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Earthworks Design Mass Balance for a Large Scale Nuclear New Build Site

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ABSTRACT: Sizewell C (SZC) is a new Evolutionary Power Reactor (ERP) nuclear power plant commissioned by Électricité de France (EDF) in Suffolk, England. The site of SZC is adjacent to Sizewell A (currently being decommissioned) and Sizewell B (operational) nuclear power plants. AtkinsRéalis was appointed as the designer for Site Establishment and Early Earthworks. Site Establishment works involve mobilising support structures for the main reactor construction and Early Earthworks involve building earthworks and other support structures within the main site for the reactor. As part of both Site Establishment and Early Earthworks, 8.6 million m^3 of material is expected to be excavated and stored with all of this material being reused within the site. The rural location of the site means that import/export of material to the site is challenging therefore the earthworks mass balance calculation was used to confirm that development at the site is viable and maximise the planned reuse of material on site. The mass balance looked at excavated volumes for each activity using the earthworks model and segregated each material into classes and types using the geological model. This material was then allocated storage locations during construction and assigned classes for reuse. This activity was constantly updated throughout the design period to account for design changes as the project evolved from concept design to detailed design. The calculation also took uncertainties into consideration and provided contingency options.

KEYWORDS: Earthworks, Mass Balance, Materials.

1 INTRODUCTION

EDF Energy intends to deliver a nuclear power station designated Sizewell C (SZC) that will make a major contribution to the UK low-carbon energy needs. The development, operation and ultimate decommissioning of the power station will be undertaken in a manner consistent with the highest standards of safety, reliability, and sustainability.

The SZC site is located on the Suffolk coast, approximately mid-way between Felixstowe and Lowestoft, to the north-east of the town of Leiston as shown in Figure 1.

The proposed nuclear power station would be located immediately to the north of the existing Sizewell A (SZA) (currently being decommissioned) and Sizewell B (SZB) (operational) power station and would comprise two UK EPR™ units with an electrical output of approximately 1,670 megawatts (MW) per unit, giving a total site capacity of approximately 3,340 MW. Once operational, Sizewell C would be able to generate enough electricity to supply approximately six million (or about 20%) of Britain's homes.

In addition to the key operational elements of the UK EPR™ units, the SZC project comprises other permanent and temporary development to support the construction and operation of the power station.

2 BACKGROUND

The SZC development site is split into three distinct areas; the Main Construction Area (MCA), Temporary Construction Area (TCA) and Ancillary Construction Area (ACA) (see Figure 1). The new power station will be constructed in the MCA to the north of SZB. A number of permanent and enabling works construction features will also be present in the MCA including a marine bulk import facility, beach landing facility and temporary and permanent sea defence.

The TCA and ACA will be prepared by the enabling works contractor for use by other contractors for compounds, laydown areas, buildings, warehouses and prefabrication facilities. The TCA also includes the main project storage stockpiles and borrow pits, a haul road and rail link with sidings. The TCA and MCA are linked by a new bridge crossing over the Sizewell Marshes Site of Special Scientific Interest (SSSI).

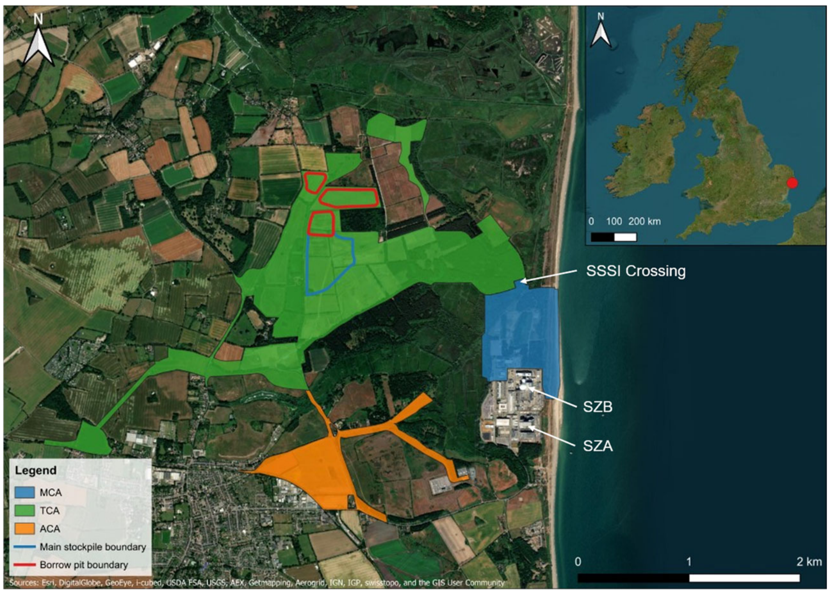

Figure 1. Site location plan.

3 SITE GEOLOGY AND GROUND CONDITIONS

The general stratigraphy at the SZC site is summarised in Table 1. The site geology and the ground conditions are based on site specific ground investigation carried out in phases. The key units of interest for the earthworks strategy are the superficial deposits of Peat, Alluvium and Lowestoft Formation and the Bedrock Crag Group. Figure 2 below shows an indicative geological section running east to west along the site. There is distinct spatial distribution to the superficial deposits. The influence of the superficial deposits on the earthworks will be significant. Simplistically, the superficial can be split into the Peat and Alluvium around the MCA, and the Lowestoft formation in the TCA and ACA.

There is a reasonably uniform thickness of 5 to 10m of Peat and Alluvium around the MCA, except for the southern part close to SZB. An east-west trending paleochannel (an infilled erosional channel) through the centre of the MCA has resulted in localised thicker deposits of Peat and Alluvium (approximately 10 to 12m).

The Superficial Deposits across the TCA and ACA are predominantly Lowestoft Formation sand and clay. Peat, alluvial sand and alluvial clay are largely absent. The superficial deposits are at their thickest in the west of the site where the Lowestoft Formation is locally 16m thick. It can be difficult to distinguish between Lowestoft Formation and Crag Group on site as both are typically encountered as sand.

The Crag Group are typically sand, very dense and slightly silty with mixed lithologies. Shell fragments and fine to medium gravel are encountered as well. The Crag Group are reasonably uniform across the development area, with the top of the stratum generally encountered between -7 and -10mAOD, deeper where the aforementioned paleochannel exists. The base is proved at -41 to -43mAOD in the MCA, with limited boreholes proving the full thickness outside of the MCA.

Groundwater was encountered at the site and surrounding area within the Made Ground, Peat, Lowestoft Formation (sand and gravel) and Crag Group. The Crag water level is influenced by tidal variation of sea level and is commonly slightly higher than that of the Peat. It is therefore considered that there is the potential for groundwater within the Crag to migrate upwards into the Peat. Groundwater was typically observed to be between approximately 0mAOD and 3mAOD during groundwater monitoring at the site.

Table 1. Summary of the stratigraphy at the SZC site.

	Unit	Sub-unit	Remarks
Superficial Deposits	Made Ground	N/A	Typically re-worked Crag Group and concrete left over from the construction of Sizewell B.
Superficial Deposits	Topsoil	N/A	Typically silts, sands, clays and organic materials. Material encountered across the whole site.
Superficial Deposits	Beach Deposits	Tidal Flats	Typically sands and gravels.
Superficial Deposits		Sand and Gravel	
Superficial Deposits	Peat	N/A	Typically peat materials, organic clays and soft cohesive materials. Material is encountered in and around the MCA and is the material of the SSSI. An east-west trending paleochannel (an infilled erosional channel) through the centre of the MCA has resulted in localised thicker deposits of Peat and Alluvium.
Superficial Deposits	Alluvium	Sand and Clay	
Superficial Deposits	Lowestoft Formation	Lowestoft Till	Typically sands and gravels with local occurrences of clay. Material is located predominantly at the topographic highs in the TCA and ACA.
Superficial Deposits		Lowestoft Sand and Gravel	
Bedrock	Crag Group	Norwich Crag	Typically sands and shelly sands with occasional clay lenses. Material is present in entire regional study area. It will be encountered during the excavation of the MCA and will generally be used as a founding material for a large majority of any proposed deep foundations.
Bedrock		Red Crag Formation	
Bedrock	Thames Group	Harwich Formation	Typically, a firm to very stiff greyish brown silty clay. Material is present in MCA and there are limited deep boreholes across the rest of the development area to confirm depth. The material will only be excavated during excavation of the Cut off Wall (COW). Other than the COW, there will be no excavation of this material.

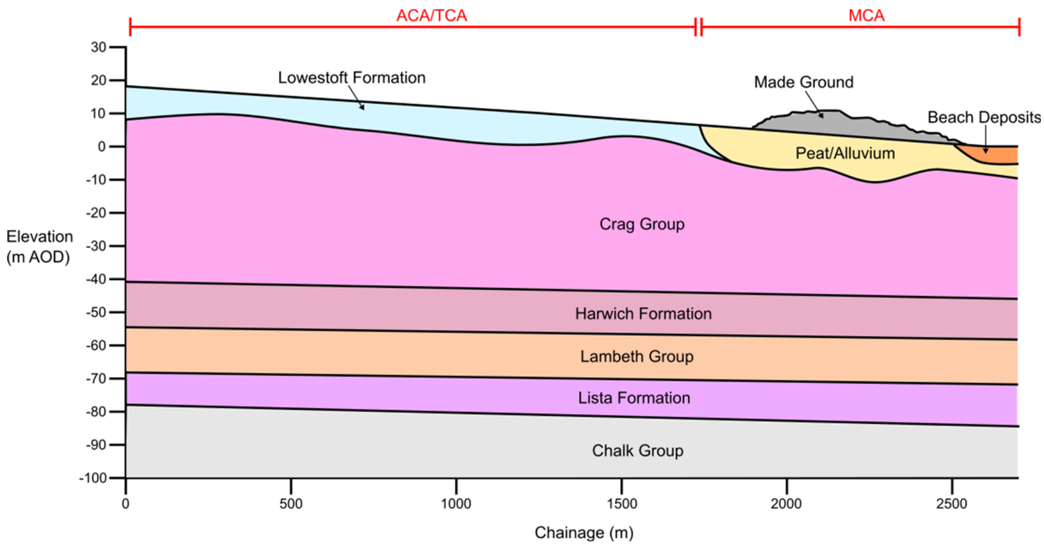

Figure 2. Indicative geological section (East to West).

4 CONSTRUCTION CHALLENGES

The ground conditions at the SZC site pose a challenge to construction. The main challenges for construction are summarized below.

- The soft compressible Peat and Alluvium in the MCA are unsuitable founding materials for permanent structures.
- The ground level in the MCA must be raised above flood level for permanent structures.
- Access between the MCA and TCA is difficult due to the presence of the SSSI and a bridge must be provided between the two parts of the site.
- The TCA must be regraded to form a series of level platforms to facilitate construction of the enabling works.
- The site is in a rural location with challenging road access therefore vehicle movements on public roads must be minimized.

5 EARTHWORKS STRATEGY

The earthworks strategy was developed to overcome the key construction challenges and to demonstrate in design that development of the site is feasible given the challenging ground conditions. The guiding principle for the earthwork strategy was to maximise the re-use of on-site materials, promote efficient movement and storage of materials and minimise the carbon footprint of the project. The following strategy and general construction sequence was developed:

1. The TCA is regraded re-using the Lowestoft formation to create level temporary construction platforms to support enabling works construction (warehouses, welfare structures etc).
2. Three borrow pits are opened within the TCA to win additional Lowestoft formation and allow the regrade of the TCA to be completed. Crag Group are also won from the borrow pits to be used in the MCA backfill. Surplus Crag Group are also required for site regrade. Figure 2. Key material movements across the site.
3. An access bridge is constructed over the SSSI between the MCA and TCA to facilitate construction access across the two parts of the site.
4. Raised areas of Made Ground (re-worked Crag Formation from the construction of SZB) are excavated and transported to the TCA to be stored in stockpiles.
5. Ground improvement using Deep Soil Mixing (DSM) is undertaken around the perimeter of the MCA to improve the strength and stiffness of the Peat and Alluvium and allow the construction of an earthwork embankment.
6. A diaphragm cut off wall is constructed around the perimeter of the MCA, using the area that has undergone ground improvement to facilitate access.
7. The Peat and Alluvium is excavated from beneath the location of permanent structures, is stabilized and is used to backfill the borrow pits within the TCA.
8. The upper layers of Crag Formation underlying the Peat and Alluvium are excavated and transported to the TCA to be stored in stockpiles.
9. Following completion of the main excavation in the MCA the stockpiled Crag sand material is blended with imported granular fill and cement and is used to backfill the MCA below the location of permanent structures of the power station. The blending of the Crag sand is required to improve its properties sufficiently for it to act as a founding layer for the permanent structures at the site.
10. Following completion of the power station construction, the remaining material in the TCA stockpiles is used to regrade the TCA area and return it to a naturally undulating landform.

Figure 3 summarises the key material movements across the SZC site.

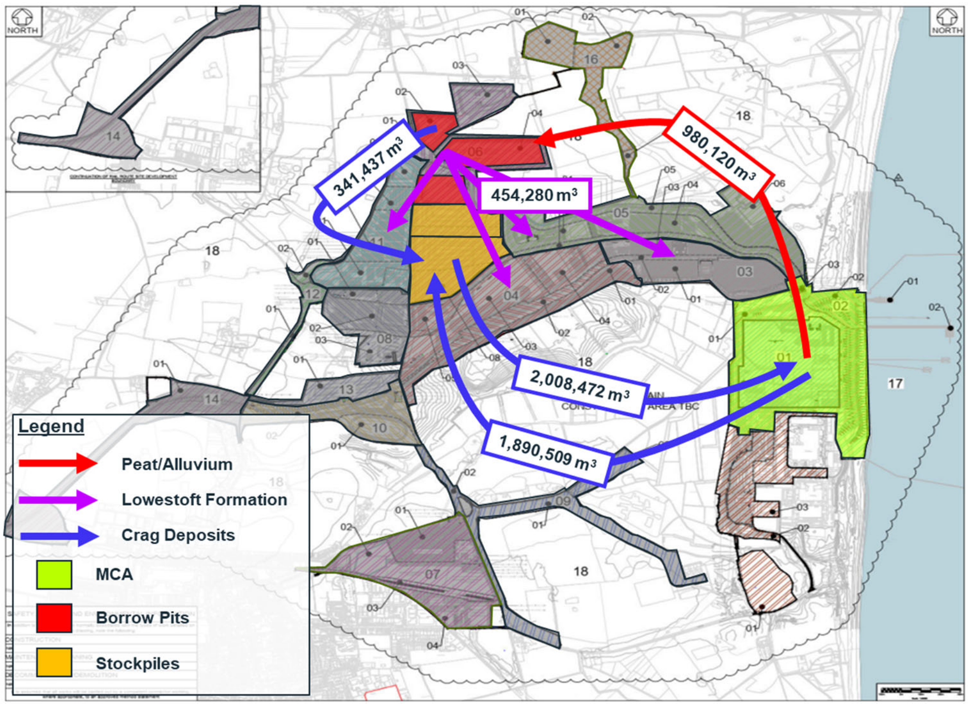

Figure 3. Material movement strategy on site

6 MATERIAL REUSE STRATEGY

One of the key aims of the earthworks strategy was to reuse site won material for site regrade to facilitate the construction phase and also provide material to support the nuclear island. Competent Crag formation will be used to backfill the nuclear island after being mixed with binder material. The ratio of Crag formation vs the binder will depend on the location of the fill in relation to the reactor building and depth. This ratio can range from 50% Crag formation: 50% binder to 70% Crag formation:30% binder.

The Crag formation excavated from both the MCA and the borrow pits will undergo further classification separating them into structural fill which is to be used for the MCA backfill and non-structural fill which is to be used for reprofiling activities around the remainder of the site. The material used for general site reprofiling was given a site-specific designation which deviated from the standard Specification for Highways Works Series 600 material classifications (Highways England 2016). The site-specific grading deviated from the standard SHW Class 1B grading by allowing a greater percentage of fines; increasing the limit from 15% to 25%. This modified grading was selected as the material available on site would not meet the standard Class 1B grading but was deemed suitable for use to reprofile the site and create construction platforms. The reprofiling levels for the TCA and ACA were influenced by the material balance to ensure that any additional material excavated from the site was used for reprofiling so that there isn't a surplus or a deficit of material. Due to the constraints, the material balance calculations were constantly changing to accommodate the changes in the programme and design involving other disciplines.

To ensure the site won material was performing as expected, three trial embankments were constructed on site. These trial embankment were used to understand the performance of site won fill under compaction and confirm a method compaction methodology. The trial embankments measured 3m in height, 20m in width and 20m in length. The following tests were administered on the trial embankments.

1. Dry density test
2. A 2.5kg rammer test to be carried out to ensure a Maximum Dry Density of 95%.
3. 600mm plate load test to report E_{V2} and CBR values.
4. Settlement monitoring for at least a period of 6 weeks.

Following the trial embankments, a layer thickness of 275mm to be compacted using a 19t roller was agreed as the method of compaction.

7 MASS BALANCE STRATEGY

The mass balance calculation was used to demonstrate that the cut and fill would balance across the development site and give confidence that the earthwork strategy could be implemented successfully. The mass balance calculation was used to answer five key questions:

1. Is there enough material to re-grade the TCA, ACA and MCA to enable construction on site?
2. Is there enough Structural Crag for backfill of the MCA below permanent structures?
3. Is there enough stockpile storage capacity during construction?
4. Is there enough material generated from borrow pits and borrow pit storage capacity?
5. Is there enough material for final site landscape restoration?

If the above five questions could be answered satisfactorily then there would be confidence that the earthwork strategy would be effective.

8 MASS BALANCE CALCULATION

The information for the estimated cut and fill volumes summarised in the mass balance were taken from different 2D and 3D models. Where the required information could not be extracted directly from models, the volumes have been estimated and/or calculated based on; information from other 2D and 3D models, drawings, schedules and specifications.

The 3D geological model of the site, developed using Leapfrog software, was critical for development of the mass balance calculation. The use of a 3D geological model allowed the cut volumes for individual strata to be directly extracted from the model for various construction activities across the site.

Another consideration in the calculation was material bulking. It is to be expected that materials will bulk i.e. expand upon excavation. However, after final placement there will generally be a net decrease in volume from the original in-situ state for sands (generally up to 5%) and a net increase in volume for clays (generally up to 5%) (Nowak 2015). Various factors affect bulking, and the calculations associated with material volumes, for example, type of soil, degree of compaction, loss of material on handling and settlement of underlying ground. In initial revisions of the mass balance calculation, bulking factors of up to 10% were applied. However, bulking factors were subsequently removed from the mass balance reporting to ensure no miscommunication of earthwork volumes between the various parties on the project. The impact of material bulking was considered within the earthwork strategy by applying a 10% reduction factor to total material storage capacity in stockpiles. The Contractor also considered bulking when reviewing material transportation across the site.

9 MASS BALANCE RESULTS

The outcome of the mass balance calculation in relation to the five key mass balance questions is presented below. The design volumes across the site are shown to be in balance for each of these five key challenges.

1. Is there enough material to re-grade the TCA, ACA and MCA to enable construction on site?

Across the TCA and ACA, the cut/fill balance results in a material surplus of 300,869 m3. The MCA enabling works cut/fill balance results in a material deficit of 314,771 m3. Therefore, the surplus material from the TCA/ACA re-grade is to be transported to the MCA to resolve the material deficit. Consequently, there is enough material to re-grade the TCA, ACA and MCA.

2. Is there enough Structural Crag for backfill of the MCA below permanent structures?

The MCA backfill consists of four structural fill types, denoted R1++, R1, R2 and R3. In total, 2,008,472 m3 of site-won Structural Crag is required for the MCA backfill. 1,890,509 m3 of Structural Crag is won from the MCA excavation and this material will be used as R1++, R1 and R2 Fill. 1,701,179 m3 is required for these fill types, resulting in a surplus of 189,330 m3 to allow for contingency if the amount of structural Crag excavated is lower than anticipated.

Structural Crag is also excavated from the borrow pits. However, the Crag from the borrow pits can only be used for R3 Fill. Therefore, the R3 Fill is to be exclusively sourced from the site-won Crag Group from the borrow pits. 307,293 m3 of R3 Fill is required. Therefore, based on the assumption that 90% of the Crag will be suitable as structural backfill, 341,437 m3 of site-won Crag Group from the borrow pits will be reserved for R3 Fill.

Overall, 2,008,472 m3 of Structural Crag is required for MCA backfill and there is 2,231,946 m3 available. Therefore, there is enough Structural Crag for the MCA backfill.

3. Is there enough stockpile storage capacity during construction?

There is 431,256 m3 of storage capacity for Topsoil in stockpiles and bunds. 361,264 m3 of Topsoil is required for the final landscape restoration phase. Therefore, there is enough stockpile/bund capacity for the Topsoil to be stored and subsequently re-used at the end of construction during site restoration.

There is 3,388,613 m3 of storage capacity for site-won materials (excluding Topsoil). 3,713,023 m3 of site-won material is the theoretical total amount of material excavated across the site that is required to be stored upon completion of the MCA excavation. However, due to construction sequencing and given the MCA backfill is undertaken concurrently with the excavation, the total theoretical excavated volume will unlikely be required to be stockpiled at any one time. Therefore, it is concluded there is enough stockpile capacity for site-won materials.

4. Is there enough material generated from borrow pits and borrow pit storage capacity?

454,280 m3 of Lowestoft Formation will be excavated from the borrow pits which will be used in the re-grade of the TCA. Additionally, 525,840 m3 of Crag Group will be excavated. As summarised in key question two, 341,437 m3 of the site-won Crag Group will be reserved for R3 Fill. The remaining 184,404 m3 will be used in the re-grade of the TCA.

In total, there is 1,191,286 m3 of excavated Peat & Alluvium which needs to be stored in the borrow pits. This Peat & Alluvium will be stabilised with cement prior to placement in the borrow pits. Assuming a shrinkage factor of 25% upon excavation and drying (to be confirmed following the results of ongoing stabilisation laboratory trials) and the DSM treated material will undergo no shrinkage, the total volume of Peat & Alluvium to be stored is 934,612 m3.

There is 980,120 m3 of storage capacity available in the borrow pits once they are fully excavated. Consequently, there is a surplus of 45,509 m3 in the borrow pits to store Peat & Alluvium.

5. Is there enough material for final site landscape restoration?

361,264 m3 of Topsoil is required for final landscape restoration. There is 431,256 m3 of Topsoil stockpile and bund storage capacity. Therefore, there is enough storage capacity for the Topsoil to be temporarily stored and subsequently used at the end of construction during site restoration.

Following the completion of the works, there is a material surplus of approximately 2 million m3. This surplus material will be used in the final landscaping to reinstate the TCA and ACA areas to their permanent configuration following the project's landscape masterplan.

10 MASS BALANCE RISKS

Although the mass balance calculation has demonstrated that the earthwork strategy will be effective, there remain a number of risks that will remain during construction:

- A number of assumptions have been made on the proportion of site-won material which is deemed suitable or unsuitable for nuclear structural backfill. There is a risk these assumed material splits are not achieved upon excavation.
- In addition to the site-won material designated for structural nuclear backfill, there is a risk that the amount of site-won material which meets the required criteria as set out in the project's Earthworks Specification differs from that which has been estimated.
- There is a risk of changes being instructed on site which cause a detrimental impact on the mass balance, if not managed and coordinated properly.
- There is a risk of the mass balance becoming outdated if not continually updated to reflect as-built information as construction progresses.
- All figures are presented with no allowance for wastage or bulking. There is a risk that wastage on site could increase material deficit, causing a detrimental impact on the mass balance.

11 CONSTRUCTION

The SZC project is now at construction stage and the earthworks mass balance will now evolve continually throughout construction. It is important that the mass balance is monitored throughout the construction period so that the impact of any changes on site can be reviewed to ensure that the mass balance can still be satisfied.

The movement of material and transient storage is currently being monitored through LiDAR and drone surveys on site. Drone mounted LiDAR is used to map topographical changes at the site every 4 weeks and this information is then used to calculate the level differences overtime. The accuracy of these drone LiDAR surveys is of the order of +/-25mm which is sufficient for earthwork monitoring purposes. The use of the drone survey allows the changing level and volumes of material on site to be monitored on a periodic basis. The use of drone survey has already identified variations on site such as areas where topsoil strip thickness is greater than expected in the design mass balance. The frequent periodic nature of the drone surveys means that changes such as this can be quickly identified and responded to on site before issues are caused to the mass balance.

12 CONCLUSION

This paper has demonstrated how site won material can be strategically reused for critical infrastructure. On SZC, site won material was also used to support nuclear critical structures when combined with a suitable binder. The paper not only looks at technical challenges but also considers practical and logistical challenges and demonstrates how this is managed across the site. The ground conditions also present a number of challenges to the construction activities.

This has necessitated the implementation of an earthwork strategy involving the excavation and movement of large volumes of material across the site. The earthwork strategy gave rise to five key earthworks material balance challenges which the mass balance calculation had to answer. Accurate calculation of earthwork cut and fill volumes across the development site allowed a comprehensive mass balance for the site to be developed. The mass balance calculation confirmed that the design cut and fill would balance for the five key mass balance challenges which gave confidence in the proposed earthwork strategy and gave confidence that the development of the site is feasible.

This paper demonstrates how site won material can be engineered to be reused on site reducing wastage and helping attain sustainable goals. Further reporting will be undertaken when construction work is complete to allow the effectiveness of the earthwork strategy to be assessed.

13 ACKNOWLEDGEMENTS

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