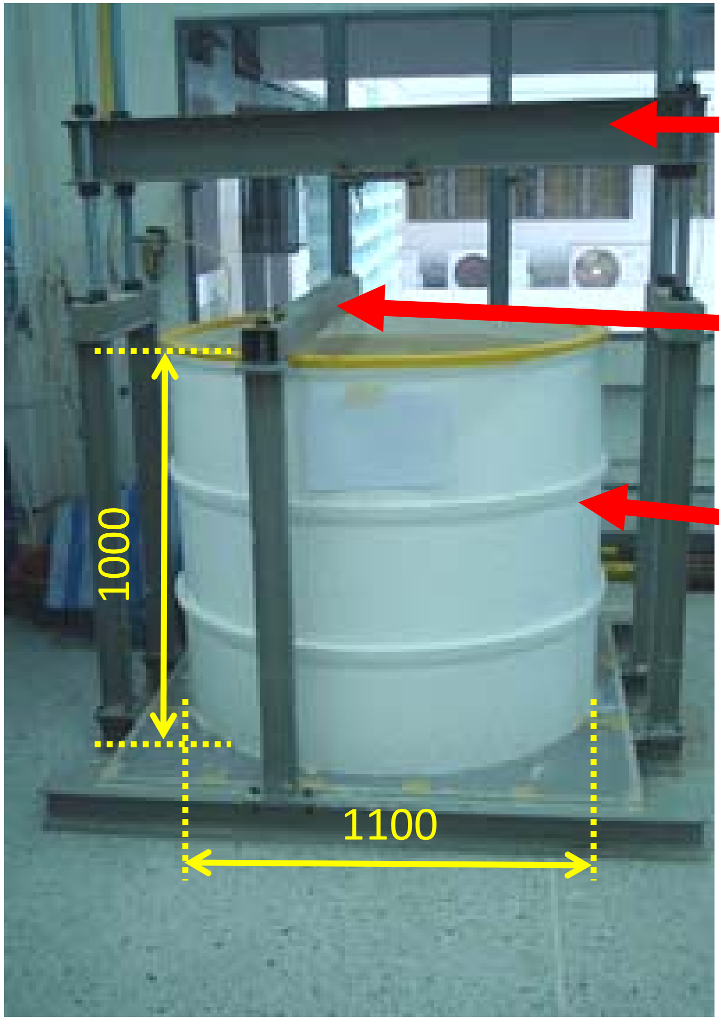
from Department of Rural Roads
Dr. Chakree Bamrungwong
Dr. Koonnamas Punthutaecha
Dr. Kitti Manokhoon

and from KMUTT
Dr. Warat Kongkitkul
Dr. Sompote Youwai
Dr. Pornkasem Jongpradist

Contents

ATRANS

Productions of FWD and supporting apparatuses



Loading frame

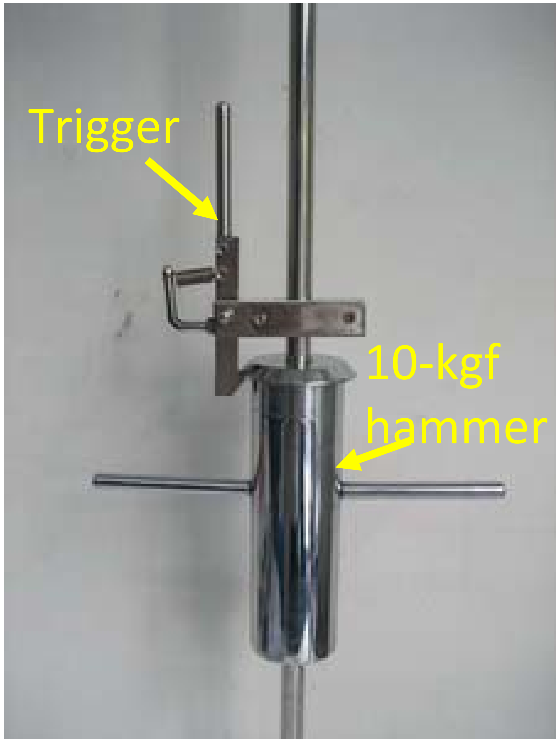
Reference beam

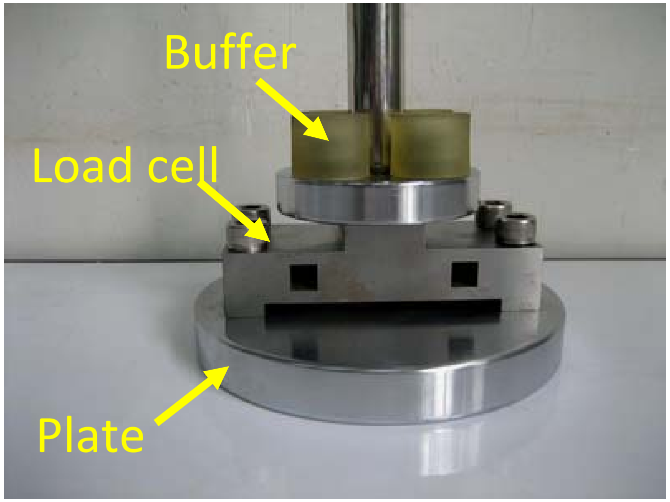
Container

* H (sand) = 900 mm
* Dia.- inner = 1000 mm

Calibration chamber (sand tank)

Productions of FWD and supporting apparatuses

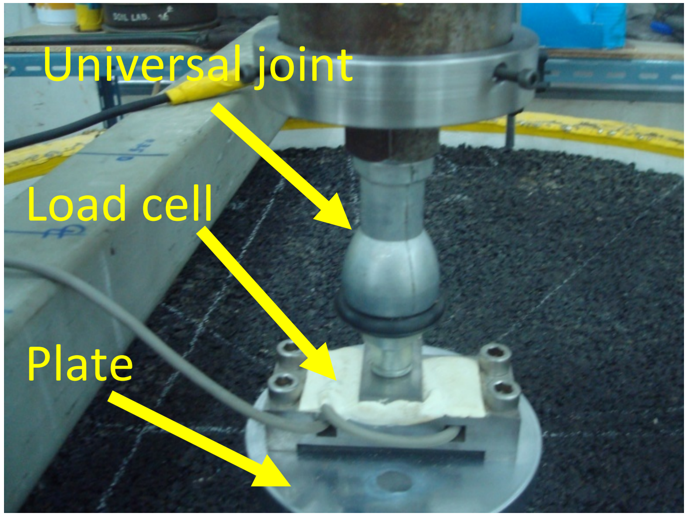


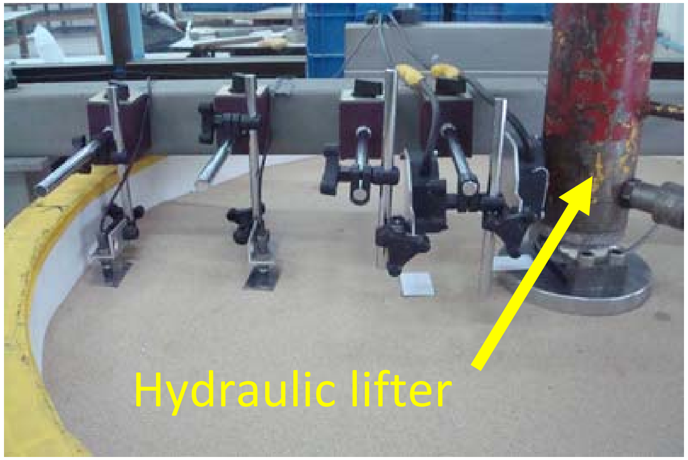


FWD apparatus

ATRANS

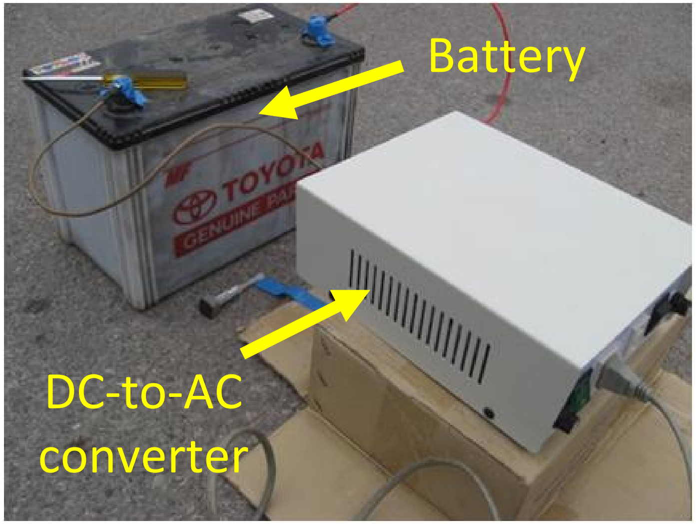
Productions of FWD and supporting apparatuses

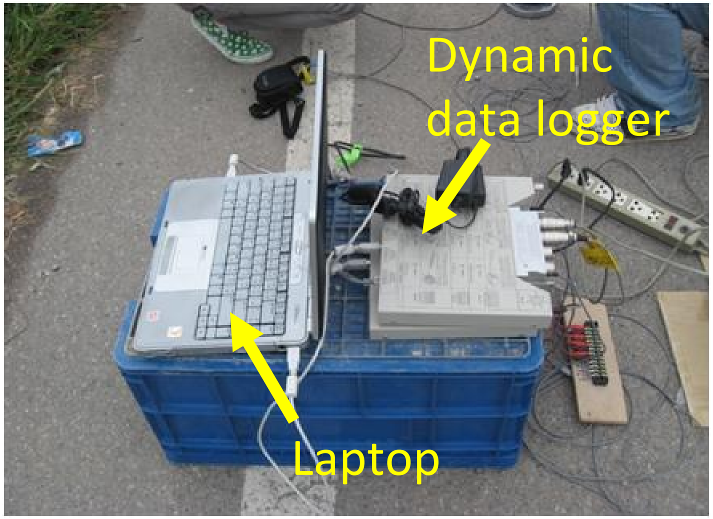




PLT apparatus

Productions of FWD and supporting apparatuses





Field test

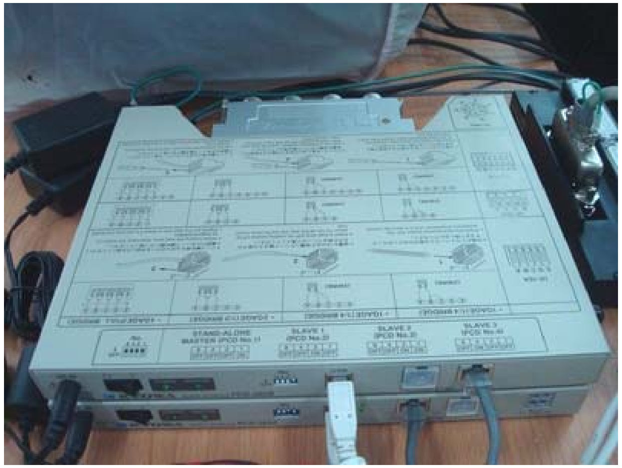
Productions of FWD and supporting apparatuses

Load cell

Laser displacement sensor

Gap sensor

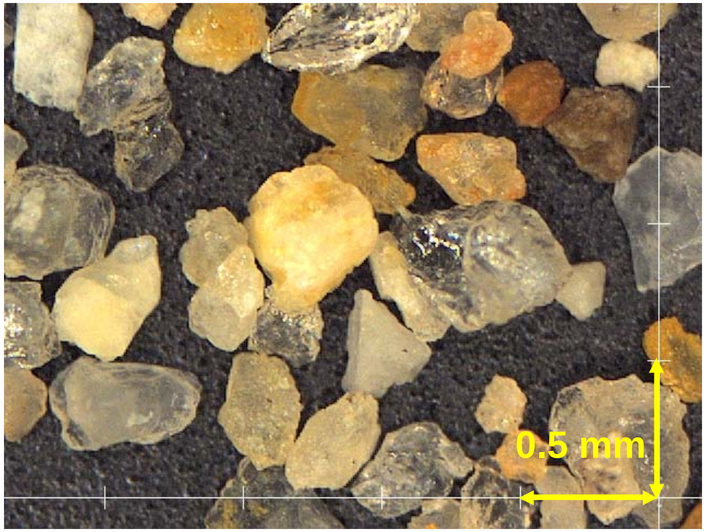
Accelerometers

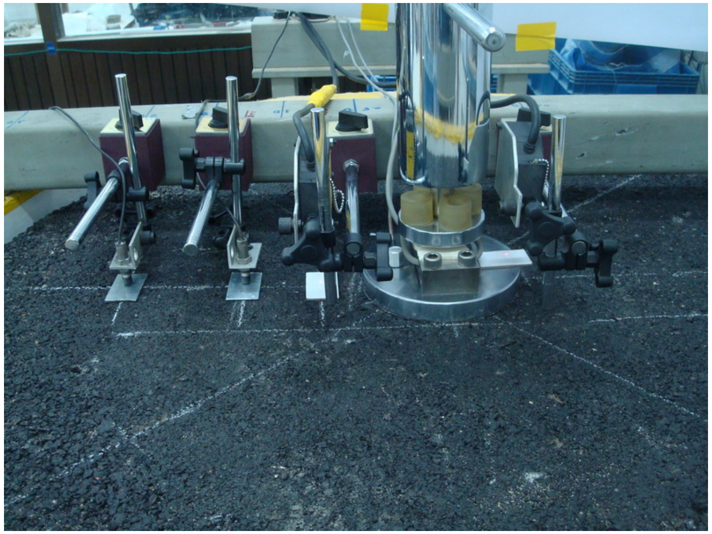


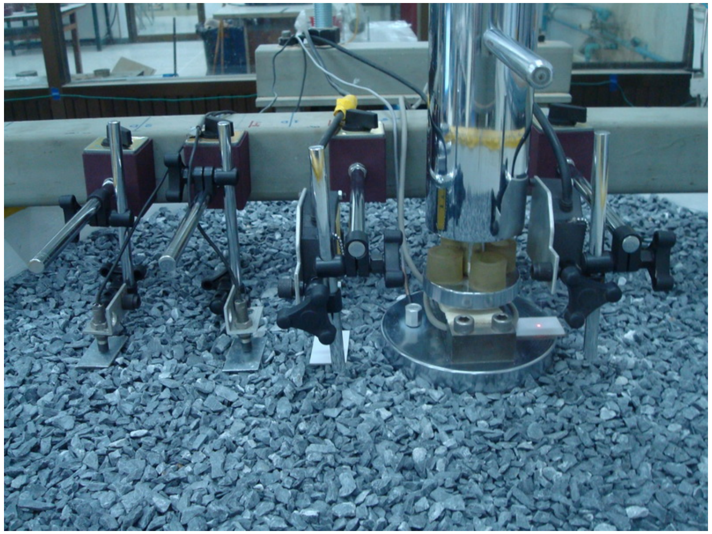
Dynamic data logger

Computer

Preparations for laboratory and field tests

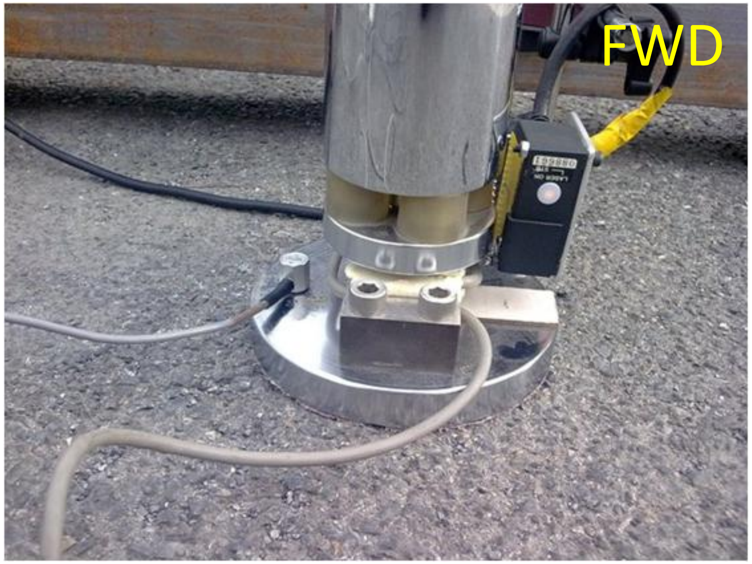


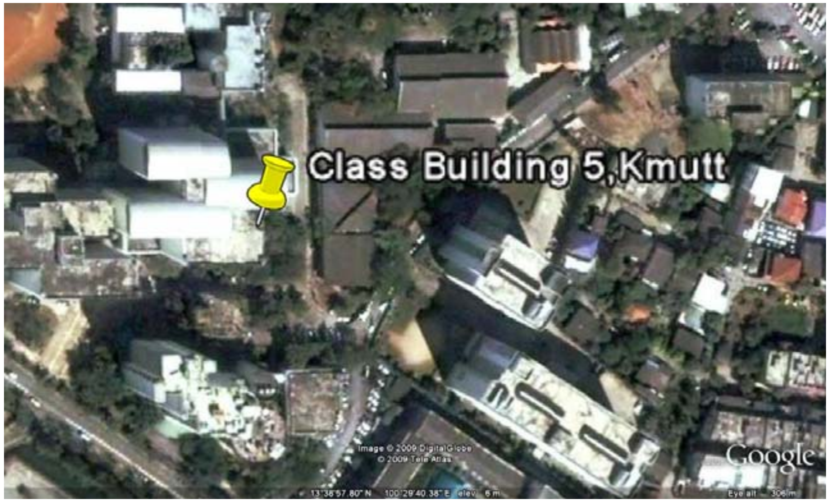




Materials for laboratory tests

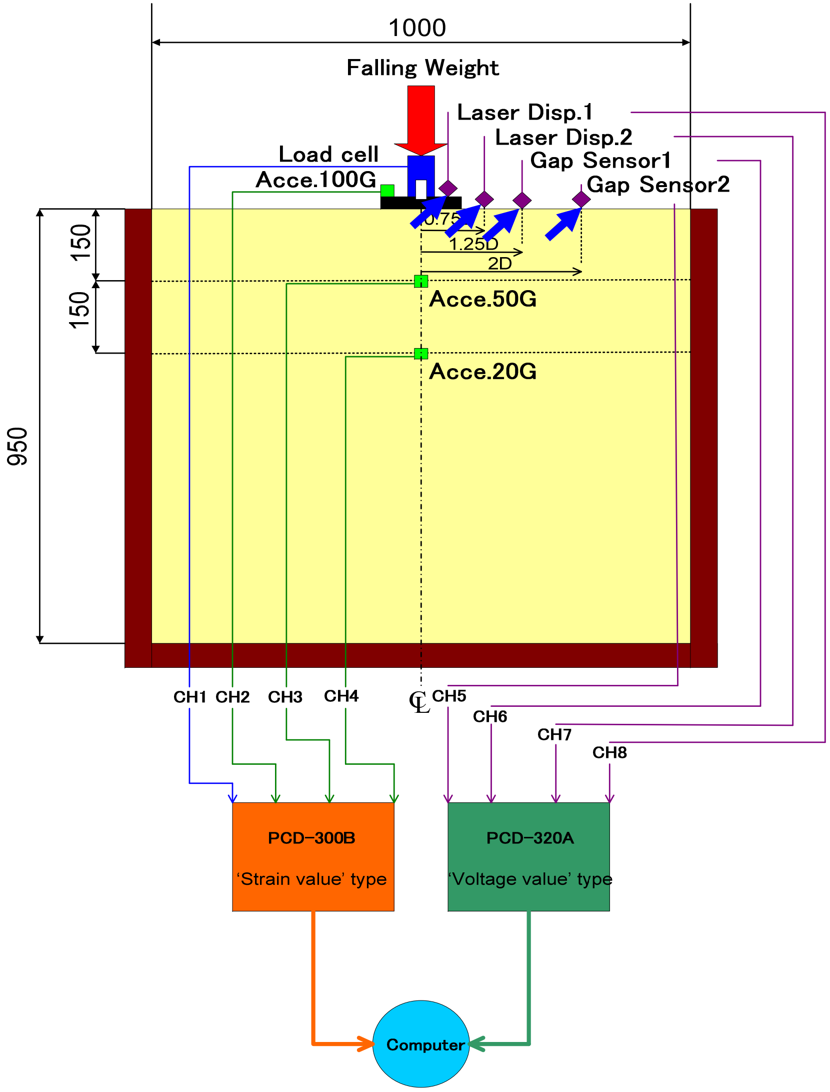
Preparations for laboratory and field tests

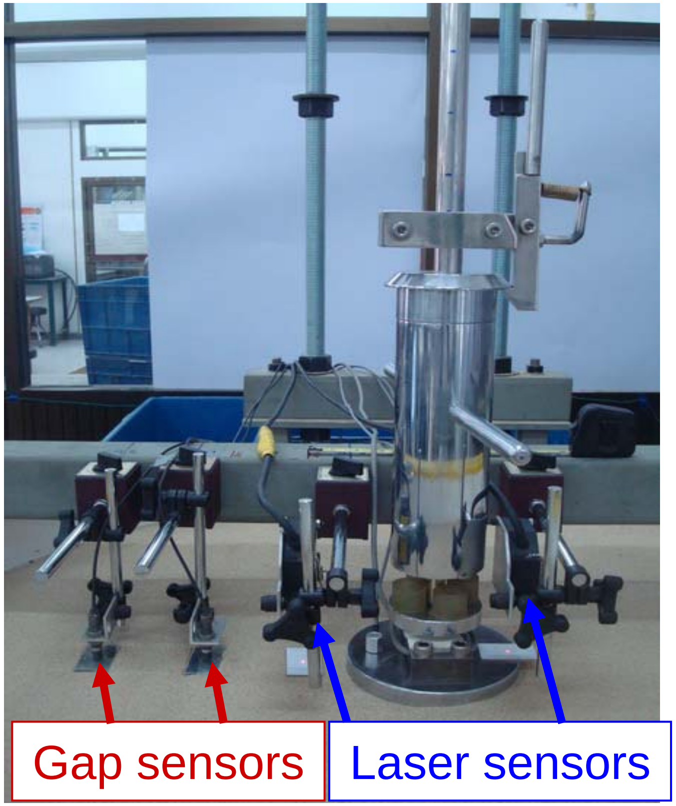




Preparation for field tests

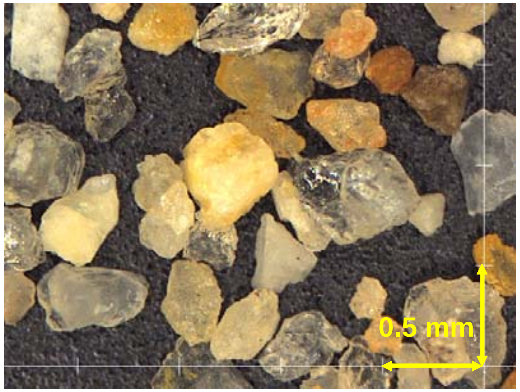
Preparations for laboratory and field tests



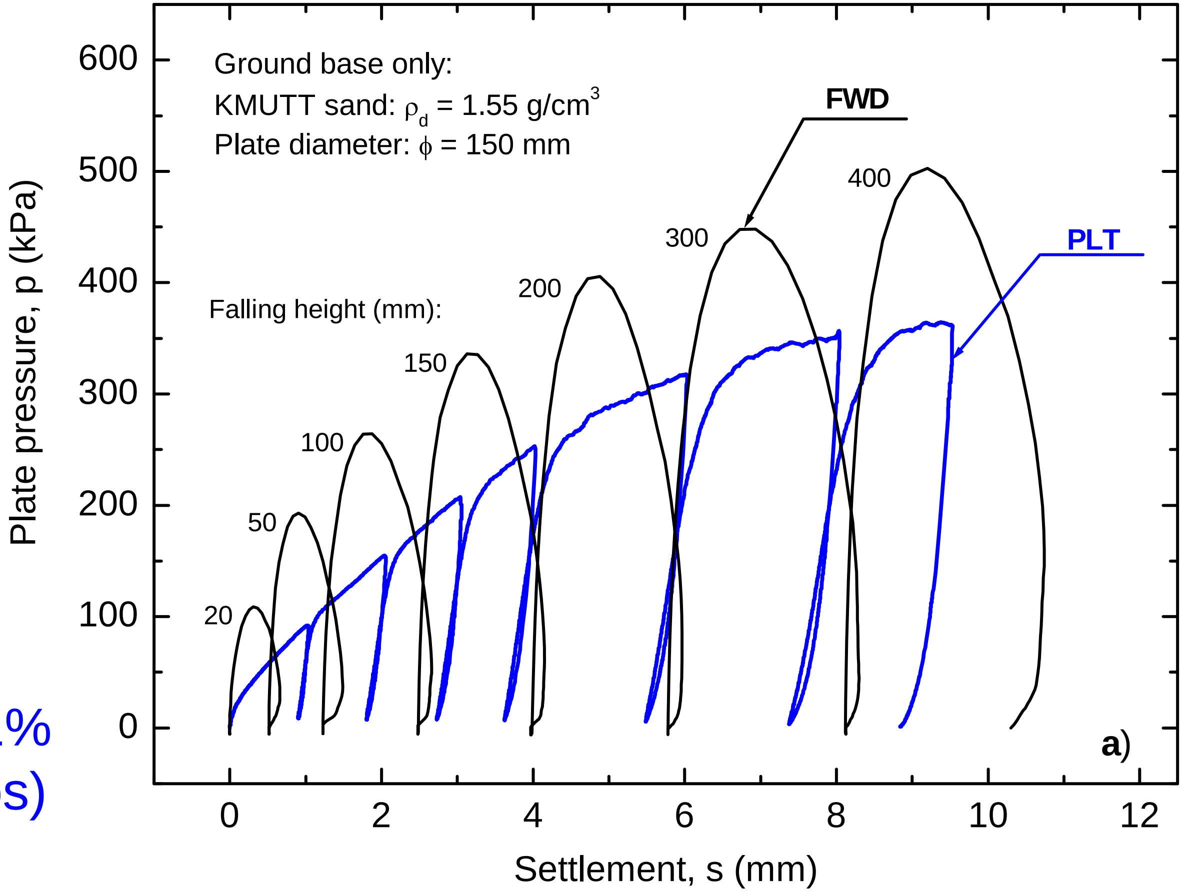


Typical set up of FWD test

FWD and PLT tests in laboratory



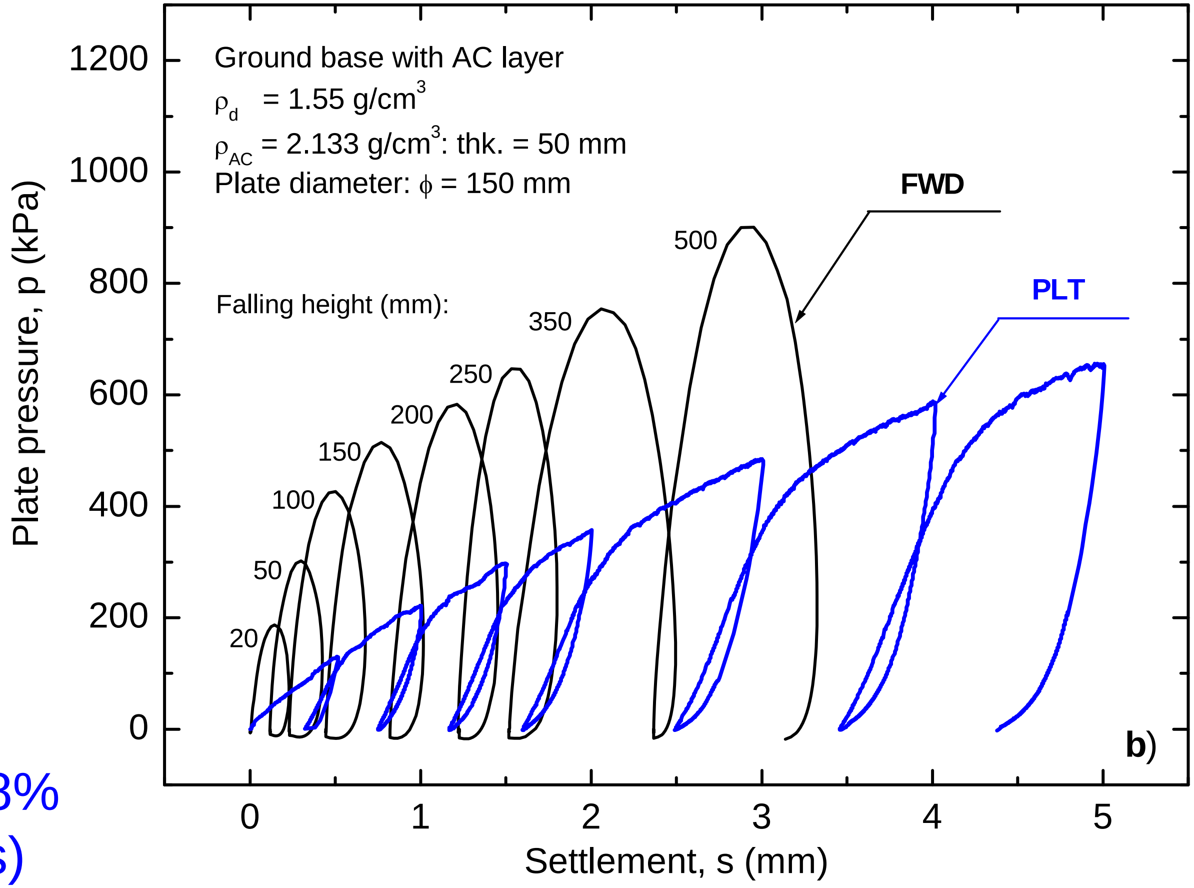
k_{FWD} > k_{PLT} about 41%
* (average for all loops)



PLT and FWD test results on KMUTT sand

ATRANS

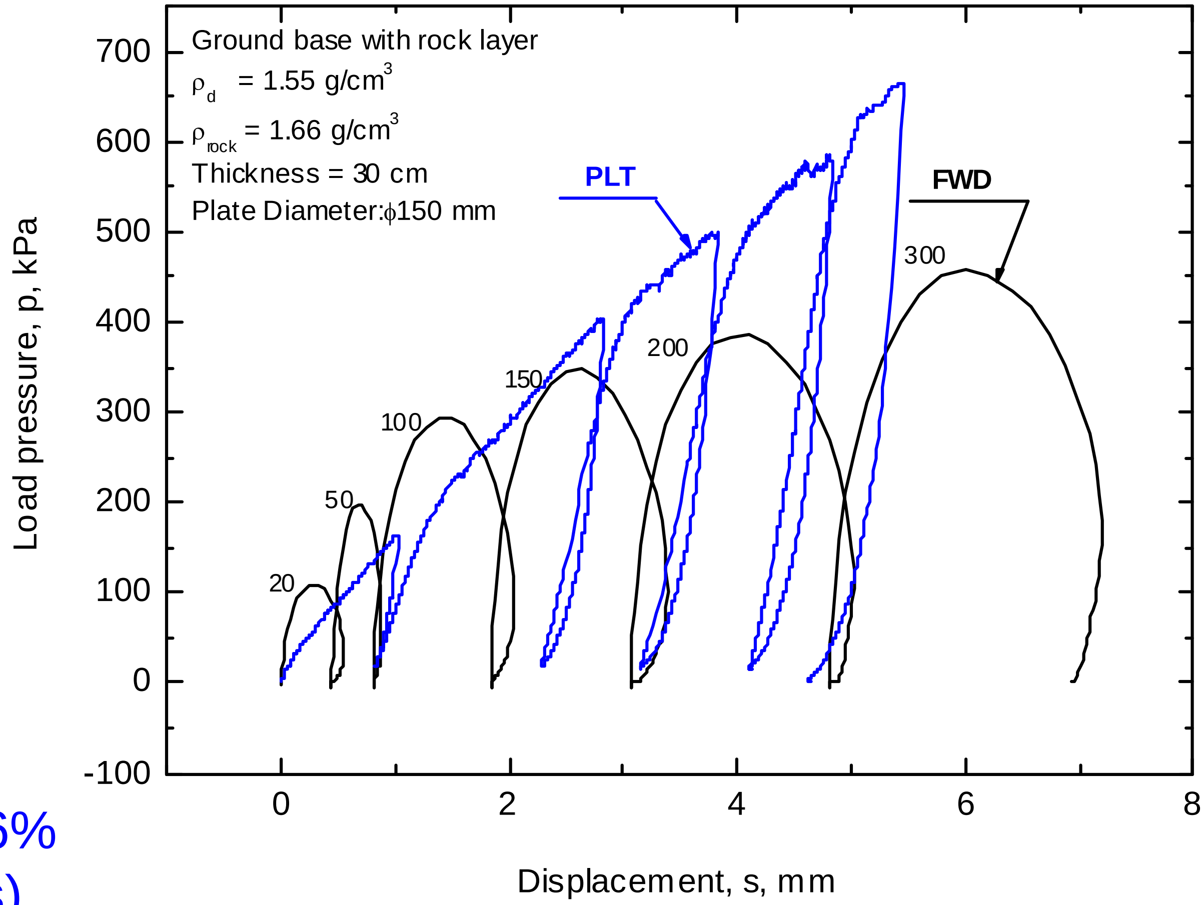
FWD and PLT tests in laboratory



k_{FWD} > k_{PLT} about 138%
* (average for all loops)

PLT and FWD test results on HMA laid on KMUTT sand

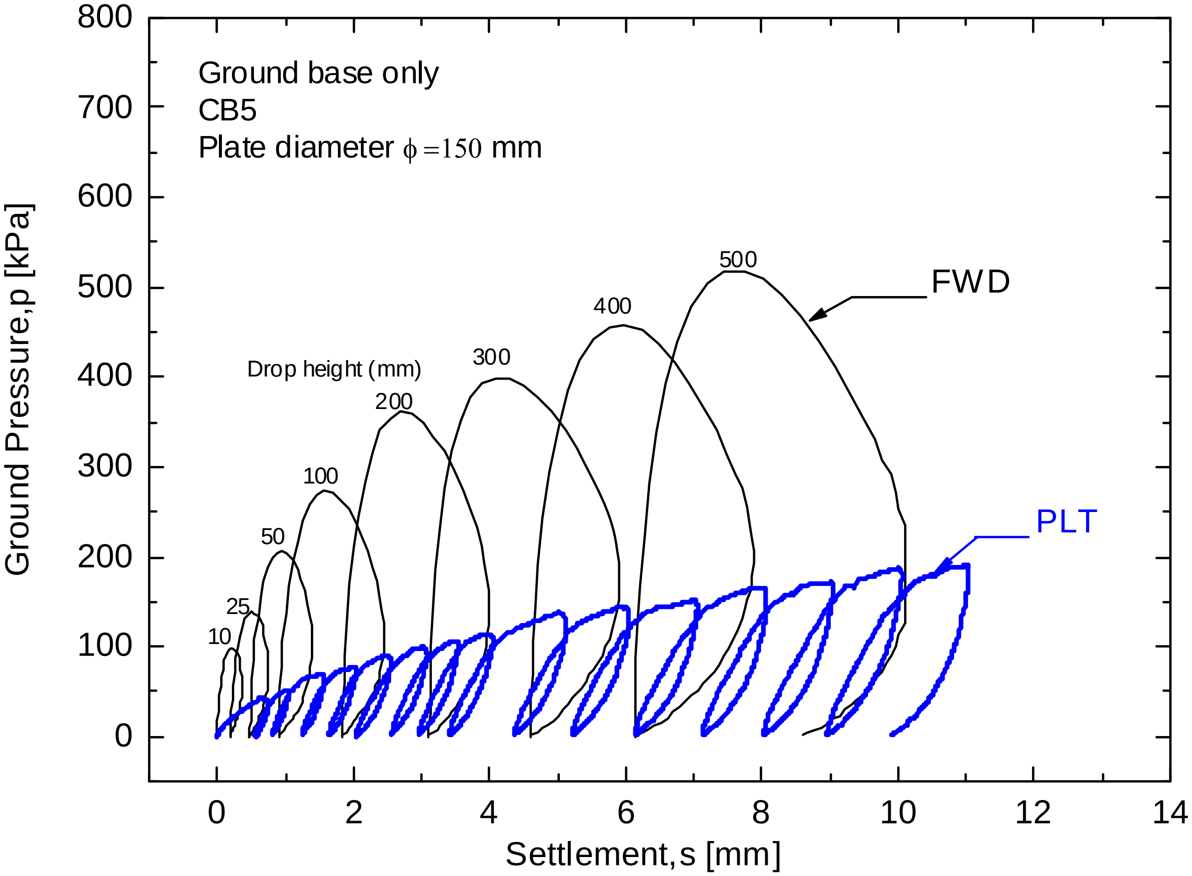
FWD and PLT tests in laboratory



k_{FWD} > k_{PLT} about 166%
* (average for all loops)

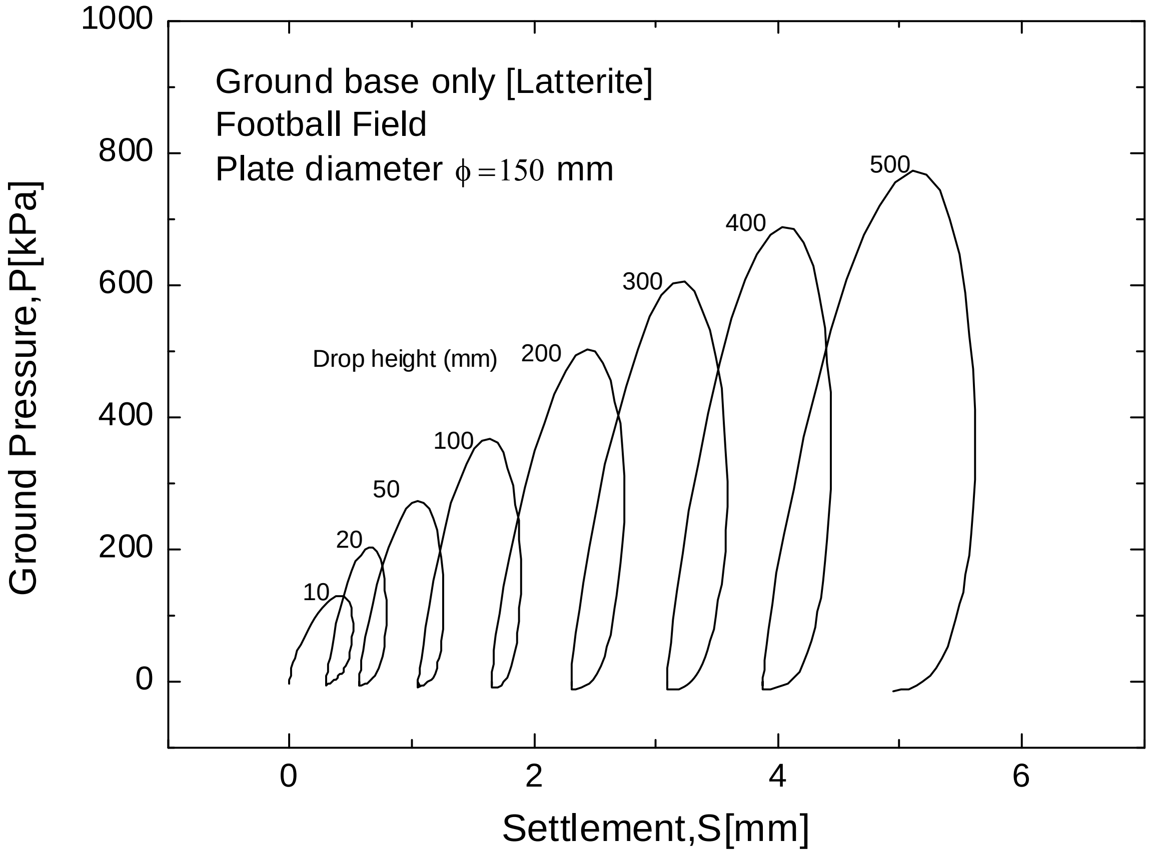
PLT and FWD test results on aggregate laid on KMUTT sand

FWD and PLT tests in the field



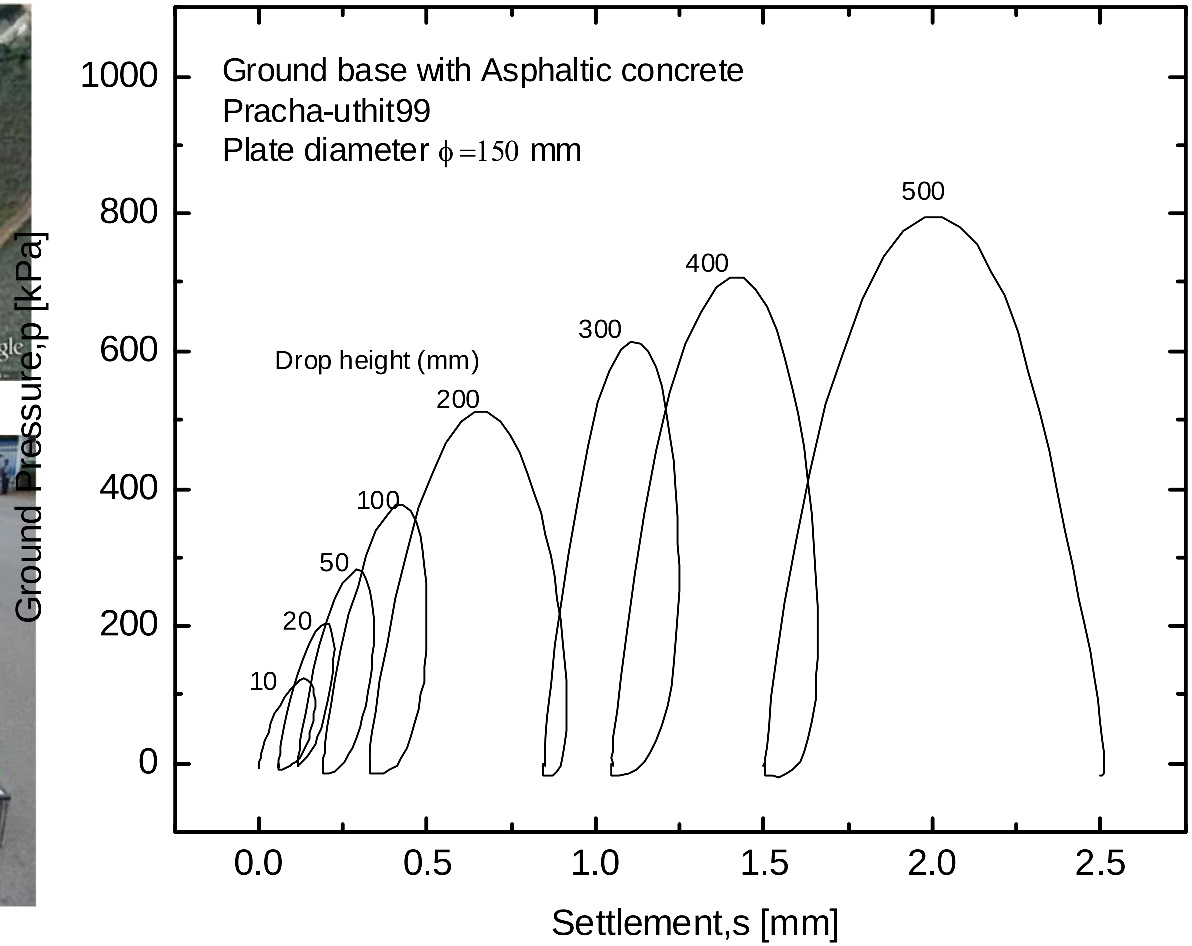
PLT and FWD test results on field top soil

FWD and PLT tests in the field



FWD test results on field lateritic soil

FWD and PLT tests in laboratory



FWD test results on field HMA (flexible pavement)

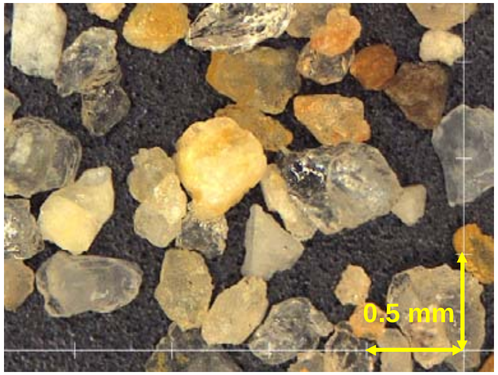
Analysis of test results

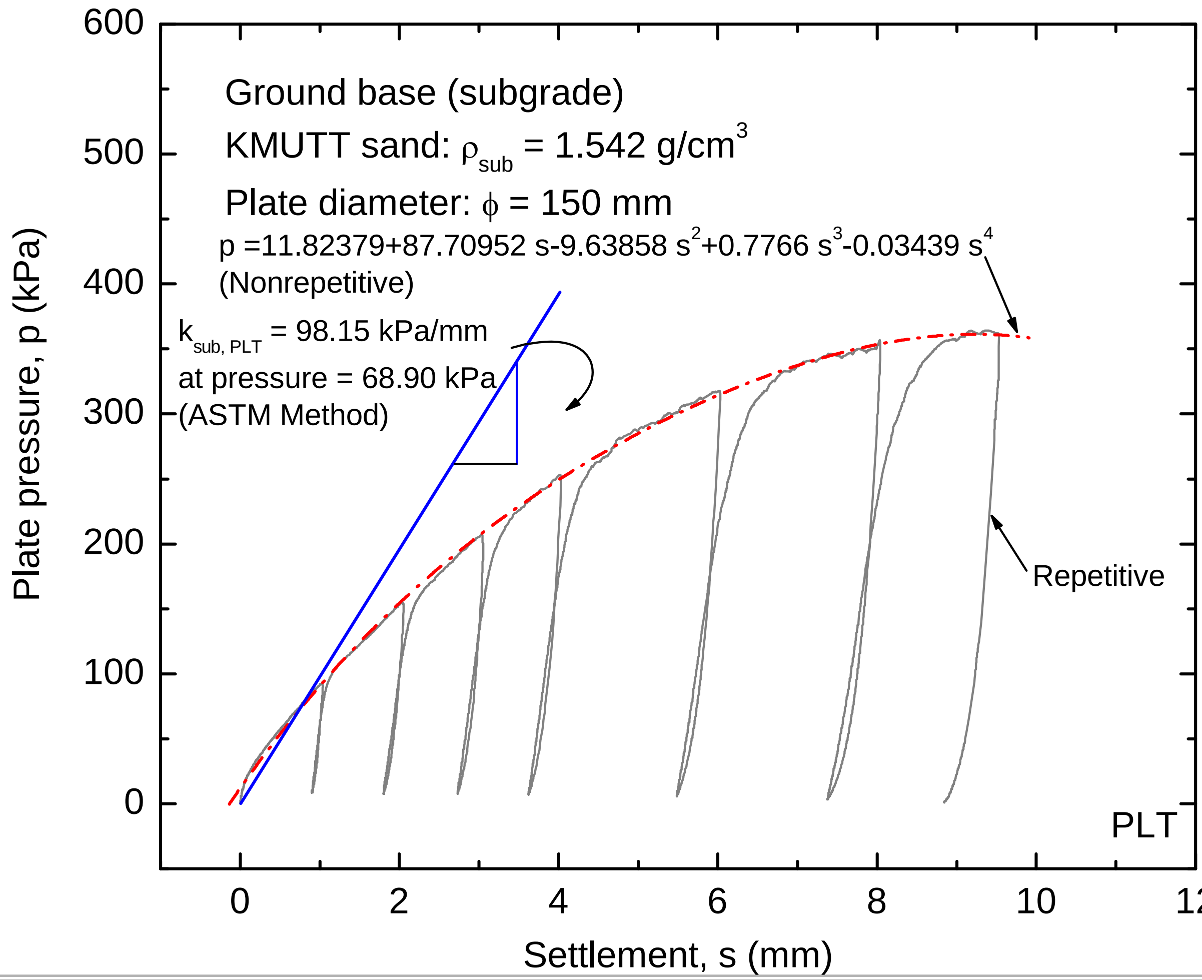
Definition of subgrade modulus by PLT:

1. ASTM Method:

k_{sub} is defined at $p = 68.9$ kPa

$\therefore k_{sub} = 98.15$ kPa/mm





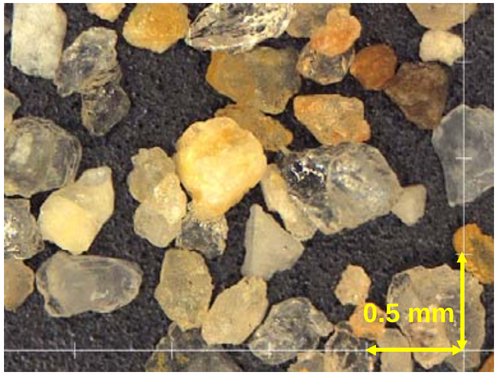
Analysis of test results

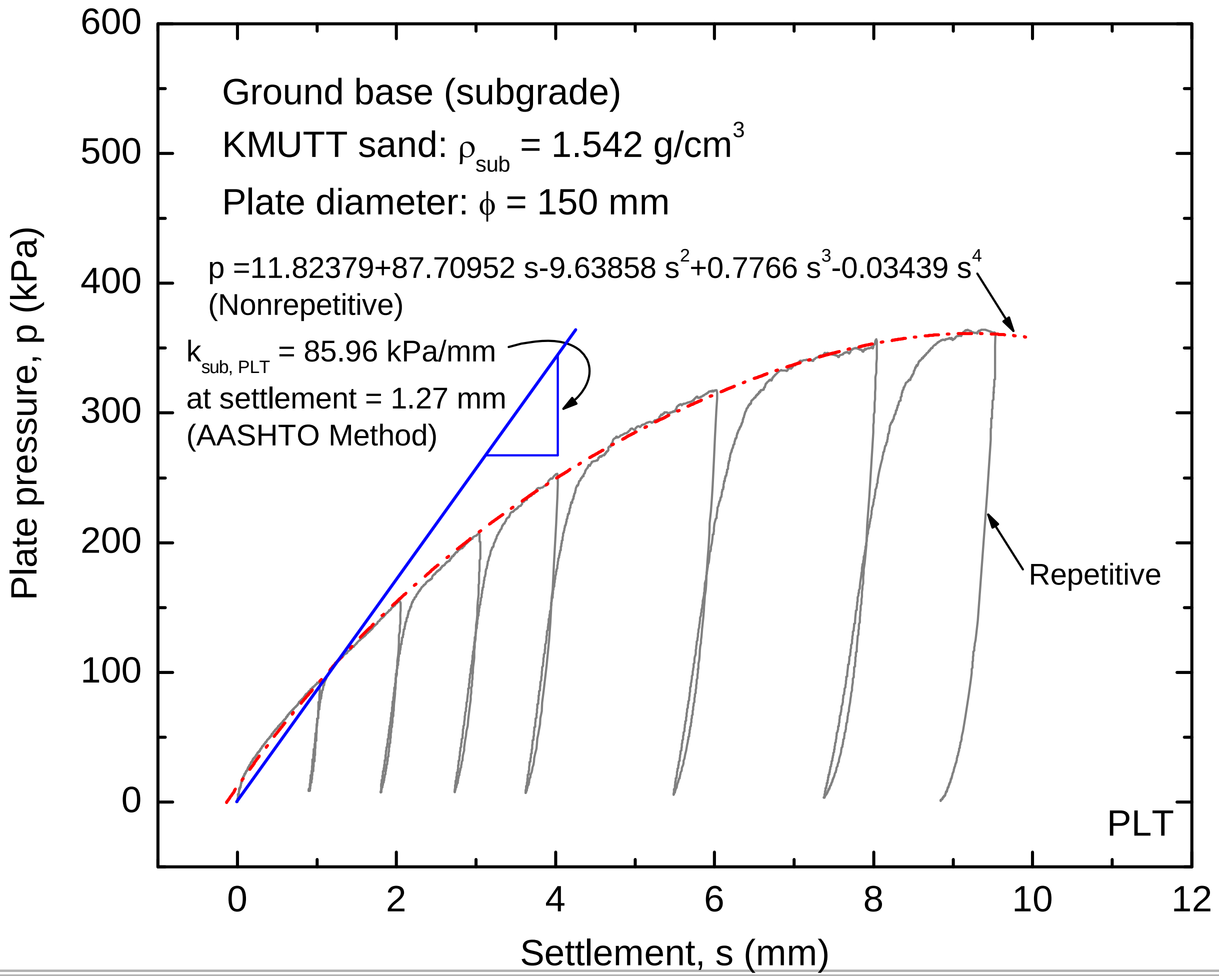
Definition of subgrade modulus by PLT:

2. AASHTO Method:

k_{sub} is defined at s = 1.27 mm

$\therefore k_{sub}$= 85.96 kPa/mm





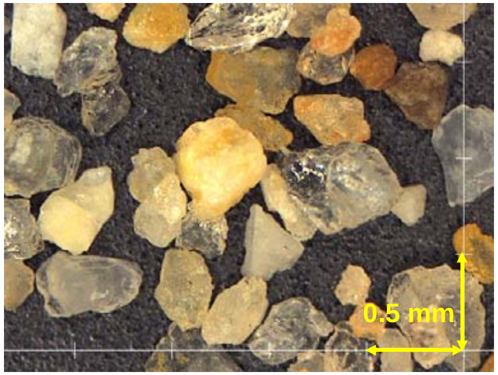
Analysis of test results

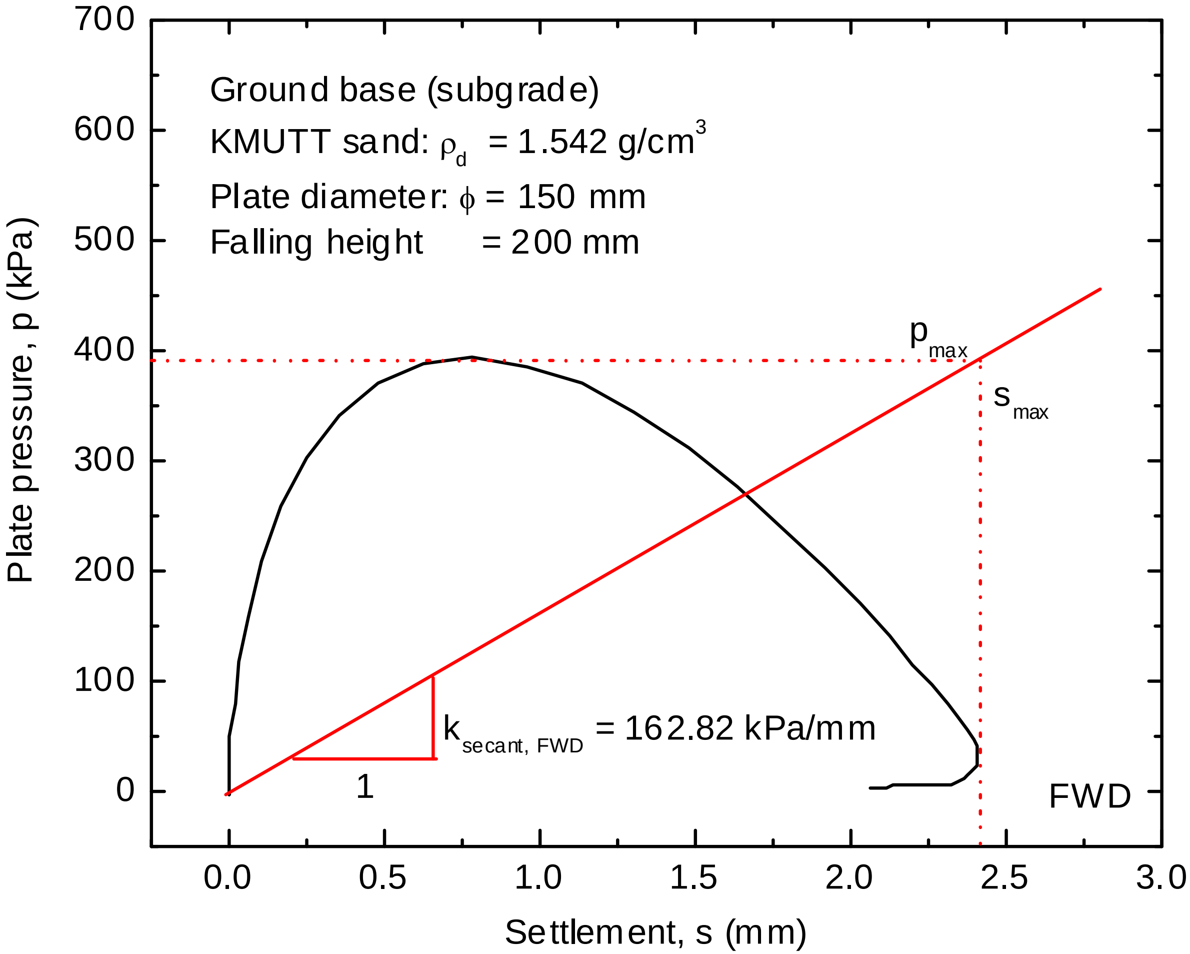
Definition of subgrade modulus by FWD:

1. FHWA Method

k_{sub} is defined by p_{peak}/s_{peak}

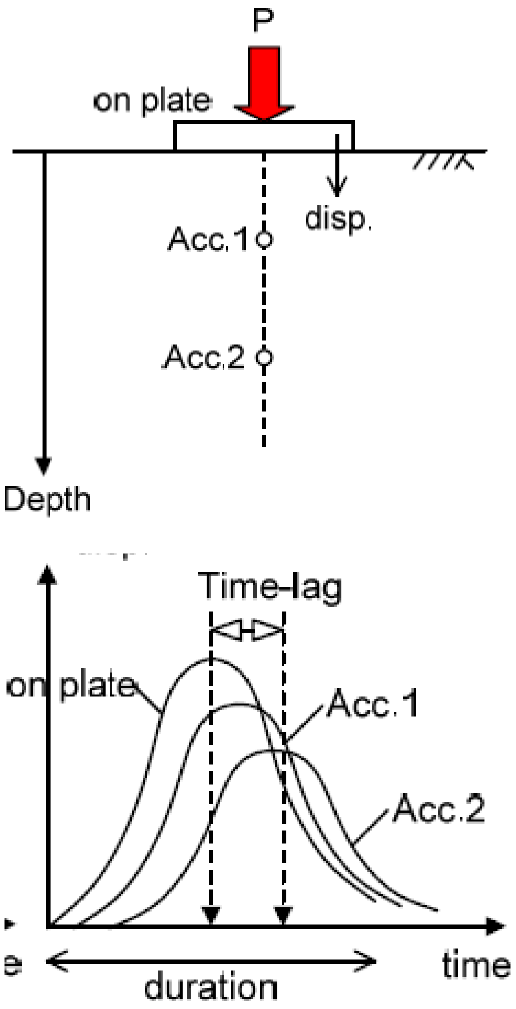
$\therefore k_{sub} = 162.82$ kPa/mm

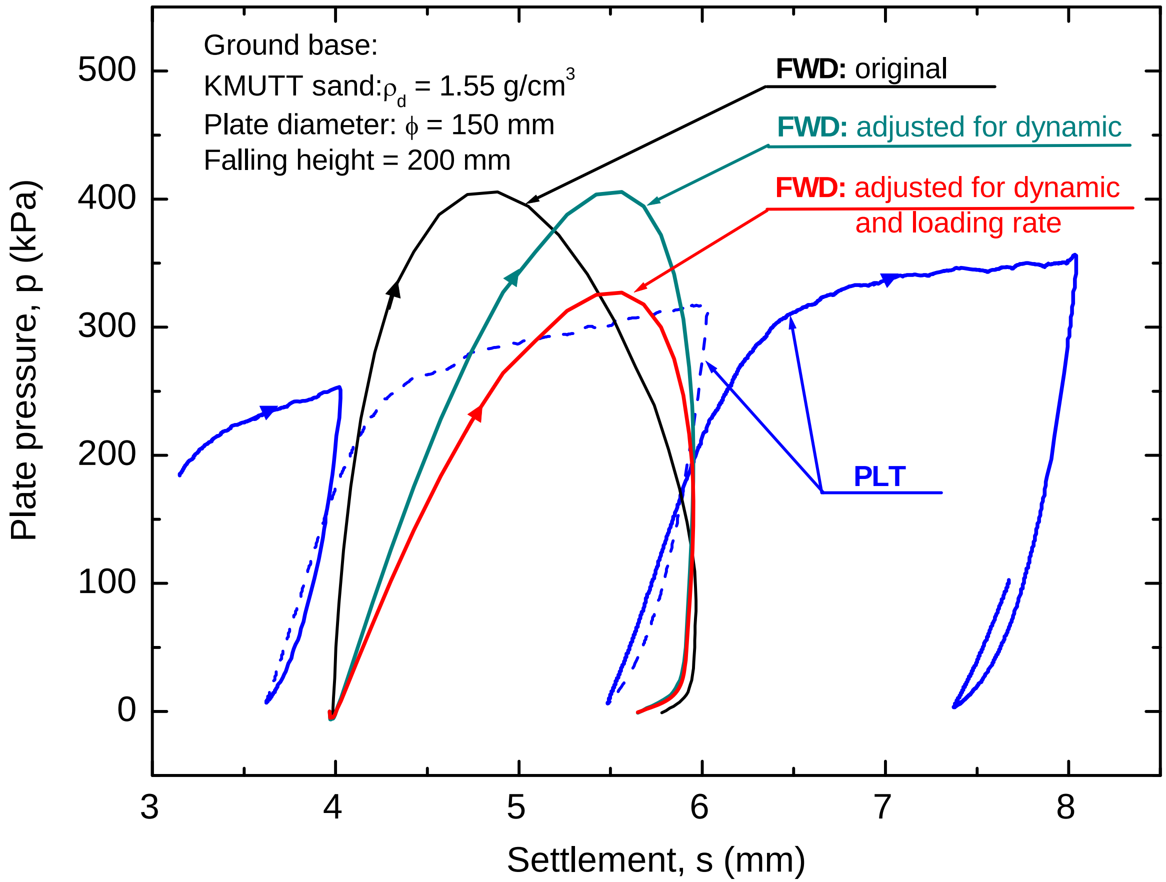




Analysis of test results

Effects of dynamic response and rate-dependent behaviour

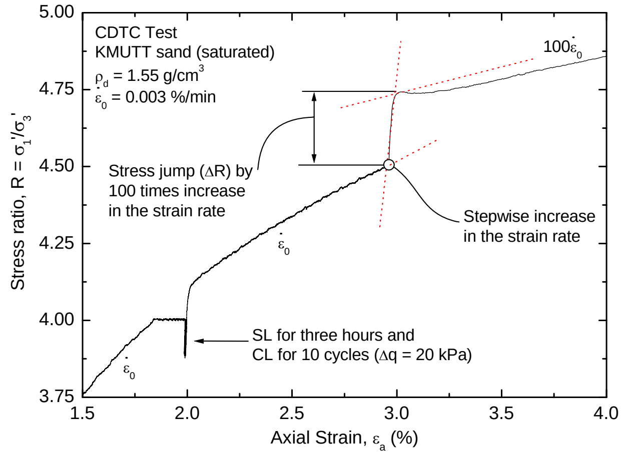


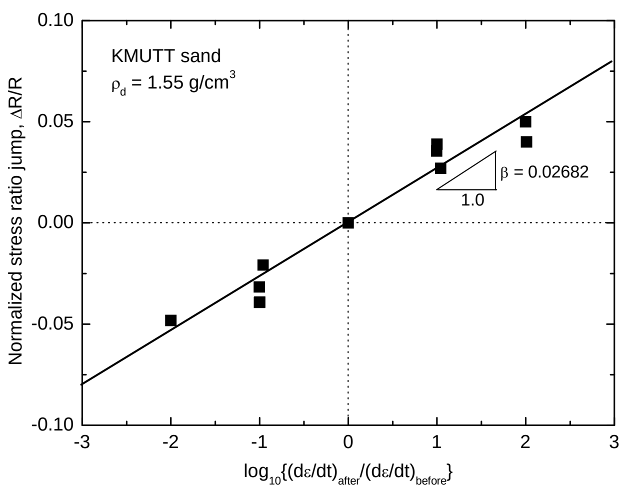


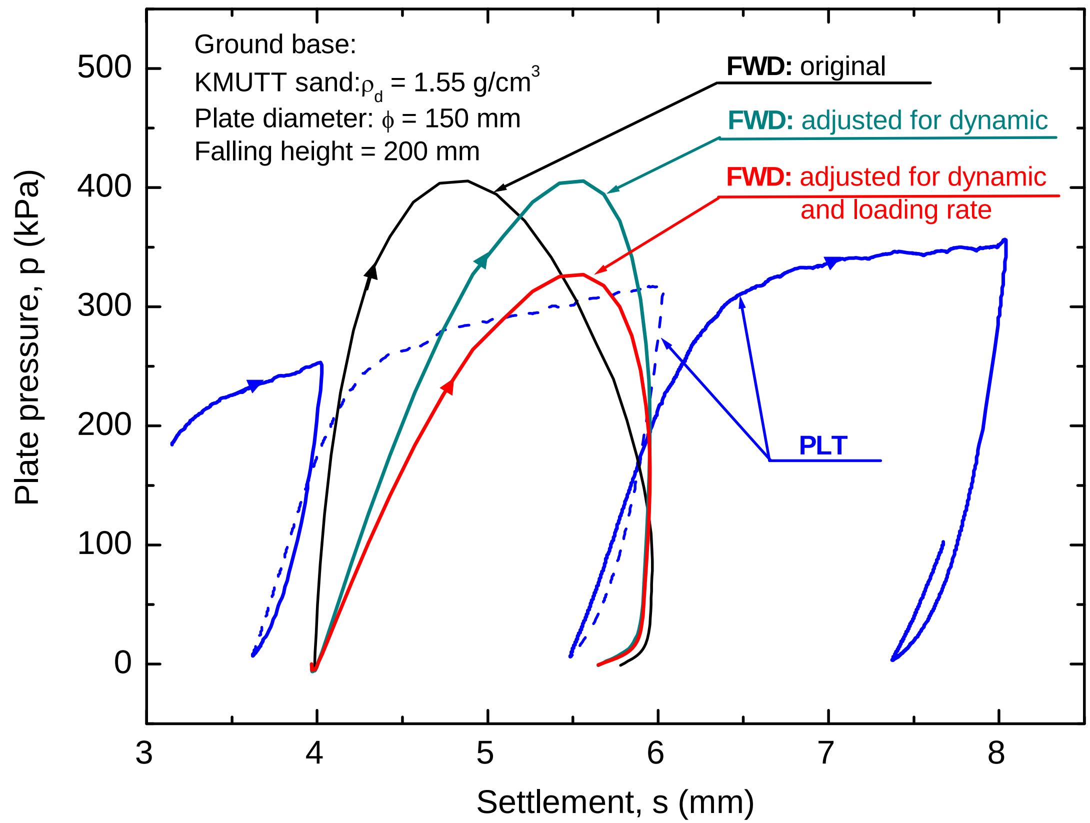
Adjustment for dynamic effects

Analysis of test results

Effects of dynamic response and rate-dependent behaviour







Adjustment for rate effects

ATRANS

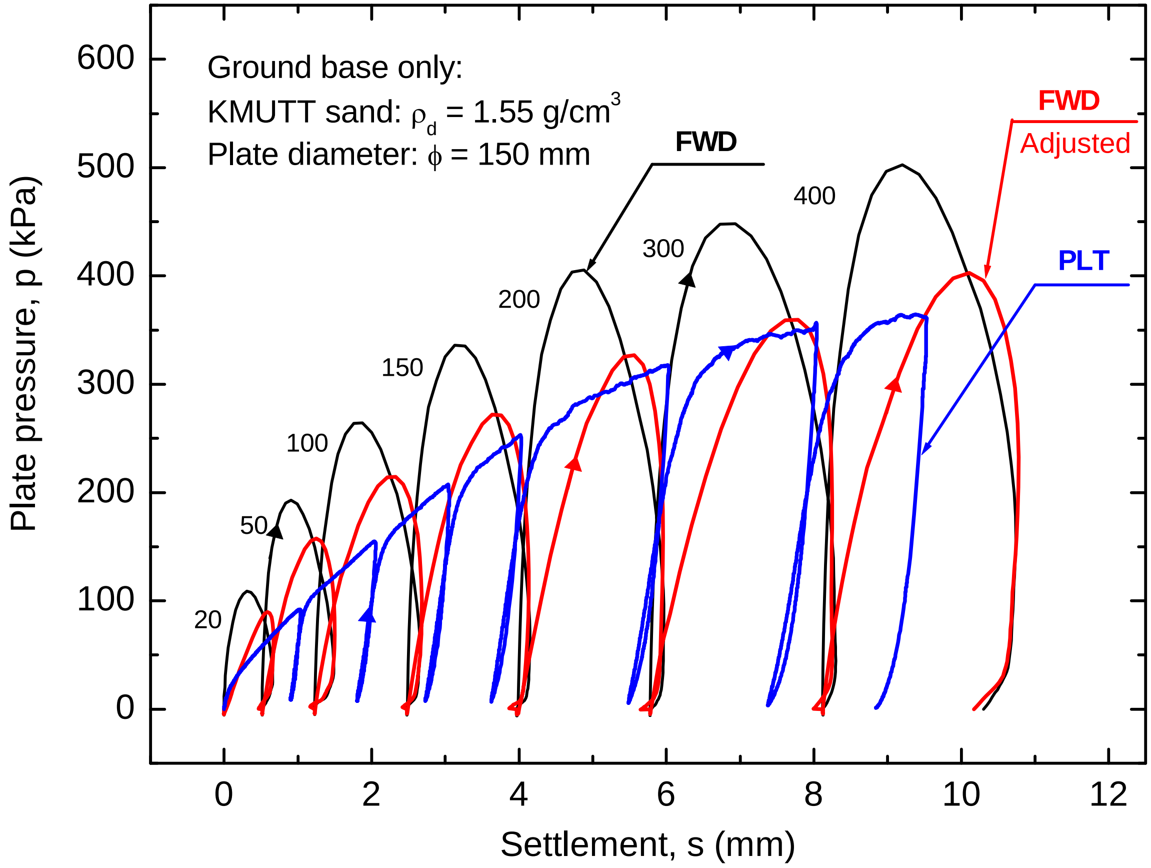
Analysis of test results

Effects of dynamic response and rate-dependent behaviour

k_{FWD} > k_{PLT} about 41%
* (average for all loops)

Adjusted

k_{FWD} > k_{PLT} about 15%
* (average for all loops)

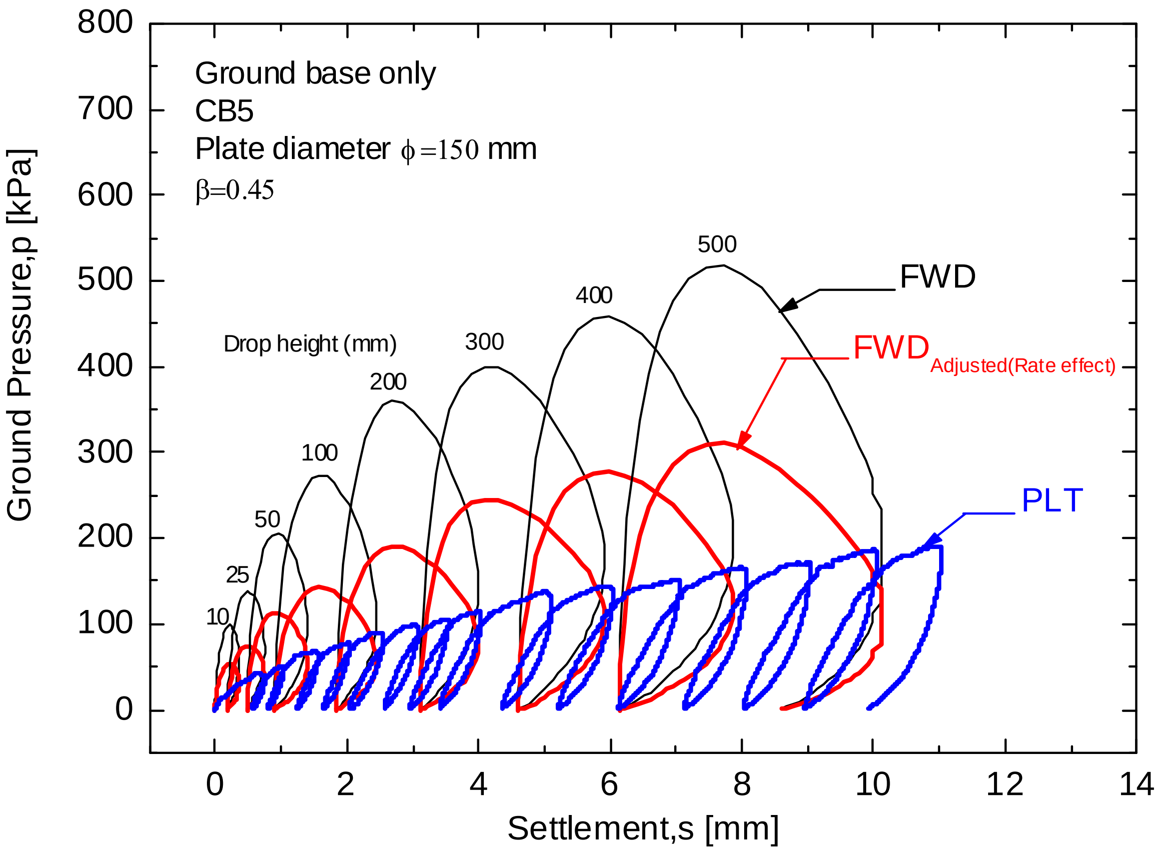


Analysis of test results

After correction for strain rate, the result from FWD can be improved.

However, it is not possible to correctly adjust for dynamic effect when ground acceleration can not be measured.

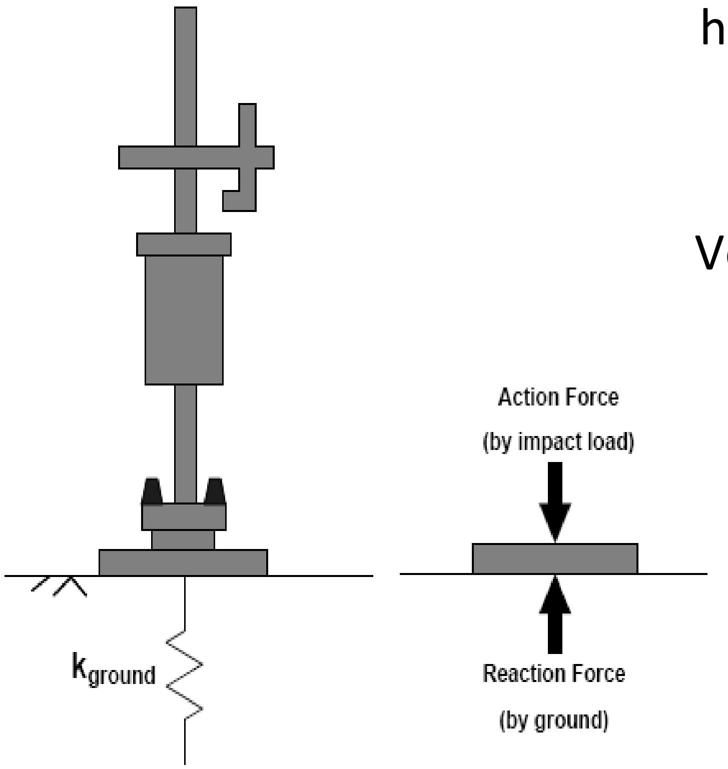
It is therefore necessary to propose alternative method to determine subgrade modulus from FWD that is free from dynamic effect.



PLT and FWD test results on field top soil

Analysis of test results

Undamped Harmonic Motion



Newton's law of motion (undamped harmonic equation) as:

$$\ddot{u} \cdot m_p + k_{ground} \cdot u = 0$$

Vertical displacement under loading plate as:

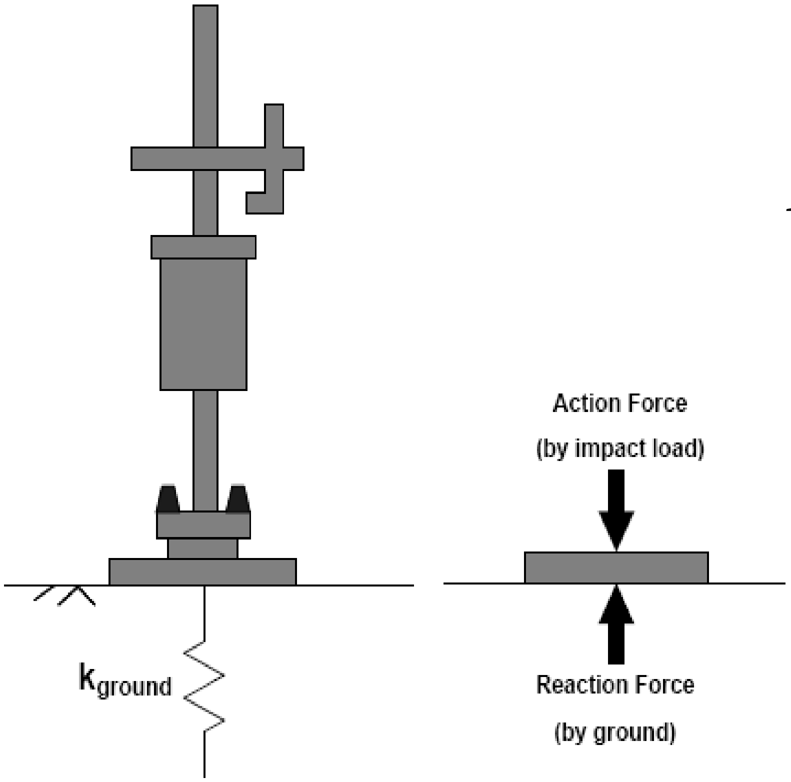
$$u = A_1 \cdot \cos \omega_n t + A_2 \cdot \sin \omega_n t$$

at $t = 0:$ $\quad u = u_0 = A_1$

when $\quad \omega_n = \sqrt{\dfrac{k_{ground}}{m_p}}$

Analysis of test results

Undamped Harmonic Motion



Peak value of vertical load can be obtained as:

$$F_{peak} = E_f \cdot \sqrt{2 \cdot g \cdot h \cdot k_{ground} \cdot m_h}$$

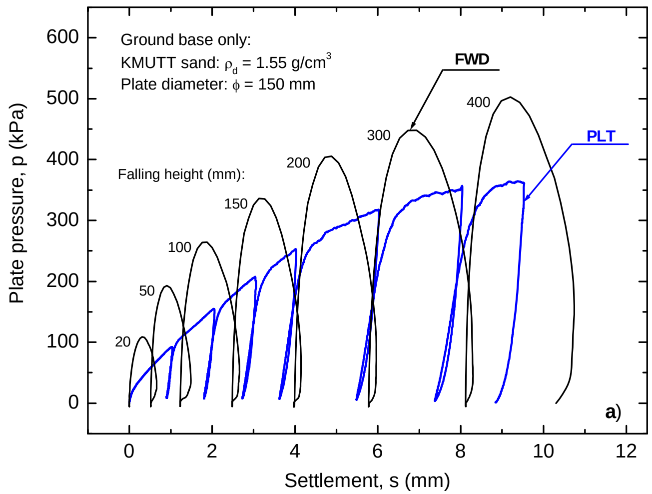
The modulus of subgrade reaction was defined as:

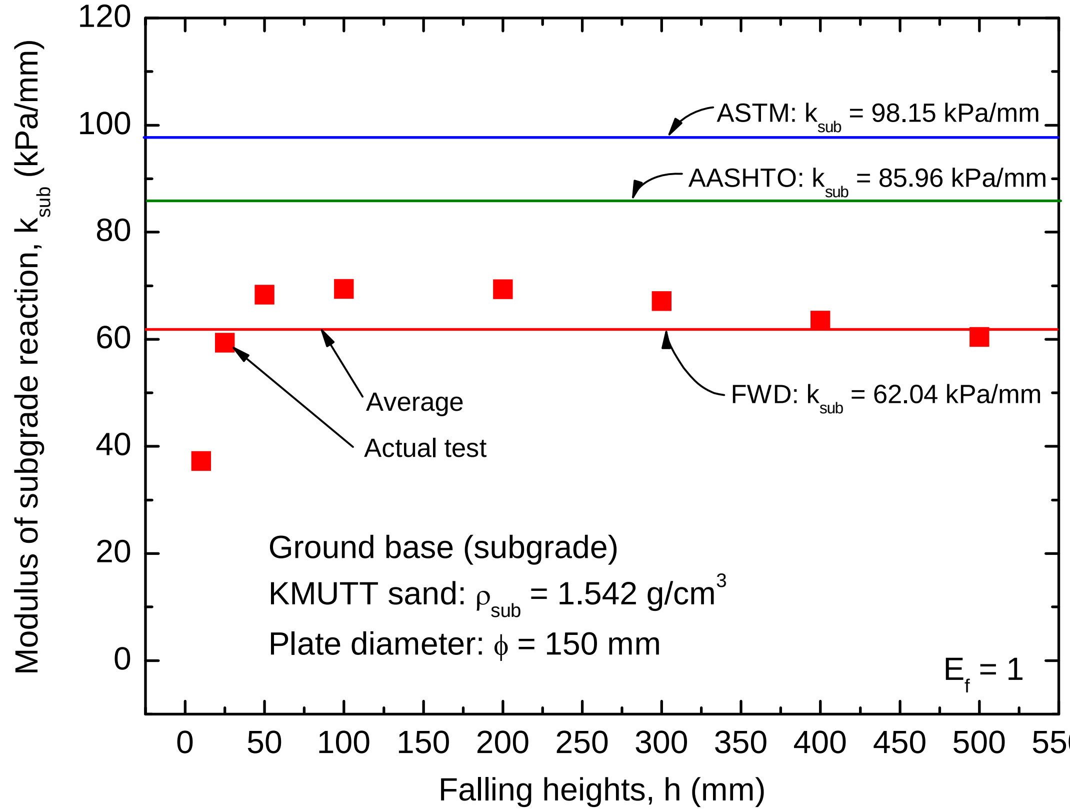
$$k_{sub} = \frac{P}{u}$$

or

$$k_{sub} = \frac{F / A_p}{u} = \frac{k_{ground}}{A_p}$$

Analysis of test results





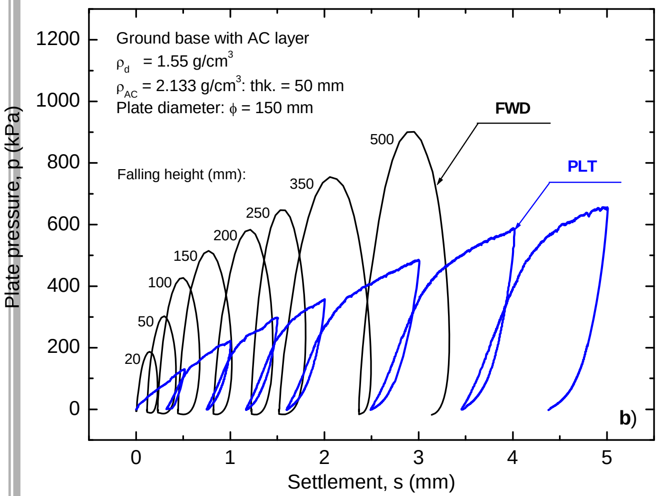
Subgrade modulus of ground base

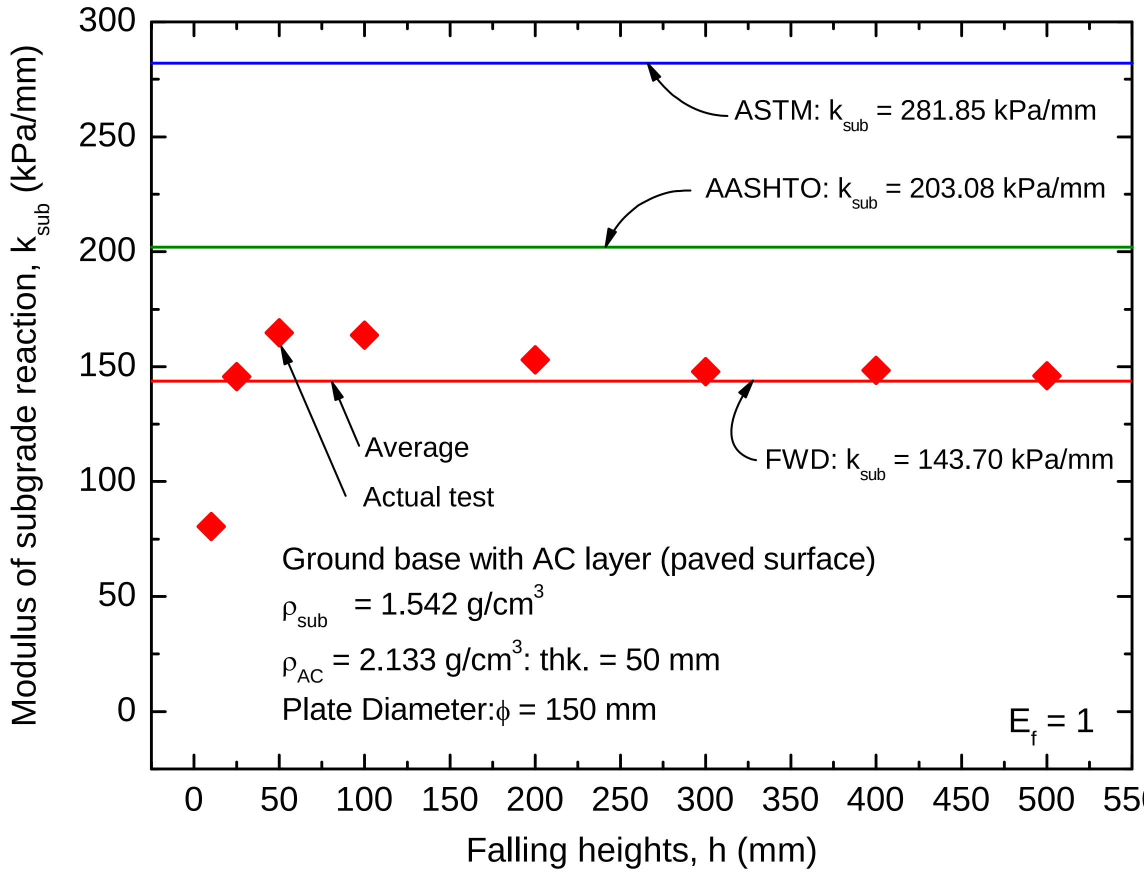
Analysis of test results

FWD test					PLT test	
Falling heights (mm)	F_{peak} (kN)	P_{peak} (kPa)	k_{ground} (kN/mm)	k_{sub} (kPa/mm)	ASTM (at p = 68.9kPa) (kPa/mm)	AASHTO (at s = 1.27 mm) (kPa/mm)
10	1.14	64.30	0.66	37.24	98.15	85.96
25	2.27	128.37	1.05	59.37		
50	3.44	194.73	1.21	68.31		
100	4.90	277.53	1.23	69.37		
200	6.93	392.40	1.23	69.34		
300	8.36	472.85	1.19	67.13		
400	9.38	530.83	1.12	63.45		
500	10.23	579.13	1.07	60.42		
Average				61.82		

Subgrade modulus of ground base

Analysis of test results





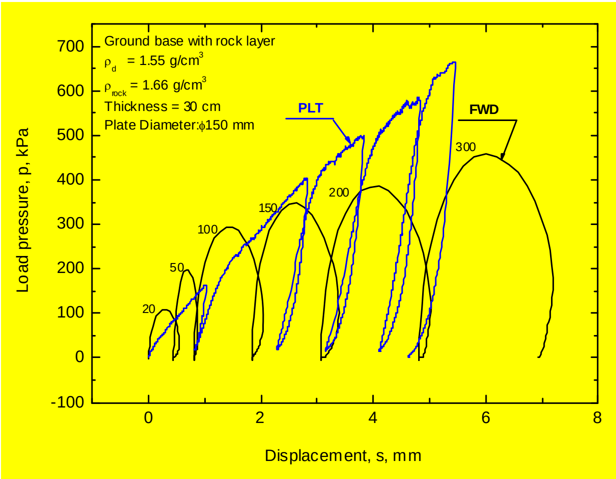
Subgrade modulus of ground base with AC layer

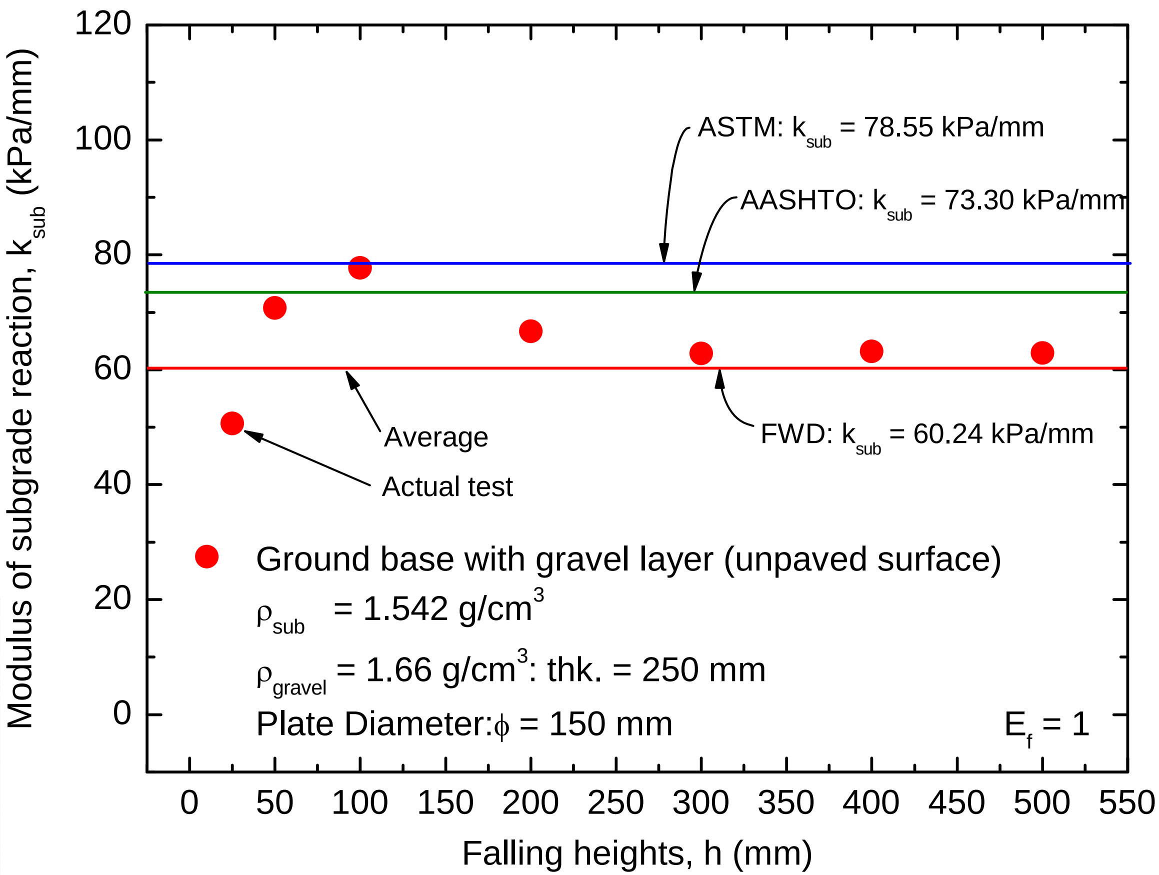
Analysis of test results

FWD test					PLT test	
Falling heights (mm)	F_{peak} (kN)	P_{peak} (kPa)	k_{ground} (kN/mm)	k_{sub} (kPa/mm)	ASTM (at p = 68.9kPa) (kPa/mm)	AASHTO (at s = 1.27 mm) (kPa/mm)
10	1.67	94.49	1.42	80.42	281.45	203.08
25	3.55	201.05	2.57	145.63		
50	5.34	302.46	2.91	164.79		
100	7.53	426.22	2.89	163.62		
200	10.30	582.80	2.70	152.96		
300	12.40	701.75	2.61	147.85		
400	14.34	811.48	2.62	148.28		
500	15.91	900.54	2.58	146.09		
Average				143.70		

Subgrade modulus of ground base with AC layer

Analysis of test results





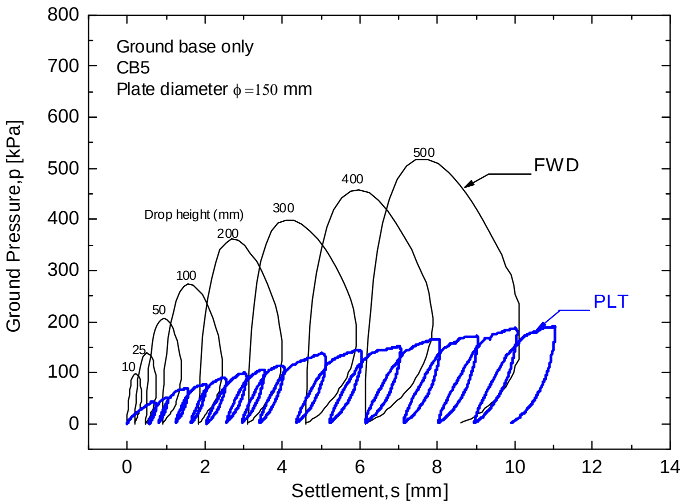
Subgrade modulus of ground base with gravel layer

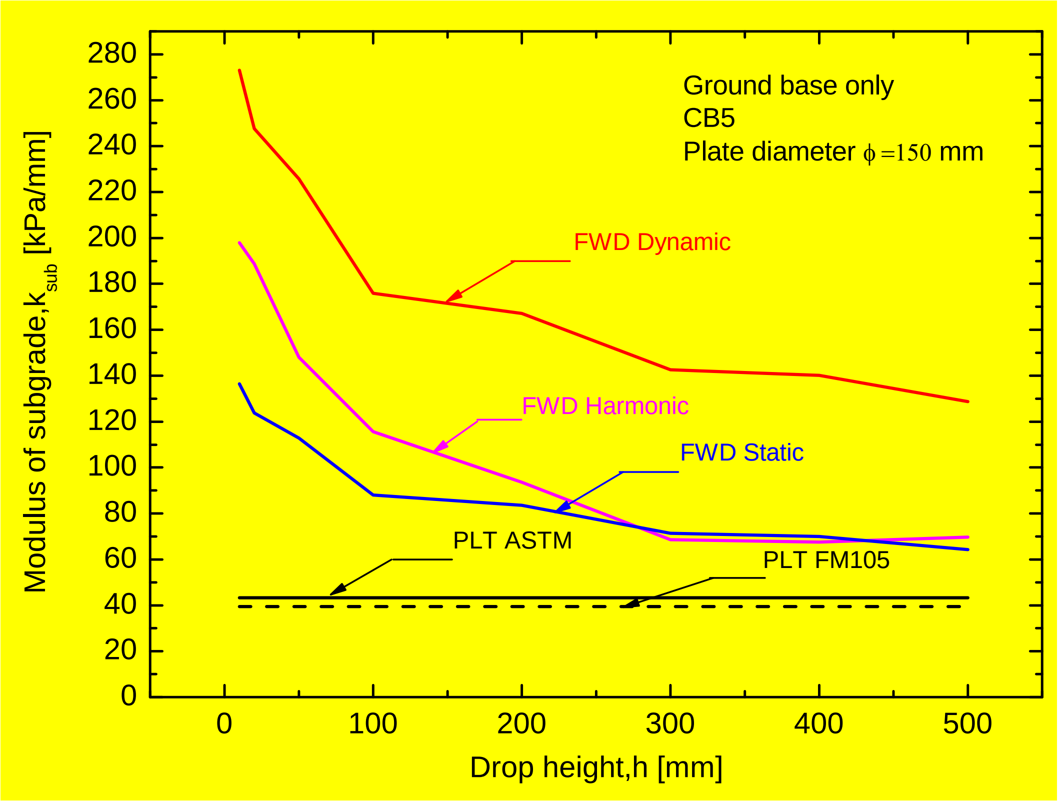
Analysis of test results

FWD test					PLT test	
Falling heights (mm)	F_{peak} (kN)	P_{peak} (kPa)	k_{ground} (kN/mm)	k_{sub} (kPa/mm)	ASTM (at p = 68.9kPa) (kPa/mm)	AASHTO (at s = 1.27 mm) (kPa/mm)
10	0.98	55.26	0.49	27.50	78.55	73.30
25	2.10	118.58	0.90	50.66		
50	3.50	198.17	1.25	70.74		
100	5.19	293.75	1.37	77.72		
200	6.80	384.74	1.18	66.66		
300	8.09	457.57	1.11	62.86		
400	9.36	529.78	1.12	63.20		
500	10.44	591.06	1.11	62.93		
Average				60.24		

Subgrade modulus of ground base with gravel layer

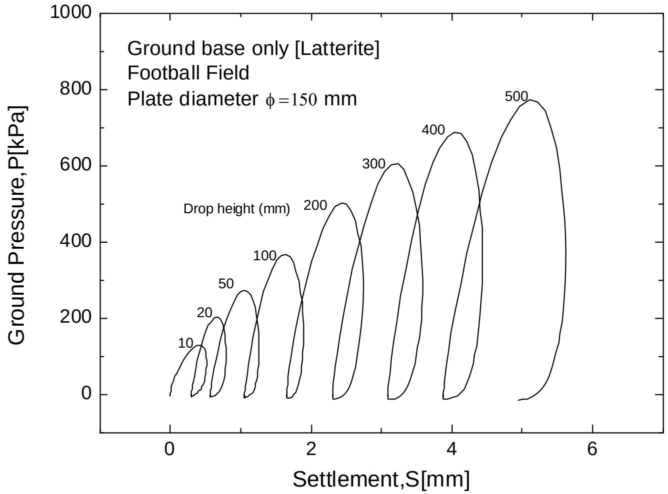
Analysis of test results

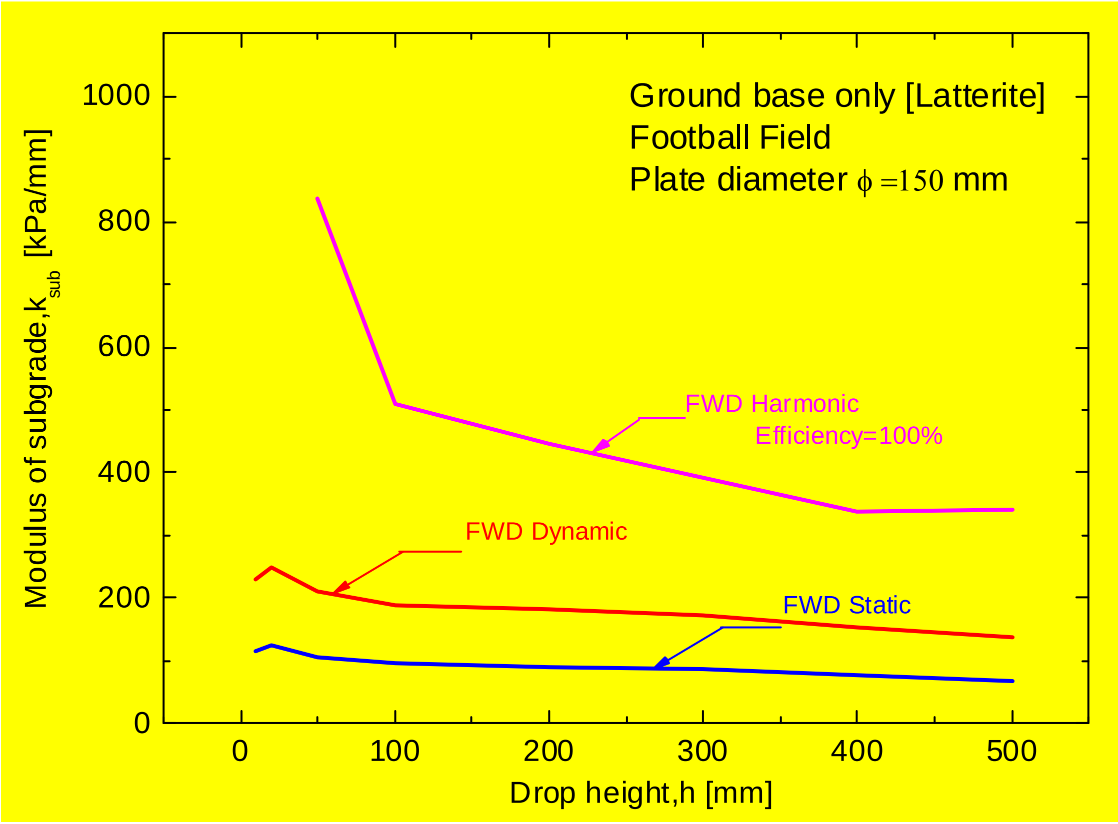




Subgrade modulus of field lateritic soil

Analysis of test results





Subgrade modulus of field top soil

ATRANS

Conclusions

1. FWD apparatus was successfully developed.
2. Dynamic effect and rate-dependent response of material are responsible for different results between FWD and PLT, which were successfully corrected.
3. Using undamped harmonic equation to obtain the subgrade modulus of test material from FWD provide similar results between FWD and PLT.
4. Item 3 is relevant for both single and multiple layer systems and both laboratory and field cases.

Publications

EVALUATION OF STIFFNESS VALUES OF GROUND BASE AND ASPHALTIC CONCRETE BY FALLING WEIGHT DEFLECTOMETER (FWD) AND PLATE LOAD TEST (PLT)

Saravut Moryadee [1]
Karun Klaycham [1]
Warat Kongkitkul [1]
Sompote Youwai [1]
Koonnamas Punthutaecha [2]

[1] *Research Center of Geomechanics and Ground Improvement, Department of Civil Engineering, King Mongkut's University of Technology Thonburi, Bangkok, Thailand, warat.kon@kmutt.ac.th*
[2] *Bureau of Planning, Department of Rural Roads, Bangkok Thailand.*

ABSTRACT: A series of falling weight deflectometer (FWD) tests and plate load tests (PLT) were performed in a laboratory to evaluate the stiffness values of ground base only and ground base with asphaltic concrete (AC) layer placed on the top and to compare the results from these two types of test. The modeled ground base and AC layer were prepared by an air-dried poorly graded angular silica sand and hot-mixed asphaltic concrete, respectively. It was found that, when performing tests on the ground base only, the stiffness values from the FWD tests were larger than the values from the PLT. In addition, these differences became larger when tested on ground base with an AC layer. The differences in the results between FWD and PLT are, at least, attributed to: a) dynamic behavior; and b) viscous behavior of tested materials. Therefore, it was attempted to adjust the FWD test results by taking the two above-mentioned factors into consideration. Then, it was found that the FWD test results became close to the ones by PLT. Therefore, after having adjusted for these two factors, FWD test can be used in place of PLT to accurately obtain the stiffness value.

KEYWORDS: Falling Weight Deflectometer (FWD), Plate Load Test (PLT), Stiffness, Asphalt, Viscosity, Dynamic.

1. INTRODUCTION

Nowadays, there are several methods to evaluate the stiffness values of a pavement structure. However, different methods give different results when performing tests on the same material and location. As the stiffness value is a very important parameter used in the design and evaluation of serviceability of a pavement structure, it must be obtained accurately. To this end, Plate Load Test (PLT) has been employed as a standard method for stiffness evaluation; however, performing PLT is time-consumed and costly.

On the other hand, Falling Weight Deflectometer (FWD) was introduced as a non-destructive testing (NDT) device that can evaluate stiffness values of pavement structure. FWD is short-time consumed, convenient and economical. However, most of NDT methods including FWD method have not been standardized [1]. In fact, it was found that the stiffness values determined by NDT methods including FWD method were generally higher than the ones obtained by conventional methods including PLT method [2].

In fact, there are many factors affecting stiffness values obtained by FWD method. Therefore, it is necessary to investigate these factors and to quantitatively estimate the effects of these factors which are the objectives of this study. It should be noted here that this paper does not constitute a standard, specification, or regulation.

2. TEST DETAILS

2.1 Test preparation

Base and sub-base materials of a pavement structure were modeled by KMUTT sand having particle shape and particle distribution as shown in Fig. 1. This sand was treated by sieving and cleaning as well as being oven to remove any organic content a large amount of river-bed sand. After being treated, KMUTT sand has following index properties: $G_s = 2.64$, $D_{max} = 0.425$ mm, $D_{min} = 0.150$ mm, $D_{50} = 0.285$ mm, $C_u = 1.879$, $C_c = 0.946$, $e_{max} = 1.06$ and $e_{min} = 0.71$. To simulate a pavement structure, air-dried KMUTT sand was pluviated through air by a multiple sieving apparatus [3] into a cylindrical concrete container having 1,000 mm in inner-diameter and 900 mm in height (Fig. 2) to prepare the ground base. The average density of the ground base is about 1.55 g/cm^3 ($D_r = 96.43$ %).

To simulate the pavement material, 50-mm thick asphaltic concrete (AC) layer was prepared by hot-mixing asphaltic cement of 60/70 grade at 5 % by weight of aggregate and aggregate together. The aggregate used

effects were adjusted again for loading rate effect using different ratios of $\dot{s}$ for FWD to PLT at different elapsed times.

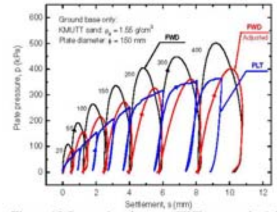


Figure 13 Comparison between FWD test results (after and before adjustments for dynamic and loading rate effects) and PLT result

Figure 13 compares the p-s relationships after and before adjustments for dynamic and loading rate effects with the ones by PLT. It is clearly seen that the results from FWD become similar to those of PLT. It should be noted that any difference remained may be likely due to the fact that there are still effects of other factors in FWD than the dynamic and loading rate effects that have not been taken into account when adjusting the FWD test results shown in this study. Yet, after having adjusted for dynamic and loading rate effects, FWD test can be used in place of PLT to accurately obtain the stiffness value of ground base.

6. CONCLUSIONS

The following conclusions may be derived from this study:

1. For the same test condition, the stiffness values from FWD are always greater than the ones obtained by PLT.
2. The differences in the stiffness values when performed FWD and PLT tests on the ground base with AC layer were higher than on the ground base only.
3. Dynamic and loading rate effects were found responsible for the differences in the stiffness values between FWD and PLT tests.
4. After being adjusted for dynamic and loading rate effects, relationships between the plate pressure and the plate settlement obtained by FWD became close to the ones by PLT. Therefore, FWD test can be used in place of PLT to accurately obtain the stiffness value, when adjustments for dynamic and loading rate effects were performed.

7. ACKNOWLEDGEMENTE

The financial supports from: the KMUTT research fund; the Young Scientist and Technologist Programme, NSTDA (YSTP: SP51-NT2); and the Asian Transportation Research Society (ATRANS) are gratefully acknowledged. The asphaltic cement and the aggregate used in this study were provided by the Shell Co., Ltd., Thailand and the Tipco Asphalt Public Company Limited, Thailand, respectively. The authors are also grateful to Dr. D. Hirakawa (National Defense Academy, Japan) for help and advice on designing FWD apparatus and to Mr. T. Korpongcharoenchai and Mr. W. In-oum for test assistance and cooperation.

REFERENCES

[1] Shahin. M, *Pavement Management for Airports, Roads, and Parking Lots*, Chapman & Hall, New York, USA.
[2] Bush, A.J. and Baladi, G.Y. (1989). *Nondestructive Testing of pavements and Backcalculation of Moduli*, ASTM STP 1026, American Society for Testing and Materials, Marryland, USA.
[3] Miura, S. and Toki, S. (1982). A sample preparation method and its effect on static and cycle deformation-strength properties of sand, *Soils and Foundations*, March 1982; Vol. 22, No.1, 61-77.
[4] Ping, W.V., Asce, M., Yang, Z. and Gao, Z. (2002). Field and Laboraty Determination of Granular Subgrade Moduli, *Journal of Performance of Constructed Facilities*, November 2002; Vol. 16, No.4, 149-159.
[5] George, K.P. (2003). Falling Weight Deflectometer for Estimateing Subgrade Resilient Moduli, *FHWA/MS-DOT-RD-03-153*, University of Mississippi, Mississippi.
[6] Loizos, A., Boukovalas, G., and Karlaftis, A. (2003). Dynamic Stiffness for Pavement Subgrade Evaluation, *Journal of Transportation Engineering*, July-August 2003; Vol. 129, No.4, 434-443.
[7] Lytton. R.L. and Michalak, C. H. (1979). Flexible Pavement Deflection Equation Using Elastic Moduli and Field Measurements, *Research Report 207-7F*, Texas Transportation Institute, Texas A&M University, College Station, Texas.
[8] Hirakawa, D., Masuda, N., Tatsuoka, F. and Kawasaki, H. (2007). Relationship between sand ground stiffness values from FWD and from plate loading tests, *JGS Journal*, May 2007, Vol. 3, No.4, 307-320 (in Japanese)
[9] Tatsuoka, F., Di Benedetto, H., Enomoto, T., Kawabe, S. and Kongkitkul, W. (2008): "Various viscosity types of geomaterials in shear and their mathematical expression", *Soils and Foundations*, Vol.48, No.1, pp. 41-60.
[10] Kongkitkul, W., Tatsuoka, F., Duttine, A., Kawabe, S., Enomoto, T. and Di Benedetto, H. (2008): "Modelling and simulation of rate-dependent stress-strain behaviour of granular materials in shear", *Soils and Foundations*, Vol.48, No.2, pp.175-194.
[11] Tatsuoka, F. (2007). Inelastic deformation characteristics of geomaterial. Special Lecture, Soil Stress-Strain Behavior, *Measurement, Modeling and Analysis, Proc. of Geotechnical Symposium in Roma*, March 16 & 17, 2006 (Ling et al., eds.).
[12] Hirakawa, D. (2003): "Study on residual deformation characteristics of geosynthetic-reinforced soil structures", *Ph.D. Thesis*, University of Tokyo (in Japanese).

ATRANS

Publications

Officers of IGS-Thailand Chapter

President :Prof. Dennes T. Bergado
Professor and ACSIG Director
Asian Institute of Technology
PO Box 4, Klong Luang
Pathumthani 12120 Thailand
Email: bergado@ait.ac.th

VP Academic:Dr. Sompote Youwai
Department of Technu Training in Civil Eng'g
King Mongkut's Institute of Technology Thonburi,
1518 Piboonsongkram Road, Bang Sue
Bangkok 10800, Thailand
Email: sompote.you@kmutt.ac.th

VP Industry:Mr. Nuttapong Kovittayanun
Managing Director
CeTeau FarEast Ltd.
Sinn-sathorn Tower 38th Fl.,
77/171 Krungthonburi Rd.,
Klongtonsai,Klongsarn,
10600 Bangkok, Thailand
Email: ntp@ceteau.com

Secretary-Treasurer:Dr. Suttisak Soralump
Department of Civil Engineering
Faculty of Engineering, Kasetsart University
50 Paholyothin Road, Ladyao, Chatuchak
10900 Thailand
Email: suttisak.s@ku.ac.th

Newsletter Editor:Dr. Montri Dechasakulsom
Research Engineer
Materials and Research Division
Sri Ayudhaya Road, Rachatewi
Bangkok 10400, Thailand
Email: montri@doh.go.th

TECHNICAL EXHIBITION

A comprehensive technical exhibition for ground improvement and geosynthetics as applied to disaster control, mitigation and rehabilitation will be organized at the venue of the Symposium which is to be announced in due course. For booking, please contact the Conference Secretariat.

Contact Information

Prof. Dennes T Bergado, Director/ACSIG
E-mail: bergado@ait.ac.th

Mr. Sonny Montablo, Manager/ACSIG
Phone: +66-2-524-5523
E-mail: acsig@ait.ac.t
Website: www.set.ait.ac.th/acsig/conference

REGISTRATION

The Registration Fees which covers the Symposium Proceedings, Lunch and Coffee Breaks are as follows:

Foreign Participants	US$ 300
IGS/AITAA member (foreign)	US$ 100
Thai Participants	Baht 3,000
IGS/AITAA member (local)	Baht 2,500

Registration Form

Name: ____________________

Title of Paper____________________

____

Mailing Address: ____________________

____

____

Telephone: ____________ Facsimile:____________

Email: ____________________

Method of payment:

Bank Transfer (Add 3%)
*Account Name: ***Asian Institute of Technology***
*Account Number: ***359 - 3 - 00001 - 2***
*Bank Address: *Siam Commercial Bank, Klong Luang Branc*
AIT Campus, Klong Luang
Pathumthani 12120, Thailand

☐ *American Express(include 4-digit personal code)*

☐ *Visa Card* ☐ *Master Card*

Amount to be Charged (Add 5%): ____________

Card Number: ____________________

Expiry Date: ____________________

Cardholder's Name: ____________________

Cardholder's Signature: ____________________

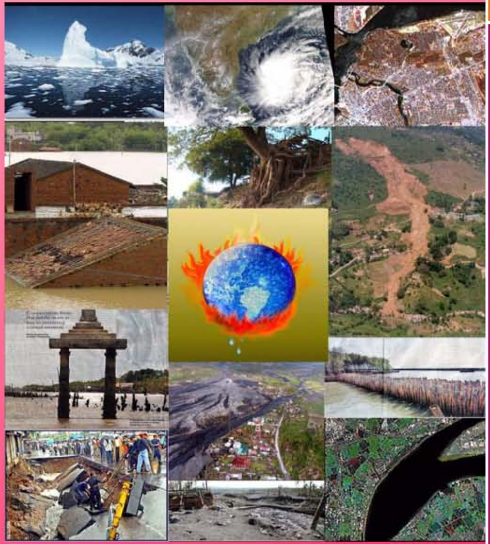
Payment in favor of ACSIG/AIT

IMPORTANT DATES

Deadline of Abstract Submission:	**31 May 2009**
Notification of Acceptance:	**31 July 2009**
Deadline of Camera-Ready Papers:	**30 September 2009**

International Symposium
on
Geotechnical Engineering, Ground Improvement, and Geosynthetics for Sustainable Mitigation and Adaptation to Climate Change including Global Warming

2 to 3 December 2009



Bangkok, Thailand

Organized by

with the support of

THAILAND