桩基工程检测技术

主　编　刘金砺
副主编　李大展　黄　强

中国建材工业出版社

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内 容 提 要

本书收录有关桩基工程检测技术的学术论文 54 篇，集中反映了我国地基基础工程科技工作者在桩基工程检测领域的最新研究成果，内容涉及对各种静、动检测方法的评价，桩的成孔检测技术，高、低应变动力检测的理论与实践，有关动力检测规范、标准问题等，可供科研、设计、教学、施工、质检和勘察部门的同志在工作中参考。

桩基工程检测技术

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4. Assessment of Pile Dynamic Testing ····· Chen Fan(24)

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13. The Converse-Probablilistic-Analysis Method for Pile Test with Ultrasonic Technology ··· Chen Ru-Gui(69)

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..... Li De-Qing(88)

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18. A Comparison between Static Loading Test and PDA Dynamic Test ... Dai Jian-Ren(96)

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19. Statistical Analysis of Pile's Bearing Capacity by High Strain Test .....
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22. Comparison of Cast-in-Situ Pile's Bearing Capacity by Dynamic and Static Testing ····· Gu Hong-Xiang, Li Xin-Rong & Wan Guo-Xing(119)

Abstract 1)Hammer peretration test and static loading test we used for obtaining dynamic and static bearing capacity cast-in-situ pile. A comparison coefficent Cdj for dynamic and static testhasbeen found for the engineering geological conditions in Xinjiang. With this method a part of static pile test we replaced by the dynamic test. 2)By compacting the slag under pile toe with hammering method , the pile's bearing capacity can be increased approximately by 20%.

23. Correlation Analysis of Penetration with Bearing Capacity of Piles ····· Luo Shun-Zhao & Luo Rui-Feng(122)

Abstract The correlation analysis of penetration with bearing capacity of piles has been made in Zhejiang Province. In the paper also presented is that pile's bearing capacity can be measured during pile driving.

24. Judging the Defects of Pile Shaft by Hammer Impact-Penetration Method ····· Shi Feng, Liu Chun & Lin Shi-Zhong(126)

Abstract The procedure of pile test by Hammer Impact-Penetration Method to judge the defects of pile shaft on coastal weak soil region in Fuzhou is introduced in the paper with case hisories. 400mm or 500mm diameter driven cast-in-place piles are used widely in 6~9 -Storey buildings in Fuzhou. Serious defects in of pile shaft often take place. It is found that the Hammer Impact-Penetration Method can notonly determine the ultimate bearing capacity of a single pile .but also judge the defects in pile shaft, such as breaking, nechkin and concrete segregation etc, by anaylzing the impact and penetration rate.

25. Judging the Defects of Pile Shaft by High-Strain Dynamic Test of Piles ····· Liu Chun & Lin Qing-Yi(130)

Abstract The principles of high-strain dynamic test of piles to judge the defects of pile shaft are introduced briefly in the paper. The following conclusion is made with case histories:

1)To judge the defects of pile shaft by high-Strain dynamic test of piles is effective. The defect position can be judged correctly.

2)Pile driving can induce stresses along the pile shaft, so monitoring pile driving and selecting suitable pile length and penetration can result in good social and economic benefit.

26. A Study of PDA Integrity Testing ····· Guo Da-Bing(136)

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27. Application of Spectrum Analysis for Inspection of Pile Foundation …… Chen Da-Li(142)

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29. Pile Dynamic Test and Wave Speed ……
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30. Research on Pile Length and Pile Natural Freguency in Pile Dynamic Testing ……
…… Ma Shi-Xi & Yu Jing-Jie(158)

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32. Pile Integrity Testing by Hilbert Transform Method …… Niu Dong-Sheng(166)

Abstract The paper intruduces a new signal processing method of Hilbert transform which efficiently reduces the influence of noiseand vibration response of the pile, so that the reflecting signal can be recovered from the noise, the precision of detection can be incresed, the ratio of lenth/diameter of the detected pile can be incressed up to 50, the reflection of pile toe and defects will be more clear.

33. Mechanical Admittance of Pile from FEM Coupled with Infinite Elements ……
…… Liang Guo-Qian, Chen Long-Zhu, Wu Shi-Ming & Chen Yun-Ming(171)
Abstract Based on the principle of elastodynamics, the paper sets up a kind of infinite element coupled with FEM for axisymmetric problems in viscous-elastic layered ground. Dynamic responses of piles under vertical harmonic excitement are then calculated. The results are analyzed considering the influences of dynamic pile-soil interaction on the mechanical admittance of pile, which shows the effectiveness of the proposed method to emulate the properties of wave propagation in a semiinfinite space.
34. Use of Twinkling-Machinery-Obstruction Way in Pile Integrity Test ……
…… Lin Su-Xiong & Chen Guo-Yao(177)
Abstract The paper introduces the use of Japan 株式会社小野测器 CF-940 type two-passage FFI analysis instrument ect. And makes a study of the use of TWINKLING-MACHINERY-OBSTRUCTION WAY in piles integrity test. Expounod are results and merits of the way for nondestructive pile testing.
35. Practical Experience with Pile Defects Measurement by Dynamic Methods ……
…… Li Yi-Wei(188)
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36. Admittance Response of Piles Encountering Sudden Changes or Boulders in Subsoils ……
…… Li Yi-Wei(191)
Abstract A new opinion is presented from the writer's several year experience with steady dynamic measurment. One condition is concerned with three different types of sudden changes is subsoil. The condition of piles encountering boulders and a synthetic analysis method of the pile shape are discussed. New characteristics and developments of steady dynamic measurement are also reported.
37. Discussion on the Dynamic Stiffness Computation and Pile Low-Strain Test ……
…… Lu Cheng-Qi(197)
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38. Correlated Characteristics between Dynamic Rigidity Obtained from Steady-State Vibration and Allowable Capacity of Single Pile ……
…… Liu Wan-En, Feng Gui-Yin & Wu Shu-Liang(201)
Abstract The characteristics of linear correlation between allowable capacity of single pile and dynamic rigidity obtained from steady-state vibration are generalized by using statistic analysis of test results of 70 piles. The linear regression equations applied to various pile length and pile types have been derived. The examples for calculating pile capacity are presented by

the regression equation.

39. Analysis of Pile Integrity Testing under Complicated Geological Conditions .... Li Gui-Hua, Shi Zhan, Sun Yuan-Gui, Xu ShiBin & Liu Wen-Chao(208)

Abstract An analysis method of integrity testing of cast-in-situ piles in hidden karst topography is presented. The soft or rigid strata under pile toe and their effects on bearing capacity are analyzed by structure dynamic method. With a major project of the 8th 5-years plan of China, some test examples under complicated geological conditions are given. In those examples a lot of hidden danger were found successfully. By digging piles on spot the analysis method in this pater proves perfectly correct. •

40. Some Views on Pile Inspection Through Hydroelectrical Effect ..... Liang Zhi-An(213)

Abstract The results of pile test by hydroelectric effect method have for many years shown that in order to increase the accuracy of pile inspections, it is very important to know well the geological enveronment and physical properties of the rock and soils of the site, and to understand the wave equation theory and the behavior of pile foundation under loading. Satisfactory results depend upon making comparison with a number of measured data.

41. Discussion on Pile Integrity Testing by Hydro-Electrical Effect method .... Wu Yu-jin & Chen Ru-Gui(217)

Abstract Results from making comparison with Hydro electrical effect method and static loading test in 69 projects and over 106 piles, are presented in the paper. Problemis in using the hydro-electrical effect method are also discussed.

42. Practical Cases of Non-Destructive Pile Inspection by Hydro-Electric Effect Mthod .... Fang Zheng-Zhong, Cheng Fu, Wu Wei-Dong & Qian Shu-Sheng(222)

Abstract Introduced in the thesis are some practical cases of nondestructive pile inspection by hydro-electric effect method. From a comparision with the samples, drilled and the static loading tests, it can be seen that the accuracy of non-destructive inspection of piles quality by hydro-electric effect method is over 88%. It is proved that this method is reliable and its accuracy is qualified. In addition, as compared with the static loading tests, the accuracy of bearing capacity compared with the static loading tests, the accuracy of bearing capacity comes to 82% or above. Thus it is satisfactory for pile inspection.

43. Quantitative Analysis of Pile Integrity Dynamic Inspection ..... Wang Jing-Tao(227)

Abstract The author proposed a quick and quantitative method for pile integrity dynamic inspection in this paper, based on which a computer program, "WANG-PIP", has been designed. The input data are only the velocity measured on pile top in low strain test, while the quantitative estimation of damage severity in pile can be obtained, and there from the integrity of pile classified. The measured data can be processed by this program in real time and in field. This method not only keeps the advantage of quickness, simplicity and low-cost in low strain test but also gives a quantitative conclusion for pile integrity. Therefore it is a significant improvement and development for pile integrity dynamic diagnosis.

44. Analysis and Study on Time Domain Curve of Instantaneous Hammering Method in Non-de-

structive Inspection of Pile Foundation ····· Lin Jian-Sheng(233)
Abstract Instantaneous hammering method is a simple, convenient and efficient method. The basic principles of this method and the basic regularity of interpreting time domain curves are discussed and some engineering examples are given.
45. Identifying Defect and Type of Pile with Time-Distance Curve Excited by Instantaneous Source ····· Zhao Zhu-zhan(238)
Abstract The paper puts forward the identification methods for integrity and various defects of pile through analysis of elastic wave travelling characteristic inside the pile and interpretation of timedistance curve excited by instantanceous source. Besides, some discussions about pile testing are presented.
46. Integrity Testing of Deep-Mixing Cement Columns ····· Hong Yong-xing(244)
Abstract Based on dynamic and static comparision data and engineering examples, the paper introduces some experiences with integrity testing of deep-mixing, cement columns.
47. Two Dynamic Methods for Evaluating Pile's Working Capacity ····· Shou Pei-xiu(253)
Abstract Two simple and easy dynamic methods for estimating pile's working capacity are presented. The umped-parameter dynamic method and the mechanical steady state excitation method are used for small and large diameter piles respectively.
48. Statistical Analysis of The Correlation Test Results betweeen Static Loading Test and Dynamic Parameter Method ····· Cai Run-Sheng(260)
Abstract The regression equation for determining the bearing capacity is obtained by statistical analysis of the correlation test results between the static loading test and the dynamic parameter method for 34 piles. An analysis of distribution of error probability and their checks are also computed. The application scope and the precision of regression equation are given. Finally, problems in this ir -h od are presented.
49. New Method of Estimating Pile Ultimate Bearing Capacity by Low Strain Dynamic Testing ····· Yang wei-Liang(266)
Abstract Based on 45 piles' static-dynamic comparative and statistical results, factors that influence the estimating accuracy of piles' bearing capacity by low strain method are found by the author. A new estimation method which will improve the accuracy of results is recommended.
50. Principles and Computation of Piles Bearing Capacity by the Dynamic Parameter(Frequency-Initial velocity)Method ····· Liang Wen-Xuan(271)
Abstract In the paper princples and the method of pile dynamic parameter(frequency-initial velocity)testing are discussed.
51. Pile Dynamic Testing by Resonance Method ····· Li Yu-Shan(276)
Abstract The basic principle and analysis method of pile integrity testing by Resonance Method and some case histories are discussed. The results of static loading test and Resonance Method are compared by mathematical statistics. Some ideas for improving the Resonance Technique are suggested also.

52. Application of Dynamic Measuring Method with Free Falling Ball in Large Diameter Piles with Enlarged Base ..... Li Zheng & Shan Zhi-Kang(283)
Abstract The paper presents the application of dynamic measuring method with free falling ball in piles to measure the dynamic paprameters of pile-soil system and computs the static bearing capacity of piles. According to the analysis of test results from dynamic measuring method and static loading test in Shandong, the predicted values of static bearing capacity of piles from dynamic measuring method basically conform to those measured from static loading tests. The predicted valurs from dynamic measuring method can satisfy the requirement of sturture design. In the paper some problems of the dynamic pile test in site are also presented.
53. Introduting《Standard Procedures for Pile Test by Hammer Impact Penetration Method (CECS 35:91)》 ..... Li Da-Zhan(286)
Abstract In this paper,《Standard Procedures for Pile Test by Hammer Impact-Penetration Method(CECS 35:91)》is introduced briefly, which has been approved by China Committee for Engineering Construction Standardization. It is the first code of dynamic pile test in China.
54. Discussion on Compiling the Technical Standard of Pile Low-Strain Dynamic Testing ..... Kong Xu-Dong, Yan Yun-Xu & Jiang Zhong-Yun(290)
Abstract It's an international problem to compile a technical standard for pile low-Strain dynamic testing, sinoe it is still developing. It is stated in the paper that two basic points must be solved and pile quality standards must be formulated before a techi nical standard can be compiled.
55. Standard Procedures for Pile Test by Hammer Impact-Penetration Method(CECS 35:91) ..... (293)
56. The Pile Inspection Part, cited from《Technical Code for Building Pile Foundations》..... (311)

综合报告

桩基工程检测技术的现状与展望

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随着我国基本建设事业的迅速发展，桩基工程由于其具有许多独特的功能而得到广泛应用。七十年代末以来，由于灌注桩的大量应用，尤其是单桩单柱形式的大直径灌注桩的采用，对成桩质量的可靠性提出了更高的要求，从而使桩基检测技术变得十分重要。

桩基工程检测技术主要包括两大方面，即成孔检测和成桩后的检测。成孔检测主要有孔径、孔底沉渣厚度以及桩身垂直度等；而成桩检测除传统的静载荷试验外，各种动力检测方法近十余年来在我国得到了迅速的发展。桩的动力检测按其桩身所受到应力水平的高低，又分为高应变和低应变两类。

本次会议论文集共收入论文 54 篇，大致包括下列内容：（一）发展现状与述评（10 篇）；（二）成孔检测和超声波检测（3 篇）；（三）静载荷试验方法的探讨（3 篇）；（四）高应变动力检测（10 篇）；（五）低应变动力检测（26 篇）；（六）动力检测规范、标准的有关问题（2 篇）。

一、发展现状与述评

我国的桩基检测技术的发展特点是成桩检测技术优于成孔检测技术，而成桩检测中的动力检测方法的发展更快，而且有多项方法为我国首创，如锤击贯入法、动参数法、水电效应法、共振法等等，并且某些动测方法已达到或接近国际先进水平。

从工程质量监督观点来看，要保证灌注桩的成桩质量，最好的办法是从成孔开始，进行严格的工序控制推行全面质量管理（TQC）。李大展等的“大直径灌注桩成套测试技术的研究与实践”一文报道了建设部“七五”重点科研项目的研究成果，经过近 5 年时间的研究与实践，形成了包括成孔和成桩两大部分的成套软硬件测试系统，提高了我国大直径灌柱桩检测的技术水平。研究中采用的先引进、消化、吸收，后提出改进方案的技术路线，使得成桩检测中高应变动力试验软、硬件系统已接近或达到了国际先进水平。该文报道的研制成果一定程度上反映了当前我国桩基工程检测技术的发展水平。该成果中研制完成的 FEIPWAPC 分析软件，不但能实现国外同类软件 CAPWAPC 的功能，而且在土阻力计算模型和屏幕显示功能方面有许多独到之处。

对高、低应变动测法的适用范围和功能，近十年来一直是我国桩基工程学术界争论的热点，焦点是低应变法能否确定桩的承载力。早在 1987 年 3 月江苏南通召开的桩基工程质量监测会议上就有两种不同观点，一种观点认为，就桩的动测而言，确定桩的承载力必须采用高应变法，而低应变法不能使土阻力得到发挥，因而无法实测桩的承载力；另一种观点认为，通

过单桩动、静刚度的对比与假定桩的允许沉降量，低应变法可以确定桩的容许承载力。近几年来通过试验研究与工程实践，继续对这一课题进行了探索和论证，并有了许多新的认识和工程实例的验证。刘兴录的“浅谈桩的动测技术”一文根据该文作者多年的研究和实践，较全面地论述了桩基动力检测中的有关问题。认为高应变动测法可以较准确地实测单桩承载力，但对其精度要求过高也是不现实的。低应变动测法是检验桩身结构完整性的好方法，但对不太严重的缺陷，判断时还要结合工程经验。并认为在桩身质量完好的前提下，可以根据地质资料、动刚度值和个人经验给出估算单桩承载力。陈凡的“动力试桩若干问题探讨”一文根据高、低应变动力试桩方法的基本原理，得出了各自的适用范围；在分析了我国桩基动测技术现状的基础上，对如何加快动测技术的发展提出了有益建议。该文认为高应变与低应变试验的根本区别是前者考虑了桩周土的弹塑性响应，后者则处于完全弹性范围，低应变法基于荷载—沉降曲线起始线性段确定桩的容许承载力，而线性段尾部对应的荷载、沉降量均非实测值，因此这种沿线性段外推确定容许承载力的方法带有任意性。该文进一步强调只有在土阻力充分发挥（桩周土产生塑性变形）的前提下才能确定桩的承载力，否则即使采用高应变方法也会极易产生随意性。因而认为，“保证承载力”尽管在概念上避开了“外推承载力”问题，但从计算精度上考虑，这一提法是不值得提倡的。杨慧的“浅析静动载试桩承载力误差之原因”一文评论介绍了试桩检测结果被误判的二个实例。一为静载荷试验时由于沉降观测系统不符合规定，而使静载荷试验结果失真；另一为高应变动力试桩由于传感器设置不符要求和计算参数设置不合理，致使动测结果失误。由该文报道可见，无论动测和静载试验，均应严格按照有关操作规定进行。特别对于动测，更应重视测试人员的素质提高。

范明均、陈龙珠的“关于用小应变振动法预测桩的承载力”一文报道了由常见的桩土系统计算模型，可导出桩顶机械导纳曲线特征参数与桩土系统工程力学量间的理论关系，认为由此说明用低应变法预测桩承载力是可行的。该文还建立了桩极限承载力与动刚度间的理论关系，提出预估桩的承载力，不但需要导纳曲线初始段斜率，而且还要用到导纳曲线较高频段的峰、谷值以及平均导纳值。该文最后还对所述方法适用范围（以桩的长径比表示）提出建议。沈定贤、孟广训的“桩基动测结果分析”一文报道了江苏某电厂桩基工程动力检测结果，检测总桩数 163 根，其中高应变法 29 根，低应变法 134 根，并进行了两根桩的静载荷试验。通过工程实践，该文作者认为，高应变法试验结果与静载荷试验较为吻合，能较准确的确定单桩极限承载力；低应变法是桩的完整性检测的良好手段，但测试估算桩的承载力往往有较大出入。但认为通过积累经验，低应变法估算桩承载力的精度可以接近于高应变法的结果。林胜天的“软土地基钻孔桩成桩质量检测技术与评价”一文介绍了采用包括静载荷试验、超声波检测、钻取混凝土芯样和动力试桩的工程实例，表明工程检测对桩基施工具有指导意义。认为对于一级建筑物，桩基检测应包括试验阶段和工程桩阶段，才能及时为设计提供依据和指导施工。朱玉义的“判断混凝土灌注桩桩身质量问题的探讨”报道了某桩基工程检测中，在静载荷试验和锤击贯入法试验后均未发现桩有异常情况，其承载力也都满足要求。但开挖后却发现该桩桩顶下 1.6m 桩身有水平断裂缝。经分析后，该文认为桩的成桩质量检测在有条件时应同时应用高应变和低应变两种方法，取长补短，才是确定桩的承载力和判断桩身结构完整性的有效方法。吴俊亮等的“夯扩灌柱桩的质量分析与动态检测”一文就济南地区近年来出现的夯扩灌柱桩质量事故进行了分析，指出工程桩进行动态检测的必要性。

二、成孔检测和超声波检测

从“防患于未然”的观点来看，桩的成孔检测应比成桩后的检测更为重要。但是目前这方面的检测技术仍较薄弱，本次会议收到的涉及成孔检测技术方面的论文很少。如前所述李大展等的“大直径灌注桩成套测试技术的研究与实践”一文报道了自行研制成功的X－1型孔底沉渣厚度测定仪和PS－1型孔径测定仪，及其用于工程实践的情况。赵欣、陈静的“PT－1型桩孔检测仪”一文对该仪器的原理和性能作了介绍。采用微型贯入仪结合自制的复合标尺做探测部分，通过光学系统将标尺反映到CCD图象传感器的镜头中，然后变为视频信号传递到彩色监视器中再现图象信号，能得到与桩孔质量有关的参数，对土层进行分层观测。该文作者认为今后应设法解决设备的密封和平衡问题，以用于水下成孔灌注桩的质量检测。

采用超声波透射法检测钻孔灌注桩的成桩质量，具有试验结果直观，仪器较轻便，能弥补低应变动测法检测桩长度有限等优点。虽然被测的桩都要预先埋设测管，但仍在许多工程中采用。魏宏志的“超声脉冲法检测钻孔灌注桩在广东公路桥梁上的应用”一文报道了采用PSD判别法评价灌注桩缺陷的原理和方法。即将各点判据值与临界判据值逐点比较，凡大于临界值的测点，初判为缺陷可疑点。然后再进行细测，进一步确定缺陷的大小和位置。该文认为，实践证明上述方法对桩局部有夹层或断桩时的判别比较准确，但对空洞、蜂窝尺寸大小的判断往往偏大，应慎重对待。陈如桂的“桩基础超声波检测技术的逆概率解释法”一文在对传统的概率统计法和目前采用较多的PSD法进行评述后，提出一种超声波检测数据处理新方法，即逆概率解释法。结合信息论中熵的原理介绍了该法的基本原理和计算步骤，认为该法能在干扰背景下分离出检测数据中的有用信息和干扰异常。通过模拟桩和工程桩的实际考核，表明用逆概率法判别桩身质量比较正确，为超声波检测的数据处理提供了新途径。

三、静载荷试验方法的探讨

桩基工程检测的主要目的之一是确定单桩承载力，而单桩承载力最直接最可靠的检测方法是静载荷试验。我国与许多国家现行的地基基础规范和工程实践，均将静载荷试验置于优先地位。

1、试桩数量的确定

一般规定在相同条件下静载荷试验的桩数为工程桩总数的1%，并不少于2或3根，显然这是针对地质条件比较均匀，成桩工艺较为成熟的情况，而实际上尚应考虑下列因素：

（1）试验目的（确定承载力供设计应用或桩基础完成后的承载力检验）；

（2）对邻近地区同类型桩的承载力了解程度；

（3）地质勘察的钻孔密度和可靠度及地质情况的复杂程度；

（4）施工工艺的成熟性、施工队伍素质及施工监理标准；如为设计提供参数，应使试桩数尽量满足不同地质区域变化的要求，以谋求工程设计安全度与经济之间的合理平衡，此时适当地增加试桩数量可能会获得更好的技术与经济效果；而在地质条件比较均匀、施工工艺比较成熟、且又有邻近建筑物单桩承载力试验数据时，则可适当减少试桩数。

2、试验方法