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# INSTRUMENTED PILE TESTS IN A STIFF CLAY

## ESSAIS DE PIEUX INSTRUMENTES DANS UNE ARGILE RAIDE

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**SYNOPSIS** A series of pile load tests were conducted on instrumented nondisplacement type piles including H-piles and open-end pipe piles driven in a stratified stiff clay. The purpose of the tests was to determine the distribution of applied load along the pile and to establish the required type and length of pile. The test results indicate that the applied test load was carried primarily by skin friction along the sides of the pile. Values of maximum adhesion were essentially equal to the undrained shear strength of the stiff clay. These results are compared to experiences reported in the literature which indicate that the maximum adhesion of displacement type piles driven in stiff clays is generally substantially less than the shear strength of these materials.

### INTRODUCTION

Prior to construction of the Columbia Lock and Dam, in the vicinity of Columbia, La., a series of pile tests were conducted on instrumented H-piles and pipe piles to determine their required size and length to carry normal design loads of 100 tons in compression and 20 tons in tension. A typical section through the lock chamber and generalized soil conditions at the site are shown in fig. 1. The structure is founded on Recent alluvial sands and clays underlain by a stratified stiff clay of Tertiary origin. Most of the construction piles are battered piles with batters ranging from 2 on 1 to 5 on 1; however, the load tests were conducted on vertically driven piles. Average spacing for the piles supporting the lock chamber walls is 5.0 by 4.75 ft. The piles extend through upper alluvial deposits into the Tertiary formation. Little or no data were available prior to construction on the driving and load bearing characteristics of piles driven into such materials. Previous studies (Tomlinson, 1957 and

Woodward, et al, 1961) indicated that the maximum adhesion of displacement type piles driven into stiff clays is substantially less than the shear strength of the clay. However, it was not known whether this reduction would also apply to nondisplacement type piles.

The pile tests were conducted in a test excavation at project grade (el +8) for the purpose of relieving the overburden pressure and skin friction effects that would exist had the piles been tested at natural ground surface (el +60). As the alluvial materials overlying the Tertiary stiff clays beneath the lock in many instances consisted of soft clays, it was decided that the design loads should be carried entirely by the stiff clays. Therefore, the pipe and H-piles were instrumented with bonded SR-4 strain gages at intervals along their full length so that measurements could be made of the load distribution along each pile and thus establish the portion carried by the stiff clay.

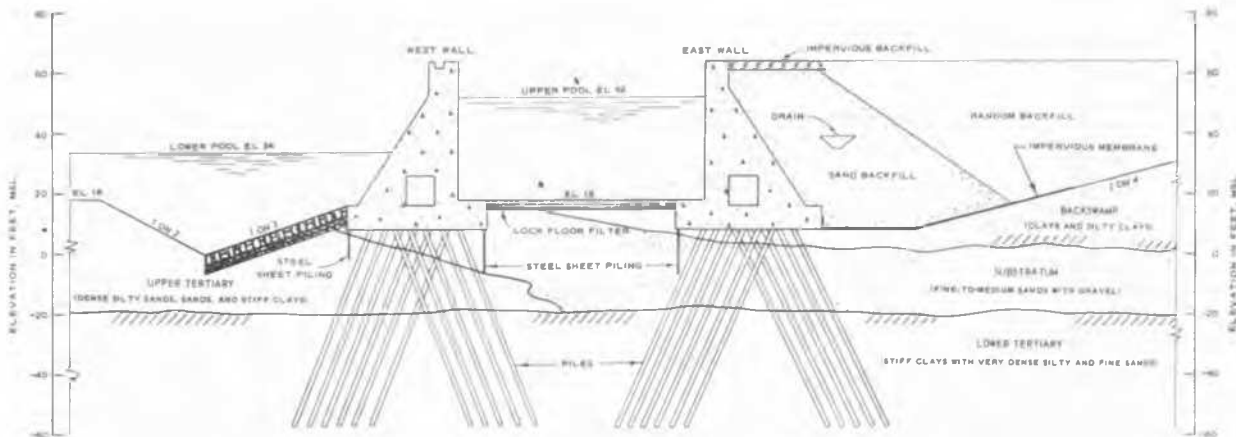


Fig. 1. Typical section through lock chamber

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### SOIL CONDITIONS

A split-spoon sample boring with undisturbed samples taken at intervals was made at the pile test site; the boring log is shown in fig. 2. In general, the Tertiary stiff clays were so hard that difficulties were encountered in obtaining undisturbed samples using a 3-in.-diam thin wall tube sampler. The penetration resistance of the stiff clays varied from about 50 to 90 blows per ft. The penetration resistances were measured in borings made from ground surface (el +60) and would be less if measured in borings made from the bottom of the excavation as a result of stress relief caused by removal of overburden during excavation.

Visual inspection of the samples of the stiff clays between el -22 and el -48 indicated that the materials are stratified with numerous silt and sand seams. The stiff clays below el -48 contain thicker (up to 1/2 in.) and more irregularly spaced silt and sand layers. Natural water contents of the stiff clays averaged about 23 percent. Unconfined compression and Q triaxial tests were performed on selected undisturbed samples of the stiff clay. The undrained

shear strength which is plotted versus depth in fig. 2 ranged from 0.8 to 2.4 tons per sq ft. The drained shear strength of the stiff clay based on direct shear tests was equal to  $\phi = 22^\circ$ ,  $c = 0$ . Drained direct tests on three specimens of stratified stiff clay and silt with the shear plane in a silt layer indicated a shear strength of  $\phi = 30^\circ$ ,  $c = 0$ . The effect of the silty sand and silt laminations on the undrained shear strength was difficult to assess. It was assumed that the stratified soils would behave entirely like a clay in regard to shear strength. The average undrained shear strength is approximately 1.6 tons per sq ft; however, in computing the required length and capacity of the test piles an undrained shear strength of  $\phi = 0$ ,  $c = 0.8$  tons per sq ft and an adhesion,  $c_a$ , of 0.5 tons per sq ft were used.

### TYPES OF PILES AND INSTRUMENTATION

Test piles included three 14BP73 H-piles and two 18-in. diam steel pipe piles driven open end. Three 18-in. octagonal concrete piles were also driven, however, they could not be driven to the planned penetration and were not load tested. A list of the test piles

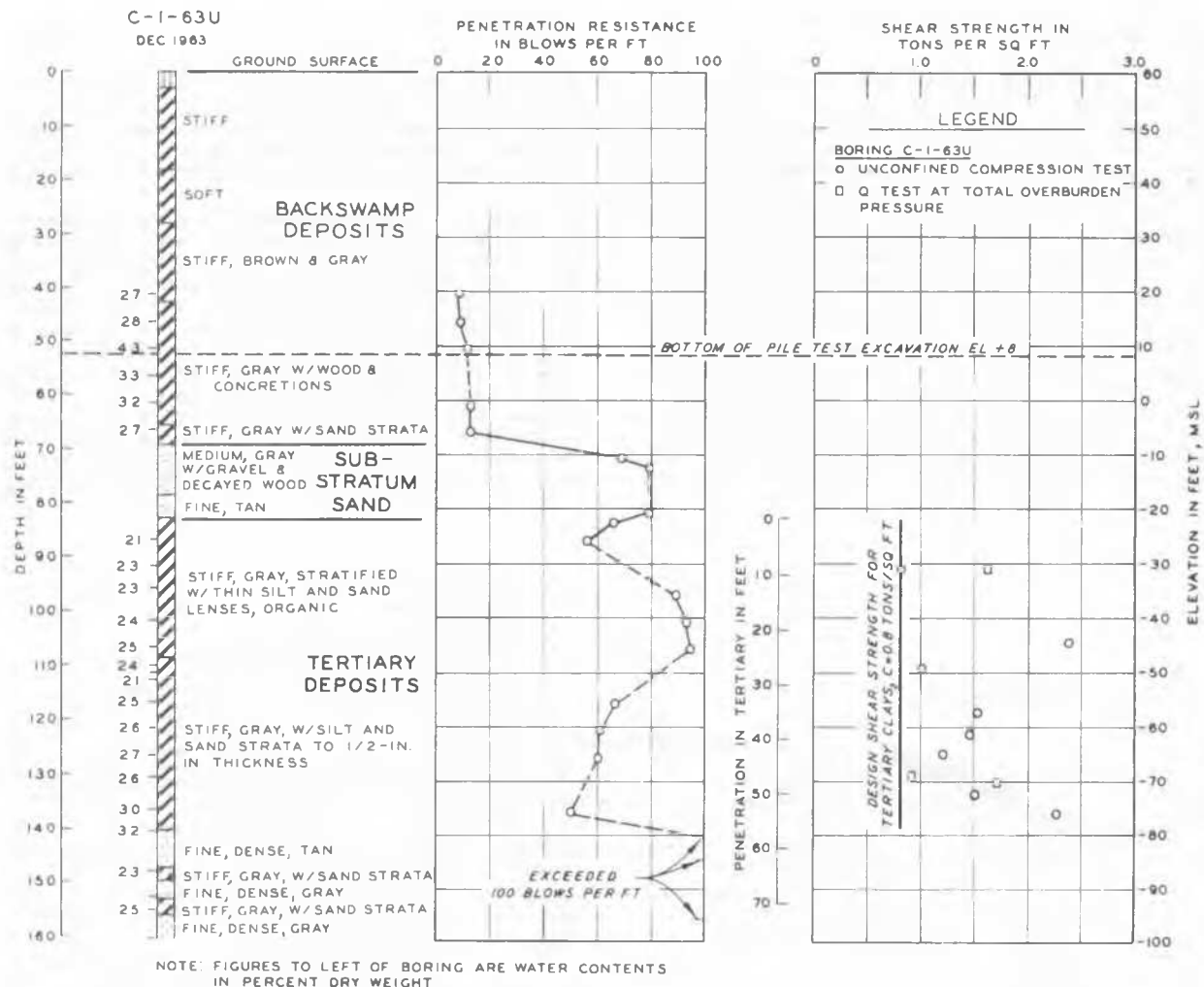


Fig. 2. Soil conditions at test site

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subjected to compression tests and penetrations into stiff clay are shown in table I. The steel piles were instrumented with temperature compensating, bonded electrical strain gages. The gages were installed along the length of the piles at the center of the web for the H-piles and on the outer face of the pipe

piles. A protective cover of 1/8-in.-steel plate was provided over the gages and cables to protect against damage during pile driving operations. Despite hard driving of the instrumented test piles, the strain gages functioned satisfactorily during the load tests.

Table I Pile Failure Loads in Stiff Clay Compression Tests

Pile No.	Pile Size, Type, and Embedded Lengths	Penetration into Tertiary Clay ft	Maximum Applied Load tons	Maximum Load in Stiff Clay tons	Load in Stiff Clay at 0.25-in.-Tip Settlement tons		
					Total	Tip	Friction
1	14-in. H-pile, 73 lb/ft (63.0 ft)	33.0	280	230	230	30	200
2	14-in. H-pile, 73 lb/ft (51.0 ft)	20.3	300	175	200	30	170
3	14-in. H-pile, 73 lb/ft (81.6 ft)	51.2	300	265	265	15	250
4	18-in. O.D. steel pipe pile 0.438-in. wall thick. (62.6 ft)	31.7	300	225	230	18	212
5	18-in. O.D. steel pipe pile 0.438-in. wall thick. (81.8 ft)	51.4	300	240	270	15	255

NOTE: Loads in stiff clay at 0.25-in.-tip settlement are extrapolated values for all piles except Pile No. 1.

### PILE DRIVING

The test piles were driven initially with a differential-acting Vulcan-140C hammer having a rated energy of 36,000 ft-lbs. The H-piles met practical refusal at approximately 50 ft depth corresponding to a penetration of about 20 ft into the stiff clays. Two of the H-piles were driven to greater depths with a single-acting hammer having a rated energy of 48,750 ft-lbs; however, this resulted in some bending and buckling of the piles as indicated by strain gage readings and visual observation of the piles after extraction. The pile driving record for test pile No. 2 which reaches refusal at a penetration of 20 ft into the stiff clay is shown in fig. 3. Driving of the open-end pipe piles apparently caused little displacement of the sur-

rounding soil. The level of the ground surface inside test pile No. 4 was 4.8 ft below its original surface while the level inside test pile No. 5 was 12 ft below its original surface.

### RESULTS OF PILE TESTS

Load testing of the piles was not started until a minimum waiting period of two weeks had elapsed after driving so as to permit the dissipation of residual pore pressures due to driving. In addition to load and deformation measurements at the pile butt during the load test, strain measurements were made immediately prior to the initial load application and then at the end of the holding period for each incremental load. The results of the compression test on test

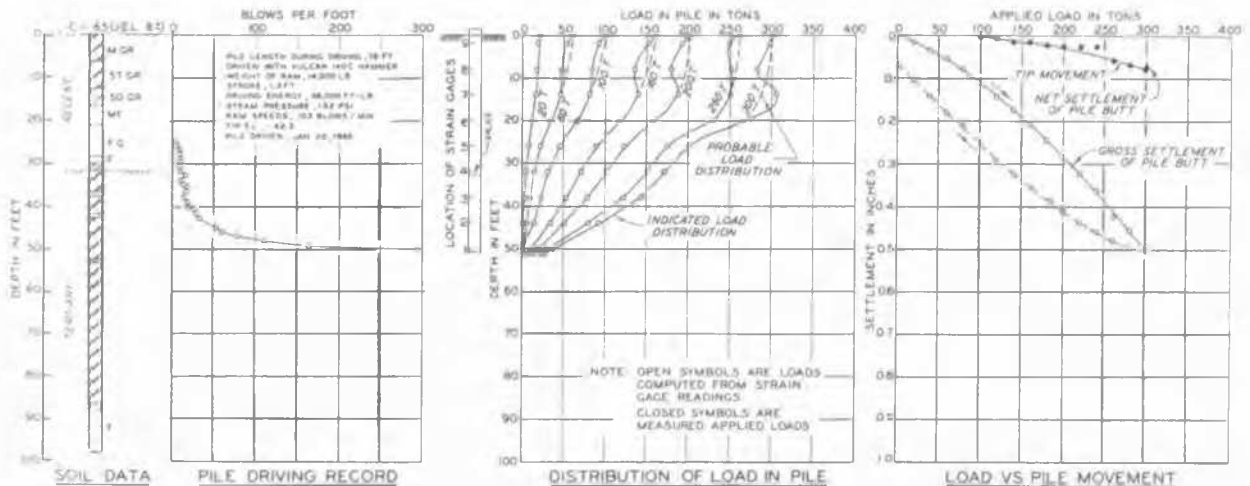


Fig. 3. Driving and load test data for compression test on pile 2

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pile No. 2 are shown in fig. 3 which includes the pile driving record, the distribution of applied butt load along the pile based on strain gage observations and the load versus pile butt movement. The distribution of applied buttload was used to determine the portion of the applied load carried by the stiff clays. The failure loads in the stiff clay were determined from curves of pile tip settlement versus load carried by the stiff clay and were based on a tip settlement of 0.25 in. In most cases the test loads were not suffi-

cient to produce a tip settlement of 0.25 in. and the failure loads had to be extrapolated. Nevertheless, the failure loads are believed to be reasonably accurate. A summary of failure loads for the piles tested in compression is shown in table I which also includes the estimated failure load for the portion carried by the stiff clays. After completion of the compression tests, and a minimum waiting period of 5 days, the test piles were subjected to tension tests. Data for the piles tested in tension are shown in table II.

Table II Pile Failure Loads in Stiff Clay Tension Tests

Pile No.	Penetration into Stiff Clay ft	Maximum Load in Stiff Clay tons	Load in Stiff Clay Based on 0.25-in.-Tip Movement tons
1	33.0	183	140
2	20.3	112	120
3	51.2	162	200
4	31.7	142	170
5	51.4	165	200

NOTE: Loads in stiff clay at 0.25-in.-tip movement are extrapolated values for all piles except Pile No. 1.

The frictional load, and the tip load in the stiff clay at failure for the compression tests are plotted versus penetration in the stiff clay in fig. 4 and a similar plot is shown in fig. 5 for the tension tests. Because of the necessity for extrapolating the failure loads in some cases, the frictional loads at failure are shown in terms of a range of values. It may be noted that the failure loads in both compression and tension tests increase linearly with depths to approximately 20 ft penetration, equivalent to 17 pile diameters for the H-piles. Below this point the frictional load tends to increase at a decreasing rate. On the other hand the tip load at failure from the compression tests appears to be relatively constant with depth. The distribution

of the maximum applied load in the piles at or near failure for the compression and tension tests is shown in figs. 6 and 7, respectively. The data for the H-piles indicate that the frictional load is carried by the lower portion of the pile regardless of the total penetration of the pile in the stiff clay. This type of load distribution is noted for both the compression and tension tests. In contrast to the H-piles, the observed distributions of frictional load for the two pipe piles appear to be more uniform but provide no definite conclusions.

Values of the bearing capacity factor,  $N_c$ , computed from the tip load and average undrained shear strength

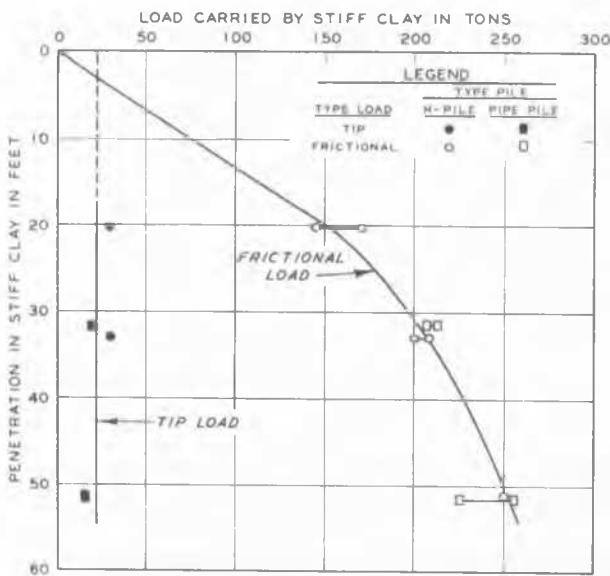


Fig. 4. Failure loads vs penetration in stiff clay, compression tests

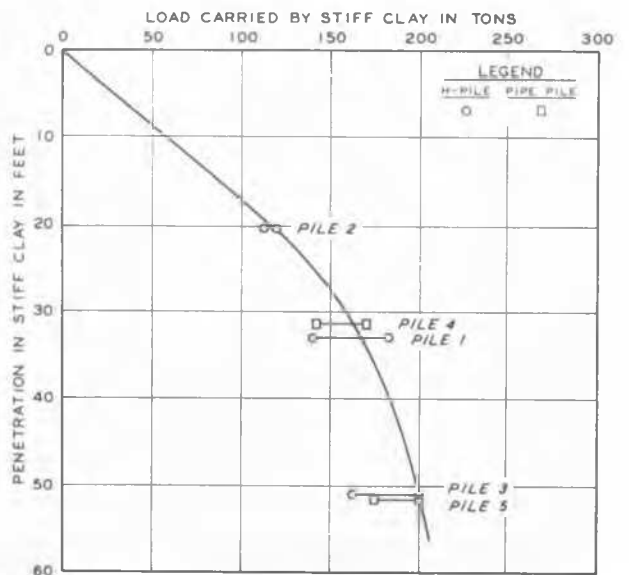


Fig. 5. Failure loads vs penetration in stiff clay, tension tests

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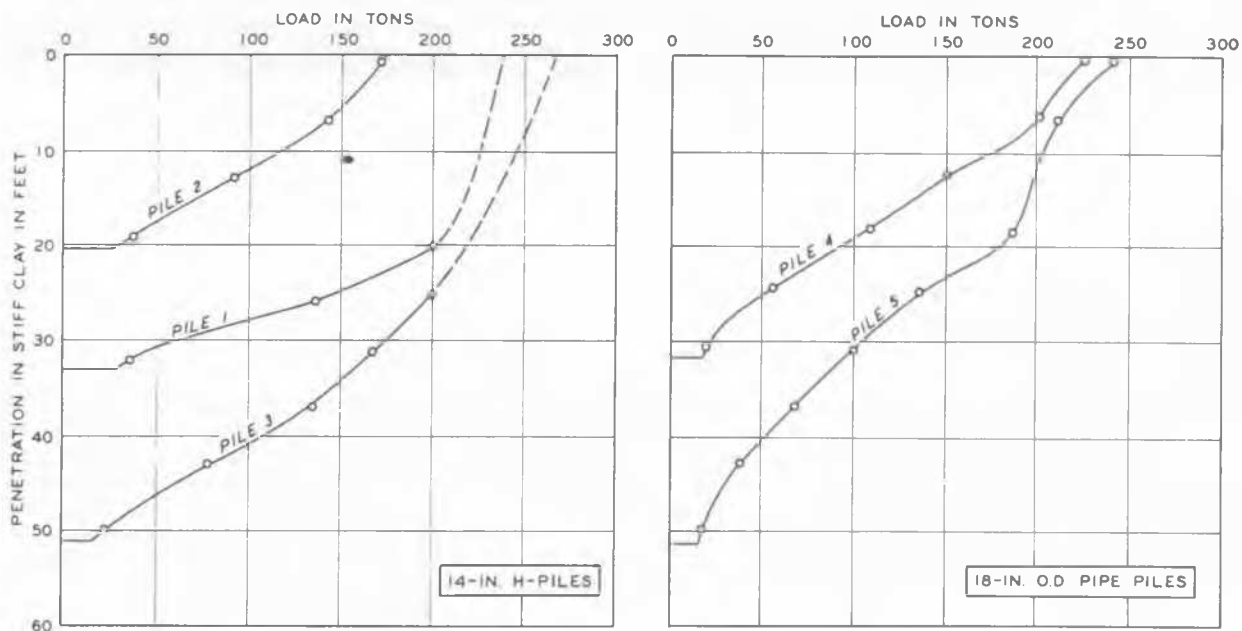


Fig. 6. Distribution of maximum applied load in stiff clay, compression tests

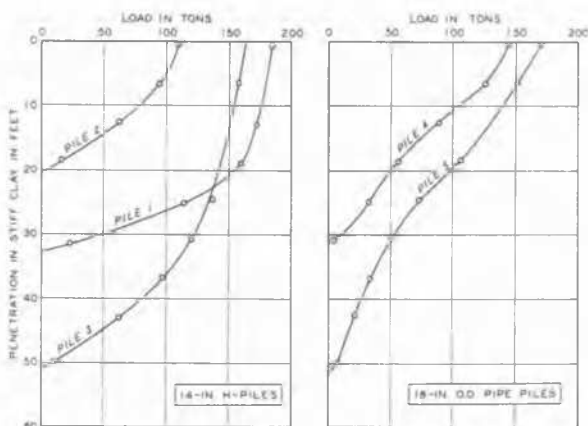


Fig. 7. Distribution of maximum applied load in stiff clay, tension tests

of 1.6 tons per sq ft varied from 5.6 to 13.6 with an average value of 9.3 for the five piles tested. This value is in good agreement with other published data on the above bearing capacity factor for deep foundations in cohesive soils. The maximum adhesion developed in the stiff clays for the compression tests was computed from the minimum slope of the load-distribution curves. The maximum adhesion for all piles averaged about 1.6 tons per sq ft which is approximately equal to the average undrained shear strength of these materials. The minimum perimeter of the H-piles was used in computing the adhesion. The computed adhesion far exceeds values normally expected for piles

in stiff to hard clays. The reason for this difference is not clearly understood but may be due to the stratified nature of the stiff clays. Furthermore, as pointed out by (Vesic, 1967), the adhesion for piles driven in stiff clays may be related more closely to the drained shear strength than the undrained shear strength. The computed maximum adhesion based on the pile loads in tension was about 80 percent of that determined from compression tests.

### CONCLUSIONS

Load tests on instrumented nondisplacement type piles in a stiff clay indicate that the adhesion is not constant with depth and particularly for the H-piles tends to be fully mobilized near the bottom portion of the piles. The computed adhesion far exceeds values normally expected in stiff to hard clay soils; the reason for this difference is not clearly understood.

### ACKNOWLEDGMENT

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