Application of the Pile Toe Test to Cast-in-Place and Precast Piles

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A Note from Jorj Osterberg

Some explanation is needed for the readers who are not familiar with Japanese methods, terminology, and requirements, which are different than in the United States. The conventional load test in which the load is applied from the top, pushing the pile down is called a "head load test". When the pile is pushed up from the bottom with the Osterberg Load Cell, it is called a "toe load test". The load cell is most often called a "jack". In Japan and in most of the rest of the world, cast-in-place concrete piles and driven piles are both called "piles" and are distinguished from each other as "bored" piles and "driven" piles. However, in Japan driven piles are virtually banned due to noise pollution. Precast prestressed concrete piles are installed in pre-bored holes which are grouted. Piles are tested using the Japanese Geotechnical Society Standard which requires that the load test be made by using successively increasing loads with a minimum of four cycles as seen in Figure Three.

The purpose of the tests described in this article is to determine whether using toe load tests give the same results as the head load tests. The first series of tests were made on drilled shafts which were tremied. A test was made on a shaft were the side friction was known to be smaller than the end bearing capacity by pushing up from the bottom until ultimate resistance in friction was reached. A reaction frame was then used to hold the top of the shaft fixed while the load cell pressure was increased until failure was obtained in end bearing. In the head load test on an adjacent shaft, the shaft was tested to ultimate load and the end bearing was calculated using readings from strain gages placed in the shaft. The load-settlement curves for end bearing from the two tests are shown in Figure Four and load-settlement curves for the top of the pile (measured in the top loaded test and calculated from the bottom loaded test) in Figure Five.

The pile toe test method has the merit of doing away with reaction piles and loading frames. This results in economy due to the drastic reduction in the time required to set up the load test. For this reason the pile toe test is considered to be expedient and promising for quality control in pile foundations.

In another series of tests on grouted precast concrete piles, a load cell placed at the top and another at the toe, with the top of the pile held fixed while the toe cell tested the end resistance. Then in another test nearby at the same site, the pile was top loaded, pushing the pile down to measure the side friction. The results are shown in Figures Seven and Eight.

The tests show that the side friction is virtually the same whether loaded from the top or bottom. (Jorg Osterberg)

Introduction

The pile toe test uses a specially designed hydraulic jack (Figure One), usually installed near the pile toe such that the end bearing and shaft friction mutually provide the reaction needed for load application. The technique was invented by Jorj Osterberg, and has been applied to more then forty load tests in the USA*, including cast-in-place concrete piles (drilled shafts) and steel pipe piles. Some of the test examples have been described in a paper by Osterberg, "A New Load Testing Device Tests Driven and Bored Piles by Pushing up from the Bottom". In this article, the writers

* The number of load tests that the technique has been applied to has increased to 150 since this article was originally published.

(continued on page 24)

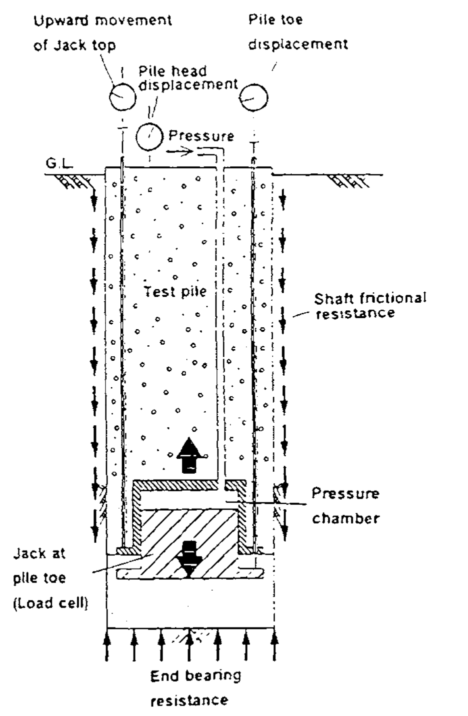
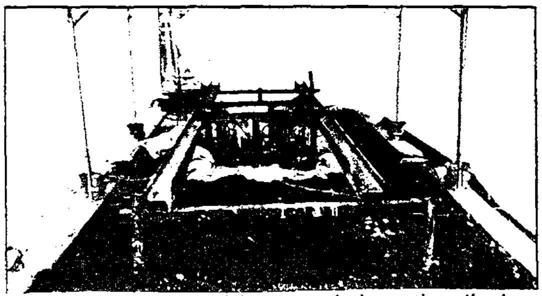


Figure 1: Method of Pile Toe Load Test



A view of the ground above the pile during testing. As the shaft friction and the end bearing mutually provide the reaction needed for the load application, the reaction frame or the reaction piles generally seen in conventional load tests are not required by this load test method.

will give summaries of sixteen tests made in Japan on cast-in-place piles, caisson type piles, and precast piles. Some aspects of the test will be discussed in detail.

The Pile Toe Load Test

The conventional load test involves the use of reaction piles, load frames and dead loads to provide a downward load to pile head (top of pile), which will be referred to as the "pile head load test". The pile toe test method has the merit of doing away with reaction piles and loading frames. This results in economy due to the drastic reduction in the time required to set up the load test. For this reason the pile toe test is considered to be expedient and promising for quality control in pile foundations. The writers were involved in the *Research Committee for the Study of a Simplified Load Test Method,* established by the Japan Association for Building Research Promotion to carry out basic studies of the advantages and disadvantages of the pile toe load test method.

In the pile head load test (conventional load test), the major part of the load applied to the top of the pile is resisted by shaft friction. As a result, it is very difficult to apply sufficient load at the pile toe to mobilize end bearing. This is an advantage with the pile toe load test method because the load is applied directly to the pile toe, making it possible to obtain a clear understanding of end bearing conditions.

Disadvantages of the pile toe test method are:

- The maximum load which can be applied is limited to ultimate shaft friction resistance or the ultimate end bearing resistance, whichever is smaller.
- The load-displacement curve at the top of the pile is not obtained directly.
- The direction of shaft friction is in a downward direction, while in the conventional test, the direction of the shaft friction is in an upward direction.

Explanations and possible countermeasures of these disadvantages will be discussed.

Application to Cast-in-Place Concrete Piles

Table One shows the results of tests on cast-in-place concrete piles. The hydraulic jacks (Osterberg load cells) used in test one and two were imported from the United States, and were based on the original design by Osterberg. The jacks used in the last four tests were redesigned and manufactured in Japan. The hydraulic jacks attached to the reinforcement cages were installed after underwater place-

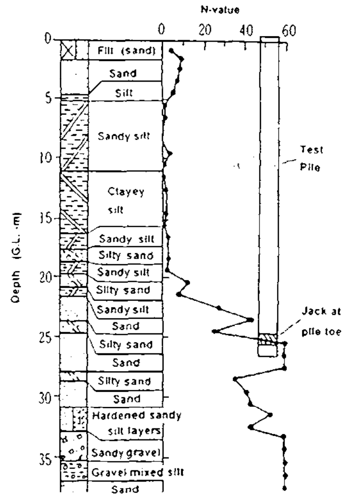


Figure 2: Ground Condition (Test No.5 in Table 1)

ment of motar (cement sand mortar with admixtures to make it resistant to segregation). The underwater placement was carried out by lowering a mortar filled cylinder with a hopper at the lower end which is designed to open as it hits the hole bottom. Of the six installations (Table One), results of test five are presented to show a comparison with the conventional test. The soil profile is shown in Figure Two. Before the test, the shaft friction was estimated to be insufficient to provide enough reaction to fully mobilize end bearing. For this reason, the additional reaction needed was provided by a reaction frame. This arrangement can be considered as one of the possible methods to overcome the first disadvantage mentioned above.

Figure Three shows the relationship between the pile toe settlement P_p and S_p were 8.1 MN (890 tons) and 300 mm (12 inches) respectively. At a value of S_p equal to 10 percent of the pile diameter, the value of S_p was 5.8 MN (640 tons). The shaft frictional resistance reached an ultimate value of P_p = 5.7 MN (627 tons), after which the upward displacement of the top of the jack increased very rapidly together with a reduction in frictional resistance of the pile

Table 1 : Summary of Results from Applications to Cast-in-place Concrete Pile

No.	Month and year	Location of pile load test	Installation method	Test pile Dia. (m)	Test pile Length (m)	Soil type around pile toe	Max. at toe Load (MN)	Max. at toe Settlement (mm)	Shaft friction (MN)	Upward Movement (mm)	Other types of test	Reference reports
1	Dec. 1991	Osaka	RCD	1.2	38.5	Fine sand	8.2	104	8.2(+)	4.2	Pile head pull-out	[2], [3], and [4]
2	Dec. 1991	Osaka	RCD	1.2	38.5	Fine sand	7.0	100	7.0(+)	3.0		
3	Jul. 1993	Tokyo, Minato-ku	ED	1.2	47.0	Fine sand	5.0	183	5.0(+)	6.9	-	[5]
4	Sep. 1993	Tokyo, Katsushika-ku	RCD	1.2	38.0	Fine sand	10.4	400	8.1	(74)	-	[6]
5	Oct. 1993	Tokyo, Chuo-ku	ED	1.2	26.5	Fine sand	8.1	300	5.7	(70)	Pile head Horizontal	[7] and [8]
6	Oct. 1993	Tokyo, Chuo-ku	ED	1.2	30.2	Fine sand	9.2	300	7.1	(50)		

RCD : Reverse Circulation Drill
ED : Earth Drill

(continued on page 25)

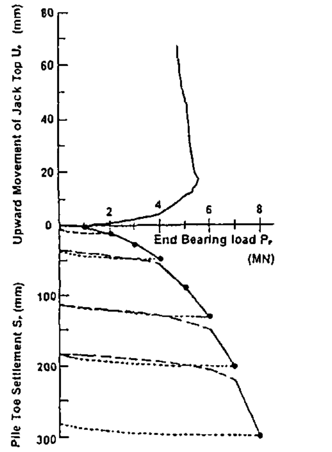


Figure 3: Load Test Result
(Test No.5 in Table 1)

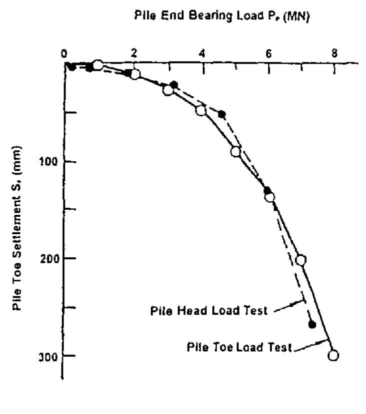


Figure 4: Comparison of P_p ~ S_p relationship
(Test No.5 of Table 1)

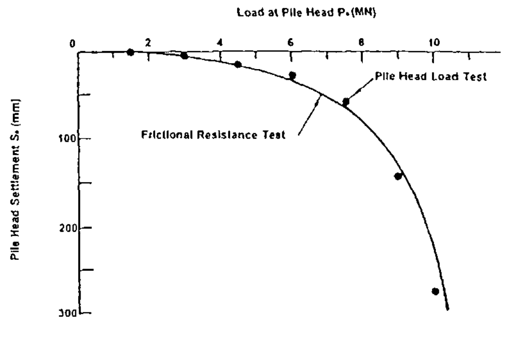


Figure 5: Comparison of P_o ~ S_o relationship
(Test No.5 of Table 1)

shaft. At this point, provision for supplementary reaction frame was utilized to support the top of the pile against upward movement. The residual frictional resistance of the pile shaft just before the use of the reaction frame was 4.9 MN (540 tons).

Figure Four compares the P_p-S_p relationship obtained from the pile head load test with that directly measured in the pile toe load test. The end bearing resistance P_p in the one head load test was obtained from strain measurements. The P_p-S_p relationships from the two methods are seen to be practically the same. Similar agreements were observed in tests one and two in Table One.

Figure Five shows the comparison of pile head load-settlement (P_o-S_o) relationship obtained from pile head and pile toe load tests. The P_o-S_o relationship for the pile toe test was obtained by load transfer analysis[1] considering the P_p-S_p relationship and the variation of shaft frictional resistance with upward movement measured directly during the test. As seen from the comparison, it is possible to obtain a pile head load-displacement curve from the results of a pile toe load test which is in close agreement with the measured load-displacement curve from the pile head load test. This provides a solution to the second disadvantage mentioned earlier.

It is understood from the above discussion that in addition to being much simpler to use, the pile toe load test is capable of providing the data equivalent to the pile head load test.

Application to Caisson Type Piles

Table Two shows the results of pile toe tests on a caisson type of pile (which is distinguished from a cast-in-place concrete pile in that the excavated hole is dry and is of comparatively larger diameter, permitting the installation of the jack for the pile toe load test by workers descending to the bottom of the hole). The first two tests (number one and number two) consist of cases where the diameter of the end bearing jack (load cell) used in the pile toe load test was less than half the diameter of the pile shaft. From this arrangement, it was possible to determine the capacity of the end bearing layer even in a situation where the end bearing resistance is small compared to the shaft frictional resistance. This is another method of overcoming the first of the disadvantages listed above.

Application to Precast Piles

The pile toe load test can also be used on precast piles. Osterberg[2] has reported the use of the pile toe load test on steel pipe piles and Fujioka[3] on prestressed high strength concrete (PHC) piles. Reported here are

(continued on page 26)

[1] H. Kishida and Y. Tsubakihara: An Analytical Method for Predicting the Displacement of a Pile and Soil Layers, 11th SE Asian Geotechnical Conference, 1993.

[2] J. O. Osterberg: A New Load Testing Device Tests Driven and Bored Piles by Pushing up From the Bottom, Kiso-ko, Vol. 19, No. 8, pp. 114–119,1991.

[3] T. Fujioka, K. Arai, H. Kato, H. Aoki and K. Yamada: The Principle and Application of a New Simplified Load Testing Method of a Pile, Symposium on the Vertical Pile Load Test and the Method of Bearing of Capacity Determination, pp. 7-14, 1991.

Table 2 : Summary of Results from Application to Caisson Type Pile

No.	Month and year	Location of pile load test	Test pile Dia. (m)	Test pile Length (m)	Toe Dia. (m)	Soil type around pile toe	Max. at toe Load (MN)	Max. at toe Settlement (mm)	Max. at shaft side Friction (MN)	Max. at shaft side Movement (mm)	Other types of test	Reference reports
1	Oct. 1992	Kogane City	1.6	11.5	1.2	Sandy gravel	9.2	125	4.1	100	Pile head	[10], [11]
2	Dec. 1993	Kogane City	1.2	10.3	0.5	Sandy gravel	2.4	70	2.4	20	-	[12]
3	Dec. 1993	Kogane City	1.2	10.3	0.3	Sandy gravel	1.0	55	1.0(+)	0.6	-	[12]

Table 3 : Summary of Results from Application to PHC Nodular Pile

No.	Month and year	Location of pile load test	Test pile		Toe Dia. (m)	Soil type around pile toe	Max. at toe		Max. at shaft side		Other types of test	Reference reports
			Nodule Dia. (m)	Length (m)			Load (MN)	Settlement (mm)	Friction (MN)	Movement (mm)		
1	Jun. 1991	Sakai City	0.5	10.0	0.5	Clay	1.10	60	1.10(+)	1.5	Pile head	[14]
2	Jun. 1991	Sakai City	0.5	10.0	0.4	Clay	0.86	143	0.86(+)	1.3		
3	Nov. 1993	Kyoto City	0.5	15.5	0.5	Clay	1.22	83	1.43	70	Pile head	
4	Apr. 1994	Miyazaki City	0.5	9.2	0.5	Fine sand	0.81	60	1.43	48	Pile head	
5	Jun. 1994	Kagoshima	0.5	20.0	0.5	Fine sand	1.00	94	3.05	75	Pile head	
6	Jul. 1994	Kagoshima	0.5	20.0	0.5	Fine sand	0.87	99	3.26	62	Pull out	
7	Aug. 1994	Kagoshima	0.5	6.0	0.5	Fine sand	0.28	73	0.71	65	Dig out	

the results of pile toe load tests on PHC nodular piles (Table Three). Nodular piles consist of nodules at regular intervals (Figure Five) meant to enhance shaft frictional resistance, and have been in use in Japan for more than sixty years. When installed by driving, a heap of gravel is maintained around the pile such that the space between the pile axis and the larger hole diameter is progressively filled by the gravel pushed down by successive nodules. The porous interface thus formed around the pile is reported to be effective in releasing the excess pore water pressure that may develop during earthquakes on liquefiable ground, thus preventing the collapse of the pile. The trade name of this type of nodular is HC-Top pile.

Compared to its large frictional resistance, the material strength of PHC nodular pile at the cross sectional area of the pile axis (and not the cross-sectional area at the nodules, where the area is larger) is comparatively small. As a result, it is common in pile head load tests to limit the load to prevent the pile section between the nodules from crushing, thus limiting the end bearing resistance which can be mobilized. The pile toe load test technique can be very effective in this case.

The results of test four in Table Three are shown in Figures Seven and Eight. The soil profile is shown in Figure Six. In this case, the pile toe load test arrangement in combination with pile head load test arrangement was utilized to carry out a "pile toe resistance test" and a "frictional resistance test". The former involves a test on the end bearing soil layer, while holding the shaft of the pile fixed to keep

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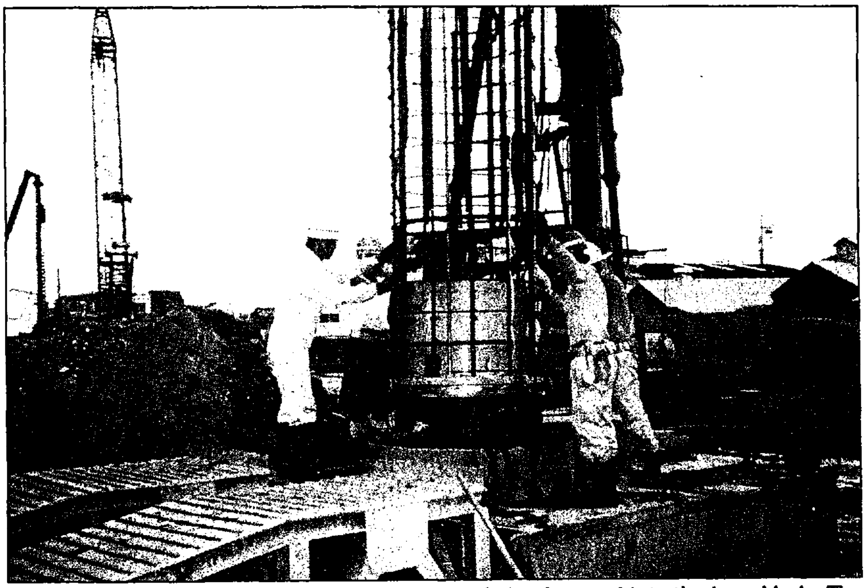


The jack together with the reinforcement cage is being lowered into the bored hole. The jack was installed after underwater placement of cement mortar (with admixtures to make it resistant to segregation) at the bottom of the hole.

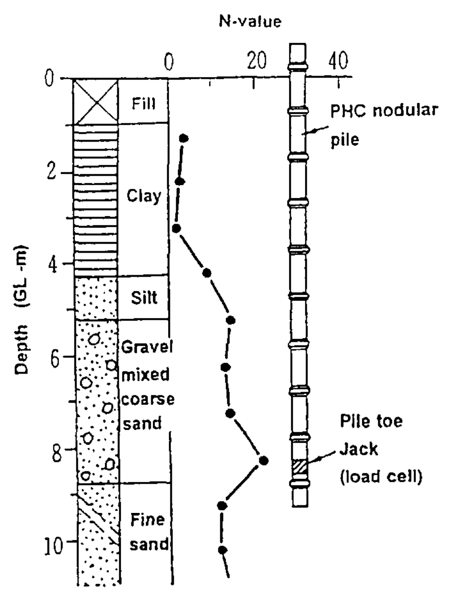


Figure 6: Ground Condition (Test No.4 of Table 3)

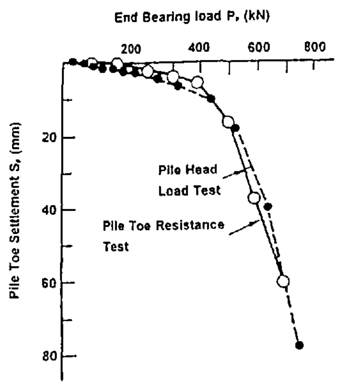


Fig 7: Comparison of $P_t \sim S_t$ Relationship (Test No.4 of Table 3)

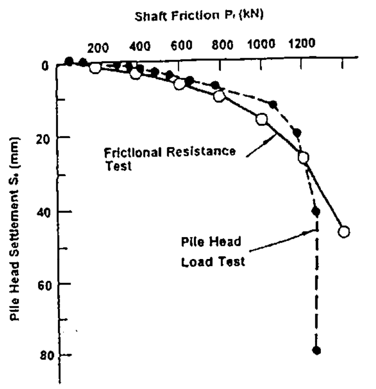


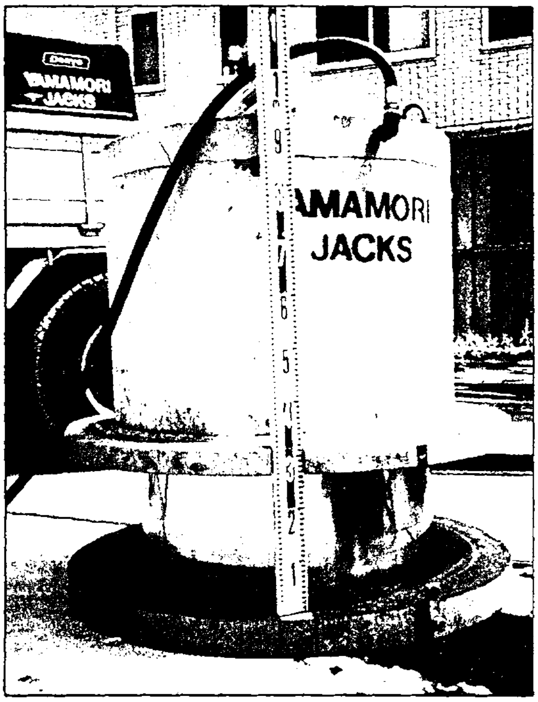
Figure 8: Comparison of $P_f \sim S_h$ Relationship (Text No.4 of Table 3)

it from developing frictional resistance. This was done by utilizing two jacks with one at the pile head and the other at the pile toe. The later test consists of load application to the pile head after completion of the "toe resistance test" with the pressure released in the jack at the pile toe ($P_p = 0$). The "frictional resistance test" was designed to directly measure the side friction in the direction of conventional loading condition, and is considered as a way of verifying the effect of directionality in side friction as mentioned in the third disadvantage listed earlier.

Figures Seven and Eight show the comparison of the results of the "toe resistance test" and "frictional resistance test" with the results of the pile head load test undertaken at the same site. There is a slight difference between the shaft fraction P_pS_o relationship measured by the two methods (Figure Eight). The tests were made at the same site, but not the same exact location. However, the P_pS_p relationship is very similar (Figure Seven). From these comparisons, it can be concluded that the "toe resistance test" and "frictional resistance test" give results similar to the conventional pile head load test.

Recently, there has been much discussion in Japan regarding the adoption of the limit state method in foundation design. For a rational approach to the design of pile foundations, simple methods are needed. The pile toe load test can be considered a development in this direction. To develop this technique to its full potential (in Japan), it will be necessary to standardize the hardware aspects such as the method of jack (load cell) installation. Similarly it is important to streamline the software aspects involved, including the compilation of a test manual explaining all aspects of the method. The *Committee for the Preparation of a Pile Toe Load Test Manual* formed under the aus-

(continued on page 28)



A typical jack used on a Pile Toe Load Test. The jack in this picture, has an outside diameter of 32 inches, an end bearing diameter of 41 inches and a design stroke of 18.7 inches.

pices of the Japanese Association for Building Research Promotion is actively involved in this process. Such activities coupled with the accumulation of experience through application examples will establish the pile toe load test method as a simple means of quality management in pile foundations.

Finally, the authors would like to acknowledge the guidance of Dr. J. O. Osterberg, Dr. Y. Yoshimi, members of the two committees concerning pile toe load tests established under the Japanese Association for Building Research Promotion, and Dr. Y. Tsubakihara of Takenaka Corporation (formerly a research associate, Tokyo Institute of Technology) during the course of the preparation of this report. The authors also acknowledge the support of Mr. T. Suzuki of Mitsubishi Estate, Mr. T. Kaino of JRE Consultants, Mr. T. Inamura of Toyo Techno Corporation and Mr. S. Yamamouri of Yamamouri Jacks, Inc. during installation and testing. ☐

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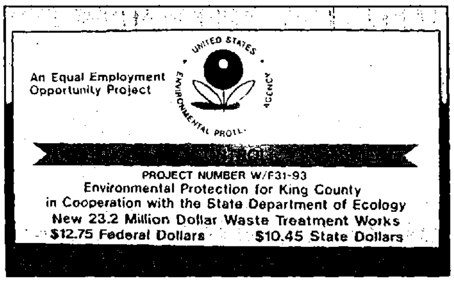
Table of Contents



One of several projects going on in Seattle. See feature page 8.

ADSC's 1995 Slurry School graduating class. See feature page 13.

FEATURES

DEPARTMENTS

COVER

Seattle provides the backdrop for multifaceted overflow sewer project at Alki. See page 8.