Grasscrete

Design Guide

GrassConcrete

INDEX

CHAPTER ONE

HOW IT ALL BEGAN

Grasscrete was invented in the late 1960's by Yorkshire architect, the late Jack Blackburn. Taken by the idea and potential of grass paving he was however less impressed by the variable performance levels of the pre-cast concrete systems available at that time. Just how Grasscrete came to address those issues will be explained throughout this publication. Key to Grasscrete's development was the establishment in 1970 of Grass Concrete Limited, the business that launched the system. Once "available", Grasscrete quickly developed not only in the UK but also internationally via a network of licensees that today stands at thirty in number.

Another milestone followed in 1981 with the introduction of a UK supply and install service. This significantly helped to develop high levels of expertise across a whole range of applications and circumstances. This acquired knowledge base is today used proactively to assist designers around the world in the selection and specification of Grasscrete's unique capabilities.

A key component of our design philosophy is our belief in the promotion of environmental solutions to hard engineering issues. In the 1970's and 80's it was generally more difficult to engage around the wider aspects and policies of a "green environment" and the focus tended to be more geared to one off local solutions rather than perhaps to wider environmental ideology.

In more recent times an increasing awareness of our environment has led to the introduction of national and local government policies that positively promote applications for Grasscrete.

Our response to all enquiries is with a "fit for purpose" mind-set. This will see us engage with a particular application, for which we will happily discuss what we consider to be the best solution. This could be a response that suggests changes to a specification or perhaps even the avoidance of one, if we feel the suggested scenario won't work.

Fig.1

CHAPTER TWO

DESIGN PRINCIPLES

Benefits of grass paving

Grass paving was very much the forerunner of permeable paving systems, which are today often grouped under the collective term *Sustainable Urban Drainage Systems (SUDS).* Whilst this designation immediately suggests a capability in storm water management it relates to only one aspect of the environmental benefits that grass paving provides.

The permeability of grass paving will vary according to type, there will also be an additional element that doesn't feature in other types of permeable paving, that of initial abstraction by vegetation, thereby reducing the overall run-off or permeability demand. The rate of initial abstraction will be influenced by types of grass, the growth height, the season, the nature of the soil and the shape of the paving's cell structure.

The passage of surface water into ground and then its re-charge into the water table is an entirely natural process and for many projects, where suitable conditions exist, this will be all that is required. Other projects may require the 'smart permeability' of a SUDS scheme and, this can be for instances where the local catchment area is greater than the paving footprint or where a greater level of attenuation is required. Later in this publication we detail our smart permeability options.

Grass paving introduces another benefit not found in other permeable paving systems, that of carbon sequestration. Within an urban environment a massive imbalance is created by human exhalation, vehicle emissions and mechanical sources such as air conditioning systems. The introduction of urban greenspace with CO_2 digesting vegetation is therefore a means of partially redressing the natural balance, particularly in a ground level scenario, close to vehicle exhaust emissions

The volume of carbon sequestration will vary as with permeability, according to a number of natural characteristics, but we can draw on some 'typical' factors that tell us that an average person will exhale 1kg of CO_2 per day and that an average level of grass cover will absorb 1gm per m^2 per day, so that in effect it will take 1000m^2 of grassland to absorb the emissions of 1 person. Likewise, the same value can be achieved from the absorbance of 15-20 mature trees. So we can perhaps say that greening up our environment won't in isolation cure the problem of rising CO_2 levels but it can be a vital component in the aggregation of marginal gains drawn from a range of emission reducing policies.

Whilst there is an inevitable focus on the need to reduce CO_2 levels we should not forget the oxygenation benefits derived from vegetation and in this respect an area of less than 3m^2 will provide the daily oxygen need for an adult human.

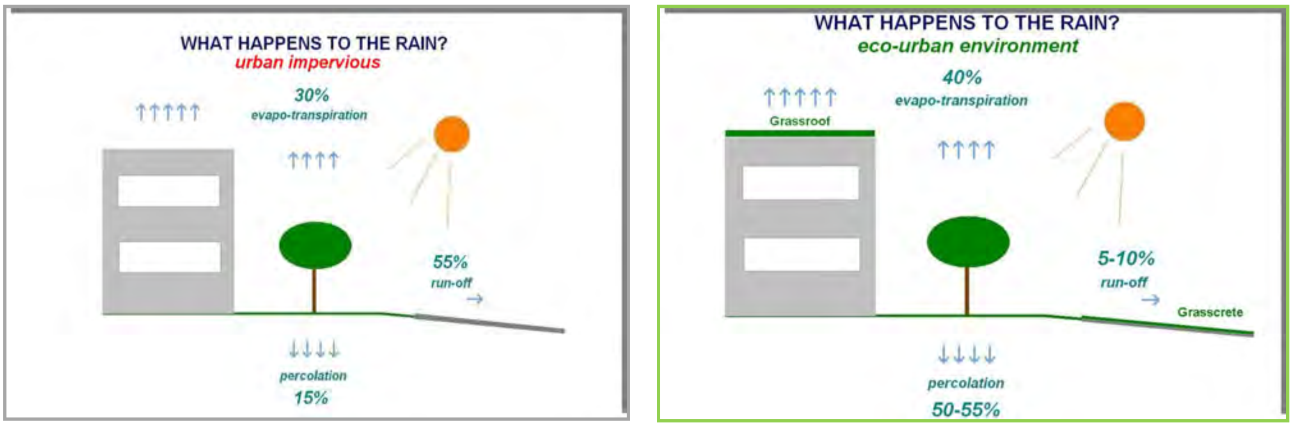


Fig.2

The natural effects drawn from this process of photosynthesis will serve to reduce the *Urban Heat Island Effect* within towns and cities, so benefitting our natural environment as well as well as improving the lifestyle and wellbeing of urban dwellers. Fig.2 above details an urban landscape without mitigation on the left and a harmonised landscape on the right.

CHAPTER THREE

Product Development

The development of grass paving systems

The original design challenge for Grasscrete inventor Jack Blackburn was to overcome a number of drawbacks commonly encountered with the pre-cast concrete grass paving systems available both then and, still today. The outcome was the adaptation of engineering design that was based on sound practise, yet was very new to permeable grass paving.

- The shape and profile of pre-cast concrete blocks can be problematic when seeking to achieve a sustainable grass growth. With individual units that need to be de-mouldable in their manufacture the resulting tapered side walls create a funnel shaped soil pocket that can be hostile to both permeability and root establishment, with a much reduced void area at the base. For instance, a pre-cast concrete block that might advertise a 75% open area at the surface is likely to have no more than 25% open area at the base. With a reduced level of permeability such types can be prone to waterlogging and a consequential wash out of the upper soil layer. This leaves in turn, a studded concrete profile that is difficult for pedestrians to negotiate and creates a high level of tyre rumble under traffic use.

- Traffic use can cause the skin created by 'block against block' contact to be significantly lost. Under continuing use the vibration of pre-cast concrete units is then likely to lead to sub-grade pumping, with the blocks settling into the base in a manner that we refer to as "elephant tracking". This progressive process leads to ultimate failure for vehicular traffic use and pedestrians and the prevention of grass cutting.

Fig.3

- With plastic systems introduced from the mid 1980's, the design often focusses on a honeycomb structure for the natural inherent strength that this suggests. In reality, however this creates soil pockets that are small, with in turn smaller still drainage apertures at the base of the units. These factors can lead to issues of severe waterlogging as well as the grass sward becoming "pot bound" within the small rootzone at the base of the units. Some manufacturers in an effort to sustain grass growth call for organic material to be introduced into the bearing layer. We would instead question the wisdom of introducing an unpredictable element that changes its volume and strength under saturation, into the very layer where certainty is needed.

Fig.4

- It is quite easy to be confused and indeed be carried away by the impressive load bearing figures often attributed to plastic paving systems. Indeed, it almost seems that there is a bidding war to display the highest tonnage loading per square metre. Any such claims should however be taken into context, given that such figures are generally achieved by the laboratory loading and crushing test of units that have underlying hard support. This sits in sharp contrast to conditions likely to be encountered with an actual installation, where a water weakened sub-base and sub-grade are likely to be components of a failure process.

- With shallow depth plastic paving systems, a loss of root anchorage will leave the units prone to trampolining under traffic use. With a consequential loss of grass growth, the units can then instead function as a press that quickly pumps and squeezes saturated soils to the surface leading to a slurried layer (*Fig.5),* that on drying bakes to a hard-impermeable crust *(Fig. 6).*

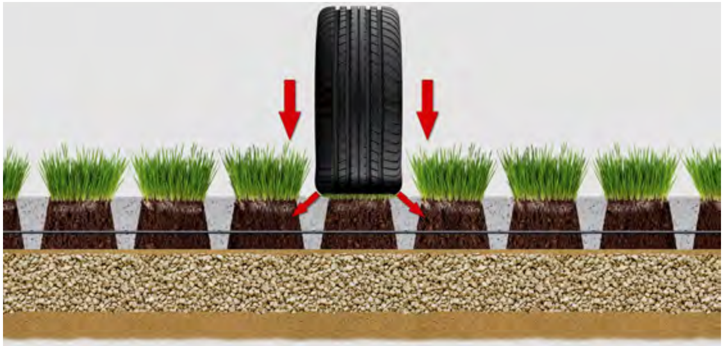
Fig.5

Fig. 6

- When subjected to load across the joints, modular paving units will tend to be displaced horizontally in a way that can shear root anchorage. To resist this displacement there is generally a requirement to introduce kerb edge restraints for pre-cast concrete and plastic paving systems. As well as being a further cost burden this can cause limitations to maintenance with denial of a single grass cutting operation from the paver to the adjacent landscape.

Fig. 7 Pre-cast concrete grass pavers under load

Fig. 8 ***Grasscrete*** *under load*



CHAPTER FOUR

Evolution of the Grasscrete Design

Using pre-cast paving as a benchmark the design process began by focussing initially on the critical shortcomings of this type of paver.

If an over reliance on grass growth and the need for favourable conditions with pre-cast concrete blocks, was a key factor in their short-comings, then a system with an independence from these issues was the design aim. A key to gaining the independence was to develop a paving layer that placed no reliance on the binding effect of grass and which wouldn't suffer from issues of settlement under differential load and bearing. If a reinforced concrete paving layer was often the engineers choice for a heavy load, then a cellular version of that designed by engineers appeared to be the way forward.

Although the concept of a reinforced cellular concrete structure was radical thinking back in the late 1960's the actual structural design process involved traditional calculative theory. The engineering design process began by adopting a low allowable ground bearing of 45kN/m² to cater for potentially variable ground conditions influenced by peak rainfall inundation and seasonally fluctuating California Bearing Ratios (CBR).

The sectional design was achieved by bending moment analysis of the concrete section in contact with the sub-base. This discounted any benefit that may be derived from the pocket fill, so as to be able to independently display the bearing capability of the reinforced concrete structure. This process would benefit the assessment of performance during a project's temporary works phase where the surface might be trafficked prior to soiling and seeding, or when after completion the surface would be called into use before grass had established.

The Bending Moment Analysis enabled a point load capability to be derived for a number of differing combinations of paving depth and the varying moments of resistance for the steel reinforcing mesh. In turn the point load capability was transferable to vehicles of differing axle and wheel layouts to achieve maximum gross vehicle loads according to these configurations.

Grasscrete vehicle loading guide

Typical vehicle load*	Allowable point load: 150 x 150mm contact	Grasscrete type	Depth	BS4483 mesh type	200 x 200mm mesh diameter	Minimum sub-base depth **	Sub-base type
0 - 3.4	8.46kN	GC3	76mm	A142	6mm	100mm	*For UK: This assumes a Specification for Highways Clause 803 Type 1 sub-base. For International projects: This relates to a 40mm down granular sub-base*
3.4 - 4.3	10.77kN	GC3	76mm	A193	7mm	150mm	
4.3 - 10.8	13.5kN	GC1	100mm	A193	7mm	150mm	
10.8 - 13.3	16.65kN	GC1	100mm	A252	8mm	150mm	
13.3 - 30.0	28.8kN	GC2	150mm	A252	8mm	150mm	
30.0 - 40.0	41kN	GC2	150mm	A393	10mm	200mm	

***** Indicated loads are based on typical number or tyres for vehicle type, multiplied by the permissible point load. For heavy goods vehicles this will normally feature 10 tyres being utilised to achieve a 40.0 tonne capability, however for abnormal loads with multiple axles this has seen Grasscrete being used for vehicles up to 220 tonnes gross vehicle weight.

** Assumes an allowable ground bearing of 45kN/m^2

Fig.9

With the structural theory in place, attention could turn to the soil pocket element and the development of the optimum plan shape and section. Existing pre-cast types had generally focussed on having either rectangular holes or rectangular concrete castellated studs with their surrounds being voided. These designs were dictated by the need be able to demould during manufacture, rather than by providing optimum benefits for grass growth. The consequential impact on performance was the creation of a hostile growth environment. Without these restrictions attention could focus on gaining the best shape for 1) optimum grass growth, 2) effective permeability, 3) ease of use,4) maintenance and 5) the overall appearance. The concept of the design was to achieve a surface that could be used regularly, rather than it being a continuously trafficked running lane.

Optimum grass growth

Healthy grass growth generally calls for a root depth of between 50 and 150mm for cool species cultivars and for the ability of root systems to expand beneath the surface layer. The actual depth of rooting will be influenced by the search for moisture; if sufficient is found within the upper 50mm then a more compact rooting structure will be experienced. The shape of the soil pocket was therefore considered and it was identified that the funnel shapes associated with pre-cast blocks inhibited root expansion with growth becoming 'pot bound' and; that although this concentrated water absorption into the upper 50mm it often resulted in peak inundation and consequential washout of the upper soil layer. The sectional profile of the new Grasscrete design was therefore identified as needing to be conical with the plan dimensions increasing with depth to accommodate rooting. At the same time the pocket should be able to hold moisture to limit the depth of rooting but at the same time resist wash out. A feature of the design brief was therefore the encouragement of skin friction around the shape and profile to enhance anchorage for both roots and soil, particularly for installations to slopes, where soil could otherwise be more easily washed out.

Effective permeability

With a need to retain sufficient moisture in the top 50mm as well as to create an effective source control of surface water, the shape needed to protect the soil layer from becoming compacted under load, enabling the soil to remain loose and free -draining. The shape of the pocket should therefore enable vehicle tyres to span the pockets with the wheel load being taken by the structure rather than the pocket. Where the soil did become loaded the outward taper of the sidewalls would help to cushion the effect.

Ease of use

Pre-cast blocks particularly the castellated types, display a tendency to lose soil from the upper layer resulting in the network of prominent concrete studs becoming the user surface. As well as becoming difficult to walk on such a surface will display a marked level of tyre rumble under trafficking, the effect of which is likely to be a progressive loosening and failure of units. The Grasscrete design brief therefore called for a surface that was significantly flat with a soil pocket that could be easily spanned by foot and tyre alike.

Maintenance

Again a flat upper surface was identified as a benefit, in this case enabling an even cut height to be achieved without compromise from settled blocks or a studded upper profile. Further benefit could be gained by the removal of a need for edge restraints, thereby enabling mowing equipment to freely run from the paver to the landscape in one operation. It was understood that the shape of the pocket should not be hostile to differing grass species. Rather than having a continuous network of soil, it was realised that a concrete surround to each pocket helped to better contain the soil as well as limiting colonisation by weeds and the spread of oil spills.

Overall appearance

The apparent approach taken by pre-cast block manufacturer's was to be able to highlight the optimum amount of grass cover at the surface. This theory suffers however in reality where the drawbacks in the block design limits the ability to sustain such levels. The lasting impression could instead be of an untidy irregular surface. With this in mind the focus for Grasscrete became that ' lasting impression' and what could be the expectation of that. A driver for example, would need to be able to identify the structure and be directed along the route using lines of concrete as a guide. A neighbour in contrast would not want to look out over an overtly concrete structure and would instead wish to see a natural green landscape. It was identified therefore, that the shape of the pocket should display a higher percentage of concrete when viewed from a parallel or perpendicular position. In all other fields of view, the impression should instead be one of an overtly grassed landscape. This is achieved by the cruciform shape of the grassed pockets that overlap each other when viewed obliquely.

Optimum design

By benchmarking each highlighted factor into a design considered to be superior to the pre-cast concrete systems, the outcome was a cruciform plane shaped pocket with a conical sectional profile . The composite design was then factored into the structural appraisal so as to achieve a system that performed better than pre-cast concrete units in all critical aspects.

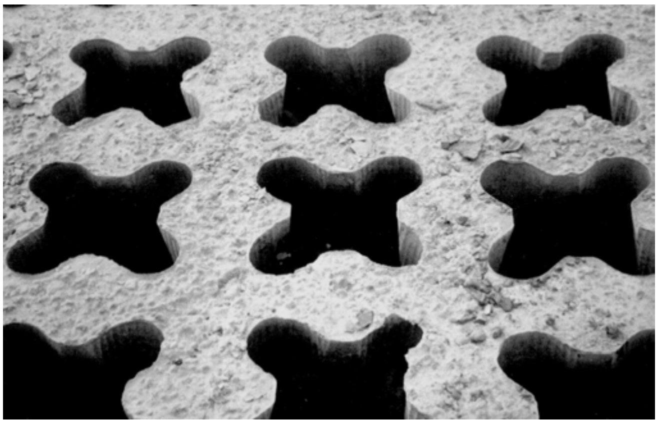


Fig.10

The Grasscrete void former

In addition to the benchmarking requirements for the completed permanent works the void former to be used for the creation of the cellular structure was also the subject of strict design criteria:

- The shape of the upstands must be resistant to the pressure exerted on them during the concrete placement.
- The side walls should have a sufficient taper to enable manufacture but be as steep as possible to maximise grass area and aid nesting together for transportation.
- The void former should incorporate an integrally moulded spacer to enable the positioning of mesh reinforcement. The spacers should be positioned so as not to induce cracking in the slab.
- The pocket profile of the moulding should be corrugated to both increase strength and create a ribbed finish to the casting for subsequent enhanced soil skin friction.
- The material used should incorporate a significant percentage of re-cycled material to meet our environmental commitments.
- The shape of the moulding should enable close nesting to minimise transportation cost.

Using this criteria a thermo-forming process of manufacture was identified as the best means of creating the profile. Vacuum forming enabled the thickness of the forming to be calibrated to create variable gauge thickness at points of live load. The material identified was polystyrene (PS) although ABS was also used for a period of time. In maintaining a commitment to the environment a significant percentage of re-cycled material was introduced into manufacture. In the early days of development this commitment was at times difficult to maintain as the grading of re-cycled materials was less sophisticated than it is now and finding suitable material could be challenging.

As international trade began to develop the maximisation of packing space became a factor. The use of the light-weight void former already provided a cost saving for transportation when compared with pre-cast blocks, but how could this advantage be pressed home. The answer came with a patented anti-slip coating that not only enables closer packing but also benefits the concrete casting process as any residual concrete becomes less likely to stick to the tops of the formers after casting.

The benefits can be displayed in a comparison between a 12 metre container which can accommodate 6300 m² of our 100mm thick Grasscrete GC1 formers. A similar quantity of pre-cast concrete blocks will require between 35 and 40 full lorry loads. This has enabled Grasscrete to be competitive when supplied to even the remotest parts of the World whilst at the same time helping to minimise the carbon footprint of delivery mileage.

Fig.11 The Grasscrete void former

Type GC2 shown

Fig. 12 Grasscrete GC2 void formers being removed from their nests, ready for installation

Concrete mix

The mix design for Grasscrete may be subject to a number of possible variables across National boundaries due to:

- Differing terminology
- Differing units of measure
- National specific codes

The actual design may then need to consider a number of variables in respect of the specific design needs such as:

- Gradients
- Levels of exposure
- Early use
- Accessibility
- Availability and grading characteristics of local materials

For the purpose of this synopsis we focus on the characteristics and typical composition of a mix rather than aligning to any specific code. The following mix design assumes that accessibility is good and that the concrete is installed to Grasscrete being laid to horizontal ground or slopes of less than 5°.

Cylinder strength @ 28 days:	28N/mm²
Compressive strength @ 28 days:	35N/mm²
Cement type:	Ordinary Portland, cement replacements can be used
Minimum cement content:	350kg/m³
Maximum water/cement ratio*:	0.55
Maximum size aggregate:	10mm
Fine aggregate:	Sand
Large aggregate:	Quarried stone or gravel
Sand percentage of aggregate:	45%
Slump on arrival on site:	100mm
Admixture/s:	
1)	* Optional water reducer added with the mixing water
2)	Superplasticiser added on site
Final slump:	Flowing, with a flow table reading of 600mm +

In addition to these standard elements consideration can also be given to the introduction of micro-synthetic fibres into the concrete, in addition to the mesh reinforcement. This can be a consideration where early use might subject the pocket walls of the Grasscrete to damage by impact and abrasion during the temporary works phase. Metallic fibres should not be used as they can damage the void formers during casting.

The standard cement that we detail is an Ordinary Portland Type, which is commonly designated as a CEM I material. It is also possible to utilise composite cement replacement types under the designation Cem II, which will increase levels of sulphate resistance for installations subjected to severe exposure such as marine applications. The use of a cement replacement can lead to a surface grout residue that 'dusts' under consistent traffic use, with a consequential exposure of the aggregate, beyond this the structure would not be impaired.

Bespoke installation features

Concrete colour

By default Grasscrete is installed with a natural grey concrete finish, that reflects the colourisation of the aggregates, this will over a period of time tone down, with a textured surface being encouraging of natural patina and lichen growth. An additional feature can be the use of a *Terratone* finish which sees a through coloured concrete being used. The preferred colour using Terratone, is normally a natural earth, which enables the installation to immediately blend with its surroundings. On large scale projects it can also be possible to colour match the concrete to local soils for complete harmonisation of the Grasscrete with its surroundings. A designer might also wish to create a contrasting finish and a dark grey colour is particularly effective as in the example of Fig 13. where Grasscrete has been used for this Artwork installation at a landscape exhibition

Fig. 13

Delineation

As a general guide wherever the Grasscrete void former is positioned there will be a resulting cellular structure once the concrete is cast. In situations where a void former is omitted there will be a section of solid concrete. This feature is particularly useful in car park installations where a network of aisle and bay markings can be achieved without resorting to painted markings, an example of two types of configuration can be found in *Fig. 14* for an aisle managed scheme and in *Fig.15* for an aisle and bay managed scheme. Further details together with other examples such as Helipad markings shown in *Fig. 16* can be found in our DWG/CAD files, which can be downloaded in PDF format from our website www.grasscrete.com or in editable format on request.

Disabled users

The combination of a flat upper surface and cruciform shape pockets, helps to ensure that wheelchair users aren't disadvantaged in their general movement across the surface. Wheels will always be in contact with a running surface that has low levels of vibration when compare with other grass pavers. More specifically "Disabled Parking Bays" can be incorporated into the design using the advantages identified in our previous paragraph. For a "Disabled Parking Bay" we recommend that the 200mm solid concrete delineating strip identified in *Fig.15,* is increased in width and, this can be to a dimension of either 800mm, 1000mm or 1200mm. In addition, if a 600 x 600mm former is omitted from the centre of the bay during pre-set, the subsequent casting will provide a solid concrete pad of the same dimension. This can then be utilised to stencil in place a wheelchair logo.

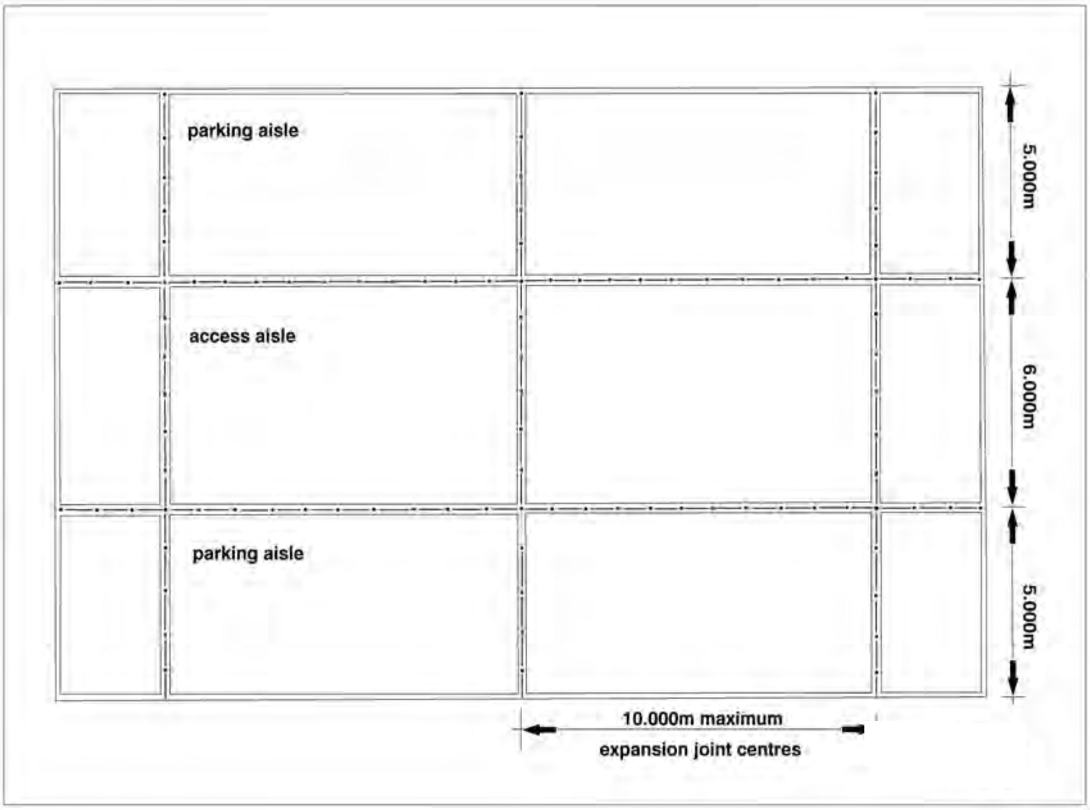


Fig. 14

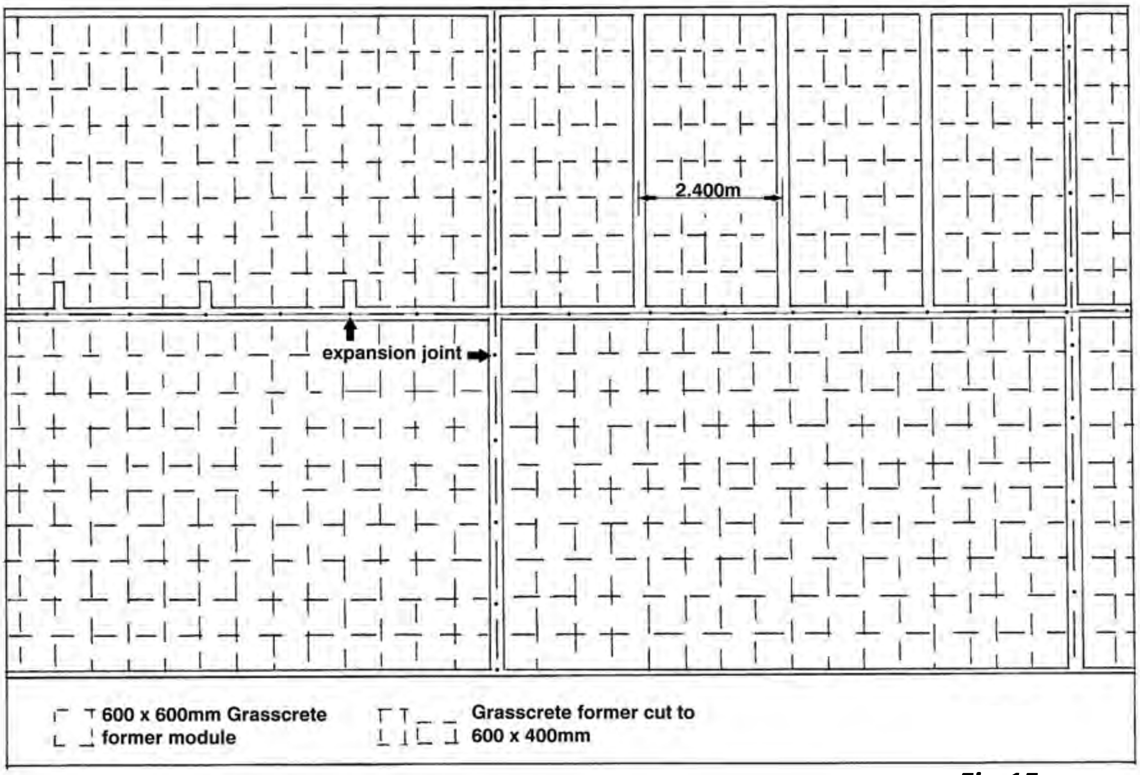


Fig.15

Plan layouts

The combination of a void former and cast insitu concrete means that there are few limitations in the plan layout that can be achieved, with the ability to free-form a plan shape. This feature is particularly useful in examples such as vehicular turning heads where a variable edge profile can be achieved that forms an even edge alignment. This contrasts with precast concrete or plastic pavers where either a stepped edge must be formed or alternatively individual units have to be cut to profile, something that is likely to create a weakness in the installation. *Figs. 16* and *17* display some of the benefits of this flexibility.

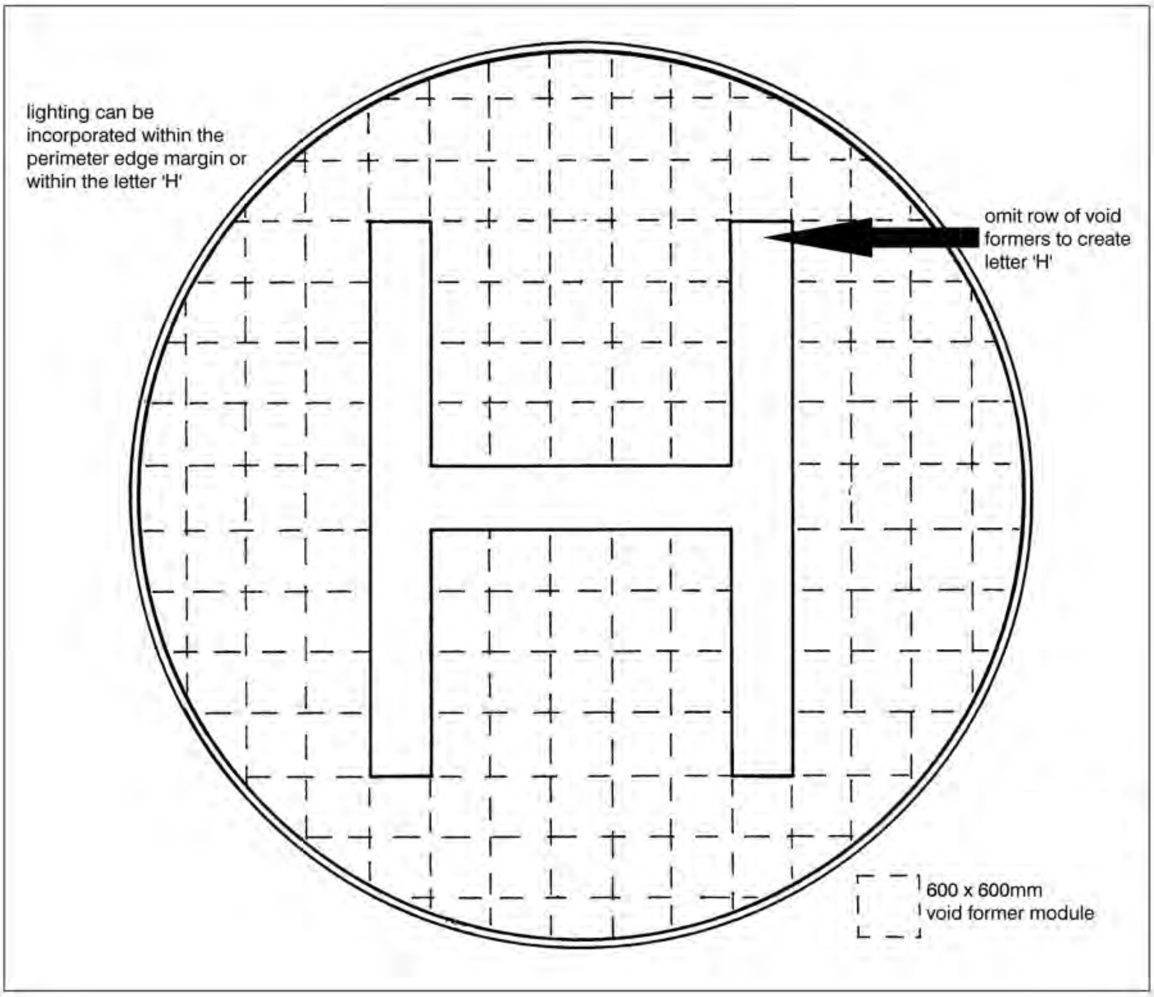


Fig.16

Helipad design

Fig. 17

Grasscrete void formers in position to a curve. With formers stepped tangentially to the edge

CHAPTER FIVE

Fire and Emergency access

A fire and emergency access road is required to enable essential function and the design shouldn't be compromised by a notion of probable infrequent use. Indeed in many cases this 'infrequent use' will actually see the road heavily trafficked as a haul road during the construction phase, after which it might become a regularly used maintenance track. Even without these un-planned uses some careful thought should be given to the circumstances surrounding an emergency. An access route required to service operational fire and rescue equipment would probably need to function in ground that's saturated by fire fighting water and in circumstances where heat may be intense. The structure and material composition should therefore fit those needs.

This section of our publication is intended to offer an objective guide, where other official reference works might not cater for current needs or circumstances. This is no more evident than in the UK where the Building Regulations have been criticised for specifications in respect of fire control within high-rise buildings. Outside of the buildings there is also a lack of clarity with Part B5, Table 21 detailing access requirements that do not conform to modern appliances or operational practises. In recent years it is noticeable that individual brigades have developed their own tailored requirements to achieve greater clarity and we would always therefore recommend that a building designer seeks counsel with a local fire officer as these tailored requirements do vary.

Our own position is to offer what we consider to be 'Fit for Purpose ' design input based on almost 50 years of specification and use. For a designer it can be difficult to sort through paving product types with widely ranging claims often developed on a desktop rather than being proven in application, so let's begin our input by showing in *Fig. 18* that we do have history.

Fig.18

An early consideration in the design process needs to be the actual type of appliance that might be sent to an emergency situation. Traditionally for buildings up to 3 storeys the brief would be for a pump appliance and for above that a 'high reach' requirement would call for an aerial platform or turntable ladder. The UK Building Regulations Part 5B Table 21 tells us that the pump appliance would have a weight of 12.5 tonnes and would require a width of 3.7m. For the high reach that would be 17 tonnes with the same access width of 3.7m although this is clarified further in Diagram 49 , which calls for hard-standings to be 5.5 and 5.0m wide respectively for hydraulic platforms and turntables. Sadly much of this information is now outdated and not fit for purpose due to the following:

- Pump appliances have grown in size and to reflect this the Building Regulations up-sized some years ago from a figure of 10.8 tonnes to a figure of 12.5 tonnes. This is now out of date however as many pumps now have gross vehicle weights of 13 tonnes. Our own recommendation is for 13.3 tonnes in instances where the use of a pump is clearly identified.
- The modernisation of Fire Authorities has led, in some cases, to a shift in approach away from the distinct pump or platform categories and their scope of use. This has seen the development of the hybrid, a 'Combined Aerial Rescue Appliance (CARP), which takes a chassis similar to a pump appliance, but instead of a ladder it features a hydraulic platform capable of accommodating 27 metre reach requirements. When compared to 32 metres typically associated with aerial platforms, the additional flexibility of a CARP has encouraged some authorities with limited high rise buildings to rationalise their fleets. The increased specification comes however with an increase in weight, which can see 18 to 26 tonnes gross vehicle weights and with outrigger legs, a wider operating pad is also required.
- High reach appliances in current use can weigh up to 32 tonnes as opposed to the 17 tonnes from the Building Regulations. There is however an the example from one authority that gives the curious advice that because of its number of axles a road design based upon 14 tonnes should not be damaged by a 32 tonne vehicle, but for structures such as bridges a 32 tonne limit should be designed for.
- With any building, it's important to future proof requirements and no more is this the case than in provisions for high-rise buildings. Will for instance a re-focus on the integrity of external cladding mean that provision will widen beyond the use of internal risers to fight fires? If attention shifts to fighting a fire and rescuing to and from the exterior of the building will this call for appliances with a rescue reach of over 100m, with an attending increase in the spread of outriggers?

Taking all of these factors into consideration we believe that careful consideration should be given to both the immediate and future fire and emergency access requirements for a building design. This may call for discussions to take place in consultation with specialists including building insurers. To assist in design considerations our *Fig.19* summarises how Grasscrete can feature in the design.

In considering a particular design we recommend that attention be paid to the wheel trace of differing types of appliance . In particular long wheelbase vehicles will call for a variable plan geometry to curves. There will generally be no less a requirement in the temporary works phase where concrete trucks will usually require access along the route and so tight knuckle bends should be avoided.

For further detail guidance please see the PDF details on our website: www.grasscrete.com or request an editable DWG. version of the same.

Grasscrete Fire and emergency access design guide						
Application	**Appliance Type**	**Appliance weight**	**Grasscrete Type & depth**	**Reinforcement size**	**Access width**	**Operating pad width**
Building						
Low-rise	Pump	< 13.3 tonnes*	GC1/100mm	A252 (200 x 200 x 8mm)	3.80	3.80
Low / medium rise	Combined Aerial Rescue Pump (CARP)	< 26 tonnes	GC2/150mm	A252 (200 x 200 x 8mm)	3.80	5.00
High-rise	32m Aerial Platform	< 22 tonnes	GC2/150mm	A252 (200 x 200 x 8mm)	3.80	5.60
High Rise	32m plus Aerial Platform	< 32 tonnes	GC2/150mm	A393 (200 x 200 x 10mm)	3.80	6.00**
Special						
Airport crash tender	< 8 x 8 wheeled	<35 tonnes	GC2/150mm	A393 (200 x 200 x 10mm)	3.80	n/a
Note *	Where a Fire Authority's fleet includes CARP vehicles we recommend up-grading to that specification					
Note **	The introduction of extreme height vehicles will require consideration of outrigger requirements on an individual project basis.					

Fig.19

CHAPTER SIX

Grass Paving in the Water Environment

In the early 1970's the advent of grass paving enabled engineers to take a new look at the armouring of slopes. Up until then much of the design focus was around the need to resist internal hydrostatic pressures within slopes. This often saw solid concrete slabs or pre-cast concrete elements of significant depth being employed to provide sufficient dead weight, to resist the active uplift forces. The downside of such designs was a need to factor in a means of managing the migration of ground water and the venting of hydrostatic pressure whilst at the same time sealing the armour layer to inundation from water flow. The resulting swathes of concrete provided little scope for environmental mitigation at a time when the World was awakening to the need to balance a desire to maintain our natural environment whilst at the same time pushing ahead with our need to build.

Grass paving provided an opportunity to satisfy both the engineer and the environmentalist with the introduction of new technology. Instead of resisting water movement it was realised that a cellular structure could instead vent the hydrostatic pressure. With this switch in emphasis it was possible to reduce the weight of armouring enabling much slimmer sections of paving to be introduced, further benefit could also be gained from being able to simplify slope drainage .

Whilst the notional benefits were readily identified by engineers, in those formative years, the lack of finite test data impeded the widescale take up of grass paving to slopes. In the absence of proven data, engineers naturally assumed that a grassed surface was hydraulically 'rough' and as such a Manning's 'n' value in excess of 0.10 might be applied. The outcome of this would be most noticeable in drain channels where the impact on velocity of a rough surface would call for a larger channel than would be the case with a solid concrete design. Under such circumstances the economic benefits of the reduced paving depth would be lost to the increased area, leaving the specification to hang on the wider environmental benefits.

The need for a benchmark led to a trial in the UK undertaken by CIRIA (Construction Industry Research and Information Association) a not-for-profit body. Field trials were undertaken in 1985 at the Jackhouse Reservoir, which was at that time out of service. Twelve differing forms of grass paving were constructed in trapezoidal shaped channels running from crest to toe of the reservoir slope, with a rock armoured stilling basin at the toe. Each channel was fed by a flume through which water was pumped, with the velocity being measured by flow meters positioned within the channel. In addition to benchmarking the respective capabilities of each product type. The trial also identified several factors that were to change the way in which engineers viewed future design;

- Under slow flow conditions grass stems will further slow the flow of water. This all changes however when flow increases in velocity and the increased energy sees long stemmed grass being flattened to form a smooth carpet like layer, *see Fig. 20.* For slopes of 1 in 10 this would see a reduced Manning's 'n' value of 0.03 with this reducing to 0.02 for slopes of 1 in 3.

Fig.20

- The reduced ‘n’ value places the hydraulic performance of grassed paving closer to the theoretical performance of concrete or masonry channels. In reality however the comparison is likely to be closer still, as these types of armour layer are prone to suffering from weed colonisation in joints and cracks that can cause turbulent flow particularly where trash accumulates behind obstructions.
- A key factor in the design limit of a grassed paved cellular structure is the presence or otherwise of an underlying geo-textile. Should the paving layer at any stage suffer a loss of soil filling to its cellular structure the geo-textile will help to prevent erosion and migration of the sub-grade layer. The type of geotextile will need to be determined relative to the flow performance and the critical requirements of the type of grass paving. We describe the Grasscrete requirements on page 21 this publication.

Further information about the CIRIA Jackhouse Trials can be found in the CIRIA Report 116 *Design of reinforced grass waterways* together with the supplementary Technical Note 120.

Although hydraulic performance is expected to be the primary consideration for the selection of a grass paver, this type of system opens up wider possibilities in the promotion of a balanced eco-system . With grassed paving the following factors can be considered in the establishment of a bio-diverse environment.

- Maintenance of natural levels of greenspace that would otherwise be lost to concrete paving.
- Maintained levels of CO_2 digestion from natural grass land.
- Reduced potential for Urban Heat Island Effect.
- Promotion of natural amenities ,with reservoirs etc., more attractive to visitors.
- Return of land to grazing, subject to intensity levels conforming to required grass stem height.
- Replication of natural habitats for fish, birds and plant species.
- Integration with reed bed cultures and the re-establishment of indigenous wetland areas otherwise lost to hardscape.

The above factors can be generally considered , in varying degrees of compliance, across the range of grass paving types, the following pages will however focus on how Grasscrete commits to these benefits in comparison to other paving types.

Grasscrete in the water environment

Data provided from the CIRIA Report 116 serves to identify the performance levels of certain types of grassed paving. Using this data allied to developed knowledge we are able to offer *Fig. 21* as a guide to grassed paving types.

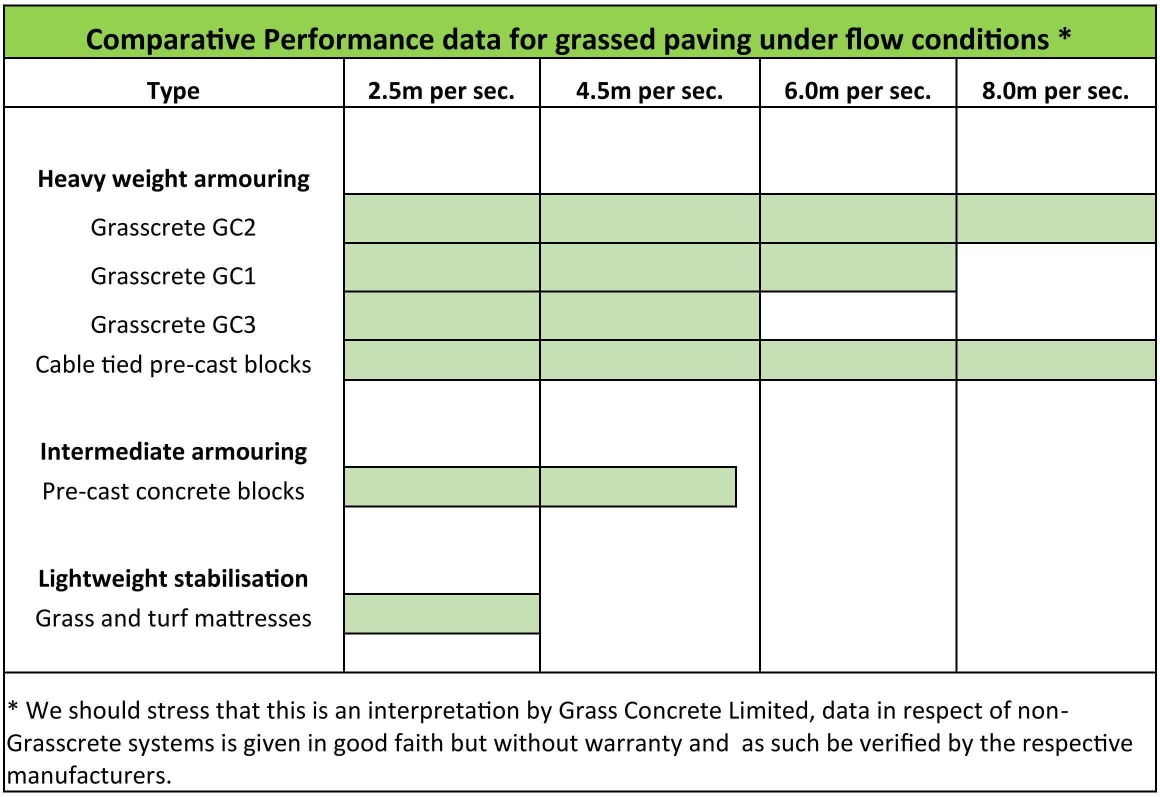


Fig.21

In developing a comparison for Grasscrete with other available types, we focus on the ***Heavyweight*** and ***Intermediate*** types shown in *Fig. 21.* where Grasscrete might be expected to feature in a comparison.

Earthworks

When considering slopes in excess of 15° it's normal to expect that the armouring layer will be placed onto a trimmed earth sub-grade without the introduction of a granular sub-base material, which would be difficult to place and consolidate at such gradients. Where sub-bases are used, this would tend to suggest a need for vehicular access in locations such as access tracks, crests and stilling areas where maintenance access is required.

As a matter of course wherever areas are designed to accommodate water flow we would strongly recommend the inclusion of a geotextile membrane beneath the paving layer.

Earthworks tolerance should be carefully considered as the finished profile of the paving layer will generally mirror that of the formation. Attention should be paid to the removal or loose scree and the filling of excavator teeth marks with competent material to avoid them from becoming a source for the development of runnels. When installing to clay slopes, particularly when imported material is used ,we recommend that the trimmed material is maintained in a wetted condition prior to installation of the paving layer.

As a cast on site system Grasscrete will require a formation to be clear of flowing or standing water and provision should be made for any damming or diversion works required, to enable this.

Grasscrete Slope Design

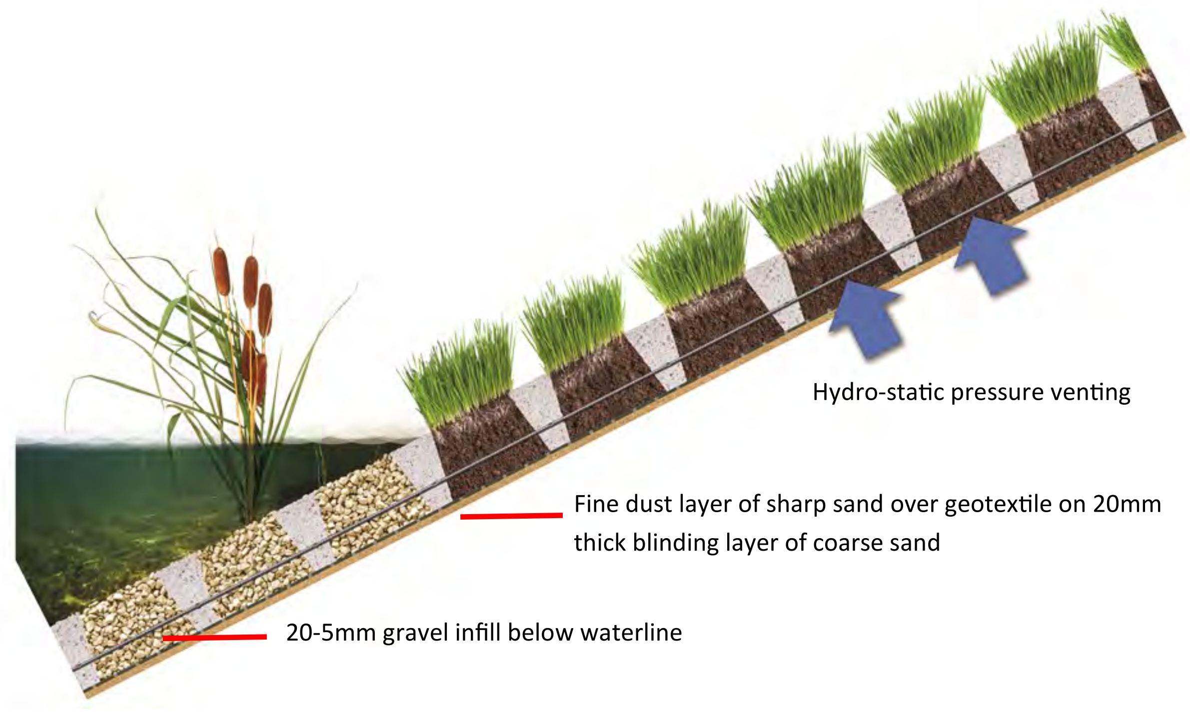


Fig. 22

Gradients

Gradient selection may feature precise calculations based upon the required flow velocity to a spillway, or it might instead be a less sophisticated approach of simply getting from level's A to B in the easiest and most cost effective method. Whatever the reasoning , we can offer some simple guidelines for design and construction.

- Grasscrete can be generally laid at gradients of up to 1 in 1 using traditionally cast ready-mixed concrete. It is also possible to install at steeper gradients using a sprayed concrete technique and anchorage of the mesh reinforcement.
- In most cases the matter of maintenance will play a part in the selection of the gradient with the need to be able to negotiate the slope for grass cutting often being a consideration
- Grasscrete is a slope reinforcement/stabilisation system it isn't a retaining structure. Consideration should therefore be given to the internal stability of a slope . If the angle of a slope is greater than the internal angle of friction of the underlying earth then the weight of an armour layer could potentially mobilise a failure. As a safeguard we would therefore always recommend that a slope stability analysis is undertaken by a suitably qualified engineer.
- As a continuously reinforced slab, Grasscrete isn't prone to shear in the permanent structure, consideration should however be given to underlying materials that could be mobilised. Depending on the gradient this might call for the introduction of toe beams, which we describe elsewhere.

Design features

Beyond the issue of a superior flow capability Grasscrete also has a number of features that enable it to stand out in comparison with pre-cast systems:

Pocket shape

The shape of a pre-cast block is generally dictated by a need to de-mould during manufacture. Pocket walls will therefore tend to be funnel shaped with smooth sidewalls tapering down to give a small open area at the base. A consequence of this feature is the resulting reduced area of root zone and a low level of skin friction with the side walls, which can see grass sods being plucked out during water flow. In contrast Grasscrete has a conical shaped pocket with a greater open area at the base than at the surface, ally this to the ribbed profile of the sidewalls for added skin friction and Grasscrete becomes very effective in resisting pull out under water flow.

The cruciform plan profile of the Grasscrete pocket is designed to afford maximum protection to the grass sward from traffic and water flow, by optimising the level of structural concrete, whilst at the same time maximising the impression of a grassed area. The shape and section of the Grasscrete pocket also lends itself to the use of gravel as an alternative pocket fill for areas of installation that might be subsequently permanently immersed. In such applications a 20-5mm irregular gravel will tend to bind within the pocket and be held in place.

Geotextile membrane

If all grass paving systems require an underlying geotextile for water flow applications then the specification requirement for Grasscrete is probably the least demanding. A geotextile is required to prevent a loss of sub-grade fines back through the paving cells, should those cells be stripped of soil and grass. With a pre-cast block such a process can also have a mechanical impact on the structural integrity of the blockwork with units potentially being punched out of position by a combination of loss of support and surge pressure. Under such conditions Grasscrete would however remain as a continuous structural slab which limits the extent of any undercut and ensures that the structure will span isolated scour rather than either falling into the eroded bowl, or being punched from the face as would be the case with pre-cast. As a consequence the specification of a geotextile beneath Grasscrete can be less intense utilising the following guidelines:

- Material to be either a needle punched thermally bonded non-woven polypropylene , or a mono filament open weave polypropylene membrane, either of which should match the filtration and flow requirements of the individual project.
- To protect the membrane during the subsequent hot works operation of removing the tops of the void formers, we recommend that a fine layer of sand (less than 10mm) is placed over the geotextile . The two types of geotextile identified above should provide sufficient skin friction to ensure that neither the sand or the overlying void formers slide during the temporary works phase.
- Multi-filament flat close-weave geotextiles should be avoided as their smooth surface can cause sand and formers to slide during the temporary works phase.

Toe-beams

When installing to slopes consideration should be given to the edge detail at the crest and the toe. It is important that this should include turning the edge of the geotextile down to prevent corresponding water intrusion or spillage of material below the membrane. For slopes of less than 1 in 3 this can normally be achieved with a simple 150 x 150mm thickening that will both trap the geotextile and resist water intrusion and spillage, such a slab thickening can be cast monolithically with the Grasscrete. A deeper toe beam may called for to steeper slopes or where there is to be a subsequent casting of the stilling basin with the temporary works demanding that the formation in the stilling basin is kept lower to accommodate the introduction of a sub-base. Depending on the size of the toe-beam it is likely to require a separate casting exercise to avoid the creation of a head pressure uplift from the slopes that would disrupt the ability to level concrete in the beam. Further details can be found in our standard DWG files that can be downloaded from our website.

Joints

When working to slopes the centres of the joints will tend to be dictated by the plan profile of the works. For curved profiles the side walls to the bays will need to taper in plan to create a segmental layout. To optimise the bay size and to minimise the amount of taper we would normally recommend construction using bays formed with a nominal width of 5.0 metres. The joints running down the slope would consist of alternating expansion and contraction joints, with expansion joints being formed using a 25mm wide softwood filler or if required a 20mm wide PE filler with sealant. The contraction joints would be concrete to concrete with no filler.

The type of joint running along the slope and therefore perpendicular to the flow will normally be engineer designed taking into consideration the flow rate and the potential for settlement or uplift in the slope. For the applications using Grasscrete GC2 this may see the introduction of a dowelled joint as detailed in *Fig. 23* and later in *Fig. 29*. We would not however recommend the introduction of dowels to all joints as this can create a wedging effect particularly to areas with a curved plan profile. Here the differing expansion levels around circumferences of differing lengths will call for the slabs to be able to slide laterally face against face and dowels will prevent this.

Fig. 23

In locations where bays need to be mechanically connected to ground beams, but where again lateral sliding will be a needed this can be achieved by forming a tongue and groove connection with meeting faces being de-bonded.

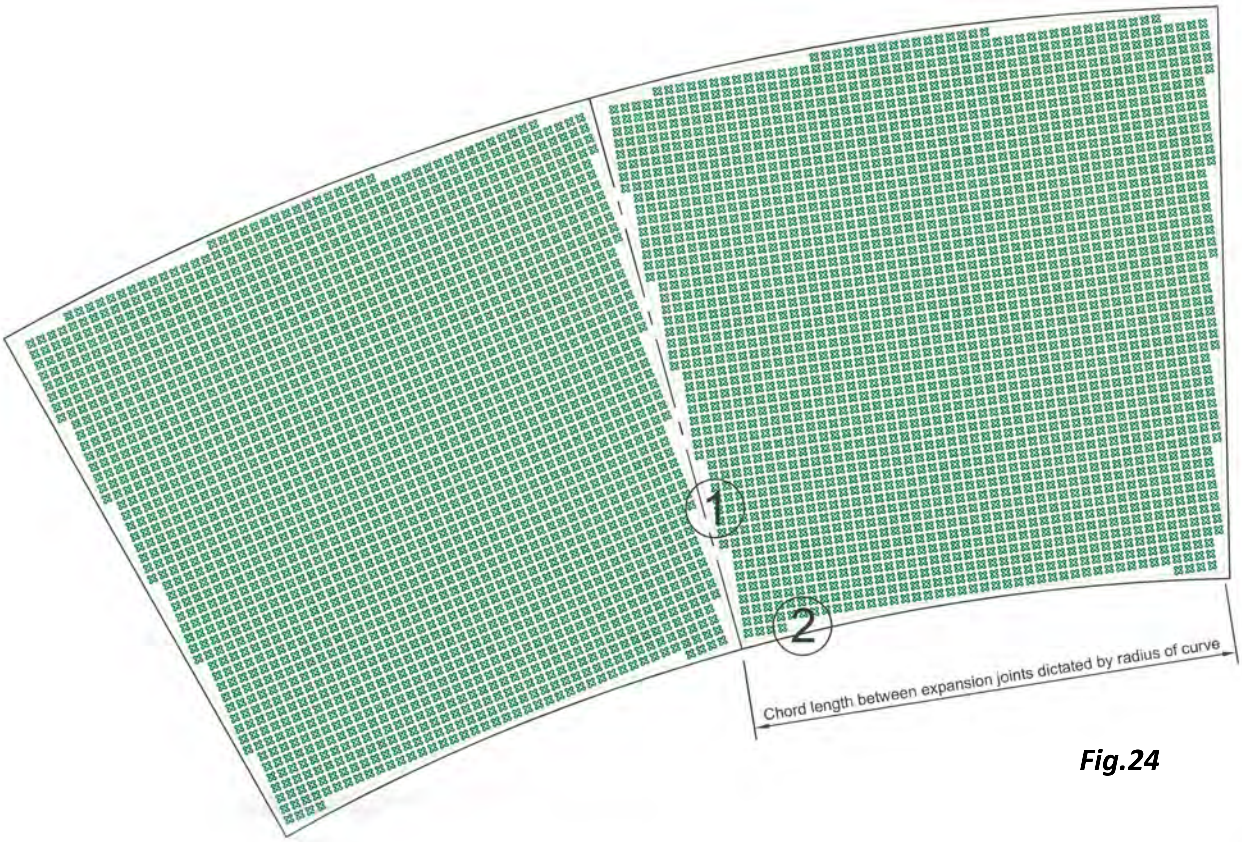


Fig.24

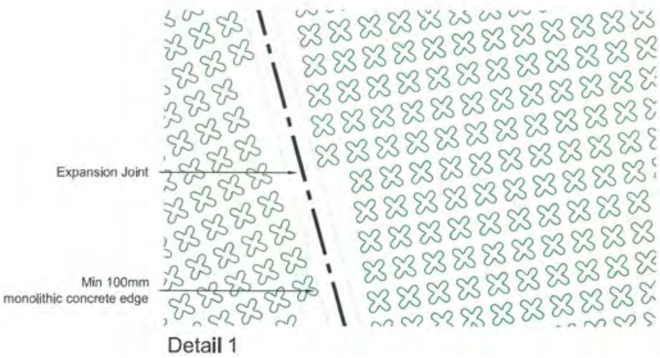


Fig. 25

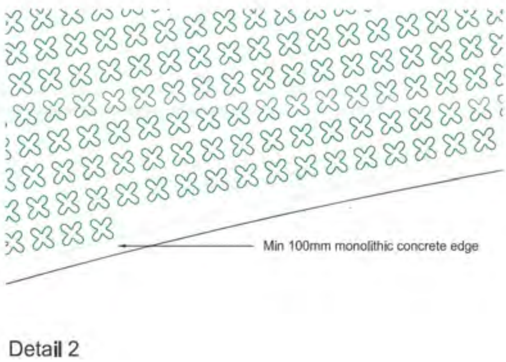


Fig. 26

When working to bunds or channels the plan profile will often be variable, calling for individual modules to fit into segmental layouts as panels are re-aligned. For pre-cast block systems this will call for a secondary labour intensive process of gap filling the resulting tapered break joints with concrete. With this being a material of different surface texture the slope or channel might then be prone to turbulent flow caused by the variability of the hydraulic roughness. *Fig's 24, 25 and 26* show how this is overcome with Grasscrete. The same process of stepping will instead be focussed on the Grasscrete void formers which are easily cut to fit a curved or raking profile. When in place the concrete is cast to create a seamless structure that requires no secondary labours and maintains a consistent hydraulic roughness.

The seamless flexibility of the Grasscrete former and the resulting structural continuity is also a benefit when finishing up to engineering details such as pipe inlets or headwalls. This contrasts with pre-cast block installations where such transitions often see a failure in the armour layer, which can be due to turbulent flow or slumping in the sub-grade against a structure.

The Grasscrete flexibility can also be put to good use in the programming of the works, as the ability to easily connect bays together means that a number of bays in different locations can be constructed concurrently with a certainty that they will all come seamlessly come together. This can be compared to pre-cast units that require an end to end linear operation to ensure fit, this need will often limit output to single gang working.

CHAPTER SEVEN

Grasscrete Construction

Ground conditions

As this publication is intended for international circulation, we generally avoid making specific reference to national standards and codes and would recommend that these are instead source referenced in individual project specifications. Where specific references are made they will relate to UK terminology.

Grasscrete is a permeable paving system but it will not by itself create underlying permeability. By specifying Grasscrete it is however possible to introduce a source control for surface water to manage aspects such as re-charge, attenuation and harvesting. As a permeable system that pre-dates current day referencing to *Sustainable Urban Drainage Systems* (SUDS) it is true to say that the benefits of Grasscrete have never been more relevant; driven by increasing awareness of the need for sound environmental engineering.

As both central and local governments increasingly call for source control solutions for surface water, there comes with that a risk of inappropriate specification. This usually stems from a lack of investigation into both the ground conditions and the paving system selected for use. As a general guide Grasscrete can expect to offer a rate of permeation at ≤ 90% the rate of the original ground when in a horizontal aspect. It won't of course force water to permeate through impermeable ground and it's important therefore to assess the nature of the existing ground to determine the most suitable form of construction. We would therefore recommend that an appropriate level of site investigation is entered into as part of the earthworks process. There are natural signs that can point toward potential drainage issues and an initial 'walkover' inspection should take note of the following.

- Surrounding high ground, particularly recently constructed earth bunds, as this can cause water tables to be elevated under a pressure head.
- Potential for the area to be a catchment for run-off from adjacent hard landscaping.
- Evidence of vegetation more native to wetland environments.
- Un-seasonal soil conditions or levels of growth.

With an allowable ground bearing requirement of just 45kN/m² the emphasis on bearing capability isn't a particularly onerous one. Care should be taken however to identify potential soft spots that could lead to subsequent voids beneath constructed paving, or the limiting of construction access along designated routes. For sites of significant size, we recommend the engagement of a site investigation survey, this work can include trial / bore hole reports as well as California Bearing Ratio tests (CBR's). Ideally, we would recommend that the tests be undertaken as close as possible to the rainy season to identify soil properties under peak demand. For smaller sites information can be gained from a combination of a simple walk over survey, as described above, combined with evidence drawn from shallow hand dug trial pits.

The two extremes of a low, or very high CBR reading can also suggest a potentially low rate of permeability. If the cause of a low reading is a clay of high plasticity, then notice should be taken of the potential for this material to become unstable under an alternating process of water-logging and drying. Variability in CBR's is also likely in 'brownfield' sites particularly sites that have featured significant demolition works and where the remains of underlying structures or voids from poorly compacted fill may remain.

Preparation of earthworks for trafficked installations

Traditional paving systems that have piped surface water drainage will have a need to create surface falls to capture run-off. This can significantly influence the extent of the earthworks as well as imposing a limit on the design flexibility of a scheme. Grasscrete's permeable structure can alleviate this issue, enabling flexibility in the construction profiling. It also means that for phased construction the extent of the earthworks can be limited to the actual paved area in that phase, rather than it needing to be undertaken to the whole of the works, to cater for main drainage requirements. For sites with topsoil to excavate, consideration can be given to stockpiling and re-using suitable material in the later Grasscrete construction.

For traffic installations it is normal to introduce a sub-base, further details of which can be found on Page 27.

Preparation of earthworks to slopes

Grasscrete is regularly used for works to slopes, where there is unlikely to be an underlying sub-base. This may be due to a need to overlay natural soil or it may simply be due to the angle of the slope exceeding that which a sub-base can be laid to.

When laying to natural earth slopes, the finished level of the Grasscrete will be dictated by the profile of the sub-grade. A sand blinding layer may be specified but with a thickness of say just 20mm it is unlikely to be capable of regulating a formation layer. As a consequence the finished tolerances for a Grasscrete installation should be generally similar to those of the formation layer for works to slopes.

Where the slope has been formed by a backhoe excavator, care should be taken to grade out any scalloping caused by the arc of the dig, as well as the removal of any loose surface material. Any indentations caused by excavator teeth or proof rolling should be filled with competent material to avoid the development of runnels or cells beneath the paving layer.

Where work to slopes involves installation to a clay formation, the formation layer should be maintained in moist condition in advance of the installation to avoid over-drying and cracking. When forming new earth structures consideration should also be given to natural settlement in the design of the permanent works.

Sub-base construction

The specification of a sub-base should be intended to cater for one or more of the following factors:

- The need to transfer and distribute load evenly to the underlying ground.
- To be a component of permeability as well as increasing storage capacity and attenuation.
- The need to carry the load of construction plant and material deliveries during the temporary works phase.

The selection of a material type and grading offers some flexibility but again there are some factors to consider:

- The material should be evenly graded and this normally suggests the use of a quarried stone, typically graded from 40mm down but with a low proportion of dust. In the UK this would typically be referred to as a Specification for Highway Works Clause 803 Type 1 granular sub-base.
- Re-cycled materials can be used, where compliant to the same specification, but they should be free from contaminants that could be released into the water table during permeation.
- The material should have a low plasticity level, so as to avoid volume change under saturation and drying.
- The material should not be frost susceptible, when used in cold climate zones.
- We would not recommend the use of gravels, due to potential for particles to roll against each other under load.
- We do not subscribe to the view that low fines granular sub-bases are appropriate for installation immediately below permeable grass paving. In particular for UK specifications this would commonly extend to Type 3 materials. Our concern lies in the potential for the voided structure to induce the drawing down of topsoil from the pockets during permeation. That some specifiers position a geo-textile membrane above the Type 3 layer to prevent this merely serves to slow down the rate of permeability, which negates the original intention, as well as being a likely cause of the liquification of the sand layer.
- Where CBR tests are undertaken, a result of 4% or greater will generally suggest that a sub-base depth of 150mm is sufficient for Grasscrete types GC3 and GC1 and GC2 up to 30 tonne loads. For 40 tonne loads a minimum of 200mm depth is recommended. For lower CBR figures an increase in depth of 100mm per 1 percent is normally considered to be appropriate.
- Where low permeability conditions are encountered we would normally recommend the introduction of a simple drainage blanket layer as detailed in *Fig. 27.*

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- To enable load transference the width of the sub-base should project beyond the slab at each edge by a dimension not less than the depth of the paving and this should not be less than 100mm.

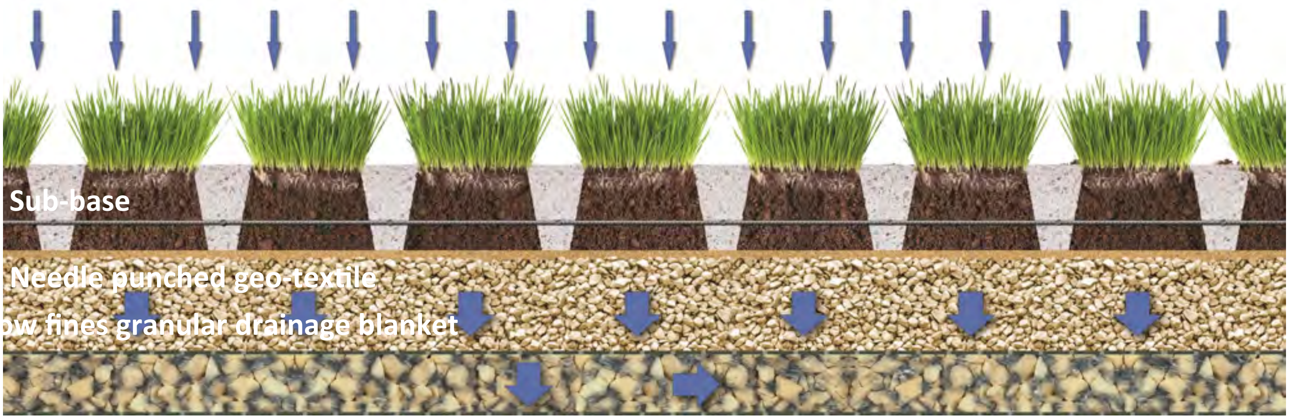

Fig.27

Grasscrete offers a major benefit in areas subjected to freeze / thaw cycles. In such locations, the required depth of non-frost susceptible material is generally 450mm or more, this can be significantly deeper for colder climates featuring winter perma-frosts. The introduction of non-frost susceptible granular sub-bases can be a costly exercise but this can be mitigated by specifying Grasscrete. The voided structure enables hydro-static pressure to be vented to the surface with this process extending to frost heave. During freeze / thaw cycles the topsoil and grass will rise and fall within the pockets as the pressure is accommodated and vented. This benefit was utilised during construction of the Channel Tunnel between Britain and France. For this application some 20,000m² of Grasscrete was constructed at the worker's site village; located on a chalk sub-strata. By using Grasscrete the 450mm frost free requirement was waivered and the sub-base and overall envelope was kept at between 250 and 325mm according to the depth of the Grasscrete used.

Specifications will normally call for a 20mm thick sand blinding layer to be applied above the sub-base. The Intention of this is to provide a medium onto which the void formers can sit. It isn't intended that this should be used as a regulating layer. It should be loose laid and not compacted, to maintain optimum permeability Where the depth of the sand approaches 50mm, we recommend that a 10-0mm graded hard granular material is used to make up the levels.

Consideration should be given in assessing tolerance levels for earthworks and sub-base. As a rule, the profile of the preparation at this point will be mirrored in the finished level of the Grasscrete. The controlling factor here is the styrene void former that is manufactured with a controlled depth. It is unrealistic therefore to expect that the finished tolerance will differ significantly from that of the sub-base, as it will simply follow that profile. This of course differs from the installation of solid concrete slabs where the depth of the slab can be varied independently from the formation level, to achieve level control.

The sand blind should be of sufficiently coarse grading to enable permeability and to withstand being trafficked during construction. It should also be free draining to avoid volume changes during saturation and drying.

Grasscrete edge features

The process of construction is more fully detailed in our separate Grasscrete Installation Guide, as well as in our range of DWG details, available on request. In this document we focus on the factors that a designer will need to be aware of. For UK based projects this will fulfil the requirements of the Construction (Design & Management) Regulations (CDM)

With its wide range of applications the apparent "theme" of construction can vary from hard, controlled level engineering, associated with highway projects to the follow the lie of the land scenarios found under landscape themes. The interpretation of level requirements may differ across projects, but the determining factor in each case will be the shape of the underlying ground. The Grasscrete former ensures that concrete will be cast to a consistent thickness and therefore the shape of the upper surface will mirror that of the base below. Where tolerances are to be prescribed they should therefore reflect what can realistically be achieved in the earthworks preparation.

Another factor in the establishment of levels is the interaction with adjacent finishes. Typically Grasscrete doesn't require a kerb edge restraint, thereby allowing the levels to harmonise with those of adjacent landscape areas. This provides for an easy grass cutting exercise with mowers able to pass directly from one grassed surface to another.

There will be occasions however where changes of level are required and this will see the introduction of a separate kerb edge. The choice of kerb does need some consideration as it can influence the performance of the Grasscrete both structurally and in its maintenance. When considering concrete kerb edges there are types to avoid and types where some preparatory work will be needed.

Types to avoid are 50mm wide path edgings; they add nothing to the structure and will tend to spall under traffic use when used as a transition between Grasscrete and another trafficked surface. They also suffer the need to have extensive haunching to hold them in position and this causes an issue that we describe below.

Conservation kerbs whether in concrete or natural stone are being increasingly specified for their enhanced appearance. The dressed or riven face of these kerbs does however create frictional resistance with any surface that is cast up to it. This can inhibit the expansion performance in a concrete slab by slowing, or even preventing movement. As it would be normal to place kerbs ahead of casting the Grasscrete ,we would recommend that the face of any such kerb is prepared with a bond breaking solution or membrane ahead of casting the Grasscrete.

As with any grassed surface consideration should be given to cutting the grass and the machinery that will be used to undertake this work. Just as traditional lawns require mowing strips when laid adjacent to buildings there will be a similar requirement for Grasscrete. In such circumstances the Grasscrete should commence at a dimension of not less than 150mm from the building. This not only enables grass cutting to be undertaken without impacting the face of the building, it also means that temporary formwork can be installed and a working platform gained to enable a more accurate control of the edge levels.

Where Grasscrete is laid against the face of pre-cast kerbs, it is important that the full edge depth of the Grasscrete shall be in contact with the actual kerb face and not its concrete haunch. Laying up to a haunch will cause additional friction that limits the ability of the expansion joints to function correctly. It will also limit the ability to position the void former at the prescribed 100mm offset from the kerb.

When laying to cast in-situ kerbs or plinths consideration should be given to the location of transverse expansion joints in these structures. An uneven edge alignment or face texture to an adjacent structure could cause the Grasscrete slab to be locked to it, causing the Grasscrete to only expand and contract under the control of the adjacent structure. This could then create a crack inducer to the Grasscrete if the expansion joints don't coincide or if the rate of expansion differs between structures. To avoid this we would recommend that the face of the kerb or plinth is either de-bonded or has a longitudinal expansion joint at this transition point.

Expansion joints

For temperate climates our standard detail *Fig. 28,* features a 25mm (nominal) wide softwood filler incorporated at a maximum 10 x 10m centres. For this material it isn't normal practise to seal the joint. To each face of a joint there should be a solid concrete margin that is established as a minimum 100mm offset from the outer edge of the base flange on the void former to the face of the formwork.

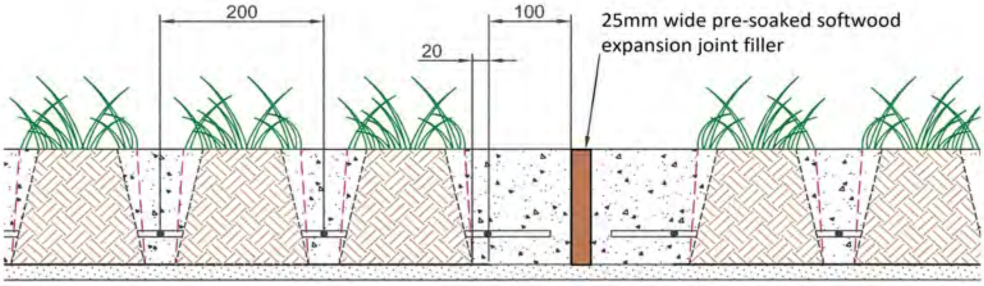

Fig. 28

For heavy load transfer or water applications dowelled joints may be specified, as shown in *Fig.29*. They should however only be used with the 150mm thick Grasscrete GC2 variant and normally only in conjunction with 10mm diameter reinforcement within the slab for traffic applications. To accommodate the dowel within a band of solid concrete the offset dimension from the edge of the base flange of the void former to the face of the joint filler should be increased to 150mm.

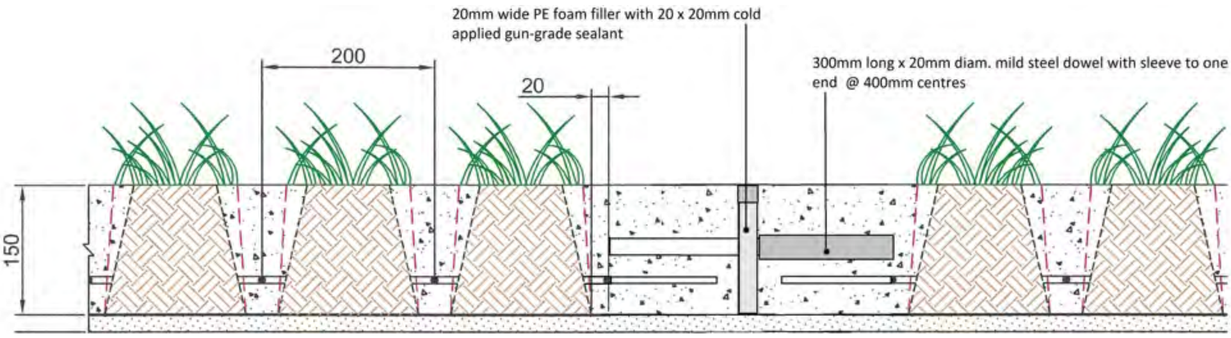

Fig. 29

Filling the pockets

The first step in undertaking the pocket filling, is to remove the top of the void former, which will have been left exposed after the concrete placement. We would normally recommend that a period of 48 hours is left after casting before this process begins, although this period can be shortened if early strength has been achieved by combination of concrete mix design and high ambient temperature. As shown in *Fig. 30* The top of the former is melted by an LPG flame gun that will see the polystyrene formers quickly melt under the heat intensity. This does not require the complete removal of the void former and instead an inert residue can be expected to remain in place to the side walls. This process emits a low level of CO_2 similar to that found with the charring of wood, when commissioned the benefits of a CO_2 digesting paving layer will quickly addressed the carbon balance.

Fig. 30

During the casting process a void former pocket may very occasionally distort, this can result in a slight narrowing of the pocket shape or in some more extreme instances the pocket might become covered over by concrete. A slight narrowing won't require remedial attention but a more pronounced distortion can be recovered by subsequent punching through the thin concrete layer with a steel pin and if required a re-shaping with a 38mm diameter core drill.

The intention should always be to achieve as controlled alignment of the pockets as possible, there will however be some slight wavering of the alignment of the pockets as shown in *Fig. 31* due to the following factors:

- The tolerance in level of the formation will influence the plan layout of modules of set dimension that are applied to it. Where a formation is variable in level then there will need to be a compensation between the true shape of the formation and the actual dimensions of the void former modules. This can see result in some wavering.
- The mesh reinforcement is lapped side by side and the formers, which centre to the mesh, will therefore step out of alignment very slightly at the lap point.
- A 200 x 200mm nominal size mesh reinforcement can vary by up to 6mm in actual dimensions, this can cause formers to step out of alignment.

Fig. 31

When positioning elements such as manhole covers and frames we recommend that their orientation be parallel to the alignment of the void formers. This will help to reduce the amount of solid concrete that will be otherwise required to gap fill irregular shapes. The cruciform shape of the Grasscrete pocket is designed to maximise the visibility of concrete for drivers as they pass along a route and so ideally the orientation of the formers should run parallel to that route. The view then offered up from any other direction is of overlapping grassed pockets that gives the impression of a much higher grass percentage.

For a grassed application the recommended infill is a screened or rotovated topsoil. The material should be sufficiently fine and free from lumps and debris, to be capable of being worked into the pockets. Care should be taken not to over-screen the soil so that it becomes a fine dust, such a material can require frequent reinstatement as it is prone to liquifying during surface drainage. In some circumstances particularly in Sites of Special Scientific Interest (SSSI) it is worth trying to match the pH value of local soils. This can help to promote the growth of natural grasses by colonisation, with the Grasscrete then fully toning into the local environment. This process can be taken a step further with the introduction of a colouring to the ready-mixed concrete that can replicate the surrounding soils helping to fully blend the Grasscrete installation into its surroundings. Further information about coloured Grasscrete can be found in our separate *Terratone* publication available as a download from our website www.grasscrete.com.

The method of topsoil placement will be significantly influenced by the requirement for ' first use'. If the area is required to be trafficked immediately after the period of concrete cure has expired, then it is best to fill the pockets and strike the level flush to the top of the concrete. This will enable wheels to pass along the surface without intruding into the pockets so that the grass can grow relatively unhindered. This process will normally call for a later topping up of levels as and when settlement naturally takes place. A second option, where the area is not to be immediately trafficked is to apply a fine layer <10mm over the surface, this offers a number of additional benefits:

- It enables a natural process of settlement to take place with soil being washed into the pockets, to take up settlement as it occurs.
- During periods of hot weather a screen is formed that helps to cut down solar reflection, so helping to protect germination.
- The textured surface of the concrete will be encouraged to develop a natural patina with some organic material being held at the surface.

The preference for these two options should be identified to the installer ahead of construction to enable the landscaping programme to be planned.

In addition to a soil and grass infill the pockets are also ideally shaped to accept gravel or stone infill. It is common to see such applications below the water line in waterways in flood plain areas and in industrial hardstanding areas. The conical sectional profile of the pocket ensures that the fill material will knit together in the pocket and be locked by the inward tapering face of the pockets walls. This contrasts with pre-cast concrete or plastic units where the pocket walls are either vertical or funnel shaped and as a consequence offer little resistance to pocket spillage.

As a typical guide we would recommend the use of a 20-5mm irregular gravel as the infill material, see *Fig.32.* This will tend to be retained in the pocket during trafficking, limiting the possibility of Foreign Object Damage (F.O.D.) When using naturally occurring aggregates, chances are that they will be from the same source as those used within the concrete, it is therefore likely that the surface will develop in time a single tone in its appearance. Where a contrast is required this can be achieved by the use of a contrasting aggregate such as a black basalt.

Fig.32

CHAPTER EIGHT

Grass Growth

The type of grass seed will be dictated by a number of factors:

- Climate
- Aspect
- Use
- Environmental factors

The **type of climate** will largely dictate the grass cultivars to be specified. Our Grasscrete brochure identifies seed specifications native to Western European Climates, but that is not a limiting factor as Grasscrete will generally support growth from a wide range of native species from other climate regions. As in any grassland scenario hydrology plays an important part and should be factored into design, particularly in arid climates, where an integrated irrigation system might be considered appropriate. Depending on the climate zone there may be contrasting requirements of needing to quickly disperse water through the structure, or alternatively circumstances where an arid environment may need moisture to remain within the soil pocket for as long as possible.

In circumstances where the permeability rate needs to be maximised, consideration should initially be given to the natural hydrology of a site. Grasscrete's performance in permeability will tend to follow the natural rate of permeation of the original ground, with a lag experienced for horizontal surfaces of approximately 10%. What this suggests is that Grasscrete, as with any grass paving, won't increase the rate of permeability in a top soiled environment. In circumstances where the natural ground is free draining then Grasscrete can continue that capability, if that is what is required.

The hydrology of a site can be influenced by a number of factors borne out of both temporary and permanent adaptations to contours and geology. The use of elevated environmental bunds for instance can create a pressure head that causes water tables to rise and in doing so reducing the rate of permeability, through the sub-grade. Where bunds are to be introduced local to the paving installation we recommend that the bund is structured with an underlying drainage blanket and/or venting to draw-off the pressure head.

The opposite scenario can be experienced where Grasscrete is installed adjacent to breaking ground. With permeating water able to break though the face of a slope this can see an acceleration of permeability that can dis-proportionately settle the soil levels within those pockets most immediate to the edge. If considered to be a maintenance burden the acceleration can be arrested by either a modification to the sub-base such as introducing a strip of low permeability geo-textile beneath it, or by the introduction of a thickened concrete edge to the Grasscrete that will encourage water to ledge at that location rather than being drawn more quickly down.

For arid locations the permeability of the soil should ideally be slowed, this should be combined with a process of irrigation that sees water being sprinkled onto the Grasscrete after dusk, so that the water can remain within the soil for feeding, rather than being evaporated by the sun's heat. *Fig. 33* identifies a method of irrigation where pop-up sprinklers are incorporated into the solid concrete edge margins of the Grasscrete. This can be introduced with an automated timer to sprinkle car parks etc at a time when the area is closed. It can also feature a rainwater harvesting process to achieve a sustainable means of irrigation. The soil can be encouraged to retain moisture by the incorporation of soil improvers such as gel granules or coir fibre strands that will each hold moisture and then feed by slow release into the soil.

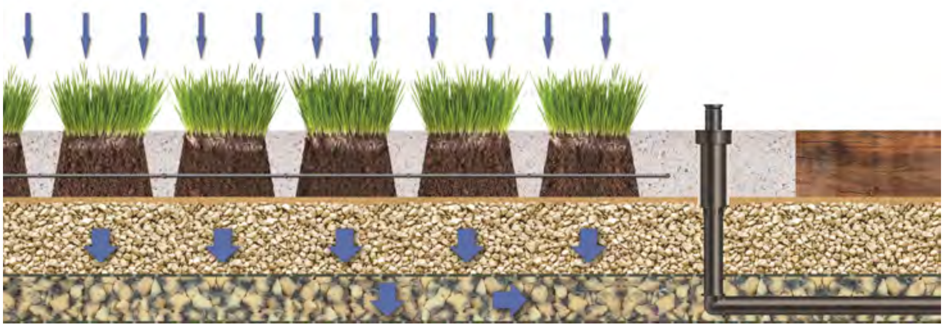

Fig. 33

Developments in seed technology have created more tolerant grass species that have enabled for European applications, the traditional March to September sowing period to be extended. Provided that soil temperatures are above 4^{O}c, grass can now be expected to geminate for most of the year. The greatest risk will sit with rapid saturation and drying that can create a hostile seed bed and so the onset of a drought after saturation should be considered as part of growth management, with the avoidance of extremes by selective watering during the onset of drought. We would also recommend the use of a pre-seeding nitrogen rich fertiliser, either as a separate application or as a germination aid coated onto the seedlings.

The **aspect** of the installation will determine the amount of light and shade that the grass will face, which will in turn influence the cultivars to be specified. For applications such as fire and emergency access tracks the likelihood will be of a grass paved area close to a building that may place the installation in shade for a good part of the day. In contrast an area enclosed by build-form with a light coloured building façade may create a sun-trap, with both factors possible within the one installation, a grass mix that is both tolerant of shade and full sun might be called for.

The type and frequency of **use** will be a significant factor in the selection of an appropriate seed mix. The specification for a fire access might suggest a low frequency of use and as such a grass mix with slow growth characteristics might be beneficial allied to a prostrate growth to give ground cover. Care should be taken however to establish whether a fire access will also double as a maintenance access, as this could suggest a greater frequency of use and a need for a seed mix that is more resilient to use and, which has a quick recovery rate.

Some roadside applications could be subjected to carriageway run-off or spray contaminated with de-icing salts, this suggests that a seed mix for such a location would need to be saline tolerant.

In Chapter 6 we identified that in a waterway the hydraulic roughness of a grass paved surface is improved by grass being flattened under heavy flow. To facilitate this the grass stems should be slender and erect with no resistance to leverage so that they can bend easily. This suggests the specification of species such as smooth stalked meadow grass, with an avoidance of invasive prostrate growth such as found with clovers or stolonic grasses etc. which could otherwise prevent the grass from bending at the base of the crown with a resulting stress to both the stem and the root.

Our final consideration in the process of grass selection focusses on **environmental factors** and the potential need to integrate within a harmonised environment. Our own philosophy is to adopt a first principle of maintaining wherever possible the indigenous fauna and flora, in so doing avoiding the introduction of non-native species that might adversely effect the local eco-system. This could see a need to replicate soil types to promote natural growth, which might be sensitive to local nutrients of pH values. It might also raise an expectation that in time, the indigenous order of species which have thrived on local conditions will in turn colonise and dominate new installations by combinations of wind drift and bird transportation. Such examples are particularly likely in locations such as heath or marshland where native species have adapted to trying conditions and may therefore dominate over new species.

A departure from this harmonised approach may be called for on projects that are a feature of urban renewal. In such examples an intervention may be needed to introduce a new eco-system, which creates both urban greenspace as well as a mitigation of issues such as flooding and air pollutants. This is likely to see the introduction of amenity mixes able to establish on soils of marginal quality and in aggressive environments as part of a long term strategy of regeneration. In such applications it is often the case that a local authority will have in place an amenity mix that has been tailored to the wider needs of the development project. In such circumstances these amenity mixes will generally prosper within Grasscrete and will support the type of usage that will be asked of the system.

In *Fig. 34* we detail our standard grass mixes for UK applications, which are also suited to Western European applications. Elsewhere we recommend consultation with local growers who should be able to advise the most suitable type. In applications where conditions for germination may be hostile it is also possible to lay grass turf in pre-cut cruciform shapes. This enables the turf to quickly establish and has been used to good effect in Middle Eastern Climates using paspalum and zoysia grass types.

In *Fig. 35* we show an example of early growth with our Grassmix No. 1 in a UK application. Our UK seed mixes are coated with *Headstart* germination aid. This example of a ryegrass based mix displays an initial erect growth pattern ahead of the establishment of the ground covering creeping red fescues.

Grasscrete standard seed mixes for Western Europe.			
Mix	**Sowing rate**	**Specification**	**Application**
No.1	35gms/m^2	50% perennial ryegrass 20% slender creeping red fescue 25% strong creeping red fescue 5% browntop bent	Vehicular parking and amenity areas
No.2	30gms/m^2	20% chewings fescue 20% slender creeping red fescue 30% strong creeping red fescue 25% hard fescue 5% browntop bent	Fire and emergency access, shaded low maintenance areas.
No.3	20gms/m^2	25% perennial ryegrass 20% strong creeping red fescue 30% hard fescue 10 to 15%* smooth stalked meadow grass 10% browntop bent 0 to 5% white clover*	Slopes* and road verges
** where subjected to high rates of water flow, clover is likely to be omitted and the percentage of smooth stalked meadow grass increased.*			

Fig. 34

Fig. 35

CHAPTER NINE

Maintenance.

It would be tempting to suggest that Grasscrete is maintenance free, to match occasional expectations. As 50% of the structure is essentially of a natural landscape form, then the reality is that some basic maintenance will be required. A planned process will ensure that the system remains in perfect working order and that usage interruption is minimised.

The culture of maintenance will vary across the wide range of applications where Grasscrete is specified and to simplify our guidelines we therefore break these down into two categories of **Traffic** and **Slopes.**

Traffic

In a regular use scenario the passage of wheels along the Grasscrete surface will tend to trim the grass to the extent that cutting is rarely required. This can lead to some variable growth with areas not subjected to traffic featuring the prostrate growth of creeping grasses, whereas the growth in trafficked areas is likely to be predominantly of hardy perennial species able to quickly recover under use. Accessibility for grass cutting equipment will be geared to the presence or otherwise of road kerbs. Should kerbs not be required we recommend that the adjacent landscape areas, if grassed, be finished with a slight fall down onto the Grasscrete. This will enable mowers to traverse to and fro without the need to raise the mower blades. Where kerbs are installed this will generally call for the perimeter grass within the Grasscrete area to be cut by strimmer.

For applications such as fire access lanes it will be important to maintain visibility of the solid concrete edge margin for driver's identification, prostrate grass growth over the edge margin should therefore be strimmed.

The main focus of attention will be the regularly trafficked areas such as in the access aisles of car parks as well as those areas that have full time parking during daylight hours. The cruciform plan shape of the Grasscrete pocket is designed to resist wheel intrusion and so growth at the root bed will develop and continue under use. To help maintain optimum grass levels in a trafficked area we would recommend a bi-annual Spring and Autumn maintenance regime, which would feature the following:

- Grub out any pockets that have been subjected to oil spills, this is likely to have caused die-back but only on a local scale as the concrete surround to each pocket will have prevented further migration. Re-fill the pockets with topsoil and grass seed.
- Loosen any compressed soil that has led to die-back, this may be more evident in entrance and exit areas. Top up soil levels and re-seed as required.
- Top up low soil levels with a screened top soil material, maintaining soil levels at not greater than 12mm below the surface should ensure that the concrete edge to each pocket is protected from impact.
- Apply a liquid based nitrogen rich fertiliser in Spring and a liquid based phosphate fertiliser in Autumn, to respectively promote Spring /Summer growth and Autumn/Winter consolidation. The use of granule preparations should be avoided as there will be a residue retained on the concrete surrounds , which will then be washed into the pockets causing an overdose.
- To guard against inappropriate loading and use for Grasscrete GC3 and GC1 installations we recommend that, width and height limiters be considered in the design, where the potential exists for unplanned overload.
- Should damage occur to isolated areas of installation, particularly the methodology identified in *Fig. 36* can be used to effect a structural repair.

During periods of initial topsoiling and subsequent topping up, a need for some care should be advised to users of the installation. We would for instance recommend that a notice identifying *Caution temporary surface, walk with care* be erected in an appropriate position. Once the grass has firmed up within the pockets then the surface will be much easier to walk on.

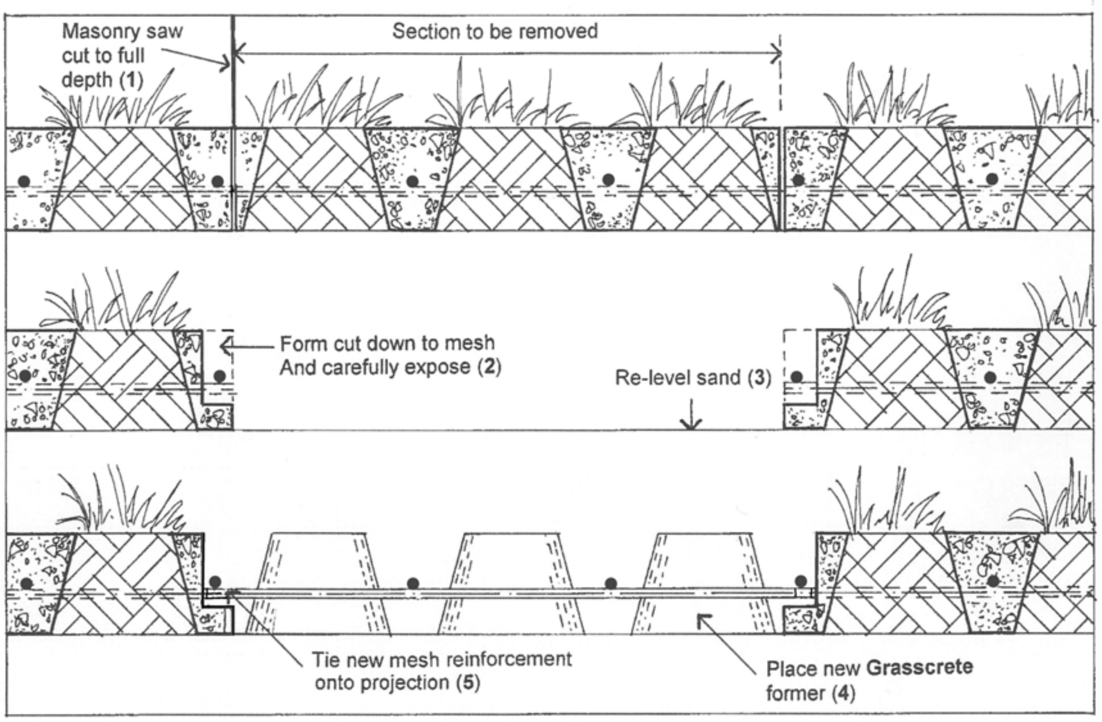

Fig. 36

Slopes

The expectations of maintenance requirements for slopes will generally be somewhat different to those of traffic applications. 'Less is more' might be the typical approach, although there are some elements that should be considered.

For slope applications the Grasscrete will normally have been installed as an armour layer and often to defend against water flow. We therefore recommend a periodical inspection of the surface to identify any instances where soil has been eroded from individual pockets. If left without treatment the empty pocket could cause turbulent flow and a progression of the problem to adjacent pockets.

More often than not the maintenance issue is of "over-maintenance" this can be a consequence of the height of grass mowing or intensive grazing by cattle or sheep. It is important for water flow applications to maintain a grass height that is long enough to flatten under impounding and under such circumstances a grass height of not less than 150mm could be expected. This can be reduced for applications that are not likely to be subjected to water flow.

The principle element of maintenance is likely to focus on colonisation as rivers, reservoirs and lakes are normally to be found in areas of diverse fauna and flora. There could be potential for shrubs and grasses less appropriate to hydraulic efficiency to intrude into the landscape. Such growth should be attended to at an early stage to prevent long term establishment and the subsequent down-grading of performance.

Grass cutting to slopes can be undertaken with tractor mounted gang mowers where access and angle of slope permits. In less accessible areas grass cutting may involve a simple hover mower an pull chord as shown in *Fig.37.* In waterside applications this process should always be undertaken with the operative positioned on the crest side of the mower.

Where the Grasscrete installation is linked to water flow ,either by direct contact or by secondary run-off, the use of chemical fertilisers and weed killers should be prevented and machinery should be used under a strict anti-pollution protocol.

Fig.37

The continuously reinforced Grasscrete structure won't suffer the problems of displaced blocks, a problem that can occur with pre-cast blocks particularly when manually removed for a use as fishing perches.

The Grasscrete pocket shape and profile also enables the introduction of aquatic planting at the water line and elsewhere planters can be incorporated to enable shrubs to develop, in tropical climates this has included intensive growth including mangroves as shown in *Fig.38*. In such bio-diverse examples maintenance is not a key factor but an occasional removal of debris and a pollarding of shrubs and trees will help to maintain healthy growth.

Fig. 38

CHAPTER TEN

Programming

Phasing that car park installation

Where a client wishes to consider a phased construction programme for a car park or access road, using an impermeable paving system, the following elements will need to be considered as part of the initial enabling works:

- Bulk excavation to achieve required drainage falls, this may call for a earthworks and drainage works for subsequent phases to be undertaken as part of the preliminary enabling works.
- The possibility that the above might call for a land to be taken into consideration that might not be available at that time due to other use or ownership.
- Adaptations to sewers where the piped drainage is to be taken off-site.

The above factors can significantly add to the start-up costs of a project as well as creating a building site feel extending across the phases, with landscape being replaced by open excavations. As an alternative, by replacing an impermeable paving with a low run-off permeable system such as Grasscrete the following benefits can be achieved:

- There will, on many sites be no requirement for extensive excavation works to create falls, Grasscrete can be laid to profiles that are sympathetic to existing levels.
- On reasonably draining soils there is generally no requirement beneath Grasscrete for piped drainage.
- The combination of the above bullet points means that the excavation and earthworks element can normally be limited to the immediate footprint of paving to each phase.
- There will generally be no requirement for adaptation to off-site sewers.
- The combination of these points enables a simple m^2 budget to be considered for each phase for the paving and excavation.

Programme works to slopes

A particular feature of pre-cast or pre-formed pavers is the need to ensure a full unit against unit contact. On linear projects such as river or storm drainage channels this can limit the works to being an end to end installation process. With such schemes there is limited potential to accelerate progress beyond introducing longer shift patterns as there will generally be scope to have only one layer working on each face. Progress will also be hampered by a need to have a follow up gang that infills the un-zipped transition joints that are required with a modular paving system. In such examples the earthworks preparation will therefore be slowed by a need to gear to the pace of the block laying. It will also mean that with grass growth required for stability the installation is 'at risk' until grass has established, so that the soiling and seeding will also need to be progressed at the initial stage.

With Grasscrete, the cast on site structure is continuous, with changes of direction being created by re-alignment of the void formers. Beyond this however the subsequently cast concrete will fill the whole area of the bay in one single operation. This feature means that areas can be worked independently with an assurance that the flexibility of the void formers will enable each bay to become joined with its neighbour irrespective of when or where installed. The weight of a fully cast bay also means that the slope will be effectively armoured without the soil and grass, the operation for which, can therefore be progressed independently.

Availability for use

A pre-cast concrete or plastic component will generally require a full season of grass growth prior to use as each will tend to depend on the binding effect of grass and roots to create an effective tensile layer. This can be a limiting factor in programming particularly for fire and emergency access roads that need to become available for operation at an early stage. This early use can also include access for temporary works, the nature of which could destroy early stage grass growth.

Grasscrete doesn't require grass for stability and can therefore accept load prior to germination. This feature also suggests that the soiling and seeding element can be deferred until after temporary haul activities have been completed. As a general guide, in ambient temperatures, *Fig. 39* details the appropriate levels for interim loading of Grasscrete types. Loading at anytime by tracked excavators should be avoided as this is likely to cause abrasive damage to the walls of the soil pockets.

Grasscrete; Interim loading schedule					
			Age after concrete cast and load (GVW in tonnes)		
Grasscrete type	**Depth**	**200 x 200mm mesh reinforcement**	**7 days**	**14 days**	**28 days**
GC3	76mm	A142 (6mm Ø)	1	2	3.4
GC3	76mm	A193 (7mm Ø)	1.3	2.5	4.3
GC1	100mm	A193 (7mm Ø)	2	6	10.8
GC1	100mm	A252 (8mm Ø)	2.7	8	13.3
GC2	150mm	A252 (8mm Ø)	6	20	30
GC2	150mm	A393 (10mm Ø)	8	26	40

Fig.39

Fig. 39 identifies a first use capability in context of structural loading under ambient weather conditions. When interpreting this schedule consideration should be given to factors such as cold weather that may slow the curing period. We would also recommend that where the works have been soiled , consideration should be given to the potential impact of trafficking the surface if the soil has become saturated due to heavy rainfall etc.

CHAPTER ELEVEN

Cost and Logistical Evaluation

To create an effective **cost** evaluation for Grasscrete in comparison with other paving forms it is important to take an holistic view of both the direct and consequential costs for each type. Without this, comparisons are likely to focus solely on individual components. With this in mind *Fig. 40* identifies a wider scope of elements that should be considered for a truer comparison, in a typical car park installation.

Comparison of System Requirements				
Element	**Grasscrete GC3 (76mm)**	**Pre-cast concrete block (100mm)**	**Plastic paver (40mm)**	**Macadam (80mm)**
Sub-base depth (CBR 4% plus)	150mm	150mm plus	225mm plus*	225mm plus
Kerbs required	No	Yes	Yes	Yes
Separate line marking process	No	Yes	Yes	Yes
Surface water drain-	No	No	No**	Yes
Use before grass growth	Yes	No	No	N/a
*significantly dependant on rate of permeation in underlying ground				
** Potential for water-logging may call for a drainage intervention				

Fig.40

Our comparison intentionally avoids introducing a rate analysis, as this is a publication for Worldwide use the actual figures and their level of importance will vary. The intention however is that this should stimulate a process of drawing together the cost centres to be collectively considered for the actual construction. An extension of this could see a 'whole life' analysis, which would project an end cost by factoring in life span and maintenance requirements. For such studies we would be happy to be of further assistance.

Making a product available on a Worldwide basis from two manufacturing sources might on fist impressions suggest a challenging **logistical** operation, lengthy lead in times and high costs. To address this notion we can provide an example of how a project of 4000m² was supplied to an internationally funded project in Africa. The whole consignment of Grasscrete void formers required just 1No. Sea container with a land transfer from port to site of less than one day. The concrete was provided from an on-site batching plant using locally sourced aggregates. The installation was by a locally based team. The whole process was fully compliant with the funding requirements to stimulate the local economy as part of the construction. The alternative consideration would have been the importation of 30No. loads of pre-cast concrete blocks that would each have needed to travel a considerable distance due to lack of a local manufacturing plant.

With a network of over 30 International Licensee Partners, Grasscrete is readily available throughout the World and to any required quantity.

SUMMARY

Our aim with this Design Guide has been to provide a mix of historical background and design philosophy to sit alongside the practical aspects of design detailing and construction. With a history extending back 50 years the editing process of condensing the information down to a functional size was a challenge. If therefore you have a project where we haven't covered your requirements within this guide, then chances are we will have information available, so please ask.

Our philosophy is to develop more opportunities for environmental engineering and to be a challenger of practise that is not sensitive to a sustainable build environment. We are proud of our achievements that have included engaging with government departments and environmental groups around the World. In some cases this has seen a real and fundamental change, with the adoption of robust environmental impact assessments leading to better environmental practise. This shouldn't however suggest that we have reached a point where we can be trusting of our future in the hands of policy makers, until that is, those policies have global resonance and consistency.

With a Worldwide network of Licensing Partners we know all too well that consistency is still a distant target and that there remains much to be done before our need to develop is matched by our commitment to our environment.

We therefore welcome dialogue, with Architects, Engineers and Developers to engage around seeking a *better way.*

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