sis of Pile Driving, WEAP Program: Volume IV--Narrative Presentation. FHWA, Rept. FHWA-IP-76-14.4, July 1976, 66 pp.
31. A. Kezdi. Pile Foundations. In Foundation Engineering Handbook (H.F. Winterkorn and H.-Y. Fang, eds.), Van Nostrand Reinhold Co., New York, 1975, pp. 556-600.
32. Design of Pile Foundations. NCHRP, Synthesis of Highway Practice 42, 1977, 68 pp.
33. Piles Under Axial Compressive Load: Standard Method of Testing Designation D1143-74. In Annual Book of ASTM Standards, ASTM, Part 19, 1980, pp. 236-246.
34. Bridge Approach Design and Construction Practices. NCHRP, Synthesis of Highway Practice 2, 1969, 30 pp.
35. R.D. Holtz. Preloading by Vacuum: Current Prospects. TRB, Transportation Research Record 548, 1975, pp. 26-29.
36. Soil Improvement: History, Capabilities, and Outlook. Committee on Placement and Improvement of Soils and the Geotechnical Engineering Division, ASCE, New York, 1978.
37. R.D. Barksdale and R.C. Bachus. Methodology for the Design and Construction of Stone Columns. Presented at FHWA Research Review Conference, Springfield, VA, 1980.
38. J.K. Mitchell. Soil and Site Improvement Techniques to Enhance the Use of Shallow Foundations. Presented at FHWA Research Review Conference, Atlanta, GA, 1977.
39. A.W. Bishop. The Use of the Slip Circle in the Stability Analysis of Slopes. Geotechnique, Vol. 5, No. 1, 1955, pp. 7-17.
40. J.M. Ducan and A.L. Buchignani. An Engineering Manual for Slope Stability Studies. Department of Civil Engineering, Univ. of California, Berkeley, March 1975, 83 pp.
41. D.H. Beeson. Integration of Maintenance Needs into Preconstruction Procedures. FHWA, Rept. FHWA-TS-77-216, April 1978, pp. 104-105.

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Caltrans Prestressed Concrete Pipe Culvert Research: Design Summary and Implementation

ALFRED E. BACHER, ALBERT N. BANKE, AND DANIEL E. KIRKLAND

A summary of the design and implementation of a California Department of Transportation (Caltrans) research project on the use of prestressed concrete pipe in culverts is presented. The Cross Canyon installation has 96-in prestressed concrete pipe culvert under 200 ft of overfill. The following design summary conclusions were made: (a) Method A (compacted structure backfill) loadings of 140V:140H and 140V:42H are adequate; (b) fill heights versus soil pressures were approximately linear; (c) there was excellent correlation between theoretical and experimental moments, thrusts, and displacements; (d) the 96-in prestressed pipe was grossly overdesigned; and (e) earth load stresses are additive to those from prestressing. In the future, Caltrans proposes to introduce a new criterion, dimension ratio, for prestressed concrete pipe design. In addition, implementation of Section 1.16 (Prestressed Concrete-Soil Structure Interaction System) of the AASHTO bridge specifications is recommended. It is concluded that prestressed concrete pipe should continue to be used for unstable drainage site conditions.

In 1963, the California Department of Transportation (Caltrans), in cooperation with the Federal Highway Administration, initiated a $3.5 million culvert research program to assess the structural behavior of culverts embedded in deep embankments. Included in this extensive culvert research program was a prestressed concrete pipe project located in Cross Canyon. Culvert size was 96 in, and overfill height was 200 ft.

The prestressed concrete pipe research project was initiated because prestressed pipe, with its semirigid structural characteristics, offered an alternative type of underground structure with the potential for appreciable savings in material. It could sustain deformation of 0.5 to 1.0 percent without impairment of its structural capability. Furthermore, it had sufficient wall thickness to offer assurance against catastrophic wall failures.

Caltrans has used prestressed concrete pipe culverts for special designs involving unstable earth slide conditions. Examples include the extension of the 15-ft West Fork Liebre Gulch reinforced concrete arch culvert, which had suffered severe distress during construction, with a 12.5-ft-diameter prestressed pipe and replacement of a failed triple reinforced concrete box at San Pablo Creek with triple 11-ft-diameter prestressed pipes. Prestressed concrete pipe design had been historically based on Marston-Spangler design criteria. Concern that these criteria were not appropriate for culvert design under high overfills and special design conditions led to Caltrans' undertaking this prestressed concrete pipe culvert research.

CROSS CANYON PROJECT

Description of Installation

The Cross Canyon prestressed concrete pipe research installation consists of a functional 96-in prestressed concrete pipe, designated zone 11, with instrumented plans A, B, and C; and zone 12, a control segment, placed in the same fill. The center pipe segment in zone 11 was instrumented with electric resistance strain gauges at each octant point. Rebar strains in the concrete pipe were measured as were strains in the concrete pipe core. The three planes of instrumentation were placed 6 and 7 ft apart, respectively, for planes A, B, and C (see Figures 1 and 2).

Soil stress meters were embedded in the surface of the concrete pipe at all three planes and in the soil surrounding the concrete pipe. The upper half of the pipe contained meters at 45° intervals, and the lower half had meters at 30° circumferential spacings. Strain gauges were placed in plane A only.

A new, specially designed Cambridge Meter, obtained from Robertson Research, Limited, was in-

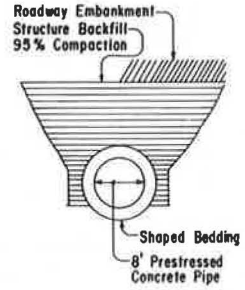


Figure 1. Cross Canyon prestressed pipe culvert installation.

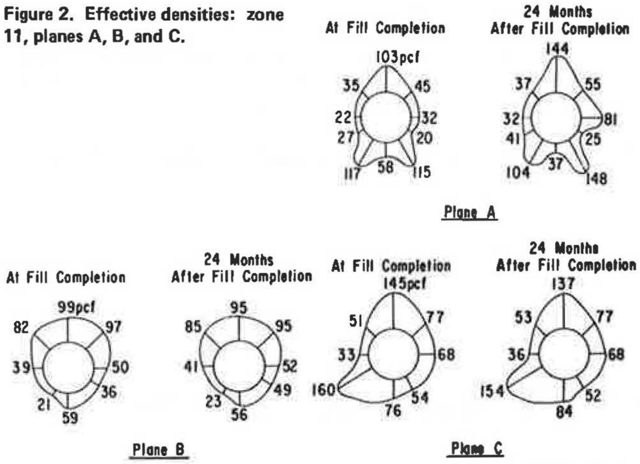


Figure 2. Effective densities: zone 11, planes A, B, and C.

stalled in zone 11, plane A. This device measures both normal pressures and circumferential shears on the pipe wall. Displacements, settlements, rigid body rotations, and joint movements were measured manually. Zone 11 was placed in a trench condition and was surmounted by 10 ft of structure backfill. Shaped bedding with a 120° bedding angle was also provided.

Design Summary and Applications

The plots of the unadjusted effective densities of planes A, B, and C of zone 11 at Cross Canyon are conclusive in the following respects. The stresses produced by observed effective densities for method A (compacted backfill structure), planes A and C, can be approximated by using an idealized loading of 140V:42H. Plane B exhibited lesser circumferential effective densities and a maximum of 99-pcf effective density at the crown. The lateral effective densities ranged between 22 and 81 pcf in planes A, B, and C.

The effective density increase after fill completion was negligible in planes B and C but did increase significantly in plane A (Figure 1). This anomaly represents the one instance in Caltrans Method A rigid pipe culvert research when such an increase did occur. However, the increased readings of 144 pcf at position 1 and 148 pcf at position 5 are only slightly larger than the 140 pcf currently specified by Caltrans.

There is approximate linearity of the soil stress versus fill height plots up to fill completion for position 2 on planes A, B, and C (see Figure 3). Note that for plane A there was an increase in effective density after fill completion.

The asymmetry of effective densities common to all Caltrans rigid culvert research results to date (1, Section I, Volumes 1, 3, and 6; Section II, Part 1; Section III, Volume 2; Section IV, Volumes 1 and 2; Section V, Volumes 11 and 12; and Section IX) was also exhibited on planes A, B, and C of zone 11. Cambridge Meter circumferential shear readings were but one of the indications of the condition of asymmetrical loading. A computational effort was made to establish rotational, horizontal, and vertical equilibrium at zone 11.

The correlation between the experimental moments, based on soil-stress readings, and the theoretical moments, based on strain gauges, using the neutral point method was excellent for plane A (see Figure 4). These moments were of considerable magnitude--i.e., 100 ft-kip.

In all previous Caltrans rigid culvert research, there had been little success in correlating the theoretical and experimental thrusts based on soil pressure readings and strain gauges, respectively. However, at plane A, zone 11, with thrusts as high as 64 kips, excellent correlation was achieved (see Figure 5).

As an indication of the gross overdesign of the 96-in prestressed concrete pipe at Cross Canyon, with a wall thickness of 24 in, the maximum deflection observed was 0.08 in (see Figure 6). The theoretical displacement based on observed soil pressures has excellent correlation with the theoretical displacements based on extensometer measurements. No cracking was observed at zone 11.

Further confirmation of the gross overdesign was provided by the theoretical prestressing steel stresses obtained for outer wrap (there were two layers of prestressed steel), due to earth load only, based on measured soil pressures/neutral point analysis (see Figure 7). The maximum tensile stress of 9300 psi, due to earth load only, is indicative of gross overdesign of the 24-in wall thickness of the 96-in prestressed concrete pipe at Cross Can-

Figure 3. Soil pressures: zone 11.

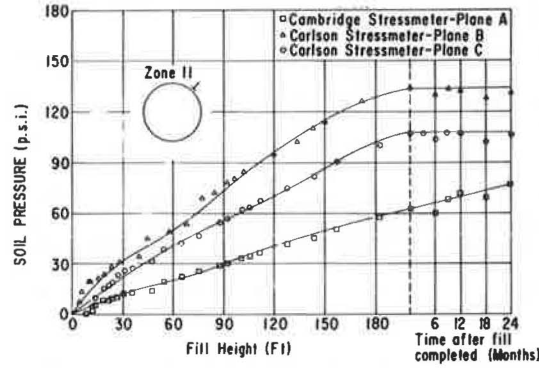


Figure 4. Theoretical and experimental moments: zone 11, plane A.

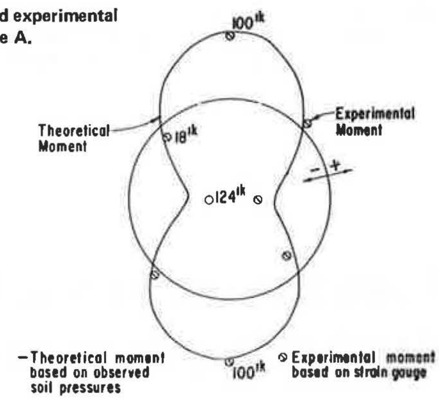


Figure 5. Theoretical and experimental thrusts: zone 11, plane A.

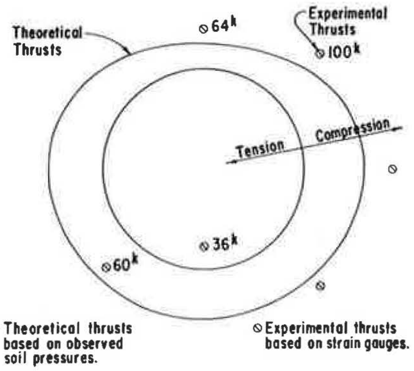


Figure 6. Theoretical and experimental displacements: zone 11, plane A.

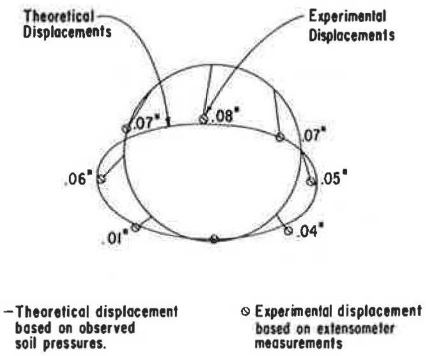


Figure 7. Prestressing steel stress due to load only: zone 11, plane A.

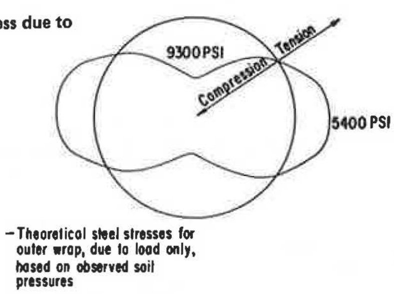


Figure 8. Inner reinforcing bar, compressive stress: zone 11.

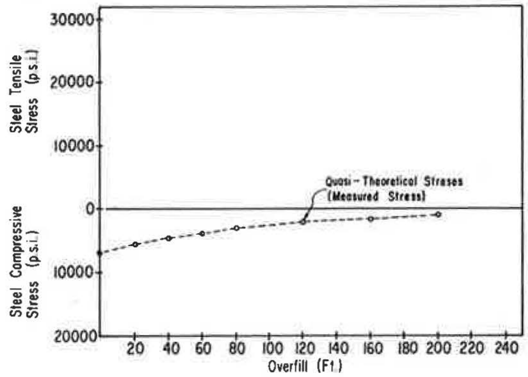
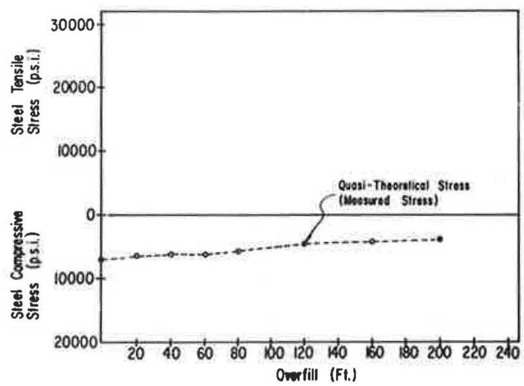


Figure 9. Outer reinforcing bar, compressive stress: zone 11.



yon. This is further supported by the fact that the 1000D pipe with an 8-in wall thickness of the dummy 84-in reinforced concrete pipe at this same site was sufficient structurally to withstand 200 ft of overfill.

A comparison has been made between the 96-in prestressed concrete pipe furnished at Cross Canyon, based on D-load equivalency, and a 1000D reinforced concrete pipe. By using Paris coefficients and the working stress method, for a prestressed concrete pipe designed for a field load of 230 000 lb/lineal ft and a 90° bedding angle, the equivalent D-load obtained is 15 000D. A comparable 1000D prestressed pipe would have a 7-in wall and 0.45-in²/ft prestressed steel.

Two cages of bar reinforcing steel were also included in zones 11 and 12 to facilitate the research of this prestressed concrete pipe. That this prestressed concrete pipe is grossly overdesigned is supported by the fact that compressive stresses only were observed for the inner and outer cages of the bar reinforcing (see Figures 8 and 9). Initially, the prestressing had resulted in a compressive stress of 6800 psi in the bar reinforcing steel. Subsequent placement of earth overfill reduced the compressive stresses to 700 psi in the inner reinforcing bar cage.

Tensile stress was observed only on the concrete inner fiber after the overfill exceeded 110 ft (see Figures 10-13). Initially, the prestressing had resulted in a 735-psi compression on the inner and outer concrete fibers. The net tensile stress of 220 psi observed in the concrete inner fiber at the time of fill completion is less than the 450-psi allowable tensile stress for concrete. The existence of low tensile stresses was affirmed by the fact that no cracking was observed in zone 11.

It is apparent that the use of prestressed concrete pipe for a high fill poses a situation in which the prestressing stresses are added to the stresses induced by the earth overfill. The design of the prestressed concrete pipe was based on Marston-Spangler criteria; experimentally, the installed pipe was found to be overdesigned.

The primary use for prestressed concrete pipe to date has been for internal pressure conditions. Ameron Pipe Products, for example, has placed more than 300 miles of prestressed concrete pipe as pressure pipe. Prestressed concrete pipe has been used by Caltrans in special designs because of its semirigid structural characteristics. Except for Cross Canyon, it has been placed where overfills were less than 90 ft and has performed extremely well.

IMPLEMENTATION

Based on reinforced concrete pipe research at Mountainhouse and Cross Canyons, Caltrans has imple-

Figure 10. Concrete inner fiber, compressive stress: zone 11.

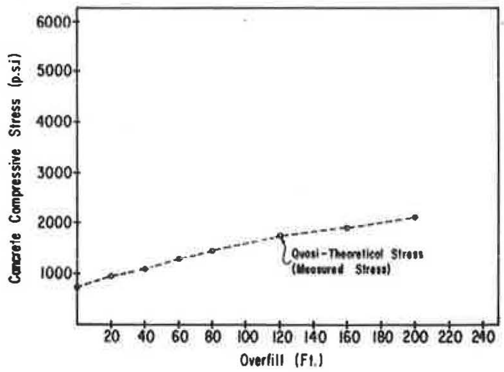


Figure 11. Concrete outer fiber, compressive stress: zone 11.

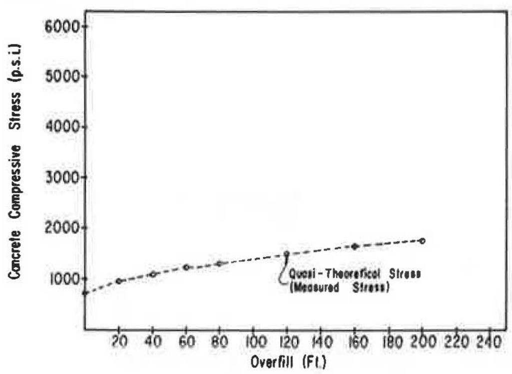


Figure 12. Concrete inner fiber, tensile and compressive stress: zone 11.

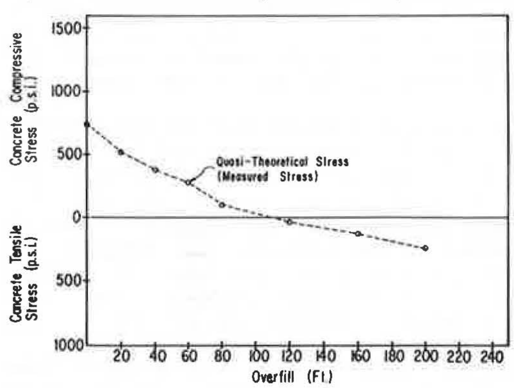


Figure 13. Concrete outer fiber, tensile and compressive stress: zone 11.

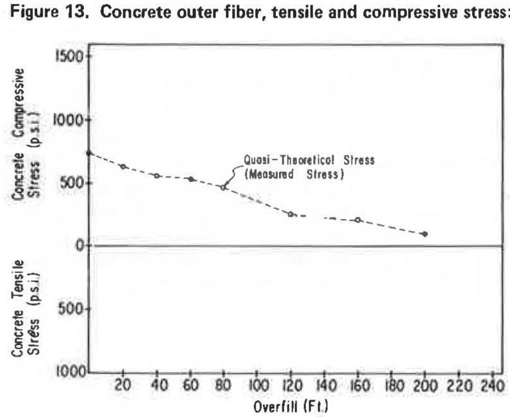


Figure 14. Caltrans criteria for unit load on culverts, where dimension ratio is 1.0-11.9.

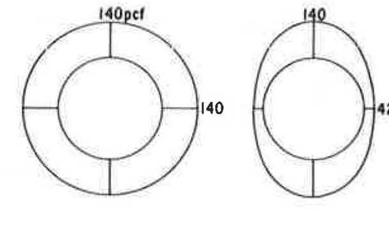


Figure 15. AASHTO criteria for unit load on culverts.

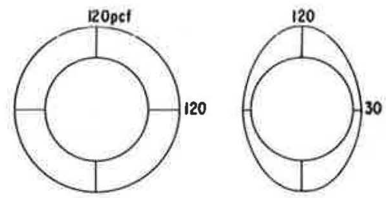
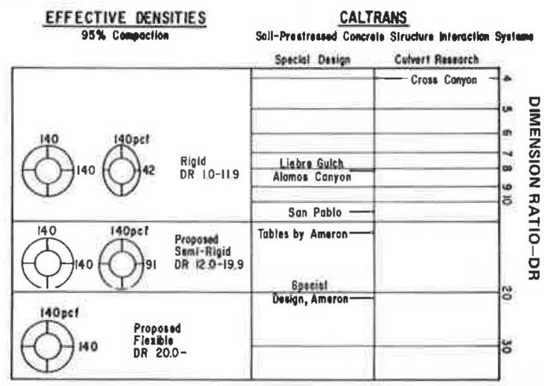


Figure 16. Dimension ratio.



mented design loadings of 140V:140H and 140V:42H for reinforced concrete pavement. They are considered equally applicable to prestressed concrete pipe design, where the dimension ratio is 1.0-11.9 (see Figure 14).

The American Association of State Highway and Transportation Officials (AASHTO) has recently revised its Article 1.2.2A, Loads on Culverts (2), to specify two loading conditions for rigid culverts: 120V:120H and 120V:30H (see Figure 15).

FUTURE CONSIDERATIONS

1. Caltrans proposes to introduce a new criterion, dimension ratio, for prestressed concrete pipe design (see Figure 16). Dimension ratio is defined as the internal diameter in inches divided by the wall thickness in inches. Caltrans reinforced concrete pipe research at Cross Canyon, previously reported, has emphasized the importance of the dimension ratio. With a dimension ratio of 4.0, the previous assumption by Caltrans that a prestressed concrete pipe always acts as a semirigid structure was not supported by this research. With a wall thickness of 24 in and an inside diameter of 96 in, zone 11 is, in effect, a rigid culvert. Ameron has developed tables based on a dimension ratio of 13.0--i.e., a semirigid condition. The initial proposed loadings are 140V:140H and 140V:91H for semirigid culvert design. Caltrans is currently developing a curvilinear relation between varying lateral effective densities and dimension ratios.

2. Initiation and development of Section 1.16 of the AASHTO bridge specifications (2)--Prestressed

Concrete-Soil Structure Interaction Systems--are recommended.

SUMMARY

The primary use of prestressed pipe to date has been for pressure pipe installations. In Caltrans, it has been limited to special drainage designs and has been considered a semirigid design. The prestressed concrete pipe research reported in this paper, coupled with the reinforced concrete pipe research by Hydro-Conduit using pipes that share common dimension ratios and Ameron prestressed concrete pipe designs, gives further support to the dimension ratio concept.

Prestressed concrete pipe continues to offer an acceptable alternative for special drainage designs--i.e., where there is an unstable soil condition in a potential slide area. Under high fills it is not recommended, since there is admittedly the adverse effect of the earth loads being added to the prestressing forces.

ACKNOWLEDGMENT

The Caltrans Culvert Committee and Ameron cooperated and participated fully in the initiation of the prestressed concrete pipe culvert research at Cross Canyon and the selection of the design parameters to be considered. Walt Creasmon of Ameron contributed significantly to the initiation of the prestressed concrete pipe research proposal and, most recently, to this paper on design summary and implementation.

REFERENCES

1. R.E. Davis, F.M. Semans, D.W. Spannagel, and A.E. Bacher. Rigid Pipe Proof Testing Under Excess Overfills with Varying Backfill Parameters. California Department of Transportation, Sacramento, Oct. 1978 to July 1982.
2. Standard Specifications for Highway Bridges, 12th ed. AASHTO, Washington, DC, 1977.

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Effect of Heavy Loads on Buried Corrugated Polyethylene Pipe

REYNOLD K. WATKINS, RONALD C. REEVE, AND JAMES B. GODDARD

Corrugated polyethylene pipe, developed originally in 4- to 12-in diameters for land drainage, is now manufactured in larger diameters for other uses of buried conduits such as culverts, air ducts, and service conduits. Tests were conducted on pipes with 15-, 18-, and 24-in inner diameter to investigate the structural performance and performance limits of these larger-diameter pipes when subjected to external soil pressures. For pipes in typical native soil backfill, compacted by typical methods to greater than 80 percent standard density (AASHTO T-99), less than 1 ft of soil cover (called minimum cover) was found to be adequate protection against H-20 (32-kip/axle) loads and up to 54-kip/axle "super-loads". The soil envelope does not have to be select material. At less than minimum cover, the performance limit is either (a) excessive pipe deflection or (b) localized reversal of curvature directly under the wheel load. Under high soil cover, both the performance and performance limit are pipe deflection (out-of-roundness), which is a function of the total vertical soil pressure and is equal to or slightly less than vertical-soil strain in the backfill material on both sides of the pipe, herein referred to as sidefill. In compacted soil backfill, pipe deflection is less than 10 percent for either H-20 loads on minimum soil cover or vertical pressures up to 2500 psf under high soil cover. Pipe stiffness is roughly equal to steel and is greater than aluminum in 16-gage, 2-2/3 x 1/2 corrugations.

Corrugated plastic pipe is one of the leading pipe materials used for land drainage in the United States. It was introduced in the late 1960s, beginning with small inner diameters (ID) (3 and 4 in), which were used primarily for agricultural land drainage. During the 1970s the uses for corrugated plastic pipe greatly increased. Sizes up to 15-in diameter were developed, and applications were extended to highway drainage and to various residential and commercial construction uses, including foundation drainage, home sewage disposal, and grain aeration. With the introduction of 18- and 24-in pipe in 1981, the uses for corrugated plastic pipe again expanded to a still wider range of applications, including mining, culverts for roads and driveways, and other types of entrance and ditch crossing applications.

In 1979, field loading tests were conducted at Hamilton, Ohio, to evaluate the structural performance of 12-in corrugated polyethylene pipe for various types of culvert installations (1). With the recent development of the larger pipe diameters (18 and 24 in), the following additional questions arise.

Are there any structural limitations pertaining to these larger-diameter pipes when they are subjected to heavy external soil pressures? Subdrainage pipe is often backfilled with gravel or similar material that provides a filter for the inflow of ground water but also provides radial support for the pipe. If the pipe is used for purposes other than subdrainage (i.e., culvert), a select backfill material is not needed as a filter. But is it needed as support for the pipe? Most drainage pipe is installed in trenches and at shallow depths that can be excavated by a backhoe or wheel trencher or plowed in with a drainage plow. The most critical pipe loadings are surface wheel loads usually no heavier than H-20 truck loads, the highest legal highway wheel loadings. Can buried polyethylene pipe, with minimum cover, resist the super heavy wheel loads of construction equipment, off-highway trucks, etc.? Can corrugated polyethylene pipe be buried under very high embankments or in very deep trenches? What about pipe stiffness?

To answer these questions, field tests were conducted at London, Ohio, by Utah State University (USU) in cooperation with Advanced Drainage Systems, Inc., to investigate the effect of heavy loads passing over shallow buried corrugated polyethylene pipe. An additional series of tests conducted at USU used a pressure soil test cell to simulate the effect of great depths of cover, which in some cases can result in very high soil pressures. Comparative