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DESIGN AND CONSTRUCTION OF A LARGE MONOLITH LYSIMETER SUITABLE FOR REMOTE SITES (NOTE)

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ABSTRACT

The design and construction of a 6 m^2 undisturbed-monolith lysimeter, containing nine narrow-leaved snow tussocks and weighing 8.5 t, are described. The methods described are suitable for remote sites and minimise the use of heavy equipment.

INTRODUCTION

With recent improvements in data-logger technology, lysimeters have become potentially attractive tools for studies in remote areas, and for some sites provide the only feasible way of separating evaporative components of the water balance. In this technical note we describe the design and construction of a large, undisturbed monolith [1] lysimeter at a remote site in Glendhu State Forest, South Island, New Zealand, some 21 km from the nearest small town. The monolith is 6 m^2 in area, and weighs approximately 8.5 t. The use of complex or heavy equipment and disturbance of the lysimeter site during construction were both minimised by the methods adopted.

The lysimeter was built for a research project by Geography Department, Otago University, under contract to Forest Research Institute, to measure interception loss and transpiration by narrow-leaved snow tussock (D. Campbell, unpublished data and Ph.D. thesis in preparation).

DESIGN CONSIDERATIONS

Design of the lysimeter was subject to two conflicting constraints: a large surface area was needed to contain 5-10 in-situ tussock plants, but the weight and overhang capacities of the balance mechanism used to weigh the monolith imposed practical limits on the area. A mechanical balance of the Aspendale type, designed and constructed by CSIRO Division of Meteorological Physics (McIlroy and Sumner, 1961), was loaned for the study by CSIRO Division of Plant Industry. It had a design capacity of approximately 6.8 t and was built for a monolith 1.6 m in diameter (2 m^2 area). This design capacity was considered conservative by 25% (F.X. Dunin, CSIRO, pers. comm., 1983) so a maximum monolith weight of 8.5 t was considered permissible.

An approximate size of 2.8 m diameter (6 m^2 area) and 0.7 m depth was

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[1] Monolith is used in the sense that the lysimeter contains an undisturbed block of soil and original vegetation.

chosen. The depth of 0.7 m, an estimated saturated bulk density of 1.8 t/m^3 for the soil mass, and an area of 6 m^2 gave a soil mass of 7.5 t. The weight of the monolith container was estimated to be 1 t. For a cylindrical monolith, these dimensions give a radial overhang of 0.6 m beyond the balance mechanism. This amount of overhang (75% of the radius of the area directly supported by the balance) was considered acceptable provided the monolith container was stiffened to prevent flexing.

At the study site there was 1.2 m of soil over bedrock and the depth to the base of the B soil horizon was 0.7 m. The chosen depth made it possible to build a lysimeter containing the full thickness of the A and B soil horizons, and provide room for the balance mechanism (30 cm high) and a supporting base 20 cm thick, without excavating into bedrock. Rooting depth of the tussock grasses at the site is 25-30 cm and coincides approximately with the A horizon thickness.

CONSTRUCTION

The monolith and the lysimeter pit were constructed adjacent to each other so that only one visit to the site with a heavy crane was needed to place the balance and monolith in the pit.

Installation of Monolith and Pit Wall.

Both the monolith and pit walls were formed by driving cylinders of the appropriate diameter (rolled from 12 mm mild steel and seam-welded) vertically into the ground. The bottom edge of each cylinder was bevelled outwards at 45 degrees to provide a cutting edge. A radial clearance of 20 mm between the outer surface of the monolith and the inside of the pit wall was adopted as the minimum achievable. In practice, the larger cylinder became distorted during transport and unloading so that the circumference of the pit wall had to be increased to fit the monolith into the non-circular pit. A radial clearance of 50 mm to allow for possible distortion is probably desirable.

A protective ring fitting inside either cylinder and overlapping the top of the cylinder wall was used to protect the cylinders during driving (Fig. 1). The driving ring was bolted to the cylinder at 6 points and was braced across its upper opening between the impact points by a triangle of rectangular hollow section (RHS) steel (Fig. 1). The driving ring was also used to transport the cylinders from roadside to the site, and to lift the completed monolith with the crane. The triangular bracing restrained distortion of the top of the cylinders during both driving and lifting.

Three conventional fence-post drivers, driven from the power take-offs of farm tractors, were used to drive each cylinder into the ground. Frequent level checks across the triangular braces and around the driving ring circumference ensured that the cylinders were driven vertically. At the beginning of the driving operation additional force was applied at the centre of the driving ring (by the bucket of a small tracked excavator) to restrain bounce of the cylinder-ring assembly (Fig. 1).

The pit-wall cylinder (1.2 m deep) was driven first and excavated inside by the tracked exavator. A trench for the access tunnel was also excavated and an access opening was cut into the side of the pit wall with oxy-acetylene

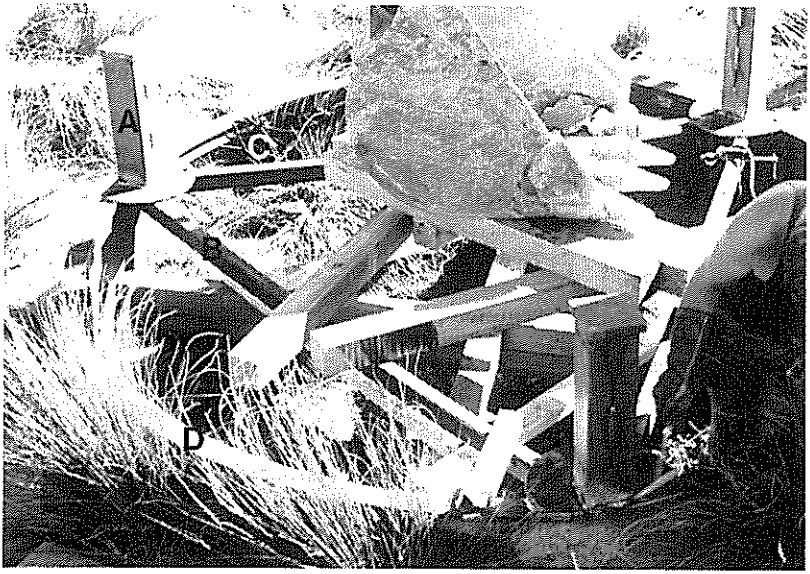

FIG. 1—Cylinder driving and lifting ring attached to partly driven cylinder. A-Impact pads for post-drivers (post-drivers not shown). B-RHS (76x38x4 mm) steel triangular brace. C-Ring fitting inside monolith cylinder and bolted at 6 points. Spacer blocks were used to fit ring to the larger cylinder. D-Protective overlap (20 mm MS) broad enough to cover top edge of either cylinder.

cutting equipment. The fit of the monolith cylinder into the pit was then tested and adjusted. The monolith cylinder (0.7 m deep) was then driven into the ground some 5 m from the pit location, within the operating radius of the lifting crane which was located between the two sites. Two trenches about 1 m wide and 0.8 m deep and a pit 3 m x 2 m and 0.8 m deep, forming three sides of a square surrounding the monolith cylinder, were then excavated to provide access for installing the monolith base.

Transporting the cylinders to the site from the roadside (some 100 m), fitting the driving ring to the two cylinders, driving the cylinders, excavating the pit and access tunnel trench, cutting the access opening in the pit wall, and excavating the pit and trenches for installing the base sections took approximately two days.

Installation of the Monolith Base

The monolith base was formed of 12 mm plate steel, driven in sections underneath the monolith cylinder in a guide frame (Fig. 2). The guide frame and its supporting fillets were bolted to the cylinder using pre-drilled and threaded holes which had been plugged with set screws while the cylinder was driven.

Two 10-t hydraulic rams and one 30-t hydraulic ram, each powered independently by hand pumps, provided the driving force. The larger ram provided the main driving force along the centreline of the base-plate sections.

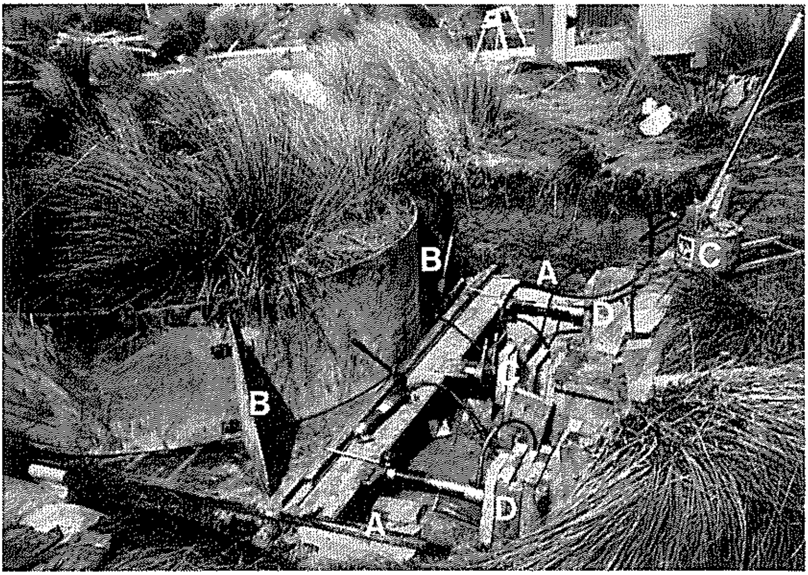

FIG. 2—Base-plate sections being driven under monolith cylinder. A-Slotted RHS tube forming side of guide frame. B-Fillet attaching guide frame to cylinder. C-Main 30-t driving ram and pump. D-"Steering" rams (10 t).

The two smaller rams were used at either end of the sections to "steer" them in the guide frame (Fig. 2), controlling rotation around a vertical axis. Each base plate section was 2.9 m wide and 0.58 m from leading to trailing edge. The sections were bevelled at 45 degrees from the bottom surface towards the leading long edge, and were bevelled at 45 degrees from the top surface towards the trailing long edge. Joiner strips between the base sections were 0.2 m from leading to trailing edge, bevelled 45 degrees from the bottom surface towards the leading edge and square on the trailing edge. The joiner strips and base sections were pre-drilled and threaded to accept 1" (25.4 mm) diameter countersunk machine screws to join successive base sections together as they were driven under the cylinder.

The guide frame located the base plate sections firmly against the base of the cylinder and restrained both sideways motion and rotation about a horizontal axis of the bottom sections as they were driven. Positive location of the sections in the frame was provided by 10 mm diameter guide rods welded onto the lower surface of both ends of each section. These guide rods ran inside slotted RHS tubes forming each side of the guide frame (Fig. 2).

The guide frame extended approximately 1 m back from the monolith into the ram pit to allow location and assembly of each base section into the frame before driving. The back wall of the ram pit was reinforced with baulks of 300 x 300 mm timber against which the hydraulic rams were blocked. Additional blocks were used as the ram stroke was taken up, until each section had been driven sufficiently far for the next section to be attached. The base sections were driven towards the unexcavated side of the monolith cylinder where undisturbed ground behind the cylinder prevented movement of the complete monolith.

After the base plate was completely driven under the cylinder it was arc-welded to the bottom edge of the cylinder and the surplus plate cut off with oxy-acetylene equipment. Cut and welded surfaces were neutralised (Jenolite RRN) and painted with red lead primer to reduce subsequent corrosion, but other steel surfaces were not treated. The guide frame and its supports were detached from the monolith and all holes were plugged with set screws. Thread-locking compound (Loctite) and RTV silicone rubber were used to ensure the set screws were firmly locked and sealed watertight. The driving ring was then reattached to the top of the Monolith walls ready for lifting with the crane.

Driving of the bottom plate took three days because problems were experienced with the leading edge of the base plate rising into the centre of the cylinder and creating resistance to driving the plate under the monolith. The V-shaped (in plan) leading edge of the first base-plate section had too long a point in relation to the length of the ends of the section within the guide frame, which was insufficient to control rotation about the horizontal axis. This problem was diagnosed after about 1/4 of the base plate had been driven and was then controlled by excavating small increments under the base sections by hand as they were driven. Rotation of the base sections was controlled sufficiently to prevent both permanent distortion of the base and cracking or distortion of the soil monolith. Using a shallower V on the leading edge of the first base section, and ensuring that at least 0.4 m of the end of the plate is restrained by the guide frame slot, would fully control rotation and reduce the time taken to drive the base-plate sections to about one day.

Monolith Sub-base Stiffening and Connection to Balance Frame

Because of the possibility of flexure at each base-plate joint, five cross braces of 64 x 38 x 4.0mm RHS steel on edge, running the full chord-width of the monolith, were welded to the base of the monolith at approximately 0.4m centres. A triangular load frame of double RHS steel matching the dimensions of the upper balance frame was welded to the underside of these cross braces, correctly oriented, and centred under the monolith cylinder. The load frame and cross braces were pre-assembled and supported on blocks. The monolith was then lifted by crane onto the assembly for welding. No flexing of the monolith base was detected during the lifting operation, suggesting that the cross-bracing may not be essential.

Pit Floor and Monolith-drainage System

The floor of the lysimeter pit serves several purposes:

1) to support the balance and monolith,
2) to support hydraulic rams for raising and lowering the monolith off and onto the balance,
3) to segregate monolith drainage from rainfall entering the pit through the gap between the monolith and pit wall and condensation dripping from pit or monolith walls, and
4) to catch drainage from the monolith and direct the drainage to measuring instruments.

The main design requirement was to provide adequate floor strength for purposes 1) and 2) and to prevent superficial cracking which could affect the accuracy of drainage measurements. A 20 cm-thick concrete floor reinforced with two layers of 10 cm mesh (6 mm rod diameter) was used. The 8.5 t load of the monolith was spread over 0.3 m^2 of the floor surface using load-spreading plates of 12 mm mild steel under the three balance feet. This loading is well within the capacity of unreinforced concrete. The reinforcing mesh was primarily to control cracking induced by thermal expansion and contraction, particularly along the centre-lines of the drainage channels (see below). The upper surface of the floor was shaped to achieve purposes 3) and 4).

A 20 cm-wide outer ring of the floor surface slopes outwards to collect rainfall and condensation. Drainage pipes dispose of accumulated water. A drip ring on the base of the monolith wall ensures that moisture on the monolith wall drips onto the outer ring of the floor. A wall of 3 mm-thick PVC set into the concrete floor inside the circumference of the drip ring separates the outer ring from the remainder of the floor.

The load-spreading plates for the balance feet and raising/lowering system sit on three flat truncated sectors of the inner floor (Fig. 3). A Y-shaped (in plan) drainage channel with a gradient of 3% along the three arms is located between the three flat pads. The drainage channel is V-shaped in cross section, and 10 cm wide at the top of the V. The floor between the flat pads and the drainage channel slopes towards the drainage channel arms at 3-5% gradient. A waterproof surface coating of neoprene rubber (Bostick N-60) was applied to the concrete surface in several coats after curing of the concrete for one month.

The base of the monolith is drained by some 400 pre-drilled 3 mm-diameter holes in the base-plate sections. The pattern and location of drain holes was designed to minimise drainage dripping directly onto the balance mechanism or the flat floor sections. Joints between the base-plate sections were welded closed for at least 40 cm in from the walls of the monolith to prevent drainage from dripping through the joints onto the outer ring of the floor.

Water collected from drainage of the monolith is piped to a tipping bucket gauge (0.6 litres/tip) in the access tunnel (Fig. 3) and subsequently drained to waste downhill from the access tunnel.

Monolith/Raising/Lowering System

A system for slowly raising and lowering the monolith off and onto the balance mechanism without causing mechanical damage is needed. Ability to raise the monolith is also needed for repairs and adjustment to the balance mechanism. Three 5-t capacity double-acting hydraulic rams located on the same radii as the three balance feet, but approximately 0.4 m further out from the centre of the monolith (Fig. 3), provide these capabilities. The rams are centred under three of the cross-braces welded to the monolith base. Individual flow-control valves for each ram allow compensation for different line lengths to each ram so that the monolith can be raised and lowered by equal amounts at each ram. An additional fine needle valve, in series with a manifold for the lower ram valves, provides extremely fine flow control to and from the lower rams. Snap-off hydraulic connectors were used to connect

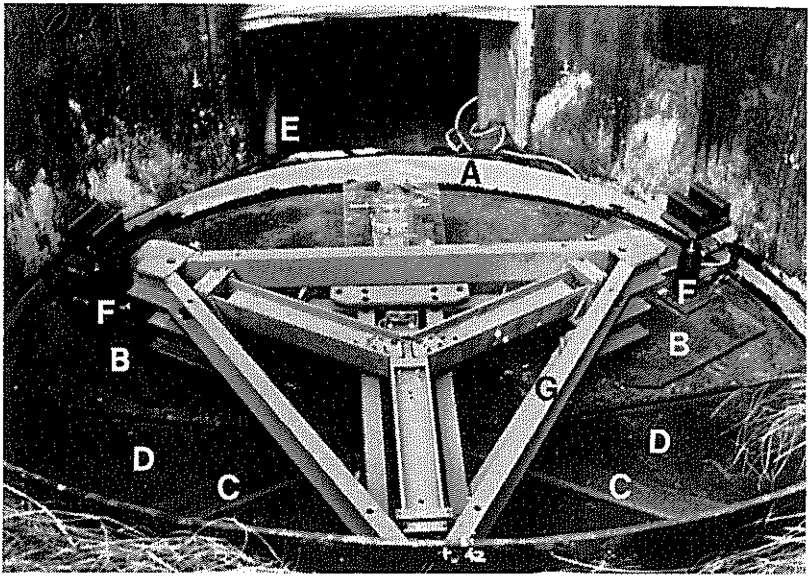

FIG. 3—Pit floor, access tunnel, hydraulic system and balance. A-PVC wall dividing inner and outer floor areas. B-Load-spreading plates under balance feet and hydraulic rams on flat sectors of inner floor. C-Drainage channels (3rd arm leading to tunnel is obscured by balance). D-Sloping floor areas directing drainage to channels. E-Drainage pipe to tipping bucket in access tunnel. F-Hydraulic rams for raising and lowering monolith (manifold and valves in access tunnel). G-Upper frame of balance mechanism.

a two-way, hand-operated hydraulic pump and hydraulic fluid reservoir to the rams as needed.

The hydraulic pump was used to raise the monolith and to pump the rams up under pressure when the monolith was placed into the pit with the crane. The monolith was lowered onto the balance by bleeding hydraulic fluid back into the pump reservoir. The overall lowering rate was controlled by the needle valve and relative rates controlled by the valves on each ram line. Positive indication of the position of the monolith relative to the balance frame at each of the three corners is provided by spring-loaded 10 Kohm slide potentiometers read by separate multimeters. These allow measurement of the distance between monolith and balance frame to better than 0.5 mm in the range 0-5 mm. The rams are fully retracted after the monolith is resting on the balance by pumping into the upper ram inlets. With the rams fully retracted there is no possibility of interference between the rams and the monolith during balance oscillations caused by load changes or wind gusts.

SITE DISTURBANCE

Site disturbance was carefully controlled. The vegetation and soil within the monolith were completely undisturbed by the construction process. Disturbance around the pit site was confined to a narrow ring (0.5 m wide) around the pit rim, except for an arc of about 60 degrees disturbed by excavation for the access tunnel. A hole approximately 4 m square was created at the site where the monolith was formed, and this was backfilled with spoil from the tunnel and pit excavations. Topsoil stockpiled separately from the excavations was used to cover the backfill, and all excess spoil was removed from the site. Tussocks of various sizes were transplanted into all disturbed ground at a qualitatively similar density to the undisturbed areas. Intertussock areas were seeded with a Chewings Fescue/browntop grass mix similar to the mix of exotic pasture species in intertussock spaces in the undistrubed areas. Vehicle and foot access to the site was confined to a single track at all times, and the 20 m of track nearest to the lysimeter was replanted with tussock, seeded and fertilised when construction was complete.

BALANCE RANGE, SENSITIVITY AND CALIBRATION

The balance is mechanically identical to that described by McIlroy and Sumner (1961) except for the following:

1) A larger tare weight is used because of the larger monolith weight;
2) the automatic balancing range was increased from 50 mm to 100 mm by using a 6 times larger traversing weight (includes the effect of a three-fold increase in area) in the automatic balancing mechanism.

The control system for the balance was redesigned by CSIRO Division of Plant Industry, with electro-mechanical controls being replaced by solid state devices. An out-of-balance state is detected by LED-Phototransistor switches which initiate, and control the direction of, traversing of a weight along the secondary lever of the balance, which restores a state of balance (secondary lever horizontal). The distance traversed along the secondary lever to restore balance is detected in units of 1/10th rotation of the drive shaft by the interruption of additional LED-Phototransistor switches. Outputs from the control and detection system are in pulse form, sent to event counting channels of the data logger, with separate channels for increasing and decreasing weight changes. One pulse represents 0.05 mm (nominal) water equivalent, or 300 gm change in mass. This resolution can be increased if desired to 0.025 mm or less (as in the original balance) by halving the size of the traversing weight, but at the expense of halving the automatic balancing range. The larger range was chosen as appropriate for the remote site, to minimise the possibility of the balance going out of range during a rainstorm, with subsequent loss of data. (The balance mechanism is protected from overloads by switches which disable the drive when the traversing weight reaches either end of its range.) Adjustment of the balance to one or other end of the range in preparation for drying periods or rainstorms is done by adding calibrated ranging weights to the secondary lever.

The balance was calibrated approximately by adding or removing known loads equivalent to its full ranges and adjusting the traversing weight until the approximately correct pulse count was obtained. Counts were taken in both increasing and decreasing traverses. Finer calibration and adjustment of the traversing weight was then undertaken over smaller count ranges at several positions within the total range, again in both increasing and decreasing directions, until repeatable (to 1 count in 200) pulse counts were obtainable in either direction at any point in the total range, after adding or removing calibrated ranging weights on the secondary lever. A final calibration constant was then determined by the addition and removal of precisely-known weights to the monolith after final assembly and a settling-in period of several months, and by precisely measuring the area of the monolith. Sensitivity is checked frequently by the addition and removal of precise weights corresponding to a few counts.

Pulse counts from the balance and drainage system are recorded by a "Pacific" data logger, backed up by electronic counters for each channel. An additional check on the net change in lysimeter weight is obtained from a mechanical counter on the drive shaft of the balancing mechanism, which records the net change in position of the traversing weight to 1/10th rotation of the drive shaft.

Wind-induced fluctuations are damped electronically using a variable time during which an out-of-balance condition must be sustained before the drive system for the traversing weight is actuated. This duration can be varied from 0 to about 17 seconds. A setting of 3 seconds has been found to eliminate "hunting" caused by wind, whilst providing a near-instantaneous and repeatable response to addition or subtraction of a 300 gm weight to the monolith.

THE LYSIMETER AS A REPRESENTATION OF SURROUNDINGS

The lysimeter is believed to be representative of its surroundings and of similar near-flat sites (which form only a small proportion of the landscape naturally covered with this vegetation). The vegetation was undisturbed by the construction; the soil monolith did not crack or distort, and no gaps formed between the monolith walls and the soil. The monolith contains the complete A and B soil horizons, and is roughly equal to the typical full thickness of the soil profile overlying bedrock in the study area.

The thermal regime of soil monoliths in steel containers can differ from that in the surrounding ground, and instrumentation was installed to measure both radial and vertical temperature profiles (D. Campbell, unpublished data). Soil water potential and content profiles are also influenced by the imposition of zero potential at the free-draining base of the monolith. The soil water potential inside and outside the monolith was measured at 30 cm and 50 cm depths, and at 90 cm depth outside the monolith, using mercury-manometer tensiometers (D. Campbell, unpublished data).

SUMMARY

The design and construction methods for a large-monolith lysimeter are described. The method of construction is suitable for use at remote sites provided 2-wheel drive road access close to the site is available. The use of heavy and complex machinery is minimised, and the complete construction and assembly process can be achieved with only a single 1-2 day visit to the site by a heavy crane. The construction methods described could probably be used for larger monoliths up to 4 m in diameter or 4 m square with only minor adaptation.

ACKNOWLEDGEMENTS

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