WHITE PAPER

SEGMENTAL RETAINING WALLS: NOTES FROM AN INDUSTRIAL DESIGN ENGINEER

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ABSTRACT

Segmental Retaining Walls: Notes from an Industrial Design Engineer

Modular walls, namely keystone reinforced earth walls, feature extensively in infrastructure and logistics distribution type projects. Focusing on the use of the modular wall systems in relation to the design and construction of large format industrial logistics and distribution facilities in Western Sydney, these types of projects typically see construction of retaining structures between 3 and 6m in height, however in many instances the walls can be in the 12-15m range or even larger. This paper explore the components of a modular block wall, what drives the need for large retaining walls for a particular project, and the opportunities and constraints of modular wall systems.

AUTHOR

Mark is a director of Costin Roe Consulting and the firm's head of civil engineering with 20 years' experience as a consulting engineer, and three as a surveyor, in Australia and overseas.

Mark possesses immense theoretical and practical knowledge about the design and engineering of modular retaining walls for large-scale industrial development infrastructure projects. He has been involved in the design and construction of modular retaining walls for almost 20yrs, being first introduced to the modular wall system in 2003. Segmental retaining wall systems feature extensively in many of the firm's recent and current projects in Western Sydney including the Marsden Park Industrial Estate, Horsley Drive Business Park and Eastern Creek Business Park Stages 3 & 4.

Costin Roe Consulting was Highly Commended for Excellence in Integrated Stormwater Design at the Stormwater NSW Awards in 2020. The firm also won the ACSE NSW Award for Excellence in Structural Engineering (Unusual Projects) for its work on the innovative Veolia Woodlawn MBT facility near Canberra.

OVERVIEW OF WALL CONSTRUCTION

So what is a modular wall? A modular wall has a few different names – reinforced earth wall, mechanically stabilised earth (MSE) wall, or commonly referred to as a keystone wall. It is essentially a mass gravity wall.

All the normal design assessment checks, including overturning, sliding, wedge failure, global stability, need to be made, however there will be other checks specific to the system like facing connections checks, creep failure, bulging and strap tensile checks.

The facing units or modular block, although an integral part of the wall, really only provide a means for connecting the earth straps and to contain the soil of the mass soil block at the face of the system.

The mass soil block comprises a select fill zone which is stabilised either by layers of horizontally spanning geogrids or steel straps. This zone forms the key structural component of the wall and its width can range between a minimum of 0.7x the wall height to 1.5x the wall height depending on loading and materials used. Typically we see geogrids being used in most wall constructions, with steel straps only being adopted for very high walls, say greater than 14m, or if a strict settlement requirement is required.

The select fill will normally need to have a reasonably high friction values of 34degree or higher, and Sydney is quite lucky in that regard with an abundant supply of sandstone which usually meets the parameter requirements needed for select fill. Lower quality materials, including clay, can be utilised in reinforced earth structures with additional closely spaced straps and extended strap lengths, however care must be taken to consider increased movement and sensitivity to moisture changes – for most applications use of a select fill with a high friction angle is recommended.

Other components of the wall include drainage systems where you might see a drainage layer between the face of the wall and select fill, and also at the rear of the wall at the interface between the retained material and mass soil block.

There are a few ways in which the design and construction of the walls can be completed. We commonly see the walls being constructed via a Design and Construct process. The geometrical and performance requirements, including loading and settlement criteria, are defined by the Engineering Designers, and then the structural requirements of the system, including strap length, type and spacing, will be completed by the D+C contractor and their wall engineer based on the defined criteria.

WHAT DRIVES THE NEED FOR LARGE WALLS?

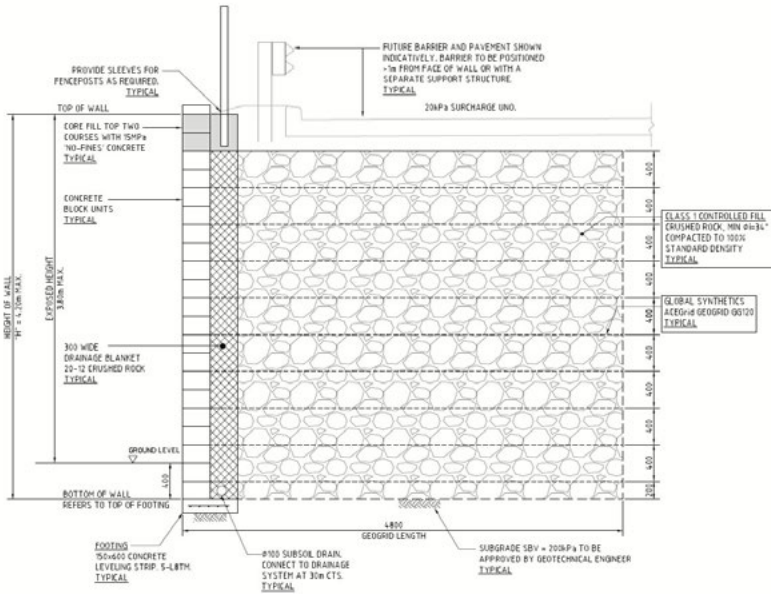
What drives the need for large walls on a distribution centre project?

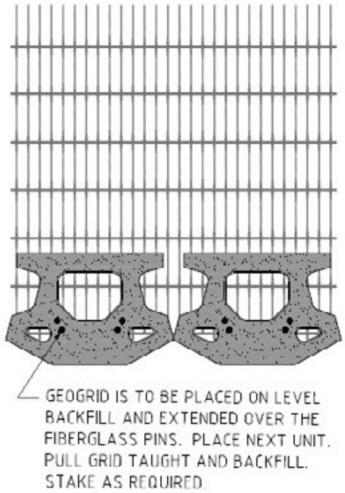
It's a simple equation – if you place a flat building which is 3, 4, even 500m in length and up to 60,000sqm in area on an undeveloped undulating site there will be a difference between the existing ground and the developed ground levels that will need to be addressed by either a steep batter or a retaining structure.

The demand for distribution facilities and the size of buildings overall has increased largely over the last 5-10yrs in response to online shopping, exacerbated by the COVID pandemic.

Sydney has moved from a period where land values were low and rent high enough that the cost of retaining structures were less a desirable design solution to address level differences and it was more common to address level changes via steep landscaped batters and limited wall construction.

As land values and rental return outweighs the capital cost of retaining wall construction,





GRID & PIN CONNECTION
SCALE 1:10

less use of battering and more use of retaining has resulted, this in combination with larger buildings has resulted in larger walls on many projects. The reinforced earth wall system can be seen to be a very economical wall system in most instances.

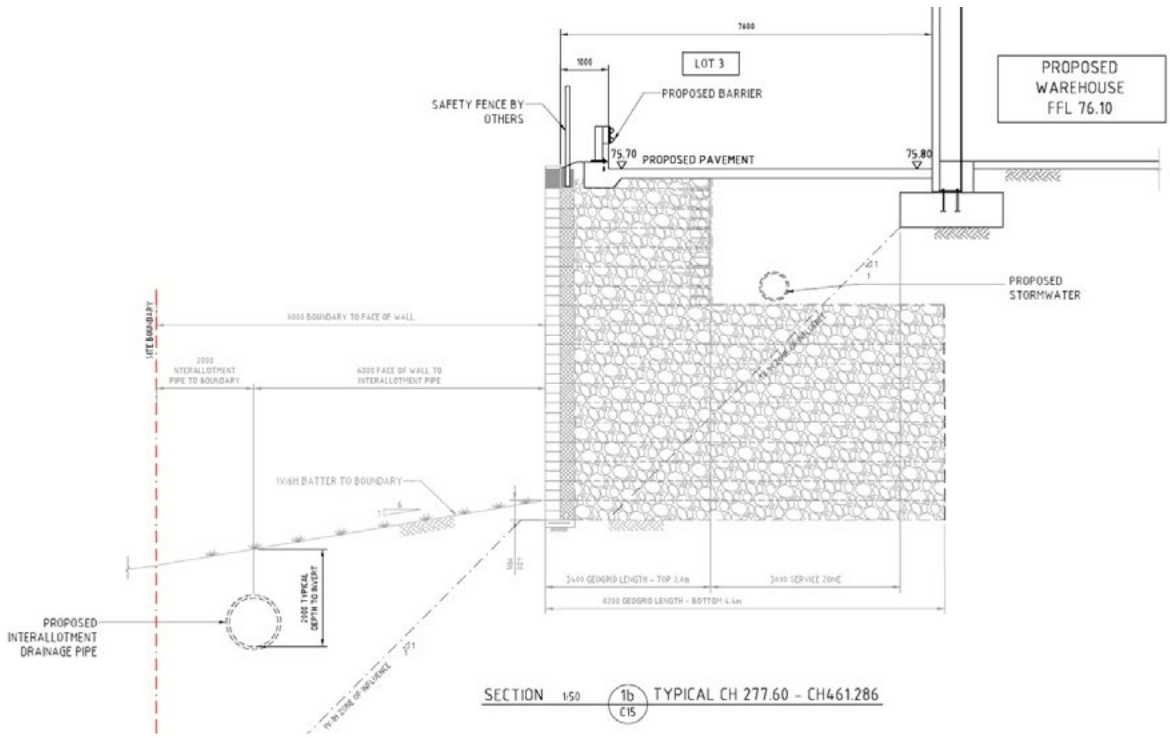
Further reasons for larger walls come about with the availability of land for development and the land which is available being more topographically challenging for large format distribution centre construction.

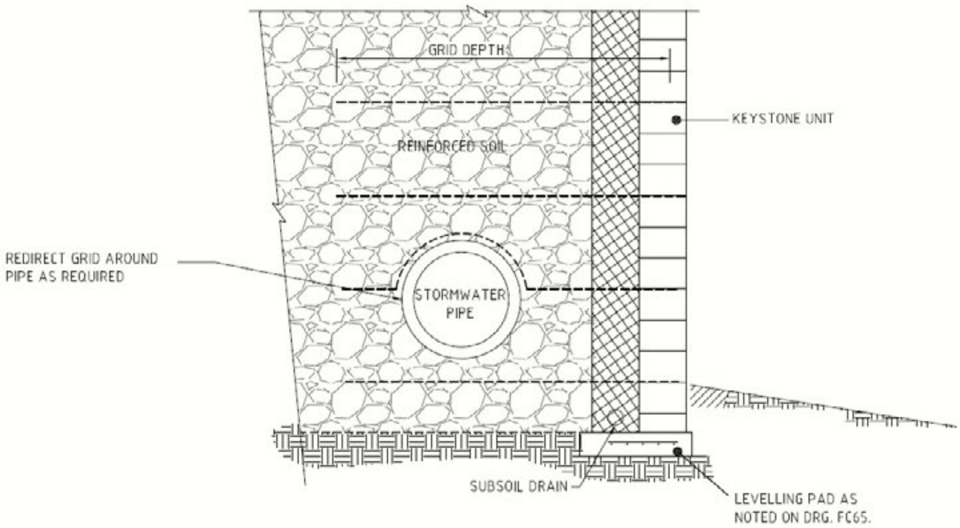
CHALLENGES AND OPPORTUNITIES WITH SEGMENTED WALLS

There are many things that need to be considered concurrently.

Where is the building in relation to the wall? What loading do we need to consider? What uses are there on the site and are any of these uses sensitive to settlement or movement? What services do we need to install to service the development?

For a distribution development, the length of the earth strap and select fill zone will typically be around 20% greater than the height of the wall. This means for a 6m high wall, the select fill zone will be 7.2m in length. A warehouse building will normally be as large as possible, and often times will be within or over the strap zone. How then do we install services if the wall is constructed before the building and service installation would damage the structure of the wall? Service zones will either need to be provided in the initial design, or the services installed as part of the wall construction.





TYPICAL WALL SECTION WITH PIPE IN REINFORCED ZONE
1:20

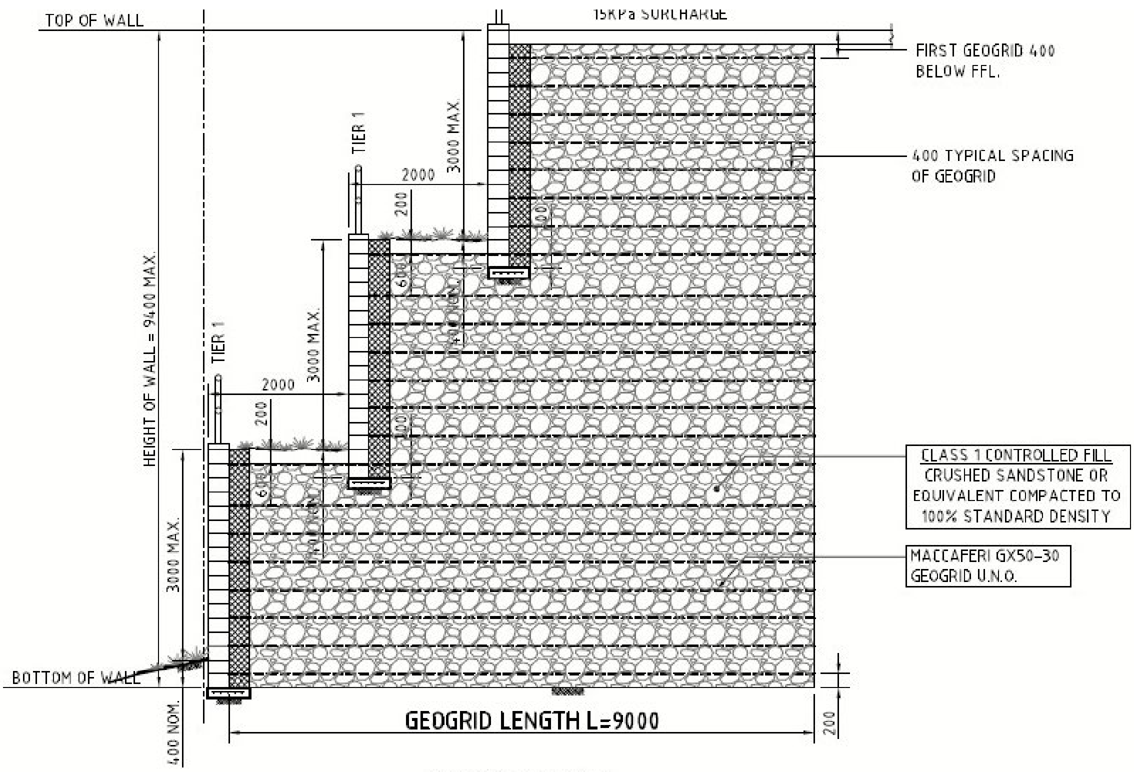
Examples of where services zones have been provisioned to enable the building to be constructed after the wall, and for services to be installed during the wall construction and integrated into the wall structure.

Most Councils have policies in place with the objective of improving the visual amenity of a retaining wall. Generally, most authorities don't like seeing large expanses of vertical walls facing the street or public domain.

The most commonly adopted measure authorities employ to overcome this issue is to introduce landscaped terraces and setbacks in their development controls.

Generally, walls and plants don't mix, due to roots damaging wall components and moisture variability in garden beds, however with shallow planting zones and additional geogrids in the upper layers on each terrace these issues can be overcome, and successful landscape planting can be introduced in a reinforced earth wall.

Some landscaping terracing has been demonstrated below on a site in Eastern Creek. The local council on this project, Blacktown Council, requires a 1.5m landscaped terrace for every 3m rise in level for any wall which can be seen from the public domain.



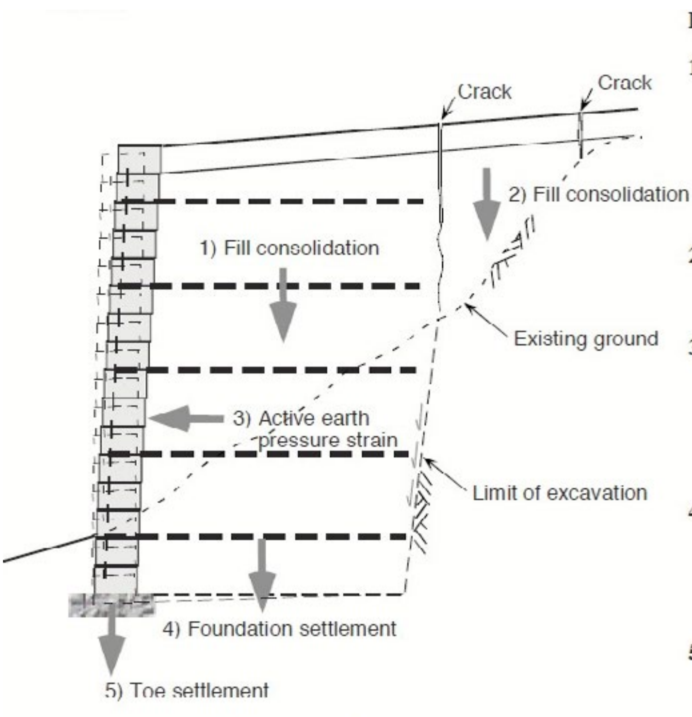
R.E. WALL TYPE 4
(UP TO 9.4m MAXIMUM HIGH)

Example of landscaping terracing on a site in Eastern Creek.

Modular walls are inherently flexible systems. Differential movement can sometimes occur between the reinforced earth fill zone and retained fill zone which results in soil cracking.

Differential movement can occur due to several mechanisms including consolidation of the reinforced backfill zone or retained soil wedge, lateral wall movement due to active earth pressure, or foundation settlement.

With careful detailing these issues can be mitigated and it is becoming more common for the top layers of geogrid to extend several meters past the remainder of the select fill zone, or for a biaxial grid to be provided between the select fill zone and retained material to reduce opportunity for soil cracking of the finished development surface.



Typical Section

Possible Causes of Soil Cracking

1) **Consolidation of reinforced zone backfill**
Any settlement of reinforced fill relative to adjacent soils may cause cracking at end of reinforcement. If soils are placed and compacted in dry condition, water can cause secondary consolidation of the reinforced fill and cracking at the end of reinforced zone.

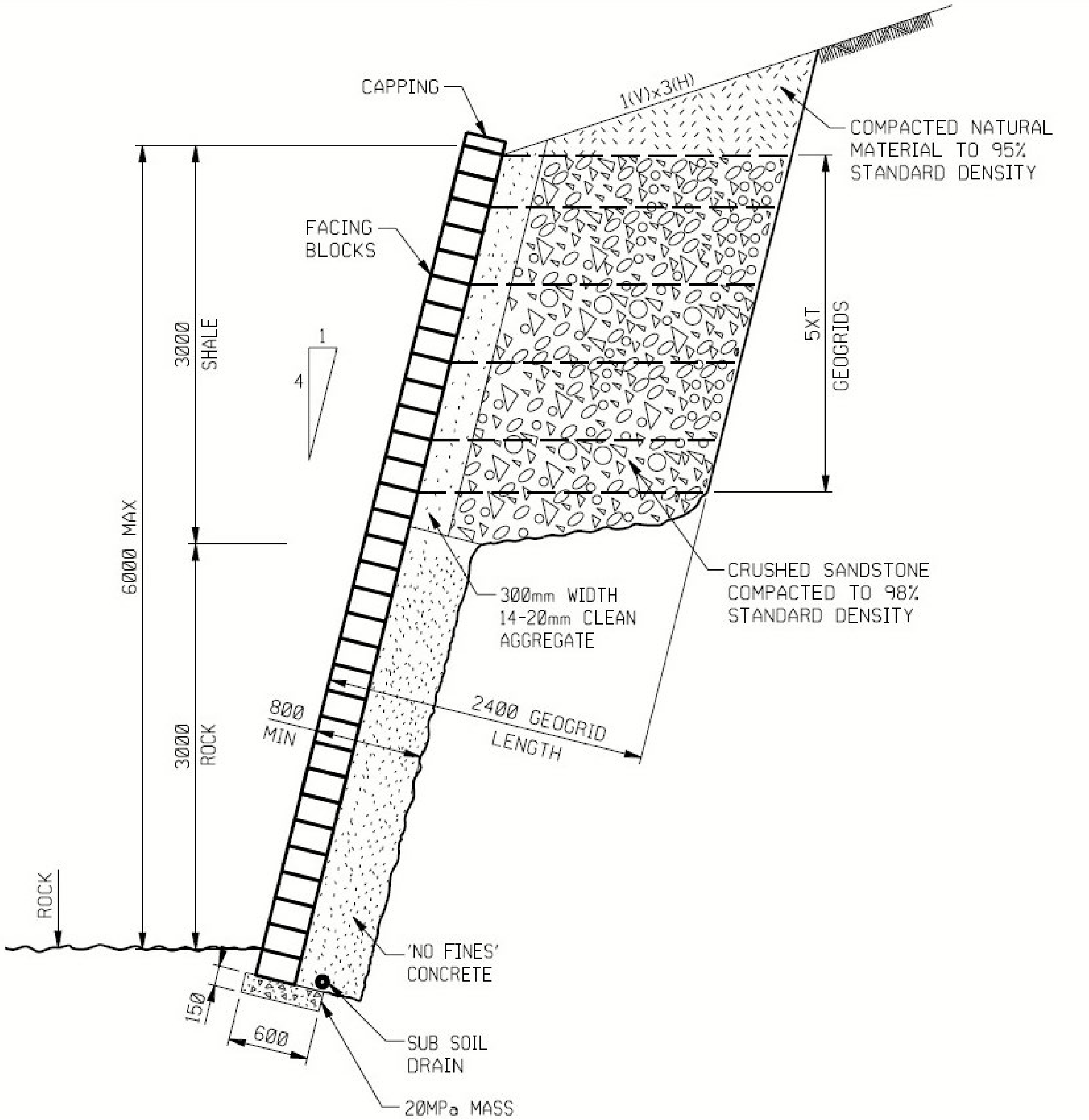
2) **Consolidation of retained soil wedge** - Similar to Item 1 causing cracking at back of fill wedge relative to existing soils.

3) **Lateral wall movement due to active earth pressure state** - Lessor quality backfill soils exhibit higher lateral movement to mobilize the active earth pressure state. If the reinforced wall mass strains laterally, the fill must settle accord ingly and cracking can occur.

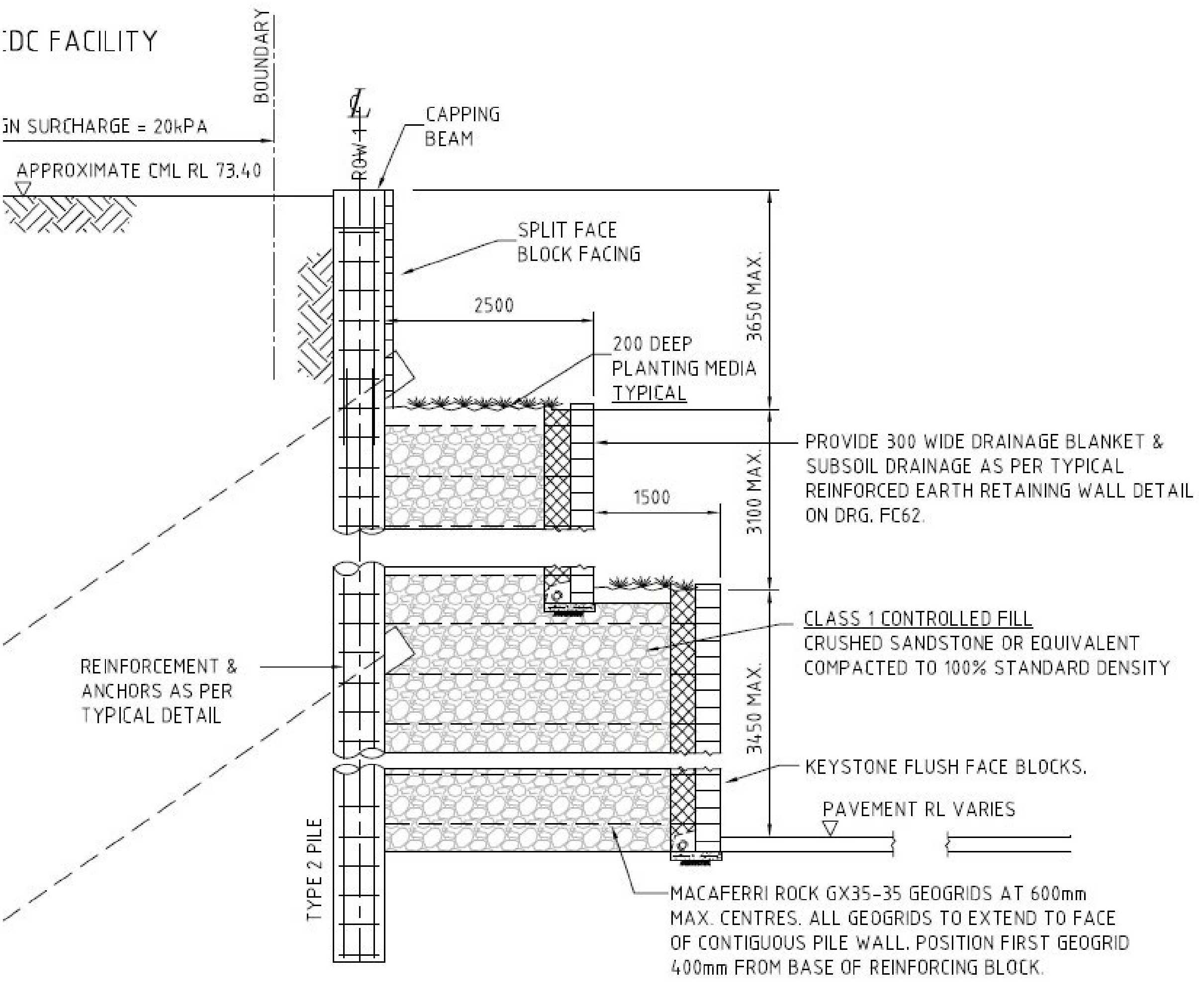
4) **Foundation settlement** - The foundation soils of many wall structures have not experienced the loading from the new fill which can cause differential settlement between the wall volume and cut slope soil.

5) **Toe Settlement** - The wall toe may experience more settlement than the wall heel due to lack of overburden or confining pressure resulting in slight lateral wall movement in the upper wall section and tension cracking at the end of reinforcement.

Below are examples of non-typical applications using modular blocks.



The above detail shows a design which includes a modular wall with reinforced earth, in combination with a no-fines concrete backfill wall. This combination has been used in a cut wall application over a rock face comprising sandstone and shale geology. Where the sandstone is present and cut face is stronger and less susceptible to weathering a thinner non-structural facing using keystone blocks and no-fines concrete has been constructed, and where the softer rock which will would also be susceptible to weathering is present, stabilisation with geogrid strapping and select fill zones are used. This application provides an economical and aesthetic means of achieving stabilisation over more traditional types of protection like shot-crete or crib wall construction.



RETAINING WALL PILE TYPE 2 WITH REINFORCED EARTH TIERS

SCALE 1:50

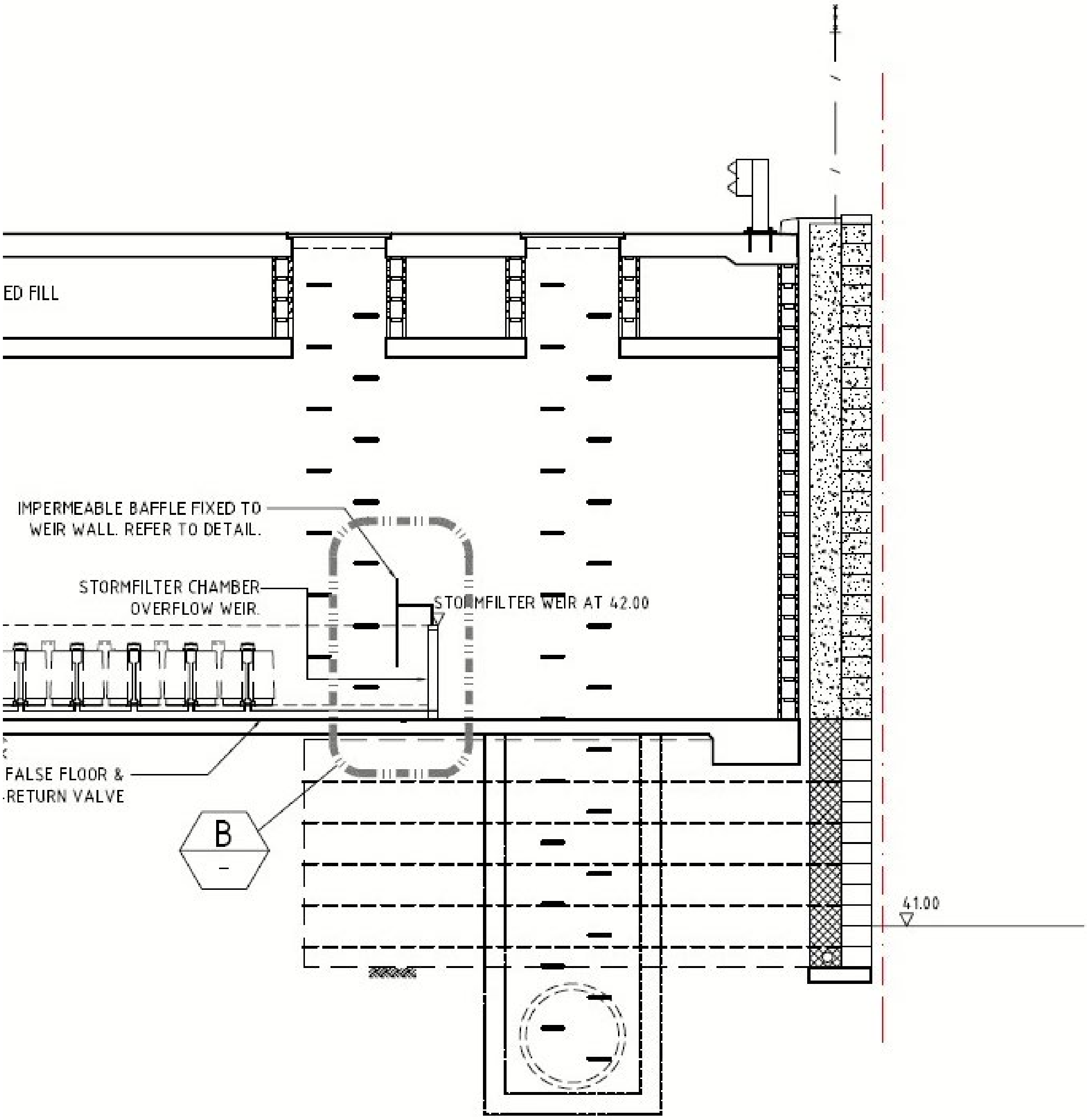
NOTE:

ALL BLOCKS (INC. SPLIT FACE BLOCK FACING) TO BE ALABASTER IN COLOUR.

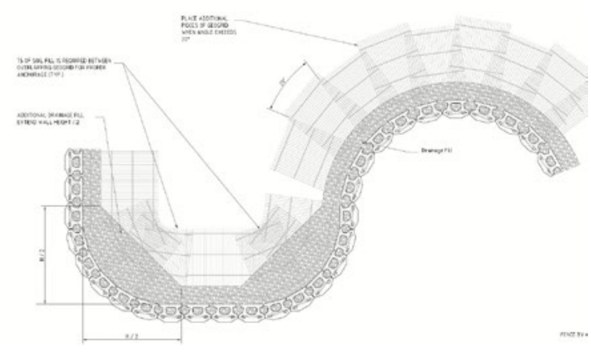
REINFORCED EARTH TIERS TO BE CONSTRUCTED FOLLOWING COMPLETION OF CONSTRUCTION OF CONTIGUOUS PILE WALLS.

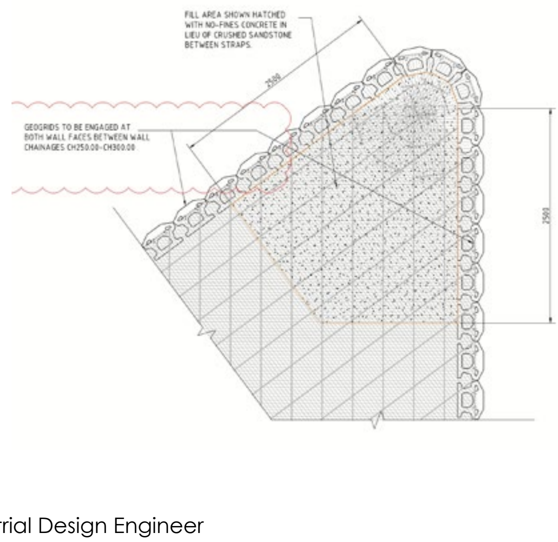
The above detail shows a non-structural application, which has been required to meet one of Councils landscape and visual amenity requirements. The reinforced earth wall was constructed in front of a short section of a 10.5m high anchored soldier pile and shotcrete wall and provides no structural support to the system. The keystone wall construction was required on the last 10-15m of the 100m long soldier pile wall where a small section of the wall was visible from the street. Where the wall was not visible from the street, the wall remained vertical with construction of the pile and shot-crete structural components of the wall without any modular wall components.

The below application was used, again as a non-structural screen to a stormwater detention tank. The client wished for continuity of the keystone wall through the entirety of the development. As such this required some careful detailing to continue the facing of the adjacent reinforced earth wall structures past the stormwater detention tank which was constructed using traditional reinforced concrete block construction. In this instance the keystone blocks were tied to the block structure and core-filled with no-fines concrete.



Modular block walls allow for interesting geometry including large and tight radius curves. Below are some examples of a curved wall detailing show the requirement for the geogrid reinforcement to be overlapping in both convex and concave curvatures.





CASE STUDIES & EXAMPLES

Marsden Park

The walls on this site, although not particularly high, each section being around 3m, is interesting in that it combines an open stormwater detention basin to detain stormwater runoff, and a bio-retention system to clean the stormwater, in and around a series of reinforced earth walls in combination with traditional reinforced concrete block wall construction.

In a 1 in 100yr rainfall event the water level adjacent to the reinforced earth wall would be up to 2m above the base of the wall, though only for a relatively short period of time. Consideration to saturation of the select fill zone and a potential for a reduction in overall strength of the wall as a result of saturation of the select fill was required.

To overcome this potential issue, the use of a more robust select fill material was adopted. In this case a crushed rock road-base gravel was used over sandstone to reduce the risk of reduced strength of the system when wet, and additional concrete core-filling of the lower block courses to reduce opportunity for water egress into the select fill zone.

Marsden Park retaining wall.

Eastern Creek Stages 3 & 4

This design at Eastern Creek in western Sydney required relocation of the Upper Angus Creek, in addition to the support of adjacent buildings and integration of stormwater treatment systems including two bio-retention basins, landscaping tiering and construction of the walls across a series of large box culverts where the estate road crosses the Upper Angus Creek.

The walls on this site were all keystone geogrid with heights ranging from 3m up to 12m.

Eastern Creek Stages 3 & 4.

Eastern Creek Stage 5

Eastern Creek Business Park Stage 5 required a combined approach, again around a stormwater management system.

The stormwater controls for this site necessitated a wetland in combination with a bio-retention basin and detention system. The overall level differences were upward of 12m.

The design included significant reinforced earth-wall construction in combination with landscaped batters, construction of trunk drainage pipelines through the wall structure and installation of large gross pollutant traps in the ZOI of the wall.

This system, constructed in 2017, provides a holistic design approach balancing the cost of the wall construction with the development potential of the land in combination with the topographical and environmental considerations of the site.

Eastern Creek Stage 5.

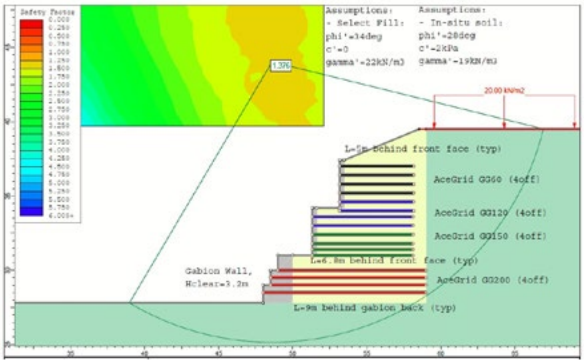
Horsley Drive Business Park

During the planning phase of this development at Wetherill Park, local Council and state authorities had significant concerns relating to the aesthetics of the 12m level difference between the development site and the adjacent roadway, and the detailing of the retaining structures required to accommodate the level difference.

The design team formulated an interesting design solution which employed a combination of curved keystone wall construction with terraced landscaped zones in combination with the lower 3m portion being constructed using gabion wall construction.

A global stability assessment was required due to the complexity of the structure. The global stability assessment required the introduction of geogrid layers and select fill to the retained zones of the lower gabion sections of the wall in addition to the upper Keystone components of the wall. This results in the select fill and geogrid strap zone being applied to all components of the wall and the upper and lower sections acting as a single mass gravity system.

The end product can be seen to provide a unique and visually pleasing result. The curved wall, stepped and landscaped terraces providing the intended reduction in overall bulk which could have resulted from an alternate design solution.



Horsley Drive Business Park.

SUMMARY

It can be seen that keystone modular wall systems can allow flexible and innovative design solutions for developments.

The key constraint for the majority of these walls is usually related to timing of construction and associated service installation, however other constraints including differential settlement can also provide some limitations. Overall, with due consideration to these items in the design phase the modular wall provides a great engineering solution to enable flat buildings be developed in undulating landform with large level differences.

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