桩基工程设计与施工技术

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本书收录有关桩基工程设计与施工的学术论文46篇，集中反映了我国地基基础工程科技工作者最近几年来在桩基工程设计与施工方面的新成果，内容涉及桩基工程设计理论、计算方法和施工实践等。可供科研、设计、教学、施、质检和勘察部门的读者参考。

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第二届联合年会论文集

桩基工程设计与施工技术

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中国建材工业出版社

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Design and Installation of Pile Foundation

Contents

Abstract Pile-cap footing under column is usually adopted in building design. It is specified in more detail in 《Technical code for Building Pile Foundations》(submitted for approval), and the calculation method is made to be more reasonable. In accordance both with the mentioned Code and the 《Design Code for Concrete Structures GBJ10-89》and based on the author's substantial calculations, an analysis of the failure mechanism of pile-cap footings under column is presented in the paper.

Abstract According to the current 《Design code for Concrete Structures GBJ10-89》, longitudinal steel bars in eccentric compression members of reinforced concrete of circular cross-section should be spaced uniformly along its circumference. It is found, however, in the case of circular piles for landslide prevention or for retaining structures that mainly resist lateral load, the calculated amount of steel is more than enough. It is suggested in the paper that steel bars for the memtioned piles could be arranged some far from the neutral axis. By this way, 40% of steel could be saved in comparison with the Code method.

Abstract Based on offshore engineering practice and deformation characteristics of single pile under horizontal load, the paper presents an equivalent calculation method for single pile, including calculations both of pile-top stiffness and the equivalent pile stub. The application method is expounded with practical examples.

Abstract The load transfer mechanism of cap with single pile is studied through experiment and finite element method with more attention paid to the case when the load exceeds the ultimate bearing capacity of pile. The mechanism of shallow foundation plus settlement-reducing pile and the feasibility of this system in engineering practice are also discussed in the paper.

Abstract Due to limitations of a certain project, special types of hand-dug piers are designed and installed. Their lengths are all 5m, while their diameters range from 1.5 to 3.6m, and their bases are enlarged by 1.16 to 2.50 times respectively. Static loading test shows that such piers meet the design requirement satisfactorily.

Abstract The program suggested in the paper is useful in calculation of pile foundation with vertical vibration, including frictional and end-bearing pile foundation. Amplitude, frequency and geometrical parameters of the pile, as well as relevent soil characteristics are taken into consideration. Effect of variations of geometrical parameters of the pile on amplitude and frequency of resonance can be analyzed.

Abstract The paper presents a method for calculation of bearing capacity of underpinning piles, which is based on the hyperbolic relationship between skin friction of pile and displacement of soil surrounding the pile. and mean-while considers the fact that the ultimate skin friction and shear modulus of a pile increase with the radial pressure on pile shaft.

Abstract The paper analyses three kinds of method usually used in determining the bearing capacity of rock. Applications of rock plate loading test results in designing large diameter piles in Nanjing are presented in the paper. It proves that this is a reliable and economical way.

Abstract A case is presented of the combined application of different types of foundation in one building, which shows that the additional stresses of subsoils under different foundations are mutually effected. So are settlements. It is necessary to control the differential settlement so that the deformation of soils under different foundations can abide by the Foundation Design Code.

Abstract Through considerative design and analysis of the pile foundation of South Commercial Building and by testimony of the results of static loading test, the author advocates that large diameter percussed and belled piles are technically reasonable and economical for tall buildings in Shantou Area. It is the first case using such piles in the area.

Abstract The paper presents a case history of applying pipe piles of φ550 and φ400 in a 3-storeied factory buildingt in Panyu, Guangdong. The determination of pile's bearing capacity and the design of pile-cap are des-cribed in the paper.

Ⅳ、Construction Practice

Abstract Based on engineering experience in a county in Guangdong Province, the author states that short pine piles are suitable for buildings in soft soil area on condition that short pine trunks are available. Such piles would be technically reasonable and economical.

Abstract The underwater concrete construction for large diameter bored piles requires that the mixture should have good construction property. The paper presents by engineering practice the construction requirements, materials needed and design method of the mixture, and their effectiveness is discussed. It improves the mixture design theory and practice.

Abstract Known from geotechnical investigation during construction of a tall building in Beihai City, as well as from static and dynamic pile loading test results, the physical and mechanical properties of soils became worse as compared with these before pile driving as reported in the detailed investigation. By the cavity expansion theory and Mohr-Coulomb criterion, and considering the average volumetric strain and in-situ over-burden pressure, formulas of lateral pressure, radial displacement and its radius in plastic zone of soil are derived. It is suggested that the bearing capacity should be determined a few weeks after driving, i. e. at the time when soils would gain its original characteristics.

Abstract The paper describes a failure case history of vibro cast-in-situ pile of a project by using pile test data. It shows the importance of loading test. Causes and treatment of the case are presented for futurereference.

Abstract The paper introduces the ramming reamed pile and its construction equipment. Construction procedures, sludge prevention measures and quality control and inspection systems are stated. Obvious technical and economical benefits would obtained with this type of pile when it is properly applied.

Abstract Through analysis of a large number of test results of pile foundation in Fuzhou, the paper summarizes some useful cognition regarding the time effect on bearing capacity, the load transfer mechanism, the interaction of pile groups, the difference between static and dynamic test, etc, all of which would benefit futrue application of piles in the area.

Abstract A case history of inclination of a dwelling building is presented. Causes are analyzed and correction measures are stated. Statically pressed piles with anchor rods were applied successfully. Some experience and lessons would be of benefit for future reference.

Abstract Some technical problems arising in the construction of vibro piles in Zhongyuan Ethylene Project are discussed. Measures to solve the problems are presented.

Abstract Through analysis of test results of vertical bearing capacity of four large diameter super-long bored piles from static loading test and other method of test, the paper comcludes that the bearing capacity of such piles are closely related to proper selection of construction technique, such as the reverse circulation method, the shortening of boring time, the quality of slurry, the inte-grity of shaft and the clearing of slim as well.

Abstract Large diameter hand-excavated belled piles were used in a large seven-storeyed supermarket in a coastal city in Fujian. The results of static loading test, of P. D. A. and P. I. T, and of sample coring showed that the bearing capacity of single pile reached only 70～80% of the design value, and some piles had serious shaft defects. High pressure grouting was used to improve them. In treating the problems, pile-soil interaction was taken into consideration. Computer analysis gives load distribution between piles and concrete slab, and about 30% of load is carried by the latter.

38. Construction Problems and Improvement Measures of Bored Cast-in-situ Pile in soft Soil Area ..... Shi Feng & Liu Chun

Abstract Construction procedures of bored cast-in-situ piles in a thirty-storeyed building in Fuzhou soft soil area are first described in the paper. Test results both of static loading and of P. D. A. showed that thick sludge existed under the pile tips. Improvement measures were taken to control the thickness of sludge during construction.

39. A Cast History of Ground Improvement by Root Piles for Reforming Old Building ..... Wang Jianping

Abstract A case history is presented of ground Improvement by root piles. The design theory, construction method and bearing capacity of root pile are discussed. The results showed that their bearing capacity is quite high while their settlement is small. So differential settlement of such foundations can be neglected. This treatment method is of practical meaniong in reforming old buildings.

40. Treatment of Drilling Accident of Large Diameter Foundation Piles ... Zhang Chengcheng

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42. Increasing the Bearing Capacity of bored Pile by High Pressure Grouting ..... Xie Wendo

Abstract The paper introduces the technique of bored pile grouted at high pressure after sealing the bore-hole. Tensile load test was conducted. Analysis is made of the high bearing capacity obtained by the method.

43. A New Technique of Constructing Rock-socketed Bored Pile ..... Qian Zheng & Zhang Cunyin

Abstract According to experience in some rock-drilling projects using submarine drill, it was found that the resistance of bit-tip was the main thing effecting drilling efficiency. Therefore, a hole was first drilled into rock mass by the normal rock-coring method, so that the resistanceof bit was reduced. As a result, drilling efficiency was raised to 3～4 times and the comsumption of alloy dropped down. By another method of 3-point friction coring, 95% of cores can be achieved.

44. Engineering Practice of Pressed cast-in-situ Pile with Enlarged Base in Fuzhou Soft Soil Area

Abstract Thin hard Sandwiched layer under the deep soft soil is often selected as bearing stratum of pressed cast-in-situ piles with enlarged base. On the basis of this engineering experience, the anthor made some rough discussion on the bearing mechanism, calculation method and economic advantage of such pile.

Abstract Some effective shock reducing measures for pile-driving for the project are summarized in the paper. Cracks on walls and beams of neibouring buildings due to pile-driving were substantially prevented.

纪念大直径灌注桩问世100周年

(1893—1993)

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提要 本文追溯了大直径灌注桩产生的历史背景,评价了它问世的意义与贡献,概括了它的技术特点,介绍了这种桩型在国内外的新动向;最后,对其发展前景作了展望。

一、历 史 回 顾

大直径灌注桩包括人工挖孔桩和机械钻孔桩两大类。人工挖孔桩先于1893年在美国问世,至今适逾100年。当时美国芝加哥、底特律等大城市由于土地紧张,建筑物层数不断增加,而某些高强轻质的新材料相继开始生产,正为高层建筑设计施工创造了条件。但这些城市地表以下存在着厚度很大的软土或仅中等强度的粘土层,建造高层建筑如仍沿用当时通行的摩擦桩,必然会产生很大的沉降。于是工程师不得不考虑把桩设在很深的持力层,并且为满足承载力要求,还必须把其截面设计得很大。但这样的桩既不可能用木材制作,若用钢管、型钢或钢筋混凝土预制,依靠当时的打桩设备也难以打至必要的深度。于是,借鉴人类自古相传的掘井技术,人工挖孔桩就在这一历史背景下试验成功,解决了上述难题。这种桩后来就被称为"芝加哥式挖孔桩"。由于其工艺简单,且不需特殊机械,故不久即不胫而走,不仅为美国其他城市而且为港、澳地区及日、英等国,乃至世界各地所采用。

钻孔灌注桩是在人工挖孔桩问世后约50年,亦即20世纪40年代初随着大功率钻孔机具研制成功,首先也在美国问世的。随着二次大战后世界各地经济复苏与发展,高层、超高层建筑物和重型构筑物不断兴建,它们中绝大多数都选择了钻孔桩。尤其自70～80年代以来,钻孔桩在世界范围出现了蓬勃发展的局面,其用量逐年上升,居高不下。

整整一个世纪以来世界各地的应用情况说明,100年以前大直径人工挖孔桩的问世,其意义和贡献不仅在于它解决了当时某些工程面临的难题,更重要的是它突破了一个沿袭了一万数千年的传统,这就是人类自从利用天然木材制桩,以至19世纪20年代曾企图利用铸铁制桩(因其性质脆而失败),乃至本世纪初开始成功地利用热轧型钢制桩,稍后又利用钢筋混凝土制桩,都一直采取先预制而后借助某种机具打入土中的传统。它取法于混凝土在上部结构司空见惯的现浇工艺,却为古老的桩基技术开创了一条崭新的工艺路线。

我国应用大直径灌注桩始于本世纪60年初,当时先在南京、上海、天津等地作为桥梁和港

工建筑基础，自 70 年代中期后又陆续在广州、深圳、北京、上海、厦门等大城市应用于高层和重型建(构)筑物，至 80 年代末 90 年代初，随着改革开放步伐加快，大直径灌注桩迅猛发展，仅数年间已普及于全国除西藏外各省市自治区数以百计的大城市及各新兴开发区，应用于包括软土、黄土、膨胀土等特殊土在内的各类地基。据估计，近年我国应用大直径灌注桩数量之多已堪称世界各国之最，可谓起步虽晚而发展迅猛。

二、技 术 特 点

自从大直径挖孔桩和钻孔桩相继在美国问世以后，小直径灌注桩于本世纪 50 年代初在意大利脱颖而出。从此，灌注桩一方面向大直径发展，另一方面向小直径发展。而中等直径混凝土桩也由单一的预制打入式，出现了沉管灌注的型式。混凝土桩乃以大、中、小各种直径及预制与灌注两种型式被灵活应用于各类工程。目前，工程界和学术界对桩按直径(d)分类的标准大致是：大直径桩 $d\geqslant 800$mm；中等直径桩 $250<d<800$mm；小直径桩 $d\leqslant 250$mm。

大直径灌注桩与传统的中等直径桩以及大直径钢管桩等相比较，概括地说，它具有以下特点：

——大直径灌注桩属于非挤土或少量挤土桩，施工时基本无噪音，无振动，无地面隆起或侧移，也无浓烟排放，因而对环境影响小，对周围建筑物、路面或地下设施等危害小。

——大直径灌注桩直径大，入土深。迄今挖孔桩的最大直径已达 8m，钻孔桩逾 4m；挖孔桩的入土深度逾 40m，钻孔桩逾 150m。

——大直径灌注桩可采取扩大底部的型式，更好地发挥桩端土的作用，这是其他任何桩型所不能做到的。(沉管灌注桩之所以能扩底，首先也是由于它采取了就地灌注的工艺。)

——大直径灌注桩的单桩承载力高，视地质条件、桩身尺寸和混凝土强度等级不同，一般可达数千至数万 kN，因此，常可设计一柱一桩，不需桩顶承台，简化了基础结构。

——大直径灌注桩由于其桩身刚度大，除能承受较大的竖向荷载外，还能承受较大的横向荷载，增强建筑物的抗震能力，并能有效地充当坡地抗滑桩、堤岸支护桩以及地铁或建筑物基坑开挖的支护桩，还可在基坑开挖后继续作为地下室的承重墙等永久性结构使用。

——大直径灌注桩通常布桩间距大，群桩效应小，设计中无需为此而进行繁琐的计算。对桩的沉降及其对邻桩和周围地面的影响，其估算也较常规中等直径桩更为简便。

——大直径灌注桩不需要搬运吊装，不必承受打击，因而可采用较低的配筋率，并可视建筑物的重要性和荷载条件仅在桩身上段配筋或沿深度作变截面配筋。

——大直径灌注桩施工工艺种类多而且日新月异。这主要是由于各国工程师为了保证这类桩的成桩质量、施工安全和提高工效，长期来针对不同的地质条件和环境条件，研制了各种适用机具和施工方法，从而形成了种种各具一定特色的工艺。

——大直径灌注桩不论采用挖孔法或钻孔法施工，对桩所穿越土层的性质均可从桩孔排出的土进行鉴别验证，当用挖孔法时，工程师更可以下孔直接检查桩端土的性质，或作必要的原位试验。

——大直径灌注桩由于是在地下或水下开孔灌注成桩，故桩身质量毕竟不可能象预制桩那样稳定而可靠，混凝土强度也较难保证；桩侧阻力和桩端阻力的发挥常随工艺而有变化，且又在较大程度上受施工操作影响。另一方面，由于其承载力高，进行常规的静载试验常难以测定其极限荷载，因此对在各种工艺条件下形成的桩的受力、变形和破坏机理至今犹未完全弄

清，系统的试验研究还不够多，设计计算理论与方法有待进一步完善。此外，当用泥浆护壁施工时，排污问题令人困扰。这都是大直径灌注桩迫切需要解决的问题。

三、新 的 动 向

1. 如所周知，人工挖孔桩不仅适用于地下水位低而且土质较好的地区，它也已广泛应用于地下水位高而且土质软弱的地区。最近，这种桩又在一些环境制约十分严格的条件下被选用而获得成功。例如，伦敦铁路查林·克劳斯车站月台上空新建一座 9 层高级办公楼，建筑面积 40,000 余平方米。由于它占天不占地，伦敦人称之为“领空”大楼。月台及铁路路轨支承在一组砖砌筒拱上，筒拱由横墙支承，横墙由次拱分为若干段，其下为连续的 R.C. 条基。因此，“领空”大楼的基础只能插在这些条基之间，并且要求施工不能影响铁路运行，新基础的沉降不能影响老基础及路轨。这些要求显然是打入桩、钻孔桩或其他任何采用大型机械施工的基础型式所不能满足。最后，这座最现代化的大楼选择了最古老的人工挖孔扩底桩。它的突出优点是施工可以完全局限在净空不大的筒拱内进行，避免了大型机械进退场之烦；而且只要配备足够劳力，几根桩可以同时并进。参见文献[1]。

2. 我国工程界有人认为长桩无需采用扩底桩。然而，近年国外有许多实例证明，当桩较长，而场地可能因大量堆载或因抽汲地下水而发生地面沉降，或因地震液化等原因致使桩侧阻力不可靠，或可能产生负摩阻力时，扩大端部直径仍然是发挥桩端持力层的作用和提高单桩承载力的有效方法。

3. 随着人们对扩底作用认识的深化和施工机具的改进，扩底桩的形式又有了新发展。我国近年推荐采用锅底形扩底桩，锅底矢高取 $0.1\sim0.15D$，扩底起始侧面的斜率取 1/3～1/2，日本的经验根据其土质特点常将扩底坡角控制在 12°，当用泥浆护壁时只要泥浆比重适当，并保证一定的静水压力，一般可不用支护而不坍孔。日本 TFP 工法扩底桩，其特点是扩底直径与桩身直径之比小于 2，而扩大头则有数米之高（已有实例达 8m，视桩端进入持力层深度而定）；换言之，它从桩底标高以上数米就开始扩大。这种型式能更好地发挥桩端土的作用，它注意到桩端面积越大时单位端阻力发挥越小，故不单纯追求扩底面积，而是以合理的扩底面积发挥最大的端阻；同时又着眼于使桩端进入持力层后，这层好土能提供较多的侧阻。

4. 上述 TFP 工法已实现扩底挖孔电脑控制，并在扩底挖土完成后用超声波探头下放至孔内不同深度进行检测和摄取扩底实况照片。

扩底挖土电脑控制的原理是用精度为±0.1%的编码器控制钻头钻进的竖向位移 l_y，并通过变换器将 l_y 输入计算机。如 x 为扩大头的坡角，则与 l_y 对应的孔径增量 $l_x=l_y\tan x$。计算机收到编码器信号后，向液压泵发出“开始”信号使钻刀张开。如钻刀臂长 L 与垂线之间的夹角为 θ，则孔径增量为 $L\sin\theta$。计算机比较 $L\sin\theta$ 与 $l_y\tan x$ 的大小，至 $L\sin\theta=l_y\tan x$ 时发出“停止”信号，钻刀不再扩张。如此重复“开始”和“停止”信号，直至扩大头尺寸符合设计要求。与此同时，钻头钻进的竖向位移 l_y 与钻刀张开的水平距离 l_x 另有 $x-y$ 记录仪制图和打印，可得桩径随深度增大的轨迹。

5. 近数年来，我国武汉、成都等地将人工挖孔桩设计成空心桩，这是国外所没有的。它与实心桩相比，可节省混凝土 50%以上，并可减少废土外运量。空心桩而且可以自上而下分段施工，工艺安全，结构合理。但各种空心挖孔桩一般仅适用于地下水位低于桩底标高的情况。

6. 大直径灌注桩常采用一柱一桩，因此任何一根桩发生过量的不均匀沉降，都有可能危及

整个上部结构的安全。为了消除桩底沉渣的隐患，英、德、荷兰、希腊等许多国家采取了对桩底实施压力灌浆的措施。英国采用U形管灌浆。当桩径≥1m时，U形管通常用4副，桩径较小时用3副或2副。混凝土灌注后约24小时，先用高压水试管，以查明管路有无堵塞。10至15天后进行灌浆。水泥浆的水灰比约为0.6，最大压力控制在50～60Pa，桩顶设百分表，以观测其位移，并可沿桩身深度埋设若干量测元件。通常灌浆初时桩顶不会上升，灌至最大压力，桩顶才徐徐上升。将桩顶上升量与桩身受压引起的弹性压缩相加，即为桩底上升量，它一般控制在1mm左右。浆液灌入量常很大(直径1m左右的桩常需浆液数百升)，这说明浆液除了压入沉渣外，可能有一大部分压入至桩底以下及其周围土层，并向上沿桩身周围涌入桩周土层，这十分有利于改善桩端土的性质。

试验研究表明，经过压力灌浆，桩端承载力一般并不提高，但桩端土的刚度(在应力不大于最大灌浆压力范围内)有明显提高，换言之，桩底沉降可相应减少。

7. 为了既能消除桩底隐患，又能提高桩端阻力，比利时近年研制了一种类似于弗兰基桩的长螺旋钻孔灌注桩，称为VB型桩。它的工艺特点是：(1)钻杆为空心，空心的直径为钻杆外径的80%，当钻进至设计桩底标高后，钢筋笼可由钻杆空心吊入，而不是在钻杆提出地面和灌完混凝土后再插入；(2)钢筋笼就位后，在灌注混凝土前先通过钢筋笼灌入少量干硬性混凝土，并用落锤夯击而在桩底形成扩大头，然后边灌混凝土边提钻杆直至成桩。

上述工艺由于钻杆外径与其空心直径之比设计得当，使单位时间内的切土量等于排土量，故可使桩孔周围的土不致松动、坍落，其强度不致于折减。静载试验表明，这种桩的承载力比常规钻孔桩高约50%，在砂土中由于夯击压密效应，桩端阻力可提高两倍以上。但因钻杆空心尺寸愈大，进钻所需功率愈大，已投产的钻杆外径为700mm，长24m，功率140kN·m。

8. 我国近年有一项发明专利，称为“钻孔压浆成桩法”。它的特点是用长螺旋钻杆钻至预定深度后，从钻杆芯管底端喷嘴以高压喷出水泥浆，边喷浆边提钻杆，直至浆液达到无坍孔危险的位置，然后起钻，置放钢筋笼，投放骨料直至孔口，然后通过绑扎于钢筋笼的塑料管自孔底向上多次以高压补浆而成桩。因此桩体是无砂混凝土，质量致密，但水泥用量较大。该法适用于杂填土、淤泥、流砂、卵石等各种地基，不受地下水位影响，不需泥浆护壁，适用桩径为1m以内，深度至50m。试验表明，其单桩承载力比常规钻孔桩高约一倍。

9. 最近，日本近20家大公司和研究机构正在合力开发一种新桩型，其主旨是力图既能保留大直径灌注桩的各种优点，又能从根本上消除其现有弱点。已进行了大量室内外试验，取得了预期成果。参见文献[2]。

这种桩尚未命名，或可暂称为“水泥土肋形钢管桩”，其工艺流程大致是：先用大型搅拌杆自地面徐徐往下，将水泥乳浆从搅拌杆喷口以高压喷入地基并强行与原土搅拌，直至预定深度而形成一浆状水泥土柱；然后将搅拌杆自下而上边搅边提，直至地面；再将有肋的钢管插入水泥土，待水泥土结硬即成桩。水泥乳浆的水灰比为1.65，进入持力层后改用较稠的乳浆。乳浆用量约为被搅拌土体体积的85%。所形成的水泥土结硬后的抗压强度，桩身为0.5～1.0MPa，桩端6～10MPa。

肋形钢管系专门卷制。钢管外表统长有肋，底端进入持力层部分则内外有肋。肋呈螺旋状，螺旋角<40°，螺距40mm，肋高3mm；钢管壁厚6～22mm不等。拉拔试验表明，单面有肋钢管与水泥土之间的粘结力为光面钢管的8倍，双面有肋的就更高。因此，这种钢管作为桩体的主要受力骨架，能与水泥土形成整体而协同工作，不发生滑移。试验表明，桩顶荷载可由钢管的肋有效地传递给水泥土，水泥土又能将荷载有效地传递给桩周及桩底土。桩的计算直径可取水泥