SUBSOIL PAVEMENT DRAINS

Panel Drains v Round Pipe Comparison

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ABSTRACT

Liaison with Australian state road authorities in recent years has been the impetus for reviewing current accepted drainage practice, with tested, technically advanced, cost effective products now readily available in Australia. Premature pavement failure commonly caused by slow drainage response has benefited from design methods incorporating geo-composite panel drains, giving improved drainage response times, high flow infiltration, efficient filtration and economical installation.

Pipe stiffness test results highlight the difference in service performance to show that geo-composite panel drains are superior in structural capacity whilst their rigidity compliments efficient installation.

Comparison of factors affecting inflow capacity and outflow discharge identify the optimum flow performance of panel drains. Inflow considerations can be shown to be more relevant criteria than design for discharge capacity. Geotextile filtration performance is an integral part of geo-composite drainage systems with research highlighting the correct assessment of EOS being critical to efficient long term drainage sustainability.

Ttype of backfill used, permeability rates for *in situ* soil, pavement materials and drainage backfill play an integral part in overall design. Design practice should consider location of the system, permeability rates for *in situ* materials and geotextile filtration along with drainage inflow and discharge capacity.

1 INTRODUCTION

Geo-composite panel drain (GPD) systems are accepted as an effective and cost efficient alternative to conventional round pipe drainage in highway applications. Design methods incorporating geo-composite panel drains (GDP) can give improved drainage response times, with savings in material and construction costs, as they incorporate high flow infiltration due to higher trench profile. GPD's provide a flow path with increased catchment surface area, giving fast response times for pavement drainage applications. In specifying a GPD like round pipe, design and material specifications must address several key areas: *in situ* soil/pavement permeability, service loads, geotextile filtration performance, drainage inflow and discharge, installation costs and outlet configuration.

The following paper compares and outlines test results, analysis of specifications, inflow characteristics, filtration and load bearing capacity to demonstrate the principal differences and in service performance of Megaflo 150 mm and 300 mm GPD compared to 100 mm diameter Class 1000 round pipe.

Figure 1: Megaflo.

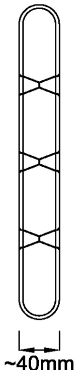

Figure 2: Megaflo Section.

2 PRODUCTS

2.1 GEOCOMPOSITE DRAINAGE PANEL

The GPD is a ribbed HDPE flat panel core that is slotted to allow water infiltration, fully encapsulated in a continuous filament, non-woven needle punched geotextile, which conforms to Main Roads MRS11.27 and RTA R63 A1 specifications, amongst others. The ribbed panel fully supports the geotextile and provides support to the filter to maintain filtration properties and prevent soil fines from entering the system. Internal supports give a significant advantage in terms of horizontal and vertical compressive strength over other subsoil drainage systems.

Due to its relatively high compressive modulus and structural rigidity preventing deflection, a GDP does not require installation with specific backfill material placement methods and standards.

Figure 3: Class 1000 round Pipe

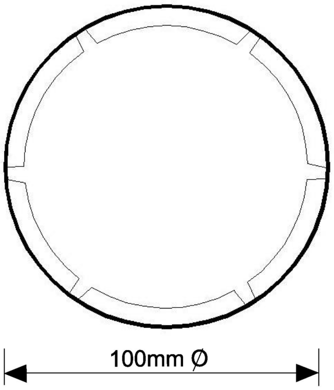

Figure 4: 100 dia. pipe section

2.2 ROUND PIPE

Class 1000 round pipe is commonly specified as a subsoil drainage system and conforms to Main Roads MRS11.27 and RTA R63 A1 specifications, amongst others. It is 100 mm in outside diameter, ribbed with 3 slots per corrugation, with 3 in the adjacent corrugation being orientated at an alternate angle. Class 1000 pipe is manufactured to withstand vertical loading deflection of 5% under load to reflect 1000 kN/m/m stiffness and is covered in a knitted geotextile sock, generally with a pore size specification ranging between 250 um to 500 um.

3 SPECIFICATIONS

Test requirements critical to in service performance under loaded conditions, are pipe stiffness and filtration. Mechanical pipe testing is performed to AS2439 Part 1 to determine conformance to seven standard requirements for pipe stiffness. Australian standard AS2566 (Plastics pipe laying design) allows for only 5% deflection during installation. Therefore it follows that under traffic load round pipe requires the load distribution properties of well graded and compacted backfill material to prevent excessive deflection and consequent decrease in internal area as shown in Figure 5 and Table 3.

AS 2566 describes criteria for the three phases of construction required when installing plastic pipe as follows;

1. Trench bedding – minimum 80 mm deep continuous levelling layer
2. Compaction – granular filter backfill placed and tamped in 80 mm deep layers
3. Backfill – structural material placed above filter backfill. (300mm above pipe soffit).

3.1 GEOTEXTILE FILTER

Retention of fines is critical to drainage inflow and discharge capacity, geotextile filtration forming an integral part of geo-composite drainage systems. Comparison of performance of two commonly used geotextile filters identifies incompatibility of filter sock with finer drainage mediums. Whilst commonly specified washed sand backfill is compatible with commonly available filtration grade geotextile, this medium would flow through a standard filter sock.

Table 1 outlines and compares the properties and flow rates of the geotextile filter that encapsulates the cores for GPD and knitted sock provided with round pipe:

Table 1: Geotextile/Knitted Sock Properties.

Properties	Units	Filter geotextile	Knitted Sock	Test Method
Mechanical				
Wide Width Tensile Strength	kN/m	10.2	8	AS3706.2
G Rating	G	1500	1000	Austroads
Hydraulic				
Pore Size	µm	110	500	AS3706.7
Flow Rate	$l/m^2/s$	235	-	AS3706.9

3.2 DRAINAGE CORE

Table 2 outlines and the core size, slot size, internal area and clear water opening GDP and round pipe drainage cores;

Table 2: Physical dimensions for GDP and round pipe drainage cores.

Mechanical Properties	Units	GPD 150mm	GPD 300mm	Round Pipe	Test Method
Core Size	mm	40 x 170	40 x 300	100 dia.	ASTM D2122
Slot dimension	mm	2 x 25	2 x 25	1.2 x 7.4	ASTM D2122
No. Slots	No./m	235	470	352	-
Clear Water Opening	mm^2/m	24,000	49,500	7668	AS2439
Internal Area	mm^2	4000	6400	6400	-

3.3 STIFFNESS

Deflection resistance in backfilled trench conditions is simulated in testing to ASTM D6244, (Kentucky Test) with a 156 kPa vertical load applied (load determined by field trial results) to show the measured loss of internal area of a drainage core and reflects a decrease in internal area, due to deflection. Testing by Geosynthetic Testing Services has revealed deflection in excess of 5%, showing that round pipe subject to high load and poor backfill construction, can experience loss of internal area and consequent flow capacity. A GPD is unaffected under the same test conditions due to its design, shape and ribbed profile with the internal support structure providing strength and maintaining a clear flow path.

Higher stiffness prevents excessive deflection of the drainage core and provides resistance to backfill settlement and localised pavement failure. AS2439 stiffness test for deflection of pipe simulates unrestrained vertical loading. The graphical representation in Figure 7 shows vertical deflection displacement under compressive force. Vertical lines indicate 5% and 10% deflection millimetres for the 100 mm diameter Class 1000 pipe and Megaflo 150 mm high GPD. Product testing by Geosynthetic Testing Services to modified AS2439 method reveals that deflection of the GPD suffers 50 percent of the deflection of round pipe for the same loading.

Calculated stiffness, expressed in kN/m/m length of core is over 80 percent higher for a GPD over round pipe. Calculated stiffness for Class 1000 pipe tested shows results in excess of specifications (Table 3).

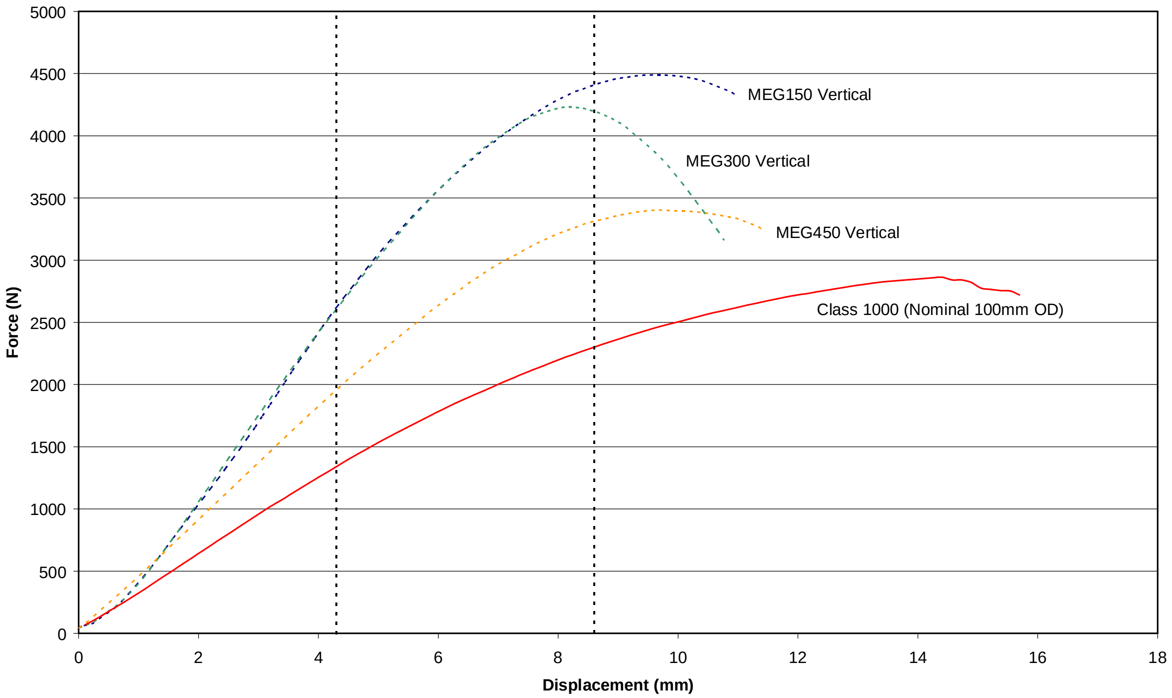

Figure 5: GPD Vs Round Pipe Deflection.

Table 3: Performance values.

Mechanical Properties	Units	GPD 150mm	GPD 300mm	Round Pipe	Test Method
Average Pipe Stiffness (at 5% deflection)	kN/m/m	1650	900	1100	AS2439.1

Note: Yield results determined are from product testing. (Geosynthetic Testing Services).

4 PERFORMANCE

4.1 INFLOW CAPACITY

It can be shown that higher rates of water extraction from pavements do not rely on trench width, i.e. horizontal water flow through the trench backfill medium to the GDP/pipe. Water inflow can be considered to flow predominately vertically through permeable backfill material to reach the installed level of the drainage core. It can be demonstrated by calculating inflow rates to top and side slots in both a GPD and a round pipe that there is equivalent performance for GPD in a 200 mm trench compared to a 100 diameter round pipe installed in a 300mm wide conventionally designed sub-soil drain.

Inflow capacity of a sub-soil drainage core is governed by its catchment area, with higher slots near the top of the core receiving vertical flows and side slots accepting horizontal flows from adjacent backfill material. The GDP considered in this paper has four slots per corrugation and its design incorporates a water proof flow channel of 20 mm depth below the level of its lower slots. This effective freeboard provides a waterproof invert ensuring no regress of water at sub-grade level. The panel design gives an increased surface area for water inflow where vertical inflow is intercepted at the top of the geo-composite panel drain. GPD slotted area percentage is 3.5% of total surface area, making it 3.5 times the area of slotted area of round pipe (Figure 6).

Gerke (1987) shows that, for round pipe with a total of six inflow slots, two slots at the base will clog as a result of silting, leaving four slots to accept inflow. Two will accept vertical flow at higher infiltration rates whilst slots either side of the pipe rely on horizontal flow through the trench backfill medium. Class 1000 round pipe has three slots per corrugation, with one generally accepting vertical flow (Figure 7).

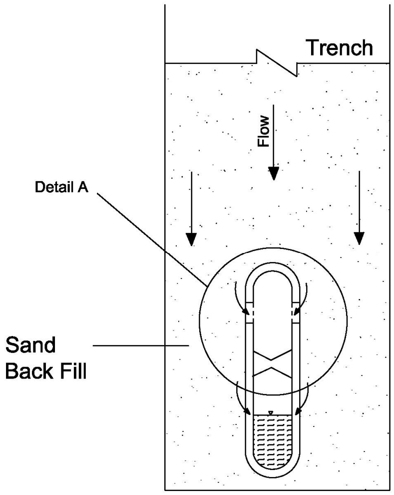

Figure 6: Typical Section – GPD.

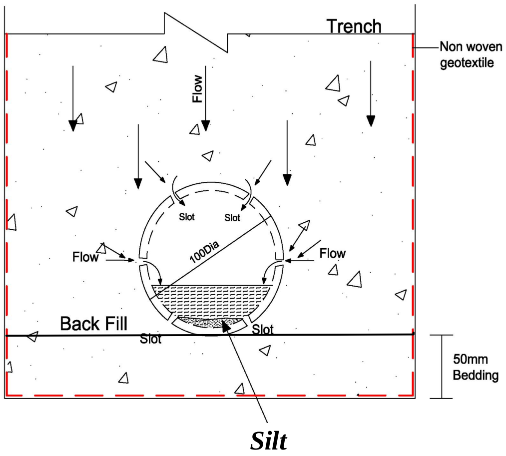

Figure 7: Typical Trench - Round Pipe.

Bernoulli’s equation for horizontal and vertical flow through slots considers drainage core catchment area. Measurement of the catchment area of round pipe for one of two top slots is 1/12 the pipe diameter, with a flow path of 30 mm long from pipe centre to the slot opening. Multiplied by the rib width of 17mm the catchment area is calculated at 510 square mm. A GDP by comparison, from top of panel to bottom of the highest slot is approx. 80mm, multiplied by the rib width of 17 mm, gives a catchment area of 1360 square mm, over 2.5 times that of round pipe.

Adapting Bernoulli’s equation (Gerke R.J) to calculate discharge flow to one slot, for flow:

$$q=1/3\ Dwkf$$

where:

q = discharge ul/sec,
D = pipe diameter,
w = rib width
kf = filter permeability

In simple terms, flow to one slot is calculated as the catchment area multiplied by the permeability of the surrounding backfill. Calculation of vertical inflow to the highest slots accepting vertical flow on a GPD, for an assumed washed sand backfill material permeability of 0.7 mm/sec, shows an increase of 2.5 times the inflow compared to round pipe. Horizontal inflow is governed by the length (width of trench) of the flow path to the side slots in the drainage core with flows lower in a narrower trench. Thus, with a GPD positioned centrally in a 200 mm wide trench, the horizontal flow in the narrower trench is lower, compared with the additional width of a 300 mm wide trench providing around 2 times the horizontal inflow rate.

However the higher inflow rates for vertical flow into the top slots of a GPD, when combined with lower flow to horizontal slots in a GPD installation, are equivalent inflow rates overall to a round pipe installed in a 300 mm wide trench. Therefore a GDP installed with a reduced trench width remains equivalent, because of efficient acceptance of vertical inflow. This design assumption can also reduce hydraulic flow head through faster response times. Slow response times result in seepage loss in the base of a drainage trench and results in water remaining in pavement base layers.

4.2 FILTRATION

Non-woven, needle punched geotextiles and knitted socks acting as secondary filters on GDPs and round pipe require design that addresses two important areas;

1. Retention of particles over 250um to prevent piping
2. Passing of fine particles in the <110um range to prevent clogging.

Round pipe knitted filter sock was originally manufactured to a specification of 250 um, however Australian suppliers specify a pore size of 500 um, potentially to cover the installed state peculiar to a knitted filter product where it can sustain a stretched condition during and after installation. Road authorities in Australia generally specify knitted sock with pore size criteria ranging between 100 um and 400 um. Non-woven geotextile filters are specified generally with a maximum pore size of 120 um. Its performance supported and substantiated by extensive testing and analysis of in service systems.

US paper 'Long Term Effectiveness of Agricultural Drainage Systems' (Mlynarek *et al.*, 1994) records results for retention capacity of filter sock and 200 gsm non-woven geotextile from tests performed on sock from exhumed backfill filter sand material. Immediately obvious is the excessive passing of particles through a knitted sock, above 75 um size, suggesting piping at unacceptable levels.

Results of percentage fines retained by geotextile/sock filters;

1. 200 gsm non-woven geotextile filter – 90% retained fines above 90 um
2. 120 gsm knitted filter sock – 32% fines retained above 90 um.

US research by Christopher and Holtz (1985) developed design procedures for geotextile filters for drainage with steady state flow conditions. Road pavement installations are often in areas of problem non-cohesive soils, e.g. silty clays with situations regarded as critical applications. Generally the envelope for retention of fines and prevention of piping in these soils ranges between 75 um and 250 um. Research by Christopher and Holtz (1985) has also shown that for non cohesive problem soils, a geotextile filter is designed to allow no more than 20% of particles passing 75 um.

By using a derived factor for geotextile filter (as opposed to layer of sand as a natural secondary filter) of 1.5, multiplied by design minimum passing particle size of 75 um, this procedure gives a recommended Equivalent Opening Size of 112 um. Thus performance of filter geotextile with a pore size of 110 um can be assumed to perform adequately.

4.3 RESPONSE TIME

Fast removal of water from the structural section of pavements can improve performance and longevity. Dempsey documents a four year research program by the Illinois Department of Transport on Interstate 57 commenced in 1991 that shows geo-composite panel drains responding more quickly and stopped flowing more quickly than conventional 100 mm pipe and gravel systems for the same rain event. In one event, on March 26, 1991, one of the geo-composites reached a maximum discharge in excess of 30 litres per minute approximately two hours after the start of the precipitation and had removed the free water from the pavement system in 6 hours, while the standard 100 mm pipe and gravel system reached a peak flow of 20 litres per minute, after responding one hour later than the fin drain and did not cease discharging water until 10 hours after the start of the rain event (Figure 8).

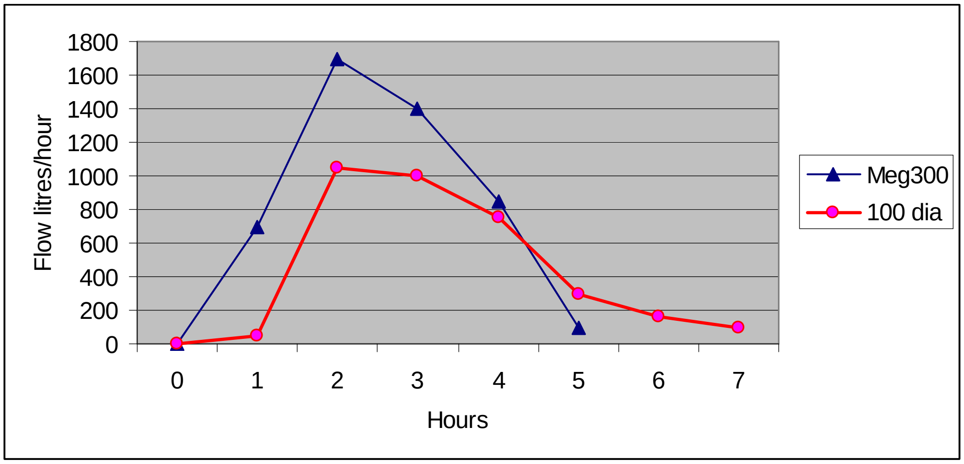

Figure 8: GPD v 100 dia. pipe response times and volumes for same rain event.

Also in Illinois, Dempsey (1989) monitored pavement performance on the FA180 near Morris, Illinois in 1989 and found a link between fast efficient drainage with fin drains (now termed GPD) and pavement performance. He assessed the road pavement by observations of joint faulting (cracking) and transverse faulting on outside lanes under traffic of around 2 million 8 tonne axle loads per year when comparing a fin drainage system with a 100 mm diameter round pipe. Dempsey measured the response times for each installation on opposite sides of the highway for the same rainfall event of approximately 100 mm for the month of April, and found that the fin drain system responded at faster rates and with higher flows than the conventional round pipe system. He ascertained that the critical time factor for drainage of pavement structural layers was two hours, the fin drain system responding immediately and reaching peak infiltration after only one hour.

5 DESIGN

5.1 PAVEMENT AND BACKFILL PERMEABILITY

The design for drainage system inflow rates adopts an accepted rule of thumb for flow capacity of trench backfill material of 10 times that of structural pavement material or adjacent *in situ* soil. The permeability of various pavement and trench backfill mediums has been the focus of much research, with permeability coefficient figures derived by Cedergren (Cedergren 1974) used in the calculation of flow rate capacity of pavement and drainage materials (Table 4).

Table 4: Permeability values for pavement and backfill materials

Drainage Medium	**Permeability = k** Um/sec
Fine Crushed Rock	~10
Open Graded Base Material	~25
Fine Washed Sand Backfill	~180
Coarse Washed Sand Backfill	~700
10/7 Screened rock Backfill	~1400

Flow rates of drainage backfill materials range from washed sand at approximately 40 times and 10 mm aggregate approximately 1000 times the flow rates calculated for pavement. Washed sand can therefore be assumed to be more than adequate as a backfill material.

5.2 INFLOW PERFORMANCE

Taking into account hydraulic head and infiltration area, flow rate calculations for various pavement and trench drainage materials assume that a point of saturation has been reached to equal the hydraulic head, hence rendering the hydraulic gradient equal to 1. Pavement drainage flow rates calculated for design permeability values are shown in Table 4.

Flow rate is based on: Hydraulic Gradient = 1 (unity)
Flow rate area calc = 1 sqm (exposed trench area)

Using Bernoulli's equation (Gerke R.J) to calculate inflow, it can be shown that inflow performance capacity of a 150 mm GPD, installed in a 200 mm wide trench, is equivalent when compared with standard installation of 100 mm diameter Class 1000 round pipe in a 300 mm trench (Table 5).

Table 5: Indicative flow Rates.

	Trench Width	**Backfill Material** k = 0.07 cm/sec	**No. corrugations**	**Inflow/corrugation** litres/min	**Inflow/metre** litres/min/m
150 mm GPD	200 mm	Washed Sand	61	0.39	23.8
100 mm dia. Class 1000 pipe	300 mm	Washed Sand	80	0.2	15.4

5.3 DESIGN FOR OUTLET SPACINGS

Taking into consideration permeability rates for road pavement width and adjacent shoulder area, infiltration rates can be calculated to show that the performance of a pavement edge drainage system is governed by design infiltration rates, rather than discharge capacity.

Applying Darcy's law for a given permeability of pavement surface, sub-grade or *in situ* soil type, calculation of infiltration per metre of trench and hence inflow to drainage system can be determined. Thus for a 150 mm GPD, using normal flow rate capacity, outlet point spacings can be calculated for a given infiltration rate.

The following table compares infiltration flow rates with pavement material and clay sub-grade permeability and provides corresponding outlet spacings based on three grades of a GPD installed in a 200 mm wide trench. Infiltration rates are based on a catchment area of 0.5 square metres, the side area of a nominal trench depth for GPD installations of 0.5 metres deep, where flow is from one side only.

Table 6: Sub-soil drainage outlet spacings

	Asphalt/Spray Seal Pavement Permeability k= 10^{-4}cm/sec	**Clay Pavement Sub-grade** Permeability k= 10^{-7}cm/sec
Infiltration Rate - GPD	1.2 l/min/m trench	0.43 l/min/m trench
Outlet Spacings – 150mm	50 m	150 m
300mm	100 m	250 m
450mm	150 m	440 m

5.4 DISCHARGE FLOW

Table 7 compares flow rates for a GPD and round pipe for normal flow.

Table 7: Flow Rates

Specification:		**Round Pipe**	**GPD 150mm**	**GPD 300mm**
Properties	Units			
Flow Rate - Normal Flow	l/min @ 1.0%	180	>65	>110

6 INSTALLATION

Standard subsoil drainage installation incorporating a 100 mm diameter round pipe requires the invert be located at 100 mm below sub-grade level to ensure positive drainage and to some extent encourage water to enter the pipe core rather than the sand bedding layer beneath. Due to faster, positive drainage response a GPD can be located with the invert at sub-grade level and retain a minimum cover of 100 mm under normal 156 kPa loading in a 500 mm deep trench.

AS 2566 requires cover of 600 mm to round pipes under sealed road pavements. Recommended cover for Class 1000 round pipe is 500 mm, requiring a compacted 150 mm cover layer of specified granular material around the pipe to limit deformation. Minimum recommended cover for the GPD is 100 mm, with 300 mm required for highway loading.

Extensive testing by Geofabrics (Geofabrics Australasia 1993) on GPD infiltration flow rates has shown that a non-woven, needle punched, geotextile filter wrap complements inflow performance when installed with washed sand backfill. This sand also saves system costs. The GPD's structural rigidity provides stability with its positioning in the trench requiring only minimal alignment during backfill operations.

6.1 BEDDING

Bedding at trench invert is not required due to GPD's rigidity, its stiffness providing bridging of any minor irregularities in the trench base profile. Round pipe, because of its flexibility, requires a levelled bedding layer 80 mm thick before installation. Care should be exercised when installing in trenches through rock with precautions taken to eliminate sharp protrusions with a sand cushioning layer placed beneath a GPD for protection of the geotextile sleeve.

6.2 BACKFILL

The GPD’s ribbed design provides support for the filter wrap and resistance to damage during installation. However backfilling operations need to be undertaken with care, as during installation the surrounding backfill material will create load not only on the drainage core but also on the geotextile filter. Recommended backfill, graded washed sand, negates the potential for damage to both if placed in with care and in measured quantity. Washed sand should be watered into place to aid compaction.

Well graded washed sand is the recommended backfill for installation of a GDP. Washed Sand specifications are shown in Table 8.

Table 8: Washed Sand specifications.

Type 1		**Type 2**	
Aust Std Sieve size (mm)	Particle Size Distribution (% passing by mass)	Aust Std Sieve size (mm)	Particle Size Distribution (% passing by mass)
		9.5	100
4.75	100	4.75	90-100
2.36	95-100	2.36	70-100
0.425	20-80	1.18	40-65
0.3	0-30	0.6	12-40
0.15	0-10	0.3	0-16
0.75	0-1	0.15	0-4
		0.75	0-3

6.3 COVER

The recommended cover for road pavements installation is shown in Table 9.

Table 9: Recommended cover depths.

Product	**Units**	**GPD 150mm**	**GPD 300mm**	**Round Pipe Class 1000**
Recommended Cover to pipe/panel	mm	100	100	500
Recommended Cover – Highway Loading		300	300	500

7 CONCLUSION

This paper has assessed the performance of a geo-composite drainage panel system, comparing it with round pipe deflection performance under simulated wheel loadings and calculated pavement drainage inflow conditions. The results highlight the difference in capacity and performance of a GPD, to show superior structural capacity under vertical compressive loading, the ability to capture drainage inflows with shorter response times and shows equivalency in performance in a narrower trench installation.

Protection of the structural integrity of a pavement can be governed by drainage system inflow performance with response time and inflow capacity of the drainage core being relevant criteria. A GPD, because of its panel configuration and larger catchment area, has a proven faster response time for design inflows with the calculated inflow rates showing an equivalent performance for a GPD installed in a 200 mm trench when compared with a 300 mm wide conventionally designed round pipe system.

Structural performance ensures that the long term hydraulic flow capacity of the drain is not compromised, as load has little or no effect on the core internal area, with type of backfill used and cover allowed not critical elements for a GPD. The properties of high compressive modulus, longitudinal stiffness and structural rigidity affect the long term performance of round pipe under similar loading conditions and requires stringent backfill requirements to ensure that shape and integrity is maintained during its service life.

Filtration performance through design for pore size (EOS) of the geotextile filter also forms an integral part of pavement drainage design by providing optimum particle retention and reducing potential for clogging.

Equivalent discharge capacity of round pipe to a GPD may be considered in subsoil drainage design. Drainage system inflow rates are affected by the nature of the surrounding *in situ* materials to be drained and the type of backfill used. Discharge capacity of a sub-soil drainage system therefore becomes an exercise in design for outlet spacings after adequate allowance is made for design flows from infiltration through backfill media and the drainage core.

The findings in this paper are currently being verified by real time testing at the University of South Australia's Centre for Water Science and Systems, where comparison of round pipe vs GPD performance is being assessed for different trench widths and backfill media. The results should confirm the hypothesis of equivalent performance for an optimum trench width, enabling designers to make informed choices with respect to protecting the long term performance and integrity of road pavements in terms of effective filtration, faster response times and economical cost of construction.

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