Corrugated Plastic Drains Plowed-In Automatically

James L. Fouss
MEMBER ASAE

NEWLY developed, corrugated, plastic drain tubing, installed with a draintube plow that is automatically controlled by a laser beam for laying the pipe on grade, shows promise as a rapid, low-cost method of subsurface drainage. The installation of corrugated plastic drainage pipe with plow-type equipment is rapid because ditching and backfilling are not required. Corrugated plastic tubing is flexible and of light weight, which simplifies the materials-handling operation when compared to that presently required for the installation of clay or concrete draintile. The laser-beam, depth-control system was developed especially to meet the needs of high-speed, plow-type drainage equipment because present grading methods using sight-bars or stretched wires are slow, costly, and unsatisfactory. To date few drainage installations have been made using any type of automatically controlled equipment.

Considerable research has been conducted on various types of plastic drainage materials and installation methods, such as by Ede (2)* and Boa (1) in England, Fouss and Donnan (5) and Schwab (7) in the United States, and van Someren (8) in The Netherlands. Research in developing corrugated plastic pipe as a new drainage material has advanced rapidly since its introduction in the early 1960s (3, 6). Small-diameter, corrugated, plastic drain tubing has been used widely in Germany since 1963, and to an increasing extent in England since 1965. Both plow-type equipment and trenching machines have been used in these and other European countries to install this new plastic drainage pipe (3). In The Netherlands, small-diameter, smooth-walled plastic drain tubing has had widespread agricultural use, but recently corrugated plastic drainpipe was also being used. In the United States, corrugated, plastic drain tubing is available in sizes from 3 to 4 in. in diameter. Its use in American agriculture has increased rapidly since mid 1967, and it is presently being installed by conventional or modified trenching methods.

CORRUGATED PLASTIC DRAIN TUBES

Corrugated-wall, plastic draintubes provide greater strength, better longitudinal flexibility for ease of handling, lighter weight, and much lower cost than do comparable smooth-walled plastic pipes. In order to have the same structural strength in a smooth-walled plastic pipe of given diameter as in a corrugated-wall tube, the plastic material in the tube walls need to be much thicker, and, therefore, the pipe would be considerably heavier. Since the cost of plastic pipe is essentially proportional to its weight per linear foot, smooth-walled pipe would cost much more.

Corrugated, plastic drain tubing is normally shipped and handled in 5 to 6-ft diameter coils, each containing from 300 to 500 linear ft, depending upon tube diameter. A typical 4-in.-diameter corrugated plastic drainpipe weighs less than 0.3 lb per ft, which is about 4 percent of the weight of 4-in. diameter clay or concrete tile. For example, a 300-ft coil of the 4-in. diameter corrugated plastic drainpipe weighs about 80 lb and can be handled easily by one man. By comparison, 300 ft of comparable clay or concrete draintile weighs slightly more than 1 ton. The cost of this new plastic material is now about 10 to 12 cents per linear ft, which is nearly the same as that of clay or concrete tile in the midwestern states.

Corrugation Design

The design of an efficient corrugation pattern for the tube walls follows very closely the procedure used for the optimized design of a structural I-beam; that is, designing for the maximum moment of inertia in the cross section of the tube wall, and a maximum strength-to-weight ratio for the fabricated plastic pipe. Only a generalized discussion of this design problem is presented in this paper†. The optimum corrugation design depends on the interrelations between the depth of the corrugation, the pitch or distance between corrugations, the thickness of plastic material in the corrugation ribs, and the type of plastic material used. As a part of the research and development program for this new drainage material, a special study was conducted to determine the relative importance of these design factors on the strength and cost of the corrugated plastic drain pipe.

A digital computer program was developed for evaluating and comparing different patterns of corrugations for the drain-tube walls. The computer program was based on the theoretical strength of the plastic tubes for conditions of loading between parallel plates and for various amounts of tube deflection. It was found that the square-wave corrugation provided slightly higher efficiency in the use of plastic material than a round-wave (sine-wave) corrugation design. For a given corrugation design, a small increase in the corrugation depth greatly increased the tube strength with only a minor increase in its cost; a rather large increase (e.g., 200 percent) in corrugation pitch slightly decreased the tube strength, but the strength-to-weight ratio of the tube increased significantly; and any increase in plastic-material thickness increased both tube strength and cost in almost direct proportion to the increase in thickness. Therefore, the most efficient corrugation design resulted when the maximum practical corrugation depth was used, with a correspondingly large corrugation pitch, and the thinnest possible plastic material in the corrugation ribs (*e.g.*, 15 to 20 mils). The corrugation pitch is limited by the maximum length of flat surface on the outside wall of the tube which can easily resist denting.

Many types of plastic material can be used to fabricate the drainpipe. The most common types used for corrugated pipe are high-density polyethylene (HDPE) in the United States, and polyvinyl chloride (PVC) in European countries. The selection of materials is based on cost for the plastic resin; HDPE costs less than PVC in the United States, and the reverse is true in Europe. PVC plastic material is stronger than HDPE. However, PVC plastic pipe tends to be brittle at low temperatures, whereas the HDPE pipe is not.

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The author—JAMES L. FOUSS—is agricultural engineer, corn belt branch, SWCRD, ARS, USDA, Columbus, Ohio.

* Numbers in parentheses refer to the appended references.

† For a more detailed treatment of this subject, refer to ASAE Paper No. 68-702 (J. L. Fouss), "Structural Design of Corrugated Plastic Drains."

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Perforations

The walls of the corrugated plastic tubing can be perforated for water entry, by punching or drilling holes, sawing short narrow slots, etc. The preferred location for tube wall openings is in the "valleys" between corrugations rather than on top of the corrugation ridges. Perforations located in the corrugation valleys are protected from clogging with soil during the installation operation, if some longitudinal slippage of the drain tube occurs with respect to the surrounding soil. A common practice is to fabricate these openings along the pipe length in three rows spaced equally around the pipe. Spacing the perforations longitudinally along the pipe, such that they occur only in every other or every third corrugation valley provides adequate water-entry opening without unduly weakening the pipe. As a rule-of-thumb, the cross-sectional area of the water-entry openings should represent approximately 1 percent of the pipe's outside wall circumferential area.

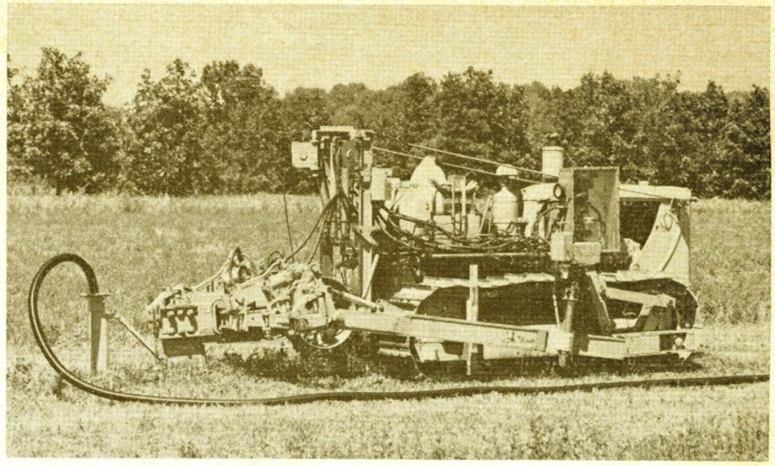

FIG. 1 Equipment for "plowing-in" continuous corrugated plastic drain tubing with the draintube plow.

Plastic Drain Strength Requirements

Most plastic drainpipes are flexible conduits, and thus gain part of their vertical, soil load-carrying capacity by lateral support for the surrounding soil. This lateral support (passive resistance of the soil) occurs as the drain tube deflects outward against the soil at the sides of the tube. The amount of deflection depends on the combined strength of the flexible tube and the bearing strength of the surrounding soil. The use of flexible-tube principles for designing these drains results in a more efficient use of expensive plastic material than relying completely on bending resistance in the pipe sidewalls, as is done in the design of rigid or thick-walled tubes.

Although research results have not yet provided us with the final word on strength requirements for plastic drain tubes under soil loading, some important guides and specifications have been developed. Tentative specifications for trench-installed plastic drain pipes up to 4 in. in diameter have been proposed by the Ministry of Agriculture in England (9), and are now used for approving plastic drainage materials installed under government cost-sharing arrangements. These specifications were developed through a 5-year field research program using smooth-walled plastic pipes of various diameters and wall thicknesses (4). The specifications require that the plastic drain pipe, loaded between two parallel plates, support a loading increment of 18½ lb per linear ft of pipe for the second ⅛-in. increment of pipe deflection (flattening). This load is in addition to that required to deflect the pipe the first ⅛ in. These specifications further require a creep resistance test whereby the plastic, drain-tube specimen is loaded with 40 lb per linear ft and the tube wall deflection should not exceed 40 percent of the tube diameter over a period of one week.

In the United States, results have now been obtained from a 17-year-old field experiment described by Schwab (7) on polyethylene smooth-wall plastic drain pipes of various diameters and wall thicknesses. These experimental drains were installed in an Iowa silty loam soil in 1949, and were pulled into a mole-drain channel rather than being installed in a conventional trench. Inspection of these drains during 1966‡ showed that the diameter and wall thickness combinations of many of the tubes included in the experiment provided successful drainage conduits from both structural and hydraulic aspects. For example, a 3-in. diameter tube with a 0.100-in. thick wall was almost perfectly circular in a cross section at the end of the 17-year test period. Samples of these 3-in. diameter tubes required an incremental load of only 6 to 8 lb per ft to deflect (flatten) the pipe the second ⅛ in. when loaded between parallel plates. For the 2-in. and 4-in. diameter drain tubes that were still nearly circular at the end of the test period, the loading increment was 14 and 3 lb per ft, respectively, for the same loading and deflection conditions. The increase in strength required for smaller diameter tubes is a function of the varying amount of support provided by the soil surrounding the flexible drain pipe; the smaller the pipe, the larger the bearing strength of the soil must be to support the shape of the flexible drain tube. Soil-bearing strength is not as important to structural stability when a stronger drain tube is used. The strength requirement for the plastic drain tubes installed in a mole-drain channel is probably lower than that required for trench-installed plastic pipe, because of the excellent bedding conditions provided by the curved bottom of the mole channel. From a hydraulic standpoint, the experimental plastic drains inspected in Iowa are still functioning well, and ¼-in. diameter tube wall perforations for water entry appear to be satisfactory in the silty loam soil.

‡ Conducted cooperatively with the Iowa Agricultural Experiment Station at Ames.

For comparative purposes, the 3 to 4-in.-diameter, corrugated plastic drain tubes currently being used in the United States have a strength of approximately 50 lb per ft for the second ⅛-in. deflection, when loaded between parallel plates.

Plastic Drain Installation

Draintube plow-in equipment, called a "draintube plow," is being used in research trials to install the corrugated plastic drain pipe. The plow consists of a vertical blade with a horizontal torpedo-shaped "moling" point at the bottom. The blade is rigidly attached to a tool bar and 10-ft long draft links (beams), which are hitched to a large track-type tractor capable of developing 30,000 lb or more of drawbar pull (Fig. 1). The plow was hitched at the sides of the tractor to improve traction efficiency of the track-type tracks. The plow's operating depth in the soil is controlled by the tractor's hydraulic system through a mechanical linkage that raises or lowers the plow hitch point. Because the plow's hitch is situated 10 ft in front of the moling point, the plow operates with a "floating-beam" action. That is, changes in the vertical position of the hitch are not

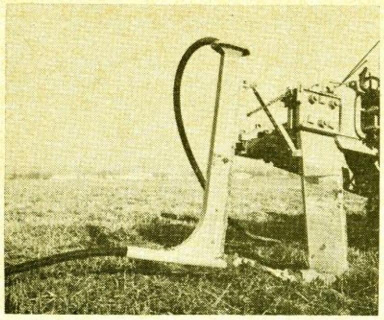

FIG. 2 Hollow-blade tool attached behind plow standard guides corrugated plastic tubing into "mole" channel.

immediately reflected in the operating depth of the mole point; the moling point adjusts or "floats" to a new equilibrium depth as the tractor moves forward.

The plow was adapted to install 2½ to 3-in. diameter corrugated plastic drain tubing by attaching a hollow vertical blade behind the soil-cutting standard (Fig. 1). As the draintube plow "tunnels," the plastic pipe is pulled down the hollow blade and around a sharp turn to guide it into the mole channel (Fig. 2). Normal ground-speed for the drainage machine is 125 fpm when operating at a 30-in. depth. Under usual field working conditions, the installation of 2,000 ft of drain per hr is common. The opening made by the vertical blade of the draintube plow is closed, after the pipe is installed, by the weight from one track of the track-type tractor driven over the opening on a return trip along the drain line. Soil and crop disturbances are considerably less with this installation equipment than with conventional ditching and backfilling.

One practice of handling the corrugated plastic drainage material in the field is to uncoil the pipe and lay it offset but parallel to the proposed drain line (Fig. 1). Another practice is to place the coiled tube on a spindle, mounted on the drainage machine, from which it feeds directly into the hollow-blade installation tool. More than one coil of the plastic pipe can be carried on the machine, and as one roll is nearly installed, a brief pause in forward travel permits splicing to the next roll so installation can continue. It is also possible to change sizes of drain tubes to be installed at any desired location in a drain line by a similar splicing procedure. The cost savings in using small diameter drains at the upper end of long lines and increasing the size toward the outlet can be significant for large-scale installations.

The installation cost using the draintube plow equipment has been estimated to be about 2 cents per ft (6). With an average cost of 10 cents per foot for 3 or 3½-in-diameter corrugated plastic drain pipe, the total cost for this new drainage system would be 12 cents per ft. This indicates a savings of about 6 to 8 cents per ft as compared with the average cost of tiling in the lakebed region of the United States. The savings can be even greater in areas where tile are not readily available.

The plow-in method of installing plastic drain pipes has been satisfactory in stony glacial till soils, and even under such adverse field conditions as 20-percent sideslopes with large sandstone rocks beneath the soil surface. When numerous rocks are present, a preliminary pass of the plow is made to break or move the rock. The plastic drain is installed during the second pass of the machine. In very dry soil, the power required to pull the plow is often excessive. The use of a vibrating (or oscillatory) blade and point on the plow is being considered as an attempt to reduce the machine draft in dry soil.

Laser-Beam Grade Control

A uniform gradient for subsurface drains is necessary for their efficient and maintenance-free performance. The drainpipes should be laid to a minimum grade of 0.1 to 0.2 percent, but steeper grades should be used whenever possible. Without some automatic means of controlling the highspeed draintube plow, it is virtually impossible for the tractor driver to adjust accurately the plow depth rapidly enough to compensate for rough and uneven field surfaces. The laser-beam, grade-control system was designed to regulate automatically both the installation depth and grade of the plastic drainpipe installed with this equipment.

The Laser

The laser, developed in 1960, has been adapted to a variety of uses in industry, medicine, photography, and agriculture. The word "laser" is an acronym derived from the phrase, "Light Amplification by Stimulated Emission of Radiation." A laser concentrates and emits light in a collimated (straight and narrow) beam.

The laser unit used in this grade control system is a compact and lightweight helium-neon gas type with a light-beam output power of 0.3 milliwatt at 6328 A wavelength from a 12-in. long laser tube. Basically, this laser consists of a glass tube, filled with helium and neon gases, with parallel mirrors at each end. One mirror is entirely reflective; the other is highly but not totally reflective. The gas molecules within the tube are activated electricity, causing the tube to glow. Light within the tube reflects off the mirrors. The light passing through the mirror that is not totally reflective becomes the monochromatic and directed brilliant red laser beam. The intensity of light in this collimated laser beam does not decrease with distance from the projection unit when projected in clear air. Dust and/or moisture in the air will reduce the effective range, but not to the extent as such atmospheric conditions limit human sight (such as in optical surveying).

System Design and Operation

The grade-control system developed utilizes a portable, tripod-mounted, low-power laser beam as an elevation reference and an electronic, machine-mounted receiver device which automatically operates a hydraulic, depth-regulation mechanism for controlling the elevation of the plow hitch point. Under normal conditions, the laser beam is projected above the proposed drain line and parallel to the design grade toward the drainage machine (Fig. 3). The laser-beam receiver device for intercepting the laser light is mounted on the frame of the drainage machine near the hitch point. This receiver consists of two closely spaced horizontal rows of photoelectric tubes (Fig. 4). These phototubes receive the

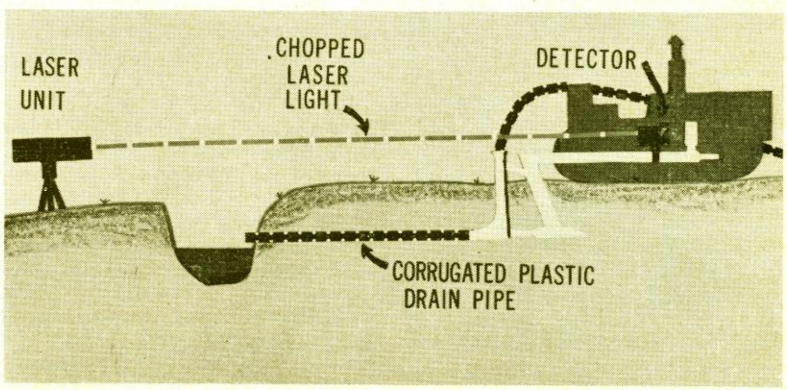

FIG. 3 Schematic of laser beam automatic depth and grade control system for the draintube plow.

laser light and transmit voltage signals to a master control box. The phototubes are mounted within a shallow box to reduce the electrical current flow in the phototube current caused by direct sunlight rays. Spectral density band-pass filter film can be used to shield the phototubes from sunlight yet pass the laser light, but it was not readily available at the time of the prototype development.

The tractor driver steers in a reasonably straight line across the field to maintain horizontal alignment with the projected laser beam; autosteering can be incorporated into the control system if desired. The principle of the automatic grade-control operation is to maintain the vertical position of the receiver unit such that the laser beam shines exactly centered between the two rows of phototubes. Any time the laser light shines above or below the exact center of the receiver, an electrical "imbalance" is created by a difference in voltage output of the two rows of phototubes. This voltage difference is very sensitive to small vertical displacements of the receiver from the centerline of the laser-beam, because the light intensity across the diameter of the laser-beam is distributed in a Gaussian wavefront. As the detector moves off-center of the laser-beam reference, the light energy received decreases very rapidly for one row of phototubes and increases very rapidly for the other row. The polarity (direction) of the imbalance is discriminated in the master control box which automatically activates a solenoid valve to adjust hydraulically the draintube-plow hitch-point position to maintain the desired drain depth and gradient. The system was designed to operate with a "pulsed-sampling" mode of control which causes the hydraulic depth-adjusting cylinders to move in small but rapid increments or "steps." If large ground surface irregularities are encountered, the master control box causes the cylinders to move in large steps. This provides a very sensitive but stable mode of control.

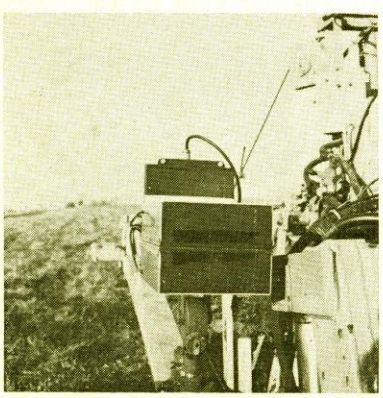

FIG. 4 Laser beam receiver device, consisting of two horizontal rows of phototubes, is mounted on frame of draintube plow.

The laser light beam is mechanically "chopped" by a motor-mounted slotted blade so that it is transmitted at a frequency of 150 cycles per second (Fig. 5). Electronic filters in the receiver unit circuitry pass voltage only at this frequency, thus the performance of the system is not affected by extraneous light, including reflected sunlight.

Because the laser light beam is slightly divergent, as it is emitted by the laser unit and thus becomes larger in diameter with distance, a 10-power telescope is mounted in front of the laser to decrease the divergence or further collimate the light beam (Fig. 5). With this telescope the light beam is about ½ in. in diameter at the telescope and expands to about 5 in. in diameter at a distance of 1500 ft§.

Field Test Results

Following preliminary testing and adjustment of the autocontrol system on an analog computer using simulation techniques‖, selected field tests were conducted to evaluate and study the control-systems performance. To date, the laser-beam-actuated grading system has controlled the draintube plow depth accurately at distances up to 1500 ft from the laser source. At this range the control circuit made corrections for vertical deviations of the hitch point as small as ⅜ in. from the centerline of the laser-beam reference; the hitch point was maintained within approximately ± 1 in. of the desired elevation at all times. Similar results are expected for ranges of 2500 ft or more. The automatic grade-control system is sensitive and rapid enough to respond to normal ground-surface irregularities without excessive "hunting" for the following conditions and system parameters: (**a**) tractor ground speed up to 2 ft per sec (**b**) a 2.5-in.-per-sec rate of up-and-down motion for the plow's hitch point; and (**c**) a stepping frequency for the hydraulic cylinder or hitch-point motion of one "step" every two-thirds second.

Because the moling point of the plow is located 10 ft behind the plow hitch, fluctuations in the operating depth of the moling point are much less than changes in the vertical position of the hitch point on the tractor. Thus, small deviations of the hitch point from the desired line of travel are smoothed out at the moling point. With the degree of control of the hitch-point position that is possible with this automatic system, for most conditions, deviations of the drain pipe from design grade are insignificant.

§ For a more detailed description of the components used in the laser projector and the receiver device of the grade-control system, refer to "Laser Beam for Autocontrol in Pipe-Laying," by J. L. Fouss and R. C. Reeve, "Laser Focus," December 1968.

‖ The analog computer simulation of the autocontrol system is to be reported by the author in a future paper.

FIG. 5 Portable, tripod-mounted laser beam projection unit. Cover removed to show components: He-Ne gas laser, 150 cps beam "chopper," and 10-power collimating telescope. Unit is "sighted-in" as shown to establish laser-beam grading reference; after initial setup, battery-powered unit operates unattended.

Current and Future Research

Experiments have been conducted with a laser beam that is optically spread by a special telescope into a thin horizontal reference plane (sector of circle). Projecting this modified laser beam over a field will make it possible to lay more than one drain for each setup of the laser projection unit, and steering the machine in a straight line will not be required. Tests include the use of a 1-milliwatt helium-neon gas laser projected into a 1 to 2-in. thick horizontal planner beam of 13-deg angular spread. The laser-beam receiver described above is operational at a range of 500 ft from this new type laser beam projector unit. The phototubes in the receiver unit will be replaced by photomultiplier tubes so that the sensitivity and range of the original system can be retained in this modified grade control system. Ultimately it may be possible to optically spread the laser beam into a 90-deg "pie slice," which will establish an elevation reference plane over an entire field with only one setup of the laser projection unit in one corner of the field. This latter approach also lends itself to the simultaneous operation of more than one drainage machine in the same field using a common laser-beam reference plane. The newly developed laser-plane reference generated by a sweeping or rotating laser source also shows promise in this regard¶.

The grade control system presently

¶ The "Laserplane System of Grading and Surveying" by Laserplane Corp., Dayton, Ohio.

used on the draintube plow can be adapted to various types of equipment that require guidance and/or elevation control. For example, it can be adopted to provide both automatic steering and depth control on trenching machines currently being used to install subsurface drains. With modification in the grade control system as described above, adaptations are possible to other machines for such operations as earthmoving, land leveling, ditching, road grading, etc., not only for agricultural purposes but for civil and military projects as well.

Comments

From a research and development standpoint, structural stability of the corrugated plastic drains is of the prime concern. In terms of life of the plastic material, most of the plastics presently in use are essentially inert to microorganisms and chemicals found in the soil.

For the small-diameter plastic drains, grade control is probably more important than hydraulic capacity. This is particularly true in areas requiring intensive drainage where close lateral drain spacings are needed; the closer the laterals are spaced, the less water each drain must carry for a given drainage coefficient. In many soils, the hydraulic conductivity of the soil rather than the hydraulic capacity of the drain limits outflow of the drain.

The draintube plow installation of corrugated plastic tubing looks promising as a means for more effective and more economical field drainage. The draintube plow eliminates the need for ditching and backfilling; the corrugated plastic drain tubing is lightweight, low cost, and can be easily handled in coils; and the laser-beam automatic grade-control system makes high-speed installation of subsurface drainage a reality. With the draintube plow equipment, 2,000 ft or more of corrugated plastic drain can be installed per hour under many field conditions. This is about the amount of draintile laid in one-half day with present trenching machines. The low installation charge with the draintube plow, now estimated at about 2 cents per ft, could result in a cost reduction of one-third or more for the installed farm drainage system in comparison to the cost for conventional tiling.

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