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Attention: Klaus Fuerniss
Klaus Fuerniss Enterprises Inc.
PO Box 570
Gibsons, BC
V0N 1V0

July 27, 2017
The George Development, Gibsons, BC
Job No.: 17.037
No. of Pages: 7

Technical Memorandum No 3: Deep Mixing Design Basis Memorandum

Dear Mr. Fuerniss,

This Deep Mixing (DM) Design Basis Memorandum has been prepared in support of the Development Permit Submission for Development Permit Application (DPA) 1, 2 and 9 for the proposed "The George" Mixed-Use Development, Gibsons, BC.

The objective of this DM Design Memorandum is to outline the design strategy adopted for DM, planned steps for detailed design and recommendations for DM construction. Deep Mixing 'Issued for Construction" Drawings and supporting technical specifications and field trial specifications will be prepared as the project advances to Building Permit stage.

This technical memorandum has been sub-divided into the following categories:

1. Deep Mixing Scope
2. Isherwood's Role and Responsibilities
3. Reference Documents Review and DM Risk Assessment
4. Site Characterization
5. DM Design
6. DM Construction

1. Deep Mixing Scope

Isherwood Geostructural Engineers (Isherwood) has been retained by Klaus Fuerniss Enterprises Inc. on May 25, 2017 to provide Professional Engineering Services for DM ground improvement design for foundation support of the George Hotel and Residences structure only. It is understood that deep mixing is required for the main hotel and residences structure only, whilst all other proposed structures including the structures in the near-shore and off-shore areas are anticipated to be supported on deep foundations and not deep mixed areas.

The DM for foundation support will be designed to meet project-specific performance requirements under static and seismic load conditions. Refer to Horizon Engineering Inc. (Horizon)'s Geotechnical Investigation Report (Revised, July 27, 2017) for details pertaining to the proposed development. At this stage of design, the structural performance requirements for foundation support are as follows:

- **Static Conditions:**
  - Total settlement: in the order of 25 mm.

- Differential settlement: between adjacent columns and between adjacent columns and walls, approximately 19 mm over 9.0 m.

- **Seismic Conditions** (in accordance with British Columbia Building Code 2012):
  - Lateral displacement: between floors, 13 mm without damage to non-structural components, 50 mm without collapse of non-structural components.

Refinement of design requirements is anticipated to be carried out during detailed design, where an iterative process will be followed for structural foundations (raft, strip and pad foundations) and DM ground improvement design.

This DM Design Basis Memorandum has been prepared to provide an outline of the design approach and recommendations for DM construction including additional geotechnical and hydrogeological investigation and a DM field trial, to be carried out prior to the start of production DM. This technical memorandum provides confirmation that the DM design approach and technical recommendations for construction (including additional geotechnical and hydrogeological investigation and DM field trials) will be implemented as the project advances.

For all other geotechnical, hydrogeological and environmental aspects of this project including near-shore and off-shore areas, refer to Horizon's Geotechnical Report (Revised, July 27, 2017) and Keystone Environmental's Reports for details.

2. Isherwood's Role and Responsibilities

Isherwood has been retained as the DM ground improvement designer, responsible for DM design for foundation support of the George Hotel and Residences structure. Refer to Isherwood's Technical Memorandum No. 1 (June 9, 2017) appended to this technical memorandum for details. As part of the DM strategy, Isherwood has also provided technical input associated with contingency plans for aquifer protection. Details of the aquifer protection plans are outlined in Horizon's Geotechnical Investigation Report (Revised, July 27, 2017).

We understand that Horizon Engineering Inc. has been retained as the Project Geotechnical Engineer and is responsible for all geotechnical aspects of the project. The DM components are by Isherwood.

3. Reference Documents Review and DM Risk Assessment

Based on a review of the available reference documents prepared by the project design team and the Town of Gibsons's Peer Reviewers, a list of risk items pertaining to the DM components has been compiled. Refer to Appendix A to D as follows:

- **Appendix A:** List of available project reference documents received for DM review.
- **Appendix B:** List of risk items identified from project reference documents (Appendix A) review pertaining to DM. These risks were further grouped into three main categories for ease of assessment:
  - General risks (GEN1 to GEN7)
  - Design risks (DES1 to DES6)
  - Construction risks (CON1 to CON4)

- **Appendix C:** List of general and design related risks with summary mitigation approach outlined.
- **Appendix D:** List of construction risks with an assessment considering the three main options for ground improvement for foundation support, previously discussed in "Evaluation of the viability of a DMM option as foundation support for "The George" development, Gibsons, BC (Geosystems L.P., April 18, 2017):
    - **Option 1**: Conventional Deep Mixing Methods (DMM) using hollow stem augers, after excavation, removal of peat/organic silt and backfilling with fill.
    - **Option 2**: Deep mixing using Cutter Soil Mixing (CSM) techniques.
    - **Option 3**: Excavation and replacement under Self-Hardening Slurry (SHS).

Based on a project-specific assessment of the construction related risks and considering the main goal, which is to provide ground improvement for foundation support for the hotel and residences whilst safeguarding the integrity and quality of the Gibsons Aquifer, the construction methodology to be adopted for DM requires careful assessment. All three construction methods, Options 1 to 3 require experienced specialist Contractors and operators and their success to achieve project-specific requirements are highly sensitive to the tools used.

Based on our knowledge of the industry standard equipment, we are not aware that the monitoring equipment for Option 1 is sufficiently sensitive to allow auger/paddle mixing in the upper material to achieve a homogeneous product whilst ensuring that the tip of the auger does not penetrate more than 0.5 m into the aquitard and potentially breaching the underlying confined aquifer. Therefore, in order to minimize the risk of breaching the aquifer during DM, Option 1 is not recommended. For Option 3, excavation and replacement under self-hardening slurry is highly operator dependent (i.e. the risk of penetrating more than 0.5 m into the aquitard will heavily rely on the "feel" of the operator and the tool that is being used for excavation). Further, if the relative density of the aquitard is a gradual resistance change with depth, it would be difficult for the operator to confidently confirm that less than 0.5 m penetration into the aquitard is achieved. Of the three methods, Option 2 possesses more sensitive monitoring equipment that enables the operator to assess whether 0.5 m or less penetration into the aquitard is achieved during DM. Further, Option 2 enables peat/organic silt to be homogeneously mixed in situ to form foundation elements without the need for excavation and replacement. Therefore, based on the need to reduce the risk of breaching the underlying confined aquifer, Option 2 is recommended to be pursued for DM. It is anticipated that if Option 2 is pursued, the native peat/organic silt is expected to be left in situ and treated with the upper soils as part of the DM process.

A field trial and a cost-benefit assessment would need to be carried out to determine the most cost and schedule-efficient construction method, whilst managing project risks and meeting performance requirements. Option 2 was deemed to carry the least amount of risk concerning potential to breach the underlying aquifer compared with the other options.

The DM design approach, consistent with industry guidelines (Federal Highway Administration Design Manual: Deep Mixing for Embankment and Foundation Support, October 2013) and recommendations outlined for detailed design presented in this Technical Memorandum would be applicable to both Options 2 and 3. For the purposes of developing field trial and construction recommendations outlined in this Technical Memorandum, recommendations associated with

Option 2 have been outlined. For Option 3, some modifications would need to be made to the construction recommendations.

4. Site Characterization

Various geotechnical and hydrogeological investigations have been carried out at the project site and these have been summarized in Horizon's Geotechnical Investigation Report (Revised, July 27, 2017). The subsurface conditions within the "land-side" of the proposed development generally consist of the following variable conditions:

Soil conditions:

- Fill (granular and organic material); overlying
- Peat/Organic silt; overlying
- Sand to silty sand to sandy silt; overlying
- Silty sand to silt and sand till (where present); and
- Sand to sand and gravel to gravel.

Groundwater conditions:

- Non-artesian conditions within the upper fill and overburden (above silty sand to silt and sand till); and
- Artesian conditions within the Gibsons Aquifer (sand to sand and gravel to gravel).

Based on a review of the available geotechnical and hydrogeological data and considering the areas where ground improvement is required for foundation design, "data gaps" were identified in areas where additional soil and/or groundwater data would be beneficial to identity the elevation and thickness of the aquitard and artesian conditions to manage the risk of penetrating into the underlying confined aquifer or increasing the risk of basal instability during DM. The additional subsurface data is expected to be obtained during DM detailed design to enable refinement of the "ground and groundwater models" for DM design. For DM design, the following additional geotechnical and hydrological investigation was proposed:

- 32 No. in situ Cone Penetration Tests with pore pressure monitoring;
- 2 No. boreholes drilled for groundwater/pressure monitoring (2 No. nested vibrating wire piezometers per borehole); and
- 3 No. mechanically excavated trenches.

Refer to Isherwood's Technical Memorandum No. 2 for details pertaining to the scope of the additional investigation, including an exploratory holes location plan (Figure 1) showing existing and proposed exploratory hole locations, relative to the proposed development areas. In addition to the above additional geotechnical and hydrogeological investigation, Horizon also proposed additional groundwater monitoring at 7 No. locations, which we understood were intended for groundwater/pressure monitoring and groundwater sampling prior to, during and following completion of the DM work. Refer to Horizon's Geotechnical Investigation Report (Revised, July 27, 2017) for details pertaining to long-term groundwater monitoring strategy.

5. Deep Mixing Design

Design Philosophy

A performance-based design approach has been adopted by considering the estimated stress-deformation response of the DM areas under static and seismic conditions. The concept DM design, generally consistent with industry guidelines (FHWA, October 2013) is based on performing the following steps:

1. Establishing project performance requirements (including identifying areas where DM is required)
2. Assessing subsurface conditions (develop soil and groundwater model and characteristic parameters for analyses)
3. Preliminary analysis (stability, bearing capacity, crushing, shear and basal stability due to artesian conditions in the underlying confined aquifer) to estimate Area Replacement Ratio (ARR), treatment geometry and DM element design properties (strength, modulus and permeability).
4. Review of reference/published data to assess feasibility of DM design parameters, considering wet mixing using the CSM method of DM.

It is expected that during detailed design, and following a review of the additional subsurface data, the above steps will be revisited in order to refine the ground model and associated soil and groundwater parameters considered for analysis and progressing with the DM design. Currently, the concept DM design properties have been estimated considering raft foundations for heavily loaded areas, continuous strip foundations for moderately loaded areas and individual pad/perimeter strip foundations for lightly loaded areas (refer to Figure 1 of Isherwood's Technical Memorandum No. 2 (June, 2017) for details), as follows:

- Raft slab at P3 level (approx. EL. + 2.5 m to El. 3.0 m) – main parkade structure (west portion)
- Raft slab at P2 level (approx. EL. +3.0 m to EL+ 4.0 m) – fuel tank
- Continuous strip foundations at P3 level (EL. + 4 m) - main parkade structure (east portion)
- Raft slab at P2 level (approx. EL. +3.0 m to EL+ 4.0 m) – main parkade structure (north core)
- Pad and perimeter strip foundations at P2 level (approx. EL. +4.0 m to EL. + 5.0 m) – ancillary structures

Concept DM Design Properties

Based on the current proposed foundation layout, structural load and performance requirements and the subsurface soil and groundwater conditions, the following concept design has been estimated (subject to verification and refinement during detailed design):

- Area Replacement Ratio of approximately 0.35 to 0.40 (within proposed foundation footprint – P2 and P3 levels)
- Treatment depth of approximately 3.0 m to 5.5 m (maximum penetration of 0.5 m in aquitard)
- Treatment geometry – grid-like system with increased treatment within core, tank and other heavy load areas
- Target unconfined compressive strength, q_u of approx. 2.0 MPa

- Target Young's modulus of elasticity at 50% strain, E_{50} is based on 300 q_u (FHWA, October 2013)

It should be noted that the above concept DM design properties are subject to verification during a full-scale field trial and further refinements are expected during detailed design.

Deep Mixing Design Information

Following completion of DM detailed design and a review of the additional geotechnical and hydrogeological data, "Issued for Construction" Drawings and Technical Specifications are anticipated to be prepared. Below is an outline of the information that is expected to be contained within the Technical Specifications (these will be developed during detailed design, prior to commencement of field trial and production DM):

- Description of the project;
- Project reference information (geotechnical report, architectural/structural/civil drawings including site plan and utility information);
- Project performance requirements (DM design properties) and acceptance criteria
- Remediation options
- List of pre-construction submittals required from Specialist DM Contractor:
    - Workplans for DM including managing obstructions and management of spoil, wet grab sampling, coring and testing;
    - Mix design;
    - Quality Assurance/Quality Control (QA/QC) plan;
    - Construction schedule;
    - Aquifer protection plan including list of equipment required; and
    - Breach of aquifer remediation plan including list of equipment required.
- List of field trial submittals:
    - Workplan and equipment required for field trials;
    - Mix designs;
    - QA/QC plan including sampling and testing requirements;
    - Data Acquisition System (including data to be submitted as part of QA/QC)
    - Aquifer protection plan including list of equipment required; and
    - Breach of aquifer remediation plan including list of equipment required.

Monitoring of groundwater conditions (quality and integrity) is anticipated to be carried out by the Project Geotechnical Engineer, Horizon. Refer to the aquifer protection plan including details pertaining to the monitoring plan and thresholds for action outlined in Horizon's Geotechnical Investigation Report (Revised, July 27, 2017).

6. Deep Mixing Construction

Full-Scale Field Trial

To verify that the construction methodology, proposed mix design(s) and aquifer protection plan meet project performance requirements and provides confirmation that a breach of the confined aquifer has

not taken place, a full-scale field trial is required. Subject to detailed design, the field trial is likely to consist of:

- 3 No. to 4 No. soil-cement elements to be constructed in various ground improvement areas (minimum 3 No. sets of design mixes with cement content of 350 kg/m^3 to 450 kg/m^3);
- Wet grab sampling and coring;
- Testing and reporting;
- Data acquisition system – review of select CSM parameters obtained during DM
- Monitoring of groundwater conditions (to be carried out by Project Geotechnical Engineer)

Where more than one method of ground improvement treatment is considered (e.g. Option 2 CSM and Option 3 SHS), additional soil-cement elements would need to be installed during the field trial.

Following sampling and testing (consistent with industry guidelines), all data including groundwater monitoring data is required to be provided to Isherwood for review and assessment. Isherwood is expected to provide full-time field support during the DM field trial and will prepare a field trial test report outlining the implementation of the field trial including method of installation, mixes considered and an evaluation of the performance of the soil-cement elements.

Subject to the outcome of the field trial, modifications could be required to the design and the construction method to be adopted for production DM.

During production DM, Isherwood is also expected to provide full-time technical field support, with full-time hydrogeological field support provided by Horizon.

We trust this memorandum provides sufficient information for your immediate requirements. If you have any queries, or require further input, please contact us.

Yours truly,

Isherwood Geostructural Engineers
A division of Brian Isherwood & Associates Ltd.

PROFESSIONAL PROVINCE OF S. W. LI # 39155 BRITISH COLUMBIA ENGINEER

PROFESSIONAL PROVINCE OF N. ANSARI 25104 BRITISH COLUMBIA ENGINEER

Marina S.W. Li, P.Eng.

Nadir Ansari, P.Eng.

Attachments:

- Technical Memorandum No. 1: Isherwood Role and Responsibilities for Deep Mixing
- Technical Memorandum No. 2: Deep Mixing – Additional Geotechnical Investigation Data

- Appendix A: Deep Mixing – List of Project Reference Documents Received for Review
- Appendix B: Deep Mixing – List of Risk Items Identified From Project Reference Documents Review
- Appendix C: Deep Mixing – General and Design Risks and Assessment
- Appendix D: Deep Mixing – Construction Risks and Assessment
- Appendix E: Additional References

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June 09, 2017
The George Development, Gibsons, BC
Job No.: 17.037
No. of Pages: 2

Technical Memorandum No 1: Isherwood Role and Responsibilities for Deep Mixing

Dear Mr. Fuerniss,

In response to the Town of Gibson's Peer Reviewer, Geosystems L.P. for "The George" Mixed Use Development, Gibsons, BC's request to clarify roles and responsibilities for engineering and field supervision, we write to confirm Isherwood Geostructural Engineers (Isherwood)'s role for this project is as follows:

- Deep Mixing (DM) Ground Improvement Designer, responsible for DM design for foundation support of the George Hotel and Residences Structure only.

- Responsibilities include:

  Design Phase
  1. Review of available reference information (geotechnical; hydrogeological; project information) for DM design;
  2. Development of DM design strategy and production of a Design Basis Technical Memorandum;
  3. DM detailed design and supporting analyses;
  4. Production of an "Issued for Construction" set of drawings and supporting technical specifications for Deep Mixing;
  5. Completion of Schedule B for DM ground improvement design and commitment to field reviews; and
  6. Production of a Field Verification Trial Report outlining design, installation, monitoring and analysis of the DM field trial.

  Construction Phase
  1. Field review during DM field trial;
  2. Production of a Technical Memorandum outlining findings from the DM field trial;
  3. Field review during production deep mixing including review of monitoring data (collected by others); and
  4. Completion of Schedule C-B for DM ground improvement field reviews during construction.

We anticipate the Project Geotechnical Engineer, Horizon Engineering Inc. be retained for all geotechnical aspects of the project, with the exception of the deep mixing components, which Isherwood will be responsible for.

We trust this memorandum provides sufficient information for your immediate requirements. If you have any queries, or require further input, please contact us.

Yours truly,

Isherwood Geostructural Engineers
A division of Brian Isherwood & Associates Ltd.

Marina S.W. Li, P.Eng.

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June 22, 2017
The George Development, Gibsons, BC
Job No.: 17.037
No. of Pages: 3

Technical Memorandum No 2: Deep Mixing – Additional Geotechnical Investigation Data

Dear Mr. Fuerniss,

This Technical Memorandum has been prepared to summarize the additional geotechnical investigation recommended for Deep Mixing (DM) design. The additional data required is supplementary to the existing geotechnical, hydrogeological and environmental data obtained through various stages of site investigations at "The George" Development site. A summary of the additional data recommended is presented in Table 1 and supporting Figure 1.

Table 1: Summary of Additional Geotechnical Data for Deep Mixing Design

Proposed Exploratory Hole Reference	Exploratory Hole Type	Location	Data
CPT 17-01 to CPT 17-21	In Situ Cone Penetration Tests (CPTs) with cone friction, tip resistance and pore pressure measurements to refusal (>200 bars)	P3 Raft and Strip Foundation Areas	• Thickness of peat/organic silt • Top of till (aquiclude) • Top of Aquifer
CPT 17-22 to CPT 17-24		P3 Fuel Tank Storage Area	
CPT 17-25 to CPT 17-32		P2 Pad and Strip Foundation Areas	
VW 17-1	2 No. Nested Vibrating Wire (VW) Piezometers per fully grouted auger hole installed between 4 and 8 m below existing ground	Western half of the main building	• Pore pressures in unconfined aquifer • Pore pressures in confined aquifer
VW 17-2		Eastern half of the main building	
TT17-01	Test trench (TT) mechanically excavated using 360 excavator up to approx. 5 m below ground (under stable conditions)	North portion of the main building	• Visual observation of soil conditions and groundwater inflow • Rising head test in test trench
TT17-02		East portion of the main building	
TT17-03		West portion of the main building	

Notes:

1. Method of in situ testing for the CPTs; drilling and installation of the nested vibrating wire piezometers; and trench excavation should be consistent with previous methods carried out during previous stages of site investigation. Contingency measures should be in place as part of

the site investigation field work. Prior to the commencement of fieldwork, work plans indicating method and procedures for drilling, installation, in situ testing and excavations should be provided to Isherwood for comment.

2. Exact location of exploratory holes as indicated in Figure 1 to be confirmed subject to suitable access on the site.
3. Maximum depth of CPTs is based on reaching refusal and is estimated to be between 5 m and 8 m below existing ground. Dissipation tests are anticipated to be carried out at 5 No. CPT locations, at typically three horizons.
4. Isherwood's proposed auger hole location for installation of VWs could be combined with nearby proposed piezometer installation locations proposed by Horizon for collection of hydrogeological data, provided the piezometers proposed are VWs installed within the upper unconfined aquifer and within the lower confined aquifer attached to data loggers to collect data at approximately 30 min. intervals for a duration of at least 2 months prior to commencement of the DM construction work.
5. Depth of auger holes for VW Piezometer installation will be dependent on the subsurface conditions encountered at the auger hole location.
6. Maximum depth of test trench will be based on stability of the side walls. On encountering groundwater inflow, a rising head test of up to 30 mins could be carried out at the location of each test trench.

It is anticipated that the Project Geotechnical Engineer, Horizon Engineering Inc. be retained for all aspects of the full-time field supervision of the geotechnical, hydrogeological and environmental site investigation including the additional investigation scope of work recommended in the above table. Isherwood is anticipated to visit the site periodically (a minimum period of 5 days) during the additional site investigation for periodic review and assessment of the data. Where additional field reviews are required due to extended field investigation and/or complications, these would be identified during the field works.

It is expected that the additional data obtained from the additional investigation be provided to Isherwood within a 24 hrs to 48 hrs period to allow for timely review and recommendations to be made.

It should be noted that the above data requested has been designed for detailed DM design for foundation support of the George Hotel and Residences Structure only. Refer to Horizon Engineering Inc. (Horizon) recommendations for additional geotechnical and hydrogeological data required for areas outside of the main structure, e.g., nearshore and offshore areas, as well as establishing control monitoring points for assessment and monitoring of groundwater pressures and groundwater quality of the confined aquifer prior to, during and following completion of the DM construction work.

We trust this memorandum provides sufficient information for your immediate requirements. If you have any queries, or require further input, please contact us.

Yours truly,

Isherwood Geostructural Engineers
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Marina S.W. Li, P.Eng.

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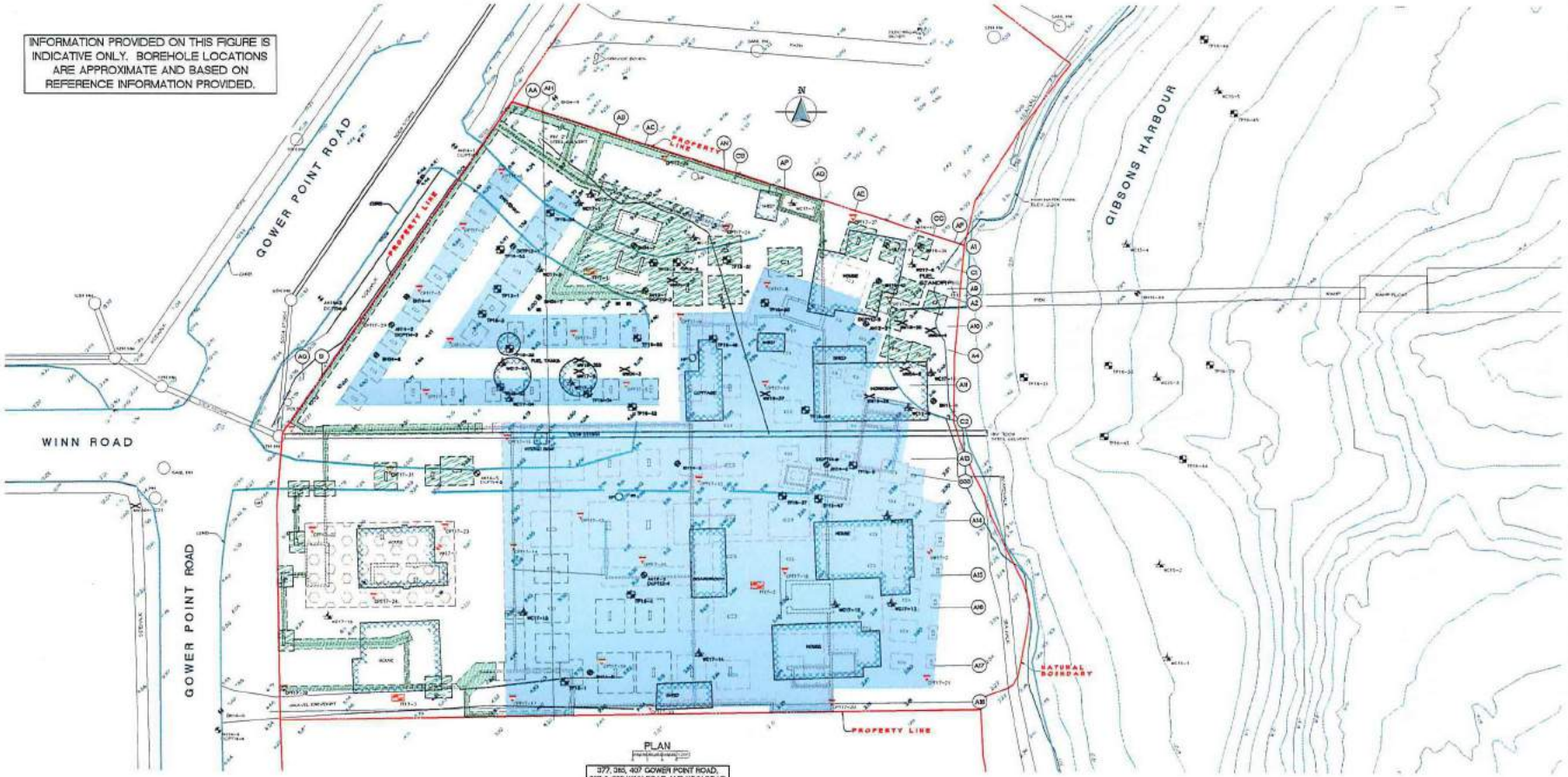
INFORMATION PROVIDED ON THIS FIGURE IS INDICATIVE ONLY. BOREHOLE LOCATIONS ARE APPROXIMATE AND BASED ON REFERENCE INFORMATION PROVIDED.



PLAN

377, 385, 407 GOWER POINT ROAD,
397 & 689 WINN ROAD AND WINN ROAD
R.O.W. GIBSONS, BRITISH COLUMBIA

NOTES:

A. Refer to Sherwood Technical Memo # 2 dated 17.06.22 for details.

B. Topographical survey data and bathymetric survey data presented are based on Geodetic Datum, refer to References for details.

C. REFERENCE:

1. Structural Drawing "The George Hotel and Residences" drawing no. S2.A01 and S2.A02, by Read Jones Christoffersen Ltd., dated November 1, 2016.
2. Structural Drawing "The George Hotel and Residences" drawing no. S2.A02 annotated with footing grouping recommendations, provided by Read Jones Christoffersen Ltd. on June 16, 2017.
3. Revised Geotechnical Investigation Report, File No. H2-1731, by Horizon Engineering Inc., dated April 7, 2016.
4. Topographic Survey "Topographic Plan of Lots 1 and 2, Block A, DL 605, Plan 19171, and Lots 1 and A, DL 605, Plan 15171", by Lang in Forsyth, received on January 25, 2016.
5. Bathymetric Survey, file name "bathymetric surveydwg" provided by Horizon Engineering Ltd. on May 30, 2019.

LEGEND

- TEST PIT
- BORE HOLE
- RADIO HOLE
- WILDCAT
- MONITORING WELL
- PROPOSED TEST TRENCH
- PROPOSED GPT
- PROPOSED VIBRATING WIRE PIEZOMETER
- EXISTING STRUCTURES TO BE REMOVED
- #1 STRIP FOOTINGS
- #2 PAD FOOTINGS
- #1 MAT SLAB
- TOWER FIELD SAW FOOTING

No.	DESCRIPTION	DATE
1	ISSUED FOR INFORMATION	17.06.22

DRAWN / REVIEWED
SCALE: 1:1L
DRAWN: D.B. / T.P.
SCALE: 1:200
DATE: 17.06.22
REVISED: 17.06.22

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GEORGE

HORIZON ENGINEERING INC

THE GEORGE DEVELOPMENT
GIBSONS BRITISH COLUMBIA

FIGURE 1

EXPLORATORY HOLES LOCATION PLAN

JOB NO. 17.037 DWG. NO. FIG. 1

PROJECT: THE GEORGE MIXED-USE DEVELOPMENT, GIBSONS, BC
PREPARED BY: ISHERWOOD
APPENDIX A: DEEP MIXING - LIST OF PROJECT REFERENCE DOCUMENTS RECEIVED FOR REVIEW

DOC. NO.	DATE	AUTHOR	TITLE OF DOCUMENT
1	12.11.26	Horizon Engineering Inc.	Proposed Commercial Development - "The George" 377 & 385 Gower Point Road, 397 & 689 Winn Road, and Winn Road Right-of-Way, Gibsons, BC - Geotechnical Investigation Report
2	13.05.13	Waterline Resources Inc.	Aquifer Mapping Study
3	13.05.16	Town of Gibsons	Agenda
4	14.02.12	Horizon Engineering Inc.	Revised Geotechnical Investigation Report
5	14.03.20	Levelton Consultants Ltd.	Geotechnical Review of Horizon's Report 2014
6	14.06.23	Levelton Consultants Ltd.	Geotechnical Review of Horizon's Report of June 5, 2014
7	14.06.25	Waterline Resources Inc.	Hydrogeological Review of Horizon's Report of June 5, 2014
8	15.04.07	Horizon Engineering Inc.	Geotechnical Investigation Report (Revised)
9	15.04.07	Horizon Engineering Inc.	Summary of Geotechnical Investigation Report (Revised)
10	15.05.04	Waterline Resources Inc.	Gibsons Aquifer Review of Geotechnical Investigation Report (Revised) for the Proposed "The George" Mixed-Use Development 377, 385& 407 Gower Point Road, 397 & 689 Winn Road and Winn Road Right-of-Way, Gibsons BC
11	15.05.07	Levelton Consultants Ltd.	Geotechnical Review, Horizon Engineering Inc. Geotechnical Investigation Report – 07 April 2015 Proposed "The George" Mixed-Use Development, Gibsons, BC
12	15.06.11	Horizon Engineering Inc.	Proposed "The George" Mixed-Use Development 377, 385 & 407 Gower Point Road, 397 & 689 Winn Road, and Winn Road Right-of-Way, Gibsons, BC, Memorandum Regarding Geotechnical Review Report.
13	15.06.12	Horizon Engineering Inc.	Memorandum Regarding the Hydrogeological Redevelopment
14	16.07.06	Keystone Environmental	Detailed Investigation - 377 and 385 Gower Point Road, Gibsons BC Project No. P2924
15	16.07.07	Keystone Environmental	Detailed Investigation - 377 and 385 Gower Point Road, Gibsons BC Project No. P2924
16	16.10.31	Keystone Environmental	Report of Findings - Detailed Site Investigation
17	16.11.01	Horizon Engineering Inc.	Proposed "The George" Mixed-Use Development 377, 385 & 407 Gower Point Road, 397 & 689 Winn Road, and Winn Road Right-of-Way, Gibsons, BC, Supplementary Memorandum Regarding Geotechnical Review Report.
18	16.12.01	Waterline Resources Inc.	DRAFT – Hydrogeological Review Update for the Proposed "The George" Mixed Use Development 377, 385 & 407 Gower Point Road, 397 & 689 Winn Road, and Winn Road Right-of-Way, Gibsons, BC.
19	16.12.19	Town of Gibsons	Geotechnical Peer Review
20	17.01.17	Town of Gibsons	Geotechnical Review
21	17.02.10	MRC Total Build	The George – Site Preparation Utilizing DSM
22	17.02.07	Horizon Engineering Inc.	Proposed "The George" Mixed-Use Development 377, 385 & 407 Gower Point Road, 397 & 689 Winn Road, and Winn Road Right-of-Way, Gibsons, BC, Memorandum Regarding December 1, 2016 Hydrogeological Review Report
23	17.03.14	WSP	Geotechnical Review
24	17.03.23	Waterline Resources Inc.	Hydrogeological Review
25	17.03.24	Town of Gibsons	Geotechnical Peer Review Next Steps
26	17.04.28	Geosystems L.P	Evaluation of the Viability of DMM Option as Foundation Support for "The George" Development, Gibsons, BC
27	17.05.15	Horizon Engineering Inc.	Response to Memorandum Regarding Geosystems Peer Review Report dated 17.04.18
28	17.05.18	Keystone Environmental	Remedial Plan and Certificate of Compliance Application 377, 385, and 407 Gower Point Road, 689 Winn Rd and Winn Road Right-of-Way, Gibsons BC
29	17.05.08	Town of Gibsons	Meeting Notes
30	17.04.26	Horizon Engineering Inc.	Memorandum Regarding Protection of Aquifer During Construction and Proposed DSM Construction Methodology
31	17.05.15	Horizon Engineering Inc.	Memorandum Regarding Protection of Aquifer During Construction and Proposed DSM Construction Methodology
32	17.05.29	Geosystems L.P	The Proposed "The George" Mixed-Use Development - Summary of Items Required as Permitting Conditions
33	17.05.29	Geosystems L.P	The Proposed "The George" Mixed-Use Development - Review of Draft Report from Horizon Engineering Inc. May 15, 2017

PROJECT: THE GEORGE MIXED-USE DEVELOPMENT, GIBSONS, BC
PREPARED BY: ISHERWOOD
APPENDIX B: DEEP MIXING - LIST OF RISK ITEMS IDENTIFIED FROM PROJECT REFERENCE DOCUMENTS REVIEW

RISK REF	RISK/REQUESTED ITEM	REFERENCE (APPENDIX A)	REFERENCE (APPENDIX C & D)
1	Risk of unknown structural loads for foundation design.	Doc nos. 1, 4, 23 and 25	GEN1
2	To ensure protection of the Gibsons Aquifer, it was recommended that the geotechnical and hydrogeological aspects of the Vashon Till confining unit be fully evaluated prior to, and during construction.	Doc nos. 2 and 6	GEN2
3	Risk that the geotechnical data is based on extrapolation due to no access to 407 Gower Road for supplementary site investigation.	Doc nos. 4 and 7	GEN2
4	Requirement that the deep foundations and site investigation do not penetrate the underlying confined aquifer.	Doc no. 4	GEN3
5	Risk that there is insufficient piezometric pressures and subsoil stratigraphy information to confirm that the excavation will not breach the aquitard or create global instability or heave.	Doc nos. 5, 6, 24, 25, 32 and 33	GEN2
6	Request for Horizon to revisit the seismic classification of the entire development as part of their review.	Doc no. 5	DES1
7	Request for Horizon to revisit the subgrade preparation and verification during construction.	Doc no. 5	DES6
8	Issue of lateral load resistance needs to be clarified by the Proponent's design team.	Doc no. 5	GEN1
9	Requirement for the Proponent's design team to describe the approach that will be implemented to address the potential issue of differential settlement relative to grade and pier supported structures (in particular, the proposed service line that enters/exits the building, the fuel line running from the building to the marina).	Doc no. 5	DES2
10	Requirement to develop a mitigation strategy to control and avoid accumulation beneath the suspended floor slab or within portions of the building, for the risk of methane generation associated with the peat deposits that are to be left beneath the building.	Doc no. 5	GEN4
11	Requirement to develop recommendations for the design water level for waterproof design of the parkade structure.	Doc no. 6	DES5
12	Requirement to perform a sensitivity analysis of the soil parameters used in models to improve the understanding of variations and risks associated with the proposed excavation.	Doc no. 6	DES1
13	Requirement to develop a monitoring program/approach to check on variations in pore pressures in the aquifer.	Doc no. 6	GEN5
14	Requirement to undertake a slope stability assessment of the proposed temporary excavation slopes along the west side of the site.	Doc no. 6	GEN6
15	Requirement to assess adequate performance of the soil-cement columns subject to lateral loads during a seismic event. This would include consideration of soil loading on the columns as well as building inertial load transfer to the columns.	Doc no. 6	DES1
16	Requirement that the current elevation survey ties in with the existing aquifer mapping data and site data (with geo-reference) to a common reference.	Doc No. 7	GEN6
17	Risk of uncertainty in a steady state seepage model and requirement to complete a sensitivity analysis of key parameters controlling groundwater pressure and flow, as well as a sensitivity analysis for a deformation model.	Doc Nos. 7 and 10	DES1
18	Requirement that the proposed excavation does not cut into the till-like silty sand materials, nor penetrate the confining layers over the Gibsons Aquifer.	Doc No. 7	GEN8
19	Requirement to include a table and figure in the report that lists/shows all of the subgrade development features that are being proposed (excavation, all individual piles, foundation, etc.) and identify the data used to design that feature. The distance offset to the nearest known data point should also be included. A comment should be provided regarding the relative risk to the aquifer system and the risk mitigation strategy that would be applied during construction.	Doc No. 7	GEN1
20	Requirement to provide estimates of expected groundwater inflow into the proposed excavation to support the statement "we envisage that the volume of water expected to be encountered at the subject site should be managed with conventional drainage measures" and comment on whether the Seep/W model was used to assess groundwater flux into the excavation.	Doc No. 7	DES1
21	Requirement that preliminary architectural drawings are needed to integrate subsurface structural features with the underlying Gibsons aquifer/aquitard system. Final drawings should include warning/notes regarding the aquifer protection design features that are in place and references to detailed documents which provides instructions to contractors for construction monitoring.	Doc No. 7	GEN1
22	Request for long-term monitoring of the water levels (pressure) using a data logger is recommended, as well as the collection of water chemistry data (routine metals, nutrients, and isotopes) to assist with determining source of the groundwater.	Doc No. 7	GEN5
23	Requirement for Professional Engineer(s) who is responsible for foundation and excavation design to be on site during construction work.	Doc Nos. 7, 10, 32 and 33.	DES6

24	Risk of artesian groundwater pressures affecting geotechnical foundation design.	Doc No. 9	**DES5**
25	Risk of high, non artesian groundwater levels affecting the geotechnical foundation design.	Doc No. 9	**DES5**
26	Risk of sea level rise affecting the geotechnical foundation design.	Doc No. 9	**DES5**
27	Risk of tsunami hazard affecting the geotechnical foundation design.	Doc No. 9	**DES5**
28	Risk of loose and compressible soil affecting the geotechnical foundation design.	Doc No. 9	**GEN2**
29	Risk of liquefaction affecting the geotechnical foundation design.	Doc No. 9	**DES3**
30	Risk of dredging on foreshore area affecting the geotechnical foundation design.	Doc No. 9	**DES4**
31	Requirement to confirm monitoring efforts during the ground improvement process to detect failures and how they will be mitigated to ensure the protection of the Gibsons aquifer/aquitard system.	Doc no. 10	**GEN5**
32	Requirement that the clarification and summarization of the subsurface data is required in order for the developer to provide assurance that the Gibsons aquifer/aquitard system will be fully protected by the proposed development.	Doc no. 10	**DES4**
33	Risk of "dam effect" affecting stability of ground improvement and the foundation scheme.	Doc no. 11	**DES2**
34	Requirement that the assumptions or the assumed design conditions presented in the April 2015 Geotechnical Report have been provided by and/or are endorsed by the Proponent and Architect. Confirmation from the Proponent that this report has been accepted and endorsed by their design group is required.	Doc no. 11	**GEN2**
35	Risk that the financial feasibility assessment has not been completed, particularly in relation to the proposed ground improvement, waterproofing and foundation concepts that have been advanced.	Doc no. 11	**GEN7**
36	Risk that the vertical hydraulic gradients in the westerly proximity of the parkade that might result in an upward seepage and the potential for soil piping, uncontrollable sinkhole, aquifer depressurization, or ground settlement has not been considered. An uncontrollable loss of ground or piping could be catastrophic, the request that this mode of failure is considered in the deformation modelling is completed and reported.	Doc nos. 11 & 23	**DES4**
37	Request to confirm in regards to the proposed use of areas like Parkade P3 and whether or not such portions of the building are actually considered "habitable".	Doc no. 11	**GEN1**
38	Request for the foundation design to address seismically induced uplift and lateral loads. The need for base shear resistance could impact ground improvement needs, associated costs, and therefore economical viability. Liquefaction will not be mitigated and therefore the foundation system will need to consider lateral spread of loose soils as well as lateral load transfer from the structure.	Doc no. 11	**DES4/DES3/GEN7**
39	Request that waterproofing and methane control requirements should be factored into the selection of the foundation design and associated potential costs.	Doc no. 11	**GEN7/GEN4**
40	Request to confirm whether the stated ultimate bearing values given in the geotechnical reports are factored.	Doc no. 11	**GEN1**
41	Risk of a seismic hazard in non-improved areas between the zones of primary foundation support.	Doc no. 11	**DES3**
42	Risk that ground improvement areas will create a series of hard points/lines within an otherwise soft soil setting. There is a potential for long-term settlement in areas away from improved ground both within and beyond the building footprint. The potential for differential settlement and "sag" should be considered in the design and layout of buried utilities, grade supported structures and roadways.	Doc no. 11	**DES2**
43	Risk that the untreated soils might displace significantly during a seismic event.	Doc no. 17	**DES3**
44	Risk of penetrating the aquitard and the risk of the breach of the underlying aquifer during DM.	Doc nos. 18, 19, and 25	**GEN3**
45	Risk of development of preferential flow pathways through the aquitard at the margin between the improved soils and the unimproved soils.	Doc no. 18	**DES4**
46	Request to submit a single updated document that collates the work to date and that is focussed to the needs of the pertinent application.	Doc nos. 23 and 24	**CON4**
47	Requirement to confirm a design life adopted for the design of the structure.	Doc no. 23	**GEN1**
48	Request to confirm a foundation system for underground pipe work (i.e. the fuel line).	Doc no. 23	**GEN1**
49	Requirement for ground improvement works to provide adequate lateral support and to safely transfer lateral loads onto the adjacent soils. These soils are expected to liquefy during a design event and/or to consist of peat.	Doc no. 23	**DES3**
50	Risk of insufficient geotechnical data for the foundation design and managing risks associated with an uncontrollable breach of the aquifer.	Doc nos. 23 and 25	**GEN2**
51	Risk of insufficient lateral support along the eastern portion of the southern area of the site.	Doc no. 23	**GEN1**

52	Request for a mitigation plan to control artesian flow in the event of a breach of the aquifer.	Doc nos. 24, 25 and 29	DES6
53	Risk that an aquitard breach is not easily repaired using grout or other sealing strategies to control artesian flow.	Doc no. 24	DES6
54	Risk that quality control challenges in the DSM column installation process exists with the auger/paddle mixing method.	Doc no. 24	CON1
55	Risk that the selection of an "assumed" hydraulic conductivity value for the piping analysis may not be conservative. No supporting data was provided to support the bulk hydraulic conductivity selected in analysis.	Doc no. 24	DES4
56	Risk of penetration into the aquifer during probing, ahead of bulk excavation/construction work.	Doc no. 25	GEN3
57	Risk of penetration into the aquifer during bulk excavation.	Doc no. 25	GEN3
58	Risk of penetration into the aquifer during localized excavation for peat removal.	Doc no. 25	GEN3
59	Risk of penetration into the aquifer during DM.	Doc no. 25	GEN3
60	Risk that additional fill is required to create a working platform for excavators and DM equipment to be supported during construction activities.	Doc no. 25	CON2
61	Risk that the construction method currently proposed relative to the depth of DM, as well as the site preparation work requirements might not be efficient or economical.	Doc no. 25	CON4
62	Risk that the DM equipment is not "sensitive" enough to halt penetration at 0.5 m or less into the aquitard.	Doc no. 25	CON3/CON4
63	Risk that during DM, an "uncontrollable" breach into the aquifer develops and that there is insufficient time to respond appropriately (i.e. maintaining temporary stability of the DM column during construction).	Doc no. 25	DES6
64	Risk that the DM equipment penetrates into the aquifer and impacts on the quality of the aquifer.	Doc no. 25	GEN8
65	Risk that the depth to the top of the peat and the thickness of the peat is variable and may impact on depth of excavation; stability of temporary trench; and construction schedule.	Doc no. 25	GEN2
66	Risk that the method of DM does not render relatively large, massive blocks of soilcrete, given the geometry of the soilcrete column.	Doc no. 25	CON1
67	Request to submit comprehensive geotechnical data and interpretive reports.	Doc no. 25 and 33	GEN2/GEN6
68	Request that an instrumented test section is required to assess the impact of DM on the aquifer.	Doc no. 25	GEN8
69	Risk of the peat layer being a potential "deal breaker" for the conventional DMM.	Doc no. 25	CON1
70	Risk that it would not be deemed economically viable to mobilize DMM operation for the purpose of treating only a few metres of soil under the peat. Furthermore the exact depth of the peat and organic silt would vary from element to element and would therefore be difficult to judge.	Doc no. 25	GEN7
71	Risk that the type of equipment needed (and hence the surface preparation and maintenance), the presence of organics, the limited depth of treatment, and the shape of the treatment (i.e. large blocks) is incompatible with the use of conventional DMM on this project.	Doc no. 25	CON4
72	Request to obtain long-term groundwater monitoring data to confirm response of the aquifer under the building footprint during prolonged pumping from Town Well 1 (24 hrs and/or longer).	Doc no. 25	GEN5
73	Request for evidence of static and seismic analysis carried out for the foundation design and DM design.	Doc no. 25	DES1
74	Risk of liquefaction of the underlying loose soils and peat affecting structural bearing.	Doc no. 25	DES3
75	Risk that the area replacement ratio of over 65% has no engineering back-up or justification and could render the scheme uneconomical.	Doc no. 25	GEN7
76	Request to confirm how hydrogeological control of the site will be maintained at all times during DM.	Doc no. 29	GEN5
77	Risk of variable artesian pressures that may be encountered affecting the foundation design.	Doc no. 29	DES5
78	Request to confirm how the impact on the confining layers will be minimized during DM.	Doc no. 29	GEN2
79	Request to consider the logistics of required materials and equipment to and from the site as part of the construction management plan.	Doc no. 29	CON4
80	Request to confirm when a complete response to peer review comments can be expected to advance permitting process.	Doc no. 33	GEN2
81	Request to consider supplementary local pits or trenches and CPTs to be located adjacent to the existing site investigation holes to allow for close correlation and calibrations.	Doc nos. 32 and 33	GEN2
82	Request to provide more detailed information for a construction procedure and a contingency plan to protect the aquifer, required prior to construction.	Doc nos. 32 and 33	CON4
83	Request to review basal stability calculations for excavation and DM.	Doc nos. 32 and 33	DES4

84	Request to provide a Design Basis Memorandum explaining the selection and details of the foundation system in relation to all the valid structural loading conditions. It is essential that the properties of the DMM material and the treatment pattern are consistent with the structural demands.	Doc nos. 32 and 33	GEN1
85	Request to confirm the addition of certain fields of expertise (e.g. in DMM) to the design team, as well as formally acknowledging the roles and responsibilities as a point of due diligence.	Doc no. 33	DES6
86	Request to provide a field verification test report.	Doc no. 32	CON3
87	Request for the development of work procedures relating to excavation; foundation treatment; breach remediation plan; personnel safety; instrumentation monitoring and analysis.	Doc no. 32	CON4
88	Risk of increased traffic affecting local area during bulk excavation.	Discussed during May 8, 2017 meeting	CON4
89	Risk of increased traffic affecting local area during peat excavation and backfilling.	Discussed during May 8, 2017 meeting	CON4
90	Risk of increased traffic affecting local area during DM.	Discussed during May 8, 2017 meeting	CON4
91	Lack of space on site for stockpiling during bulk excavation.	Discussed during May 8, 2017 meeting	CON4
92	Lack of space on site for stockpiling during bulk peat removal and backfilling.	Discussed during May 8, 2017 meeting	CON4
93	Lack of space on site for stockpiling/spoil management during DM.	Discussed during May 8, 2017 meeting	CON4

PROJECT: THE GEORGE MIXED-USE DEVELOPMENT, GIBSONS, BC
PREPARED BY: ISHERWOOD
APPENDIX C: DEEP MIXING - GENERAL AND DESIGN RISKS AND ASSESSMENT

RISK REF	RISK/REQUESTED ITEM	MITIGATION APPROACH	REFERENCE
GEN1	Risk that DM and foundation design have not taken into consideration the proposed development requirements (i.e. unknown structural loads, architectural information and proposed development information including design life of main structure).	Proposed project information consisting of architectural drawings (Nov 2016), structural drawings (Nov 2016), civil drawings (Nov 2016) and geotechnical design recommendations (Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017) were reviewed to assess feasibility for DM ground improvement. Refer to Deep Mixing Design Basis Memorandum outlining information considered for concept design, feasibility assessment and recommendations for detailed design and construction.	Deep Mixing Design Basis Memorandum and Section 4 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
GEN2	Risk that there is insufficient geotechnical and hydrogeological information commensurate with the level of risk at this site for DM and foundation design (i.e. additional geotechnical and hydrogeological information required for detailed design and construction risk management).	Refer to Deep Mixing Design Basis Memorandum for additional geotechnical and hydrogeological investigation recommended for DM design and risk management. The additional investigation is anticipated to be carried out during DM detailed design, prior to commencement of DM production construction. For additional geotechnical and hydrogeological investigation including long-term monitoring as part of the "risk of penetration into the underlying aquifer", refer to Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017, for details.	Deep Mixing Design Basis Memorandum and Section 23 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
GEN3	Risk of penetration into underlying aquifer causing uncontrolled breach of the aquifer: - A: during geotechnical/hydrogeological investigation probing; - B: during excavation and removal of peat/organic silt; and - C: during DM.	Design strategy is based on maximum 0.5 m penetration into the aquitard during geotechnical investigation (boreholes/test pits/cone penetration tests) and bulk excavation, with the exception of groundwater monitoring instrumentation where vibrating wire piezometers/piezometers will be installed in the unconfined and confined aquifers. Refer to Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017, for details. For DM, design strategy is also based on maximum 0.5 m penetration into the aquitard, with no excavation for peat/organic silt removal required. Refer to Deep Mixing Design Basis Memorandum for details. Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017, outlines the contingencies proposed for protection of the aquifer.	Deep Mixing Design Basis Memorandum and Sections 15, 22, 23 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
GEN4	Risk of methane build-up for areas where peat/organic silt is left in situ (untreated areas of DM within the building foundation footprint).	Methane venting system developed by Horizon to manage risk of methane build-up. Refer to Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017, for details.	Section 16 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
GEN5	Risk of insufficient hydrogeological data for monitoring during construction and long-term monitoring of aquifer conditions at the site.	Additional groundwater monitoring instrumentation (vibrating wire piezometers/piezometers) proposed in the unconfined and confined aquifer prior to and during DM, refer to Deep Mixing Design Basis Memorandum for details. For long-term monitoring, additional groundwater monitoring instrumentation (piezometers and/or standpipes) proposed to be installed prior to the start of DM, refer to Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017, for details.	Deep Mixing Design Basis Memorandum and Section 23 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
GEN6	Risk of uncoordinated information, request for an updated summary geotechnical investigation and interpretative report to be provided, as well as a Deep Mixing Design Basis Memorandum outlining DM design and construction approach.	Horizon has prepared an updated Geotechnical Investigation Report (Revised) dated July 27, 2017. A Deep Mixing Design Basis Memorandum has also been prepared to provide details on design approach, construction, DM field trials, reporting of field trial results, quality assurance and quality control during construction.	Deep Mixing Design Basis Memorandum and Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
GEN7	Risk that a feasibility assessment for the current proposed development, including excavation and DM ground improvement, has not been undertaken.	A feasibility assessment has been carried out by the Proponent and his design team consisting of the Project Manager, Architect, Structural Engineer, Civil Engineer, Geotechnical Engineer and General Contractor. As the concept of DM ground improvement was generally accepted by the Town of Gibsons (Geosystems L.P.'s "Evaluation of the Viability of a DMM Option as Foundation Support for "The George" development, Gibsons, BC"), the Proponent's design team has refined the DM design to further improve the technical and commercial viability of the scheme. Refer to Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017, and Deep Mixing Design Basis Memorandum for details.	Deep Mixing Design Basis Memorandum and Sections 11 and 13 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
GEN 8	Risk of deep mixing construction adversely impacting on the underlying confined aquifer, requirement for deep field trial to be carried out and construction method of DM assessed prior to production DM.	The method of DM proposed has been determined based on a risk-assessment approach considering the project risks against the three methods of DM (Option A: conventional soil auger mixing; Option B: DM using cutter soil mixing; and Option C: excavation under soil hardened slurry). Refer to the DM design and construction risk assessment for details. As part of the DM strategy, a field trial program based on installing trial DM elements in three areas of the proposed development site to verify and assess that the proposed method of DM and associated controls meet project performance requirements, whilst not adversely impacting the underlying confined aquifer. Refer to Deep Mixing Design Basis Memorandum for details of risk assessment, proposed method of DM selected and proposed DM field trial for details. Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017, outlines the contingencies proposed for the protection of the aquifer.	Deep Mixing Design Basis Memorandum and Section 15 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
DES1	Risk of geotechnical parameters (static and seismic) and design water levels not representative of varying site conditions. Request that a sensitivity analysis is carried out to determine the impact of these parameters on design, construction and protection against uncontrolled breach into the underlying confined aquifer.	The geotechnical parameters (static and seismic) and hydrogeological parameters have been updated by the design team, with further assessment to be carried out after completion of the additional geotechnical and hydrogeological investigation proposed by the design team (June 2017), refer to Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017, for details. The DM ground improvement design is proposed to be carried out in accordance with Industry Guidelines, refer to Deep Mixing Design Basis Memorandum for details.	Deep Mixing Design Basis Memorandum and Sections 9, 13 and 23 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
DES2	Risk that the DM design has not taken into consideration static load requirements for the foundation design and consideration for settlement/differential settlement including "dam effect" of DM affecting hydrogeological conditions within the proposed foundation footprint.	The Deep Mixing Design Basis Memorandum outlines the approach to be adopted for detailed design, which consists of static analysis of proposed DM elements for ground improvement and foundation support of project-specific loads including an evaluation of settlement and stability for temporary (during construction) and permanent (post-construction) conditions, in accordance with Industry Guidelines.	Deep Mixing Design Basis Memorandum.
DES3	Risk that the DM design has not taken into consideration seismic load requirements including liquefaction and impact of potential loss of material due to a seismic event.	The Deep Mixing Design Basis Memorandum outlines the approach to be adopted for detailed design, which also consists of seismic analysis of proposed DM elements for ground improvement and foundation support of project-specific seismic loads including an evaluation of settlement and stability for temporary (during construction) and permanent (post-construction) conditions, in accordance with Industry Guidelines. Refer to Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017, for details of seismic parameters recommended for analysis and liquefaction assessment, which will be considered for DM detailed design.	Deep Mixing Design Basis Memorandum and Section 9 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
DES4	Risk that the DM design has not taken into consideration impact of temporary conditions that could cause uncontrolled breach of the underlying confined aquifer (e.g. penetration into aquifer; basal stability and piping; and preferential flow path at interface between DM element and native soils).	The Deep Mixing Design Basis Memorandum outlines the approach to be adopted for detailed design, which includes an assessment of temporary conditions during DM and following installation of DM elements to evaluate basal stability and piping. The DM design approach is in conjunction with the method of DM proposed (selection based on a project-specific risk assessment) which is based on minimising risk of penetration into the underlying confined aquifer (e.g. maximum 0.5 m penetration into the aquitard; proposing DM equipment with suitable controls to limit penetration into the aquitard); DM fill and native soils in situ without the need for excavation and remove existing material, hence reducing the likelihood of basal instability, piping and creating preferential flow paths for an uncontrolled breach of the confined aquifer; and suitable equipment to mix fill and native soils including peat and organic silt with cement slurry to achieve project-specific requirements for ground improvement, foundation support and mitigation against liquefaction.	Deep Mixing Design Basis Memorandum and Section 12 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
DES5	Risk of perched water, artesian conditions, rise in sea level and tsunami events affecting DM.	The DM detailed design will take into consideration the updated groundwater recommendations (groundwater level in the upper unconfined aquifer, groundwater pressures in the lower confined aquifer, design life of the proposed structure including design sea level for foundation and structural design and waterproofing, and impact of tsunami events on the proposed structure) outlined in Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.	Deep Mixing Design Basis Memorandum and Sections 7, 10 and 15 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.
DES6	Requirement for Professional Engineers to provide technical support throughout the DM and excavation construction activities.	Isherwood is responsible for the DM components of this project and will have part-time representation during the additional geotechnical and hydrogeological investigation field work, and full-time representation during the DM field trial and production DM work, refer to Isherwood Technical Memorandum No. 1 outlining Isherwood's role and responsibilities for DM (June, 2017). With the exception of the DM components, Horizon is responsible for all geotechnical aspects of the project including excavation.	Deep Mixing Design Basis Memorandum, Isherwood's Role and Responsibilities for Deep Mixing (Technical Memorandum No. 1 dated June 9, 2017) and Section 12 of Horizon's Geotechnical Investigation Report (Revised) dated July 27, 2017.

PROJECT: THE GEORGE MIXED-USE DEVELOPMENT, GIBSONS, BC
PREPARED BY: ISHERWOOD
APPENDIX D: DEEP MIXING CONSTRUCTION RISKS AND ASSESSMENT

DEEP MIXING OPTIONS

1 CONVENTIONAL AUGER SOIL MIXING AFTER BACKFILLING WITH FILL AREAS WHERE PEAT/ORGANIC SILT WAS EXCAVATED AND REMOVED.
2 DEEP MIXING USING CUTTER SOIL MIXING
3 EXCAVATION AND REPLACEMENT UNDER SELF-HARDENING SLURRY

RISK REF	RISK/REQUESTED ITEM	1 RISK CATEGORY	1 SUPPORTING COMMENTS	2 RISK CATEGORY	2 SUPPORTING COMMENTS	3 RISK CATEGORY	3 SUPPORTING COMMENTS
CON1	Risk of quality issues affecting DM product (e.g. insufficient mixing of peat/organic silts with cement slurry to achieve design requirements; artesian conditions impacting on the quality of the DM elements. Risk of breaching aquifer during DM.	Medium/High Risk	Auger mixes in horizontal axis has difficulty with mixing vertically within a soil-cement element and has difficulty with binding organic material (particularly fibrous peat and roots) with cement slurry to give a homogeneous product (may contain soft, unmixed native soil pockets). Although the peat/organic silt could be removed prior to soil auger mixing, it would introduce additional risks such as identifying the depth to the underside of the peat/organic silt and removal of the peat/organic silt whilst maintaining basal stability, as well as additional costs and schedule impact due to the need to excavate and replace, followed by soil mixing, which requires different equipment and the need to import fill. At any time, the soil-cement element is supported either with native soils, cement slurry or a combination of native soil blended with cement slurry and therefore basal stability is maintained during soil-cement element installation. Equipment is not sufficiently sensitive to allow auger/paddle mixing in the upper material to achieve a homogeneous product whilst ensuring that the tip of the auger does not penetrate more than 0.5 m into the aquitard and potentially breaching the underlying confined aquifer.	Low Risk	Twin cutter wheels blend vertically and enables fill, peat, organic silt and native soils to be mixed with cement-slurry to form a homogeneous soil-cement element to meet design and project-specific performance requirements. At any time, the soil-cement element is supported either with native soils, cement slurry or a combination of native soil blended with cement slurry, and therefore basal stability is maintained during soil-cement element installation. Equipment is sufficiently sensitive to enable operator to assess whether 0.5 m or less penetration into the aquitard is achieved during DM.	Low Risk	Removal of the peat/organic silt would eliminate the risk of "unmixed" zones of soil-cement. Excavation would be supported at all times (i.e.. as native material is excavated, cement-slurry is introduced into the excavation area), therefore basal stability is maintained. Although cost of the equipment is low, additional costs to consider include disposal of native soils and increased volume of cement slurry (compared with Option 2). Excavation and replacement is highly operator dependent (i.e.. the risk of penetrating more than 0.5 m into the aquitard will heavily rely on the "feel" of the operator and the tools used for excavation). If the relative density of the aquitard is a gradual resistance change with depth, it would be difficult for the operator to confidently confirm than less than 0.5 m of penetration into the aquitard is achieved.
CON2	Risk of additional fill/material required to be imported to the site for the construction of a working platform and removal and backfilling of excavated peat/organic silt areas.	High Risk	Fill is required to form a working platform for auger mixing equipment, as well as additional fill required to replace peat/organic silt removed.	Low Risk	Fill is required to form a working platform for cutter soil mixing rig.	Low/Medium Risk	Whilst the fill required to form a working platform is substantially less compared with Options 1 and 2, a significant amount of cement slurry is required to fill the excavated native soils.
CON3	Risk that the method of DM proposed is not compatible with the proposed development and design requirements. Request for a DM field trial to be completed to assess the performance of DM method proposed and compatibility of proposed DM method with achieving design requirements.	High Risk	Circular soil-cement elements would need to be designed as overlapping elements to create a treatment plan compatible with the foundation requirements. Auger mixing may produce localized "un-mixed" zones if peat/organic silt is not removed prior to auger mixing.	Low Risk	Rectangular soil-cement elements with nominal overlap can be designed to obtain a treatment plan compatible with foundation requirements. Vertical mixing generally will produce fewer localized "un-mixed" zones of peat/organic silt compared with Option 1, The removal of peat/organic silt prior to DM is not required.	Low Risk	Rectangular shaped excavation zones can be created to obtain a treatment plan compatible with foundation requirements. As this method requires complete removal of native soils, "un-mixed" zones of peat/organic silt will not be present in the completed treatment areas.
CON4	Risk of significant logistics required (i.e. materials, equipment and transportation to and from site) during construction. Request for a construction management plan to be developed.	High Risk	Auger mixing units are required to be mounted on large cranes. Due to the need to excavate the peat/organic silt and replace with fill, careful logistical planning is required to transport, remove, stockpile and replace material. As peat/organic silt cannot be re-used on the site, disposal is required. Additional transportation of material on and off site will impact other environmental conditions (e.g. traffic and noise).	Low Risk	Cutter soil mixing is carried out using small base equipment (compared with Option 1). The spoil generated from the "wet mixing" can be mixed and stockpiled on the site, transportation for removal of untreated native soil is not required. Transportation of raw material is significantly less than transportation requirements for Option 1.	Low/Medium Risk	Due to the need to excavate the peat/organic silt and replace with fill, careful logistical planning is required to transport, remove, stockpile and replace material. As peat/organic silt cannot be re-used on the site, disposal is required. Additional transportation of material on and off site will impact other environmental conditions (e.g. traffic and noise).

PROJECT: THE GEORGE MIXED-USE DEVELOPMENT, GIBSONS, BC
PREPARED BY: ISHERWOOD
APPENDIX E: DEEP MIXING - ADDITIONAL REFERENCES

Bruce, M.E.C., Berg, R.R., Collin, J.G., Filz, G.M., Terashi, M. and Yang, D.S., 2013. Federal Highway Administration Design Manual; Deep Mixing for Embankment and Foundation Support. Report No. FHWA-HRT-13-046. Contract/Grant No. DTFH61-06-C-00039.

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Reed Jones Christoffersen Ltd., The George Hotel and Residences, Gibsons, BC, Drawing Nos. S1.01 to S1.08, S2.A01 to S2.A04, S2.B01 to S2.B07 and S2.C01 to S2.C05 Rev. 3 Re-Issued for Geotechnical Coordination, 28.10.2016.

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