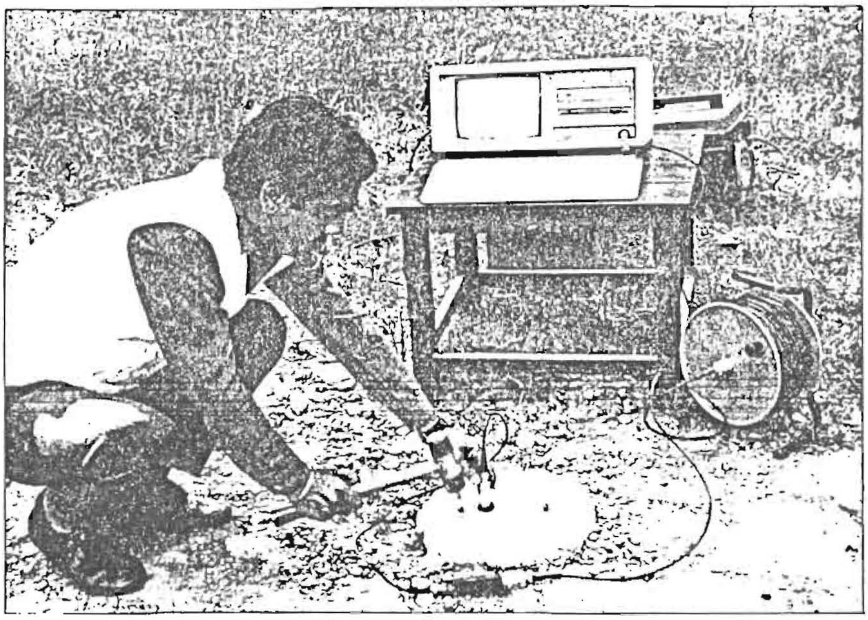
Non-Destructive Integrity Testing Of Piles

Chandra Prakash, A.K. Sharma and P.C. Rastogi, Central Building Research Institute, Roorkee

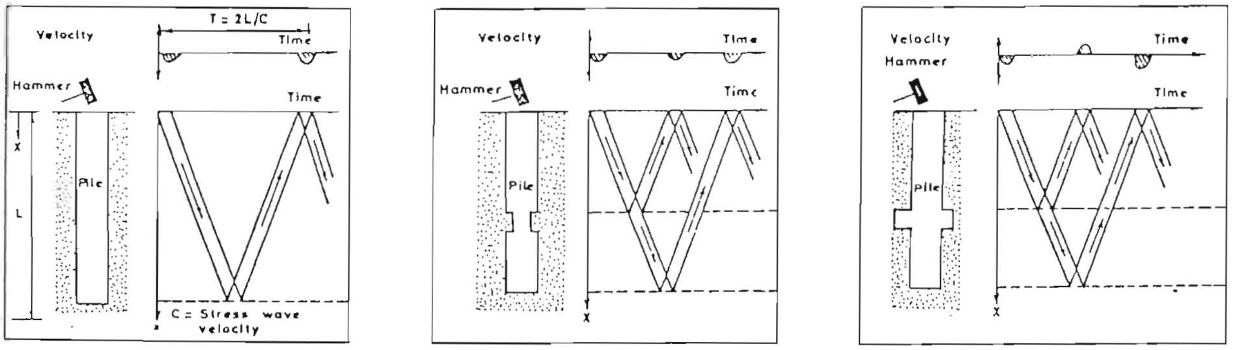
The prime component of pile foundation technology is the construction of a pile true to design with maximum speed and minimum expenditure. Structures, however, some times do end up with piles of questionable integrity with defects and irregularities in the form of voids, soil inclusions, separations, squeezing of sections, necking and honeycombing along the pile shaft, defective toes in cast-in-situ concrete piles and cracks in precast concrete piles (1,2,3 &4). This is why a need has been emphasised from time to time to have a definitive and economical non-destructive procedure to evaluate structural integrity of piles shortly after their construction. The commonly employed methods of coring, drilling, television survey vibration testing and load tests for detecting defects and irregularities in piles have, however, only resulted in varying degree of success. During the recent years, a low strain sonic integrity testing method, based on one dimensional stress wave analysis applicable to piles has been used successfully in various parts of the world (5,6,7). It is a low strain, non-destructive testing method useful for both cast-in-situ and precast concrete piles. The method basically involves recording of pile head acceleration caused by blow of a hand held hammer on pile top. In India the work on integrity testing of piles has been started very recently using one of the latest portable computerised stress wave measuring equipment-Foundation Pile Diagnostic system (FPDS). The experience gathered through the tests on different type of piles will be discussed (8,9,10,11,12) highlighting testing methodology, principle and some of the results of the tests.



Pile Integrity Test In Progress.

Principle Of Integrity Testing

The principle of integrity testing method is time-domain reflectometry of stress wave propagation through pile material acting as a one dimensional medium. The wave is generated by a short hammer blow impact on pile head which travels down the length of pile in axial direction with the speed of sound.



(a) Pile with uniform section (b) Pile with decrease in section (c) Pile with increase in section

Fig.1. Stress Wave Pattern Of Reflections.

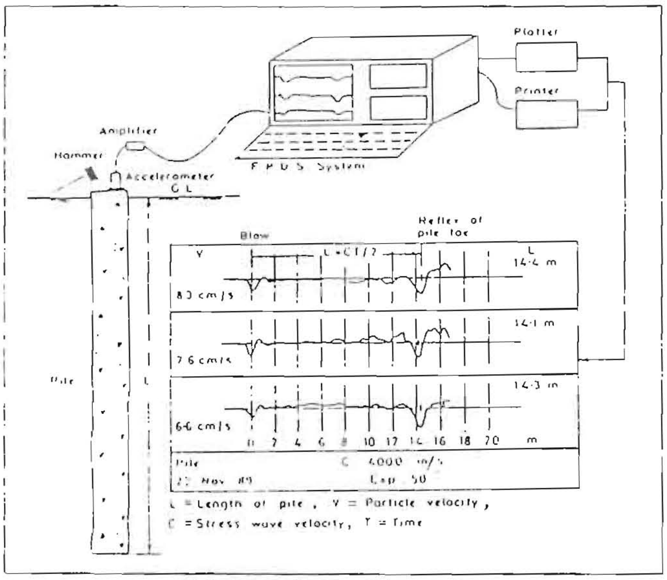


Fig.2 System Concept Of Integrity Test

The particle velocity. V resulted due to this at any level is dependent on force. F and impedance of pile, Z at that level (V = F/Z). The impedance is directly proportional to the area of cross-section of pile, A (Z=EA/C, C= stress wave velocity, E=Young's modulus) and any change in it due to irregularities or defects present in the pile stem, causes variation in the particle velocity. As a result of these changes, a part of the compression wave is reflected from the location of variations in impedance of pile shaft. If there is no variation in impedance throughout the length of pile. the compression wave will reflect from pile toe only. Monitoring and analysis of these reflections form the basis of integrity testing. Fig. 1(a) through Fig.1 (c) represent the velocity time reflectograms for a continuous pile with necking and for a pile with increase in cross-section respectively. Difference in the type of reflections in a pile with necking (Fig.1b) and a pile with increased cross-section (Fig.1 (c)) helps in distinguishing the shape of pile in two cases.

Method Of Integrity Testing

The diagnosis of a pile is based on two equally important aspects (a) monitoring of stress wave using either analogue or digital data processing technique. an (b) analysis and interpretation of velocity reflectogram. The Foundation Pile Diagnostic System incorporates the digital data processing technique for monitoring of stress wave which provides more accurate results in comparison to analogue technique. The set up for integrity test by the FPDS is shown in Fig.2. The test is conducted by striking pile head by a small hand held hammer. struck in such a way that a blow with a short rise time is achieved. The reflections are picked up by an accelerometer pressed on pile top close to the location of hammer blow. The observed signal is amplified by the computer controlled amplifier. It is then numerically integrated to convert accelerations into velocity through signal conditioning sub-system. fitting to the back of FPDS computer. Some low pass filtering is also done to improve the signal to noise ratio. The whole process is controlled by the computer and after processing of signals. the results are displayed on computer screen in the form of particle velocity versus length records providing the information about defects. if any, and approximate pile length. The results are also stored on the hard disk of FPDS computer for subsequent analysis. The generated compression wave experiences damping effect due to soil friction acting along pile shaft. However. increase in gain with time compensates for signal loss due to soil friction and to obtain a clear toe reflex, the signal can be amplified upto desired level by selecting a suitable gain value. The system concept of integrity testing procedure alongwith a typical record obtained for structurally sound bored cast-in-situ concrete pile is depicted in Fig.2.

The reflectograms obtained for each pile tested are used to

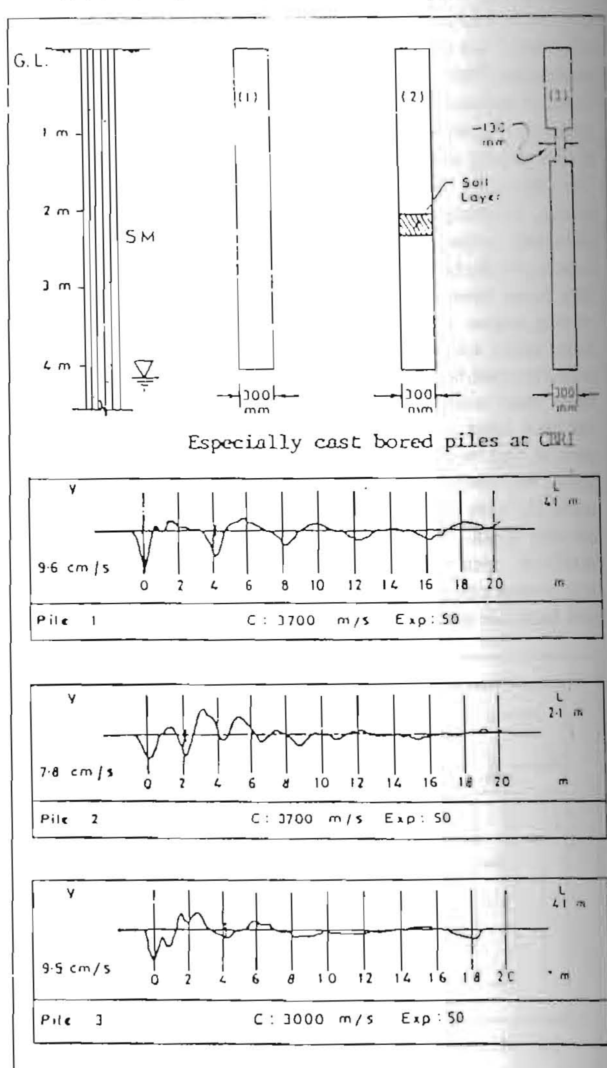


Fig.3. Integrity Test Results Of Especially Cast Bored Piles . CBRI.

evaluate the structural integrity of piles. Since each type of discontinuity, for example, changes in cross-section, cracks, joints in pile, soil inclusions, pile toe, change in soil stiffness and reinforcement overlapping in case of heavily reinforced piles, provides unique type of relfections, the first hand information about the type of discontinuities and their approximate locations can be had directly by reflectograms. The effect of sudden variation in soil stiffness on the observed signal can be ascertained using sub-soil data. A change from stiff layer to a soft one yields same type of signal as a decrease in cross-section while in case of change from soft soil layer to a stiffer one, the trend of signal is same to that of increased section. However, the reflections are not so sharp as in case of variations in pile cross-section. This helps in identifying whether the variation in signal is due to discrepancy in pile shaft or due to change in ground conditions. For a qualitative estimate of the exact locations and dimensions of discontinuities, they are processed using the TNOWAVE program.

The test can be performed on production piles without any special preparation. The top of pile should be accessible, trimmed back, levelled as far as practicable, clean and water free. In case of cast-in-situ piles, the test can be performed after about 15 days of their installation depending on the site conditions. At a site few piles are tested initially and a characteristic or reference signal is generated for that particular site to compare the observed signals for subsequent piles.

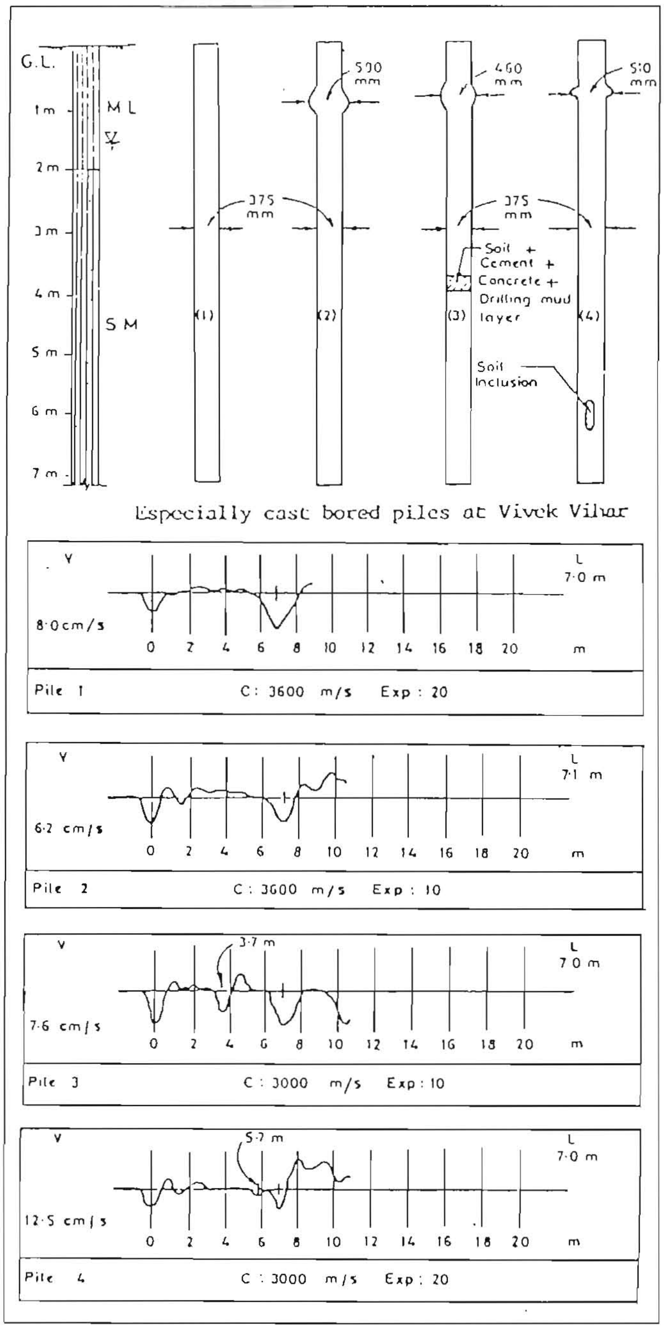


Fig.4. Integrity Test Results Of Especially Cast Bored Piles, Vivek Vihar

Examples Of Field Tests

Integrity tests were conducted on:

(i) especially cast bored concrete defective piles

(iii) driven cast-in-situ concrete production piles, and

(iv) precast concrete production piles,

at various sites covering different type of soil deposits. Some of the typical results for especially cast defective piles and production piles are given in Fig.3 to Fig.6.

Concluding Remarks

Low strain integrity testing methodology based on one dimensional stress wave approach as employed by FPDS is simple, quick and requires minimal interference with site activity enabling testing of dozen of piles in a single day. The major defects such as cracks, necking, soil inclusions and changes in cross-section, produce their own unique signal in velocity reflectograms and piles can be checked soon after construction to avoid failure at later stage. The pile length can also be estimated to a fairly reasonable degree of accuracy if the pile is not too long or skin friction is not too high. However, the minor deficiencies like local loss of cover to pile reinforcement or small inclusions and also the type of debris present at pile base are not discovered. Based on the integrity test results, the inferior most pile can be selected for routine load test.

Analysis of velocity reflectograms offer both qualitative and quantitative information. For proper interpretation of integrity test reflectograms, a knowledge of sub soil conditions, construction technique and the sequence followed in the pile casting along with the quality of concrete used, is very essential. Qualified personnel who have knowledge of the pile soil interaction and piling construction techniques are required both for conducting tests in the field and to interpret the test results.

Acknowledgement

The work reported herein forms the normal research, development and consultancy programme of the Central Building Research Institute, Roorkee (UP) and the paper is being published with the permission of the Director.

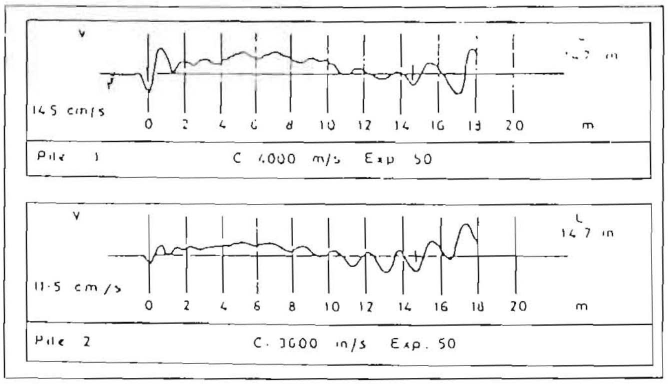


Fig 5 Results Of Bored Cast-In-Situ Concrete Piles, NCPP, Vidyut Nagar.

References

1. *Mohan, D., Jain, G.S. and Bhandari, R.K. (1978), "Remedial Underpinning of Steel Tank Foundation", J.G.E. Div., ASCE, GT5, May pp. 639-655.*

2. *Bhandari, R.K., Prakash, C. and Sharma, A.K. (1982) "Failures in Cast-in-situ Piles", Commemorative Vol. Int., Conf., Mexican S.M. Society, 25th Anniversary of Its Foundation, Mexico, August.*

3. *Sliwinski, Z.J. and Fleming, W.G.K. (1984), "The Integrity and Performance of Bored Piles", Advances in Piling and Ground Treatment for Foundations Conference. I.C.E., Thomas Telford Ltd., London.*

4. *Fleming, W.G.K. (1985), "Faults in cast-in-Place Piles and their Detection", IInd Int. Conf. on Structural Faults and repair, I.C.E. Westminister, London, 30th April-2 May, pp. 301-310.*

5. *Van Koten, H. and Middendorp, P. (1980), "Equipment for Integrity testing and Bearing Capacity of Piles", Int. Seminar on the Application of Stress Wave Theory on Piles", Stockholm, June, pp. 69-76.*

6. *Middendorp. P. and Van Brederode, J.P. (1983), "A Field Monitoring Technique for Integrity Testing of Foundation of Piles", Int. Symp. on Field Measurements in Geomechanics, Zurich.*

7. *Reiding, F.J., Middendorp. P. and Van Brederode, P.J. (1984), "A Digital Approach to Sonic Pile Testing", Conf. on the Application of Stress Wave Theory on Piles, Stockholm, Sweden.*

8. *Prakash, C. Rastogi, P.C. and Sharma, A.K. (1989), "Use of Stress Wave Measurements for Diagnosis and Analysis of Piles", Civil Engineering and Construction Review, Vol. No 7, New Delhi.*

9. *Bhandari, R.K., Prakash, C. Rastogi, P.C. and Sharma, A.K. (1989), 'Integrity Testing of Piles by Stress Wave Measurements', IGC89, Visakhapatnam.*

10. *Prakash, C., Bhandari, R.K., Sharma, A.K. and Rastogi, P.C (1990), "Indian Experience on Low Strain Integrity Testing of Piles", Conference on Deep Foundation Practice, 30-31 October, Singapore.*

11. *Prakash, C., Bhandari, R.K., Sharma A.K. and Rastogi, P.C (1991), "Pile Diagnostics by FPDS", Geotechnical Aspects of Embankments, Excavation and Buried Structures, Balkema Rotterdam, pp. 167-181.*

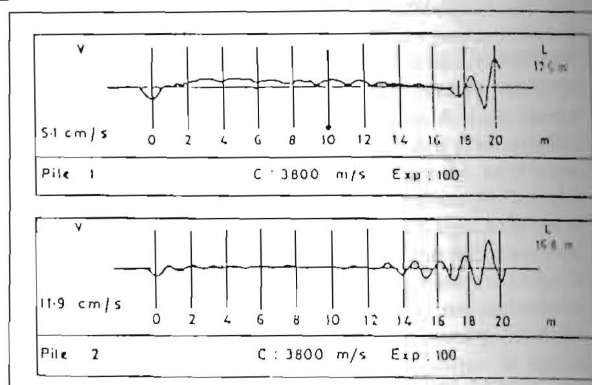


Fig.6. Results Of Driven Cast-In-Situ Concrete Piles, Delhi Cantonment.

12. *Prakash, C., Sharma, A.K. and Rastogi, P.C. (1992), Diagnosis of Cast-in-situ Piles resting on Rock by FPDS, Proc. 4th Int. Conf. on Application of Stress Wave Theory to Piles, Hague, Netherlands, 21-24 Balkema Rotterdam. pp. 305-310.*