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Geotechnical Investigations for the North Quay to Breakfast Creek Sewer Tunnel

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Summary The Brisbane City Council propose to construct a major sewer in the S1 sewerage catchment to augment the capacity of the existing main sewer. Stage 1 of the project involves the construction of a tunnel between North Quay and Breakfast Creek. The tunnel will be approximately 4km long, with a minimum diameter of 2.4m, aligned mainly beneath city streets. The feasibility and preliminary investigations were aimed at selecting a preferred augmentation solution as well as optimising the alignment to minimise the length of tunnel in soft ground. A staged detailed investigation followed comprising boreholes, insitu testing, friction and piezo cones, borehole imagery and a comprehensive suite of laboratory tests on soil and rock samples recovered. The planning, execution and methodology adopted for the above investigations are discussed in this paper along with a summary of some of the findings.

1. INTRODUCTION

The S1 sewerage catchment is the largest of the six sewerage catchments within Brisbane City, with a total area of 16,000 hectares and a population of about 320,000 people. The continual urban renewal process of the inner north eastern suburbs of Brisbane will result in a substantial increase of waste water flow in Brisbane's S1 sewerage catchment. As a result it was considered necessary to augment the existing main sewer. This project is integrally connected to other augmentation strategies under consideration by the City.

After extensive hydraulic modelling and economic analysis it was decided that a gravity sewer would be the most advantageous augmentation solution. A tunnel will be constructed between North Quay in Brisbane CBD and Breakfast Creek (Figure 1). The route of the tunnel is approximately 4km long and it is required to have a minimum diameter of 2.4m.

Given the geological setting of inner Brisbane, it was realised in the early stages of planning, that geotechnical considerations would be a major factor in the overall cost and constructability of the project. A staged approach was adopted for the geotechnical component of the project, beginning in the route selection stage. Detailed investigations were then commissioned to assess geotechnical conditions along the preferred alignment.

This paper presents a discussion of the route selection process, investigatory techniques and a description of the geotechnical model.

2. SELECTION OF AN AUGMENTATION STRATEGY

The Council considered both gravity and pumped solutions to augment the existing S1 main sewer. The selection of the preferred option was principally driven by economic analyses that considered life cycle costing. Land-use considerations and interconnectivity with the existing main sewer were also of fundamental importance in the decision making process. Geotechnical data collected from preliminary and feasibility investigations formed a basis for the development of budget estimates for the construction of the various options.

A staged approach was adopted for the selection of the augmentation strategies and investigation of the preferred route for a gravity sewer. These are described in the following sections. In parallel with the study assessing the merits of gravity systems, the Council was evaluating the economics of pumped solutions. Although these evaluations used some geotechnical information, other factors such as operating costs were more critical cost drivers.

2.1 Stage 1 - Collation of Existing Information

The Council initially considered the feasibility of placing a new sewer close to the existing trunk sewer main in Ann Street and Breakfast Creek Road, primarily for ease of interconnection with the existing branch sewer mains. The Stage 1 investigation comprised the collation of existing subsurface information along a corridor surrounding

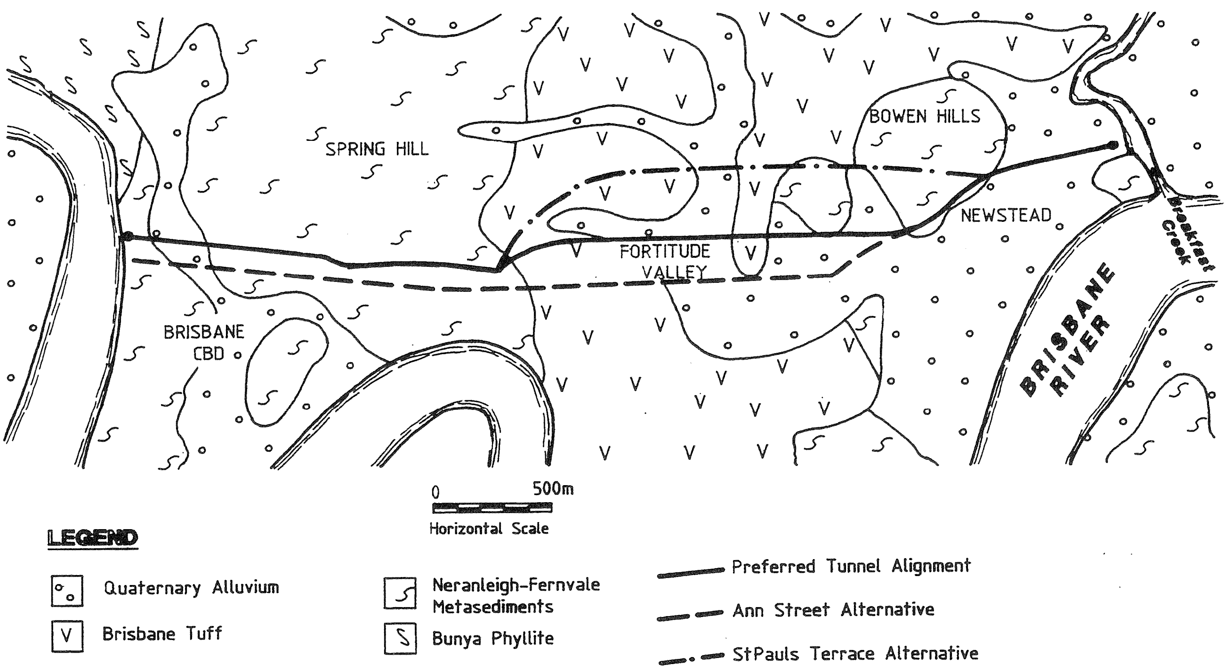

Figure 1. Surface Geology and Alternative Tunnel Alignments

the existing trunk sewer. The existing data was made available from various sources including the Council's construction records, consultant reports and reports prepared by other government agencies. Most of the historic data comprised borehole information drilled to relatively shallow depths well above the proposed tunnel invert. The standard of logging and description of soil/rock types varied considerably. However the data proved useful for defining the rock-head level along the alignment, and for indicating areas of possible deep alluvium.

2.2 Stage 2 - Feasibility and Costing Study

As part of the feasibility and costing study by Connell Wagner in early 1993, Golder Associates were commissioned to assess ground conditions along the alignment. Studies included review of historic borehole and sewer construction records, mapping of rock exposures and a limited number of additional boreholes. The NGI and CSIR rock mass classification systems were used to provide preliminary assessments of tunnel stability and ground support requirements. The investigation indicated alluvial deposits to below the tunnel invert depth in the Fortitude Valley and Newstead areas.

2.3 Stage 3 - Further Assessment of Potential Alignments

Connell Wagner, in their report, suggested that considerable cost savings could be achieved during tunnel construction if the length of tunnel in soil were to be minimised. To this end the Council, in late 1993, undertook further preliminary investigations to appraise conditions along alternative alignments. A methodology similar to that used by Golder Associates was adopted, augmented by a number of friction cone probes.

Figure 1 illustrates the preferred and alternative tunnel alignments. The preferred alignment, which follows Turbot and Wickham Streets and Breakfast Creek Road, is mainly within current road reserves, or beneath land controlled by the Council, thus minimising the impact on private property. The Ann Street alternative, as well as traversing a greater length of soft ground, would present difficulties during construction in terms of excavating adjacent to the existing sewer. The St Paul's Terrace alignment, while avoiding the areas of soft ground in Fortitude Valley, would present greater costs in terms of connections to existing sewers in Ann Street.

2.4 Stage 4 - Phase 1 Geotechnical Investigation of Preferred Alignment

After committing to the preferred alignment, the Council undertook detailed geotechnical investigations. The scope of the investigations was to obtain factual data only, as the Council considered that the successful construction consortium would interpret the data and undertake the necessary design. Dames and Moore and Insite Geology were engaged to assist the Council's Geotechnical Services Section.

The initial phase, commencing in April 1994, concentrated on obtaining data along the total length of the alignment. At the completion of phase 1 in October 1994, the Council engaged Golder Associates to review a draft report and to make recommendations in relation to further work.

2.5 Stage 5 - Phase 2 Geotechnical Investigation of Preferred Alignment

The phase 2 investigation, commenced in January 1995, was aimed at assessing the ground and groundwater conditions where the tunnel would intersect the interface between rock and soil at the margins of the alluvial areas identified in Phase 1.

3. SUMMARY OF THE GEOTECHNICAL INVESTIGATIONS

3.1 Field Investigations

A total of 86 boreholes were drilled, including three inclined holes and 14 probe holes to rock head. Over 1,000m of NMLC and HMLC rock core was recovered from 54 of the boreholes. Thirty-nine water pressure (packer) tests were carried out in twelve of the cored boreholes. Where the tunnel intersected alluvial areas, as well as the usual sampling and testing (U50's and/or SPT's), field shear vane and Marchetti Dilatometer tests were carried out in several boreholes.

A total of 14 cone penetrometer tests were performed. Eight of these were performed using a piezocone, with dissipation tests carried out at selected depths.

Rising and falling (variable) head tests were carried out in piezometer observation wells installed in the granular layers encountered at the base of the Holocene and the Pleistocene deposits. A pump-out drawdown test was carried out in one of these wells using a 25mm diameter submersible electric pump. A line of two standpipes were installed along the axis of the presumed upstream extent of the alluvial channel.

Structural geological mapping of several rock exposures in the vicinity of the tunnel alignment was undertaken to augment abundant existing information available from structural mapping done by others for projects such as the Inner City Rail Tunnel Duplication (by Hollingsworth Dames & Moore) and Cloudland Hill Redevelopment (by Golder Associates). The mapping consisted of recording the nature of the structural defects in the rock mass, their orientation, visible continuity, shape, surface characteristics and the occurrence and nature of infill material.

As an alternative to using an impression packer to obtain borehole structural data, the Borehole Image Processing System (BIP) operated by RaaX Australia Pty Ltd was selected. The BIP system provides a continuous, orientated projection of a borehole wall, allowing measurement of dip angle, dip direction and the aperture of defects.

3.2 Laboratory Testing

An extensive program of laboratory testing of soils and rock was undertaken in order to provide engineering parameters to enable the design of tunnel support systems. At the outset of field investigations, it was recognised that most of the proposed sewer tunnel would be located in high to very high strength, jointed rock, with only a relatively small portion of the alignment in "soft" ground (soils and weak rock). As a consequence, a significant portion of the laboratory testing program was targeted at determining the variability in intact rock properties; and the abrasivity, cuttability and drillability indices and the hard mineral (i.e., quartz) content of the rock to facilitate tunnelling equipment selection by the contractor.

The broad suite of testing of rock was selected in order that potential contractors could explore a range of techniques for construction of the tunnel, such Tunnel Boring Machines and Roadheaders. The testing program included rock density (bulk, saturated and dry density), strength (UCS, point load and Brazilian tensile strength), hardness (Schmidt Hammer, Sklerograph and Shore Hardness), elastic parameters (pulse velocity, static/dynamic Young's modulus and static/dynamic Poisson's ratio), abrasivity (CERCHAR, Norwegian Abrasion Value and Abrasion Value Steel), brittleness (Swedish Brittleness Value), cuttability (Core Cuttability), drillability (Goodrich Drillability/Wear Number and Drilling Rate, Bit Wear and Cutter Life Indices) and thin section petrography.

The testing of soil samples was directed at establishing relevant parameters for the Holocene and Pleistocene deposits encountered in the two major alluvial channels. The testing program included index tests, oedometer consolidation, triaxial strength tests and soil chemistry. Groundwater chemistry was assessed for aggressiveness to concrete and steel.

4. GEOTECHNICAL MODEL

4.1 Regional Geology (Figure 1)

The oldest geological unit occurring along the alignment is the Neranleigh-Fernvale Beds of late Devonian to early Carboniferous age. This unit consists of slightly metamorphosed, mainly fine to medium grained marine sediments (referred to as "metasediments" in this paper), and occasional marine volcanics (metabasalt). These rocks were subject to folding and faulting which resulted in a pervasive, closely spaced foliation overprinting the original bedding and the partial solution and redeposition of quartz as veins mainly parallel to the foliation. Uplift and weathering of these rocks during the late Palaeozoic era formed a deeply

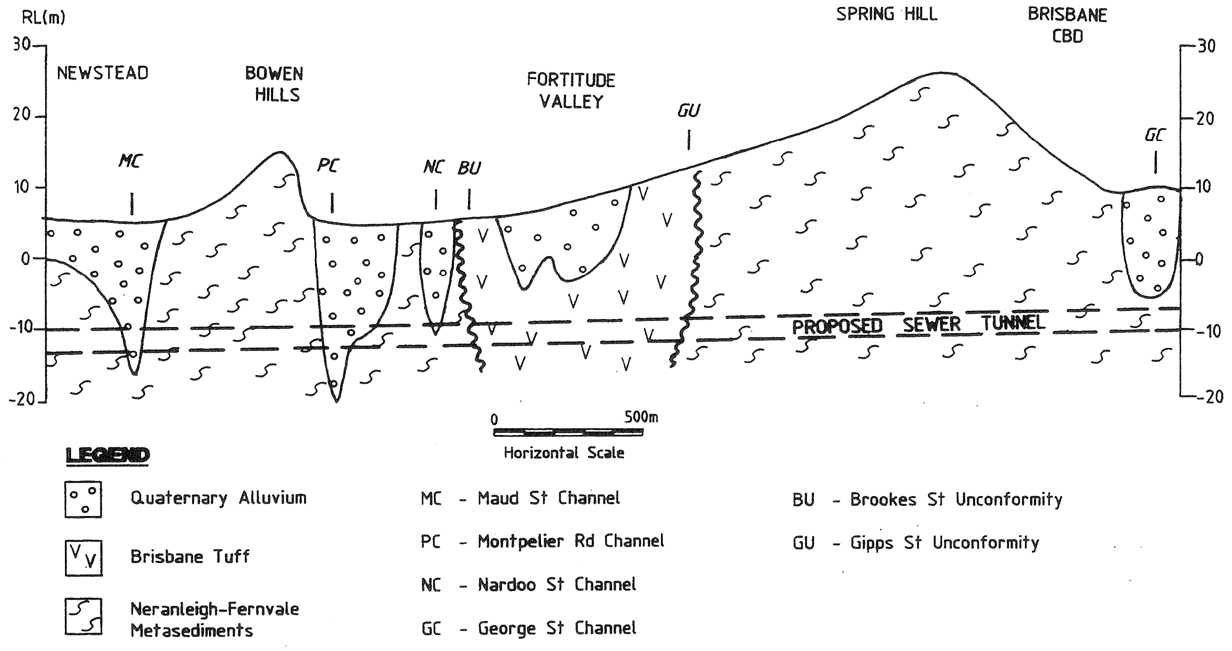

Figure 2. Diagrammatic Cross Section showing Geology Along Tunnel Alignmnet

weathered, uneven land surface prior to the deposition of the overlying Brisbane Tuff.

The Brisbane Tuff is of lower Triassic age and consists mainly of stratified or massive, rhyolitic ignimbrite (welded ash flow tuff) with volcanic breccia and locally interbedded sedimentary rocks. The welded tuff is thought to have been the result of one or several large scale, extremely hot ash flows which, on settling became welded through their own heat and weight. At the base of this formation is a variable sequence of unwelded tuff, tuffaceous mudstones, sandstones and conglomerates. These materials are often highly variable in vertical and lateral extent and contain fragments of tuff, as well as older rocks and carbonaceous material and likely represent pre-existing sediments or scree deposits, and the results of earlier, minor volcanic events that have been reworked by erosion or weathered insitu.

The youngest geological unit along the alignment is Quaternary age alluvial deposits. This material includes older sediments deposited during periods of high sea level (interglacials) during the late Pleistocene age, and younger sediments deposited since the last ice age (Holocene age).

4.2 Site Geology

4.2.1 General

Figure 2 is a diagrammatic cross section showing the geology along the tunnel alignment. The basement rock is Neranleigh-Fernvale Metasediments; Fortitude Valley is underlain by Brisbane Tuff; and four major alluvial channels were identified at Maud Street, Montpelier Road, and Nardoo Street, which intersect the tunnel horizon, and at George Street, which terminates immediately above the tunnel level. Shallow alluvial sediments also occur in Fortitude Valley. The various geological units occur along the tunnel horizon in the following percentages:-

•	Neranleigh-Fernvale Metasediments	75%
•	Brisbane Tuff	20%
•	Quaternary Alluvium	5%

The materials comprising these geological units are summarised below.

4.2.2 Neranleigh-Fernvale Metasediments

The lithology of the Neranleigh-Fernvale metasedimentary strata may vary locally, both laterally and stratigraphically. Along the tunnel alignment the unit comprises mainly arenite, argillite and phyllite with some metagreywacke, quartzite and metabasalt. The quartzite is generally localised in occurrence and appears to be associated with zones of known or inferred folding and/or faulting. The metabasalt is also localised in occurrence and was only encountered in one borehole where it is bounded by fault zones.

The metasediments at tunnel depth are mainly fresh and of very high strength. Lower strength, weathered rock occurs where rock cover decreases, near the alluvial channels. Deep penetrative weathering occurs in a zone of extensive folding below Bowen Hills. Design strength and elastic parameters for the main rock types are shown in Tables 1 and 2.

Table 1. Design Strength Parameters for Rocks

Rock Type(*)	Weathering Category	UCS (MPa)		$I_{s(50)}$ Point Load Strength (MPa)			
		Failure Through Intact Rock		Axial		Diametral	
		Mean	Range	Mean	Range	Mean	Range
Argillite	FR	60#	17-162#	3.5	1.0-9.5	1.5	0.5-3.0
	SW	46#		2.7^	-	1.0^	
	DW	29#		1.7^	-	0.8^	
Arenite	FR	60	10-167#	4.2	0.6-9.8	1.8	0.2-4.2
	SW	60#	14-119#	4.1	0.8-7.0	1.7	1.1-2.1
	DW	43#	2-114#	2.5	0.1-6.7	1.7	0.5-3.4
Quartz Arenite	FR	60	3-158#	3.3	0.2-9.3	1.8	0.1-4.8
	SW	26#	2-83#	1.5	0.1-4.9	0.9	0.1-2.9
	DW	9	2-26#	0.5	0.1-1.5	0.5	0.1-1.0
Phyllite	FR	48#	3-107#	2.8	0.2-6.3	1.6	0.1-4.6
	SW	19#	2-48#	1.1	0.1-2.8	0.5	0.1-1.2
	DW	5#	2-39#	0.3	0.1-2.3	0.2	0.1-0.9
Tuff	FR	79	15-169	3.4	0.1-9.6	2.9	0.1-7.6
	SW	60#	26-96#	3.0	1.3-4.8	2.7	1.2-4.9
	DW	2#	2-4#	0.1	0.1-0.2	0.1	0.1-0.2

* With the exception of Tuff, all rock types may be variably interbedded with other rock types.

\# Value estimated on basis of $I_{s(50)}$ (where UCS = $17xI_{s(50)}$ for all rocks except Tuff and Metabasalt.
The assumed ratio for the Tuff and Breccia is UCS = $20xI_{s(50)}$ and for the Metabasalt is UCS = $10xI_{s(50)}$).

^ Estimated.

Table 2. Design Elastic Parameters for Rocks

Rock Type	Static		Dynamic		
	Elastic Modulus (GPa)	Poisson's Ratio	Sonic Velocity (m/s)	Elastic Modulus (GPa)	Poisson's Ration
Neranleigh- Fernvale Metasediments	17	0.27	3730	26.5	0.24
Brisbane Tuff	14	0.20	3710	25.5	0.2

The rock structure varies considerably between the two sections of the tunnel in the metasediments on either side of the Brisbane Tuff in Fortitude Valley. From Fortitude Valley to Newstead the structure is characterised by relatively shallow dipping foliation (20° to 30°), which is tightly folded in places and two dominant sub-vertical, orthogonal joint sets. From Fortitude Valley to the CBD the structure is characterised by moderately dipping foliation (40° to 55°) and at least three dominant joint sets varying from sub-vertical to relatively shallow dipping.

4.2.3 Brisbane Tuff

In Fortitude Valley the metasediments are unconformably overlain by rocks of the Brisbane Tuff. In this area, the Brisbane Tuff was deposited as an elongated lobe, probably as a result of an ash flow following a major valley system. This lobe is orientated approximately perpendicular to the tunnel alignment.

Along the tunnel horizon the tuff is generally fresh and of very high strength. Design strength and elastic parameters for the tuff are shown in Tables 1 and 2. At the margins of the unit, the unconformable contact with the underlying metasediments was encountered at Brookes Street and Gipps Street, as indicated on Figure 2. At these locations the base of the Brisbane Tuff is characterised by a transition zone which comprises a number of different rock and soil types that are both vertically and laterally discontinuous.

The unconformity at Brookes Street has an apparent dip of 35° along the alignment at the tunnel horizon. The tuff above the unconformity is deeply weathered with mainly soil strength, extremely weathered material and some low to medium strength rock. At the unconformity itself there is a 1m thick layer of breccia consisting of fragments of quartz and phyllite in a siliceous matrix. This is thought to comprise a scree breccia that was welded by heat during the emplacement of the overlying tuff.

The unconformity at Gipps Street has an apparent dip of 20° along the alignment at the tunnel horizon. Where the unconformity intersects the tunnel there is a 5m thick "transition zone". This zone consists of layers of very low to high strength rock with minor black coaly bands in the upper 2m and breccia comprising rock and quartz fragments with the voids infilled with tuffaceous material in the lower 3m.

The structure in the Brisbane Tuff is typical of columnar jointing, with typically two and sometimes three sub-vertical joint sets and one sub-horizontal set. These fracture patterns were found to vary over relatively short distances. It was interesting to note that the structure in the tuff is quite similar to that of the Neranleigh-Fernvale metasediments between Fortitude Valley and Newstead which is consistent with known folding subsequent to the deposition of the tuff.

4.2.4 Quaternary Alluvium

The Quaternary alluvium encountered along the alignment of the tunnel was subdivided into two distinct geological sub-units, comprising recent (Holocene) and older (Pleistocene) deposits respectively. The Holocene alluvium comprises mainly very soft to firm, silty clay generally with a loose sandy or gravelly basal layer up to 2.5m thick. The Pleistocene alluvium comprises mainly stiff to very stiff, silty clay with occasional granular layers, mainly towards the base of the unit. The four major alluvial channels identified in section 4.2.1 are all aligned approximately perpendicular to the tunnel alignment.

The Maud Street Channel comprises Holocene alluvium to a depth of at least 6m below the tunnel floor and has an apparent width of 55m at the tunnel horizon. At the tunnel horizon the bottom of the channel has apparent slopes of between 15° and 45° between investigation locations (4m to 10m apart). The granular basal layer at this depth is up to 0.5m thick and varies in composition from sandy clay to gravelly sand.

The Montpelier Road channel comprises Holocene overlying Pleistocene alluvium and extends to a depth of at least 10m below the tunnel floor. The apparent width of the channel at the tunnel horizon is about 175m comprising 85m Holocene alluvium at the western end and 90m Pleistocene alluvium at the eastern end. Boreholes and CPT's spaced 5m to 15m apart indicate that the base of the Holocene sediments where it intersects the tunnel horizon has apparent slopes of 10° to 15° along the tunnel. The basal granular layer varies in composition from sandy clay to sandy gravel. The Pleistocene sediments occur at the tunnel depth only in the eastern side of the channel. Along much of the length of the tunnel in this area the bottom of the channel is relatively flat and is located at or immediately below the tunnel floor. The granular basal layer along this section varies from minor gravelly bands to sand and gravel bands over 1m thick.

Field permeability testing carried out in the granular layers of the Holocene and Pleistocene alluvium at Montpelier Road gave calculated permeabilities in the range of 10^{-5} to 4×10^{-7}m/second. A pump test carried out in the Holocene granular layer gave a calculated permeability of 10^{-4}m/second, a Transmissivity of 8.6m^2/day and Storability of 0.003.

At Nardoo Street the channel comprises Holocene overlying Pleistocene alluvium. Boreholes spaced about 7m apart indicate that the base of the Holocene alluvium is about 3m above the tunnel crown and the Pleistocene to about 1m below the crown for a length of about 10m. The alluvium within the tunnel horizon comprises very stiff clay with sandy zones incorporated.

Boreholes spaced 17m apart indicate that the George Street channel, which comprises Pleistocene alluvium, extends to a maximum depth of 3m above the tunnel crown.

5. CONCLUSION

The staged investigation approach adopted for this project has been successful in that it has allowed the Council to select the most advantageous augmentation strategy and the preferred tunnel alignment. In the early stages of planning, geotechnical considerations were recognised to be pertinent to all phases of the study. A multidisciplinary team was assembled to perform the geotechnical investigations and input was sought from various specialists at different stages of the project. The broad range of investigatory techniques used and the comprehensive suite of laboratory tests will provide the successful construction consortium with a sound basis on which to design and construct this project.

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