The Geotectonics and Geotechnics of Traveston Crossing Dam Foundation

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Traveston Crossing Dam is proposed for construction at AMTD 207.6 km on the Mary River about 25 km upstream of Gympie in South East Queensland. The Mary Valley at the damsite is located in a zone of complex geology resulting from formation in a tectonic accretionery wedge setting. This has been responsible for a complex current geological setting which has required a range of geological/geotechnical investigation and interpretation techniques to develop a model on which to base the dam's preliminary design. This paper describes the tectonic history and the innovative techniques used in developing the geological model for the dam foundation.

The investigation involved the following specific investigative techniques; aerial photograph interpretation, geological mapping, geotechnical drilling including water pressure testing, seismic refraction profiling, downhole geophysical logging, excavation and geological mapping of large excavations, and hydrogeological investigation involving investigative drilling and pumping tests.

A Vulcan 3D computerised geological model was constructed using borehole data, seismic refraction interpretation and downhole geophysics interpretation. The geological model has been used in the development of the preliminary design and confirms that the foundations are suitable for the proposed structure.

1. INTRODUCTION

Construction of the proposed Traveston Crossing Dam is an essential component of the South-East Queensland Regional Water Strategy (a region-wide plan to secure regional water supplies until 2050). The strategy incorporates new water storages (including two major dams, a weir and an offstream storage), a recycled water scheme for industry, a desalination plant and a regional water distribution grid, together with water saving programmes.

The Traveston Crossing Damsite is located on the Mary River at Adopted Middle Thread Distance (AMTD) 207.6 km (approximately 27 km upstream of Gympie – Figure 1).

The site has been recognised as a potential storage location for more than thirty years. Preliminary geological investigations of a site at AMTD 206.7 km (approximately 900 m downstream of the current site) were carried out by the Queensland Irrigation and Water Supply Commission in 1976 and 1977.

The current investigation programme was undertaken in 2006 and 2007.

The preliminary design for the dam envisages a 750 m long Roller Compacted Concrete mass gravity wall founded on rock underlying the central alluvial terrace deposits; a side channel diversion and spillway channel excavated into the right abutment; and a zoned earth and rockfill embankment on the left abutment. A saddle dam is located high on the left abutment (Figure 2).

2. GEOLOGICAL SETTING

2.1 Tectonics and Stratigraphy

The site lies within the North D'Aguilar Sub-province, a tectonic fragment of the Late Devonian to Early Carboniferous Wandilla Province. The Wandilla Province formed in the New England Orogen on a convergent continental plate margin above a west dipping subduction zone (Day et al, 1978). Parallel belts representing accretionary wedge (east), fore-arc basin (centre) and continental magmatic arc (west) have been recognised. (Figure 3).

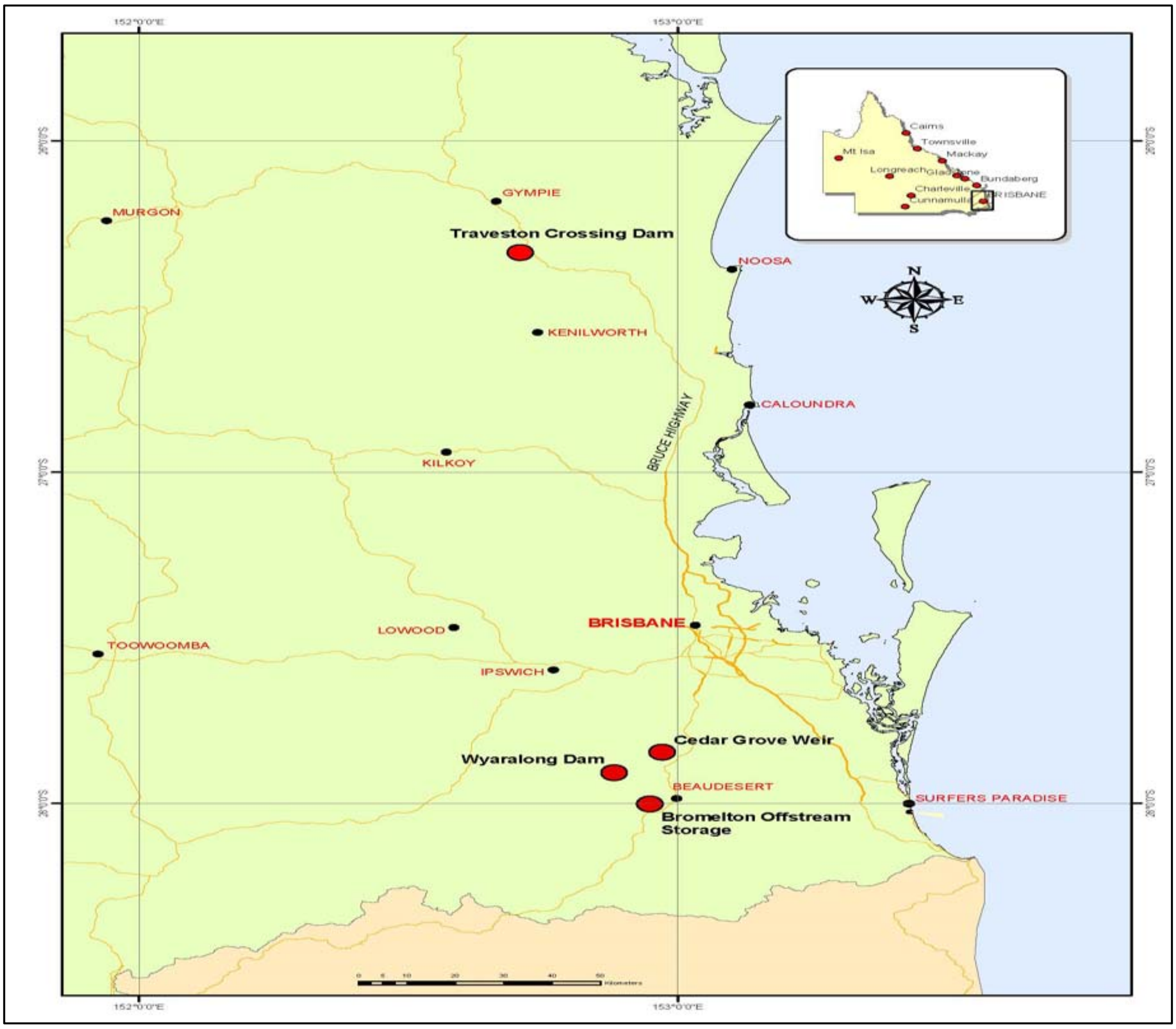


Figure 1 – Locality Plan

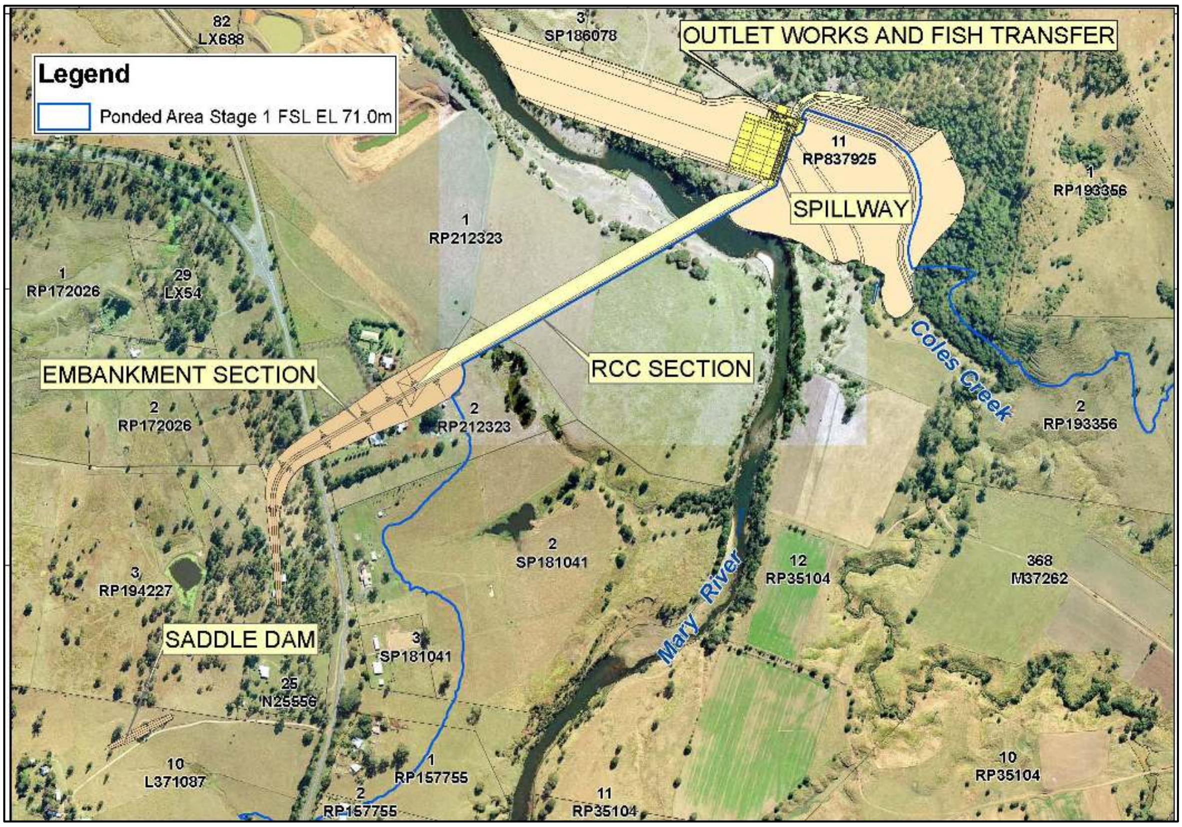


Figure 2 – General Layout

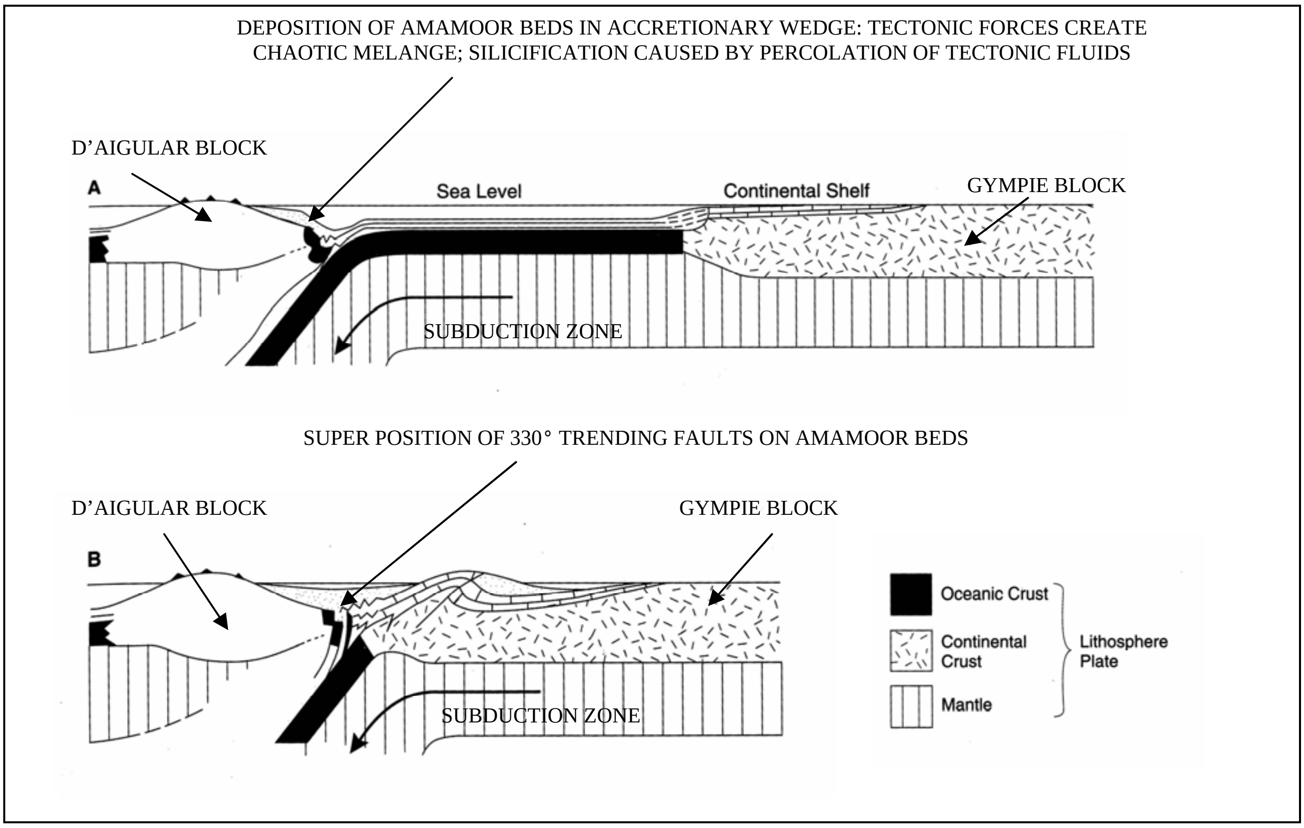


Figure 3 – Diagrammatic Representation of Docking of Gympie Block with D'Aigular Block

3.1 Geophysics

Seismic Refraction

Seismic refraction profiling was undertaken to supplement borehole information, and allow bedrock levels to be interpolated between boreholes. As results of the seismic surveys became available, they were used to target the geotechnical drilling programme towards areas where anomalies were indicated by seismic interpretation.

A Seistronix RAS-24 24/48 channel, 24 bit engineering seismograph was used for this survey and a tractor-mounted 220 kg falling weight was employed as the seismic source. This non-explosive source was chosen to limit the impact of the geophysical survey on local residents and livestock.

8 Hz geophones were planted in the ground at 5 m intervals and connected as 12, 24 or 48 channel seismic spreads. Data was recorded using a 0.5 ms sampling rate and a variable record length to suit the spread length.

Data from all individual shots within each specific seismic spread were saved and imported into PlotRefa of the SeisImager software package for further analysis by tomography modelling.

The final refraction tomography models (RTM) were converted into layer velocity plots as a simple means to display the seismic data on a long section along with borehole data.

Downhole Geophysics

To enable downhole geophysical logging of the site's bedrock, twelve (12) of the geotechnical boreholes were redrilled, generally within 3 m of the original borehole location. Downhole geophysical logging was not performed in the geotechnical boreholes as their nominal diameters of 75.7 mm were considered insufficient to allow safe passage of the acoustic televiewer and because it was not possible to leave casing in place necessary to support the unconsolidated strata (alluvium and extremely weathered rock).

The geophysical boreholes were drilled using percussion drilling techniques. In each borehole unconsolidated strata were supported by steel casing, left in place following the completion of the drilling.

Geophysical logging was undertaken on four boreholes on the right abutment and eight boreholes on the left bank.

A total of 530 m of downhole geophysical logging was performed. Natural gamma, calliper, sonic, magnetic susceptibility and acoustic scanner tools were run in each borehole. Version 2LAS format data was output for interpretation.

3.2 Large Test Pit Excavations

Five large test pits were excavated on the left abutment. The test pits were excavated to depths of up to 6 m below ground level by a 20-tonne excavator and bulldozer.

The aim of the test pitting program was to allow detailed mapping of the stratigraphy in an area of the foundation which is important in deciding the location and form of the transition between the RCC and embankment sections of the dam.

Accurate geological sketches were recorded of all test pit faces.

4. GEOLOGICAL MODEL DEVELOPMENT

A Vulcan 3-D computerised geological model was constructed using borehole data, seismic refraction interpretation and downhole geophysics interpretation.

Borehole Data

Data from 66 boreholes (54 geotechnical cored boreholes and 12 percussion drilled geophysical boreholes) was reviewed and then exported from the gINT database into a Microsoft Excel spreadsheet, and codified, before loading into Vulcan. Locations of the boreholes are shown in Figure 4. A series of model depths based on the weathering profile observed in the boreholes and soil classification of the overburden, provided the base surfaces used in creating the model.

Seismic Refraction Data

The seismic refraction data was collated and imported into the Vulcan model. This data was used primarily for the interpretation of the boundary between distinctly weathered and slightly weathered material (interpreted to occur at the 3,500 m/s refractor). This data allowed the interpretation to be extended beyond the quarry and the foundation area currently tested by drilling. Figures 4 and 5 show the location of the seismic lines and the interpretation of the bedrock surface using the seismic sections respectively.

Downhole Geophysics

The dip and dip direction of structures interpreted from the downhole geophysical logs, (including sheared/crushed zones, joints, veins and bedding contacts) were also imported into a Vulcan geotechnical database for use in the Vulcan model. Structural features were projected toward the immediately adjacent ("twin") cored borehole for comparison with corresponding similar defects in the core to assess if any lateral continuity existed between the boreholes.

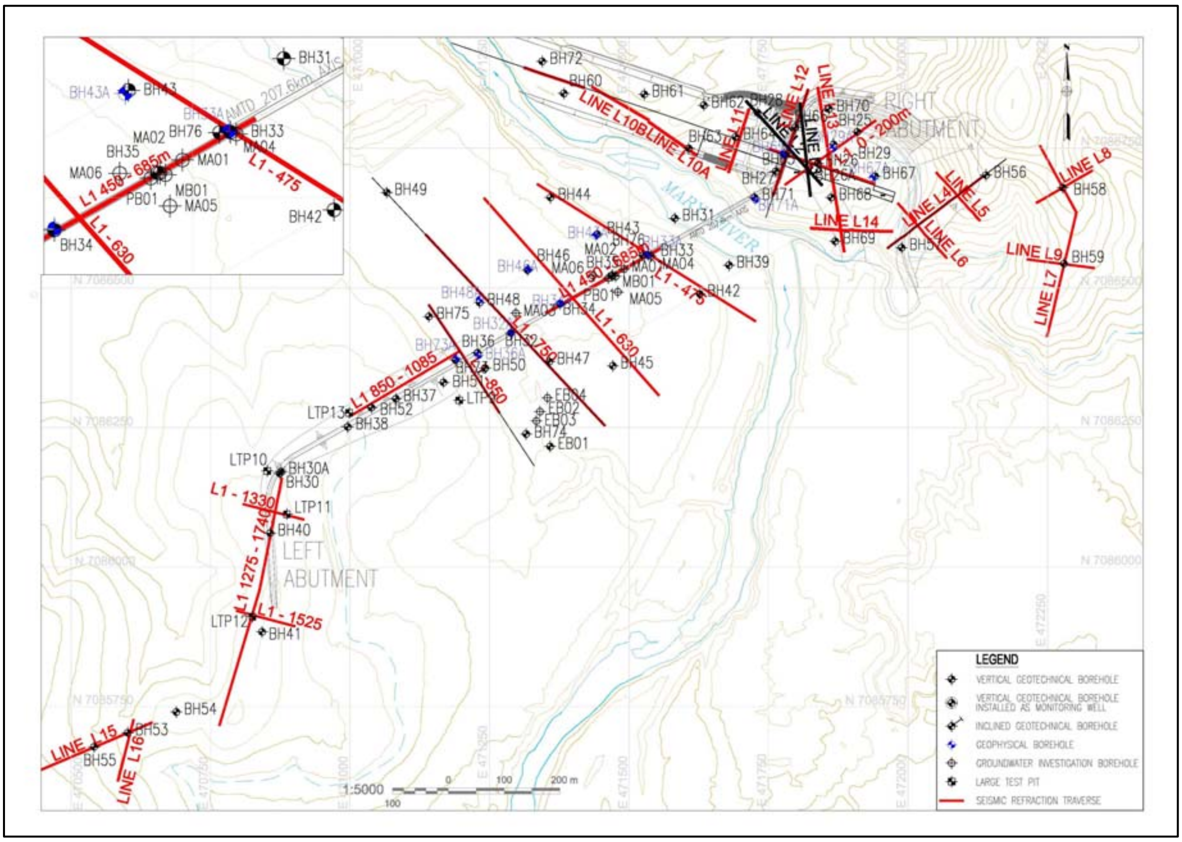


Figure 4 – Location of Investigations

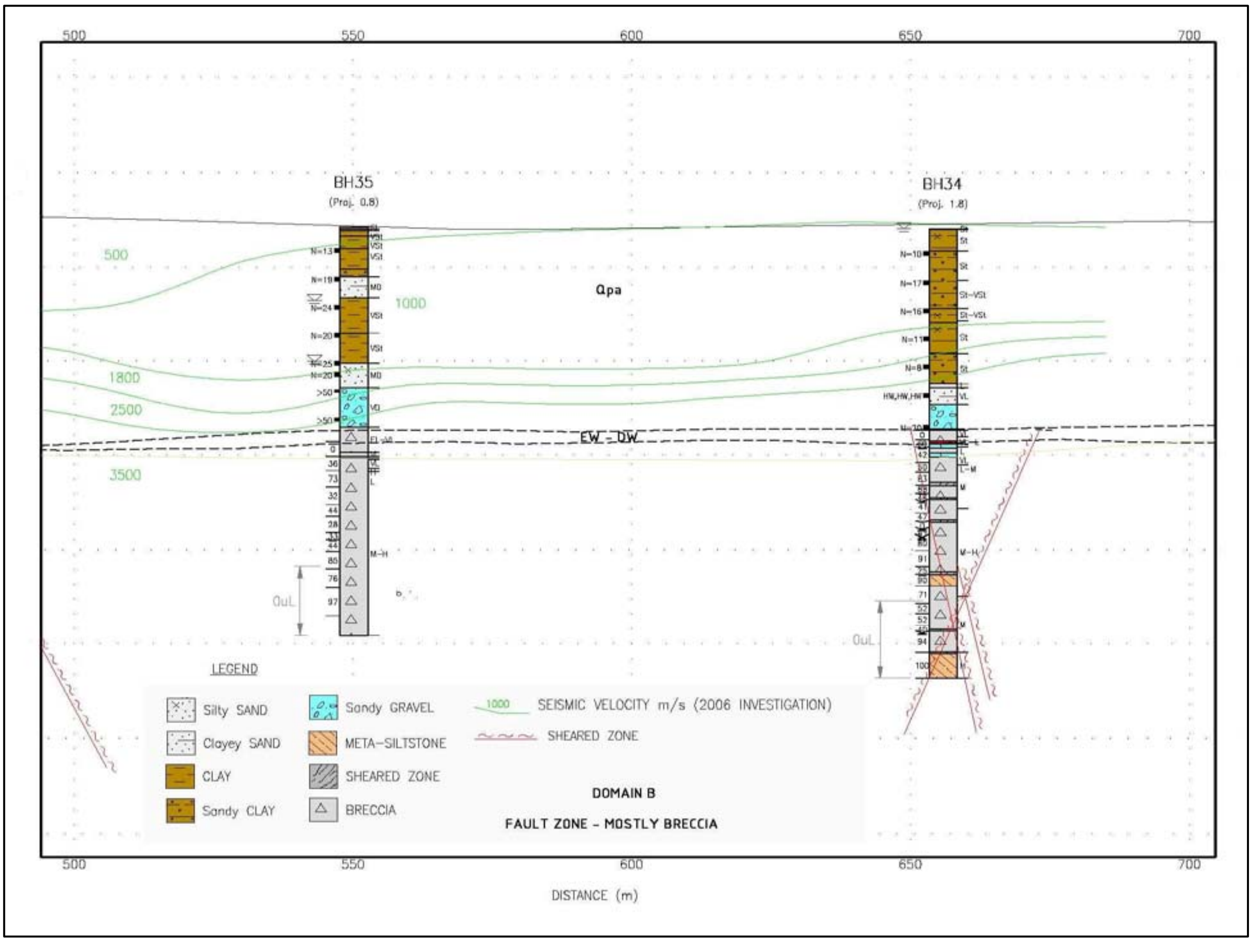
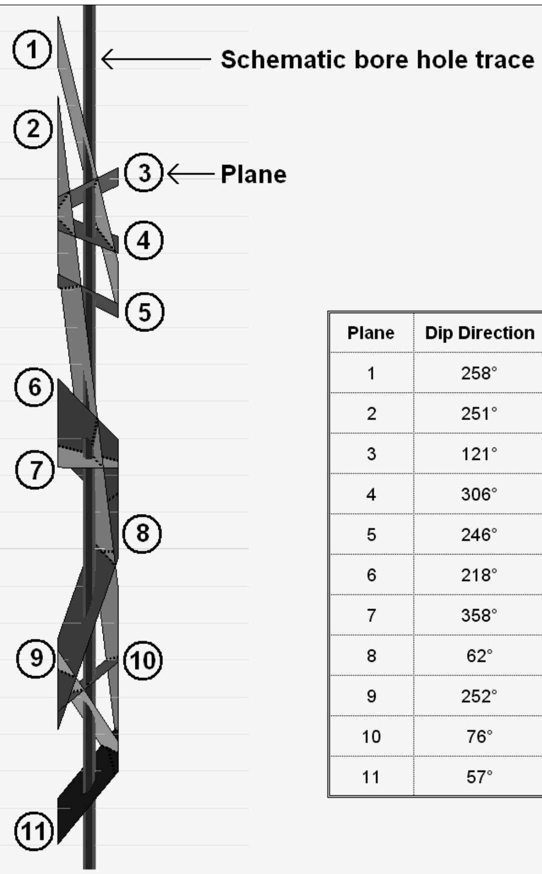


Figure 5 – Typical Geological Section



Plane	Dip Direction	Dip	Feature
1	258°	77°	Joint
2	251°	83°	Joint
3	121°	29°	Joint
4	306°	25°	Bedding Plane or Parting
5	246°	29°	Bedding Plane or Parting
6	218°	58°	Bedding Plane or Parting
7	358°	23°	Joint
8	62°	73°	Joint
9	252°	58°	Joint
10	76°	40°	Shear
11	57°	55°	Contact (Breccia above / Meta-siltstone below)

Figure 6 : Interpreted Orientations of Joints & Shears from Acoustic Televiewer

Only structures that were considered significant have been used for the final analysis. The dip and dip directions were then added to the cored "twin" at the point of the sheared zone intersection, to provide structural orientation for the sheared zone logged from the rock core. Planes were then created using these structural orientations. Figure 6 shows the interpreted orientations of joints and shears in a typical borehole.

Construction of Geological Model

Using the data outlined above a series of geological surfaces and solids was produced. The geological model surfaces (six in total) from the topographic surface down are:

- Holocene/Pleistocene Alluvium (PHa)
- Tertiary/Quaternary Alluvium (TQa)
- Colluvium (C)
- Residual Soil (R)
- Distinctly-Extremely-weathered Rock (D)
- Slightly weathered and fresh rock (B).

Theoretical solid objects have been produced to represent the major interpreted lithological units (D and B). The two major identified lithological units are breccia and meta-siltstone. These units divide the bedrock into five geological domains (A to E). These domains have been assigned from three geological sections and the structural data from the acoustic scanner logging. Four southeast striking lithological boundaries were interpreted from the acoustic logs. An arbitrary model floor of RL 15 m has been applied as no borehole information is available below this RL. The lithological units were extrapolated laterally to the limit of the borehole data. Both the breccia and meta-siltstone solids have bedrock and weathered components, with the bedrock portion being shown in Figures 7 and 8. It must be noted that there were no structural orientation data available for the contact between the middle meta-siltstone domain (Domain C) and the western breccia zone (Domain D). On this boundary a plane between the two domains was created using the borehole contacts. The modelled geological domains honour all major units represented within the cored boreholes.

5. GEOMECHANICS ASSESSMENT

5.1 Overview of Geomechanics Assessment Method

The geomechanics assessment was undertaken using data obtained from an acoustic televiewer survey and surface mapping. From these sources, 935 rock structures were identified of which 860 were from the acoustic televiewer (ATV) and 75 from surface mapping. Only 180 rock structures were classified as having high reliability and these were analysed using the Rocscience package DIPS. The majority of these rock structures (156) were joints, with 13 bedding planes and 11 identified as crushed or sheared zones.

The methodology used to evaluate the geomechanical parameters is based on the determination of the Geological Strength Index (GSI) and the Hoek-Brown and Mohr-Coulomb criteria and is as follows:

- A review of all boreholes in the vicinity of the main dam foundation and spillway areas was completed to gain an understanding of the lithology, weathering and strength of the rock.
- The peak and residual geological strength indices (GSI and GSIr) were estimated for intervals of different lithology, weathering, strength and structure within selected boreholes using the methods due to Cai etal (2004, 2007).
- Based on the lithologies recorded on the borehole logs, four main Geological Domains (A to D) were defined along the dam RCC section foundation axis and spillway area. An average GSI was then assigned to each of the domains as shown in following Table 1.

Table 1 - Averaged GSI Values for Geological Domains

Geological Domain	Lithology	GSI (averaged)
Domain A	Meta-siltstone	57
Domain B	Breccia (with sheared zones)	47
Domain C	Breccia	41
Domain D	Breccia / Meta-siltstone	45
Spillway Zone	Meta-siltstone	58

- Laboratory testing was conducted on selected core samples for uniaxial compressive strength (σci) and Young's modulus (Ei) for intact rock.
- In the absence of triaxial testing, a material constant for intact rock (mi) of 19 was used.

The rock mass modulus of deformation (Erm) for each of the geological domains was calculated using the formula (Hoek and Diederichs 2006):

$$E_{\mathrm{rm}} = E_{\mathrm{i}}\left(0.02 + \frac{1 - D/2}{1 + e^{((60+15D-\mathrm{GSI})/11)}}\right).$$

where D allows for the effects of blast damage and stress relaxation on rock during construction.

- The Mohr-Coulomb failure criterion parameters of cohesion (c) and friction angle (ϕ) were derived using the program Roclab, based on an estimated maximum confining stress on the rock (σ_{3max}) for the height of the dam wall and spillway.

5.2 Foundation (Main Dam RCC Section)

Assessment of the geological structural features on the potential behaviour of the foundation for the proposed RCC section indicated that sheared zones were the dominant structural feature and the stereonet pole (points) clusters were grouped into sets (Table 2)

Table 2 – Sheared Zone Sets

Structure Set	Mean Orientation (Dip / Dip direction)	Structure ranking
Shears 1A Shear 1B Shear 1C	67/220 63/243 67/269	Major Minor Major
Shears 2	60/075	Major
Shear 3	55/165	Minor
Shear 4	50/310	Minor

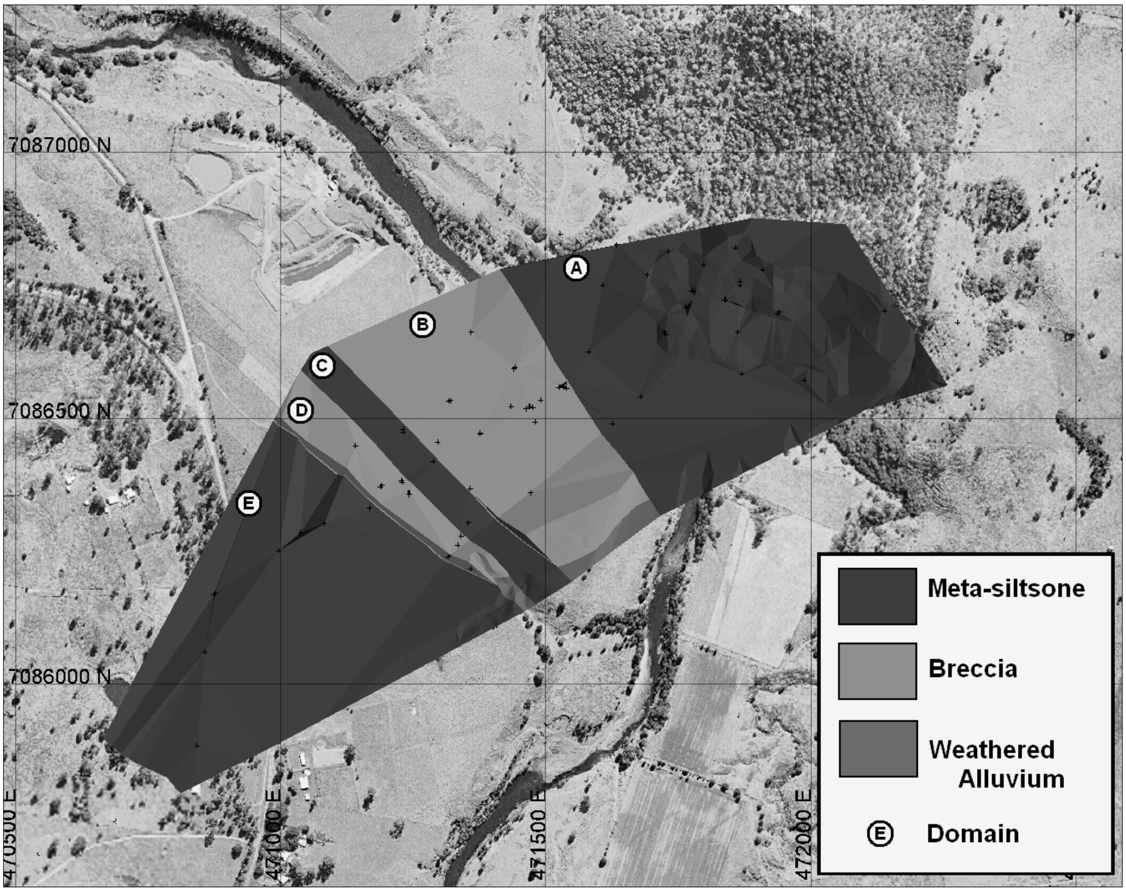


Figure 7 – Plan of Identified Foundation Geological Domains

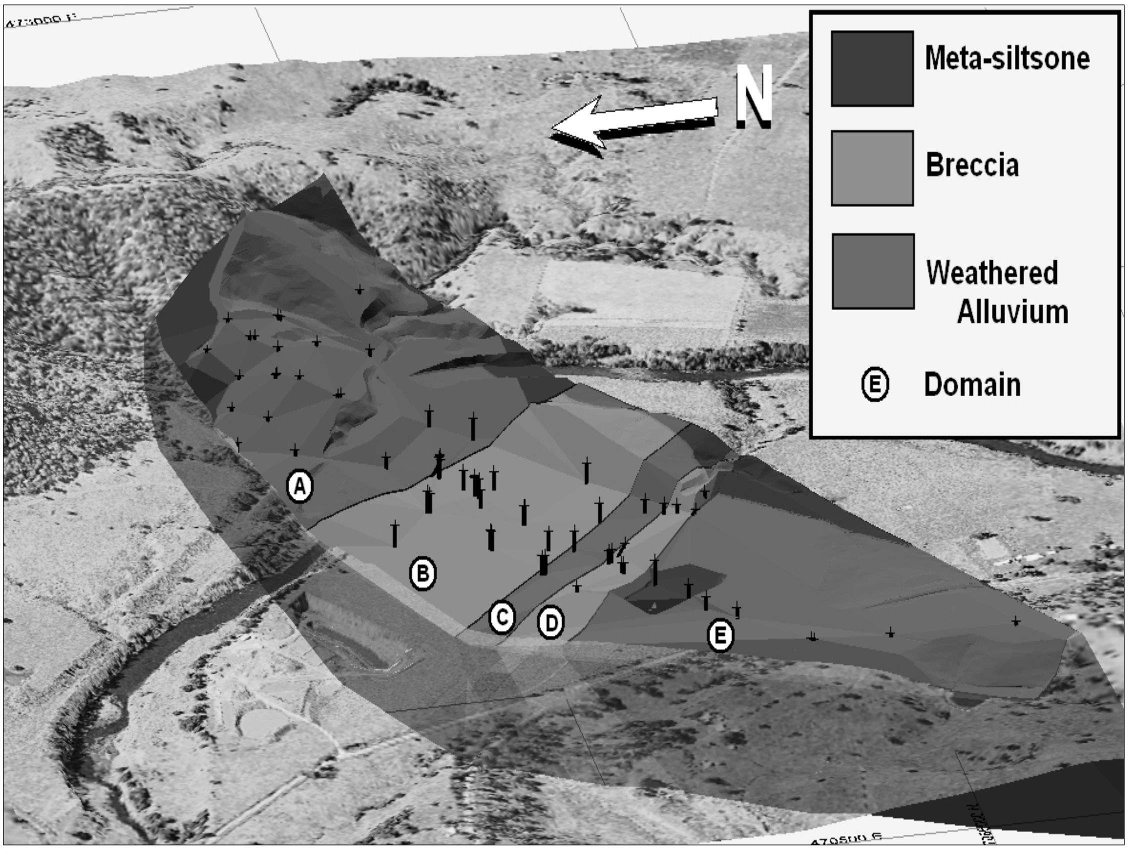


Figure 8 – Three Dimensional Block Representation of Foundation

The two most common rock structures were determined to be Shears Set 1 (with sub-sets Shears 1A, 1B, 1C), and Shears Set 2. These structures could potentially form intersecting planes (wedge block) plunging from 15° to 50° to the southeast.

Stereonets were plotted by individual boreholes to analyse the spatial distribution of the sheared zones. The individual borehole stereonets identified three boreholes as containing a large proportion of the southwest dipping Shear Set 1.

Based on the borehole spacing across the floodplain and the available structural data it could be considered that the southwest dipping shears could develop into persistent structures in the dam foundation. However currently available data is not sufficient to provide a high confidence level that the geological features observed are likely to be sufficiently persistent and continuous to develop such wedge blocks.

5.3 Foundation (Main Dam Left Abutment & Saddle Dam)

The left abutment and saddle dam foundations have been investigated by seismic refraction, geotechnical boreholes, and large-scale test pits for geological mapping of stratigraphy and structure.

The left abutment between chainages 830 and 1577 m consists of Tertiary to Quaternary alluvium including fissured clays overlying extremely to distinctly weathered meta-siltstone.

Geological mapping of the weathered meta-siltstone in two large-scale test pits located in Bedrock Domain E confirms that the significant defects (joints, bedding, shears) can be broadly classified as four major sets:

- Set E1 85°/025°.
- Set E2 75°/260°.
- Set E3 85°/285°.
- Set E4 80°/350°.

Many of these sets can be correlated with joint sets identified in Domain A, located on the eastern side of the damsite, including the proposed spillway location.

No specific laboratory strength testing was undertaken of weathered meta-siltstone core from the left abutment boreholes. On the basis of previous experience, the peak shear strength parameters have been estimated as ϕ'=40^{o} and c'=50kPa.

The Tertiary to Quaternary alluvial fissured clays were sampled for laboratory shear strength testing. Undisturbed block samples were tested in direct shear. Table 3 presents the results of the shear tests on two samples of fissured clays extracted from one of the larger test pits.

Table 3 – Summary of Results of Direct Shear Testing

Sample ID	Peak Cohesion c' (kPa)	Peak Angle of Friction ϕ' (degrees)	Residual Cohesion	Residual Angle of Friction ϕ (degrees)
LTP13 Sample "A" (4.00 – 4.50 m)	38.5	23.5	0	11.5
LTP13 Sample "B" (4.00 to 4.50)	46	22	0	10

The presence of fissured clays in the Quaternary/Tertiary alluvium reduces the mass shear strength compared to the soil substance.

Shear strength testing undertaken on the fissured clays was not able to be carried out on specimens oriented such that shearing was on actual fissure planes. In view of the fact that fissures do not appear to be slickensided, it is considered appropriate to adopt shear strength parameters for the clay (i.e., c'=0 kPa, ϕ'=22^{o}).

Based on the above the foundation level of the proposed design on the left abutment envisages removal of the majority of the Tertiary/Quaternary alluvium containing the fissured clays.

5.4 Spillway Area

Geological reporting reflects closely spaced jointing (in terms of the ISRM classification) but of very low persistence as observed from surface exposures. This implies that rock slopes are likely to be strengthened by the presence of rock bridges. Some faulting has been reported across the site (e.g. at 60°/240°) and these structures need to be projected to ensure that there are no influences within the tailrace zone.

The initial approach to the appraisal of stability of the cut slope for the spillway channel is based on a kinematic analysis of the structures referred to above in relation to the orientation of the cutting and in the context of reasonable friction angles. As such it is limited to the available data and neglects the possible influence of pervasive and possibly low strength rock structures which could be present and which could require specific designs for rock block support and therefore at this preliminary stage it only provides an indication of the potential for unravelling of these slope orientations.

This analysis shows that there are four possible sets of structures as shown in Figure 9. These have been examined kinematically with respect to slope orientations for three areas:

- the south facing slope;
- the south-west facing slope; and
- the west facing slope.

Areas susceptible to planar, wedge and toppling failure have been identified and preliminary assessments of support options undertaken.

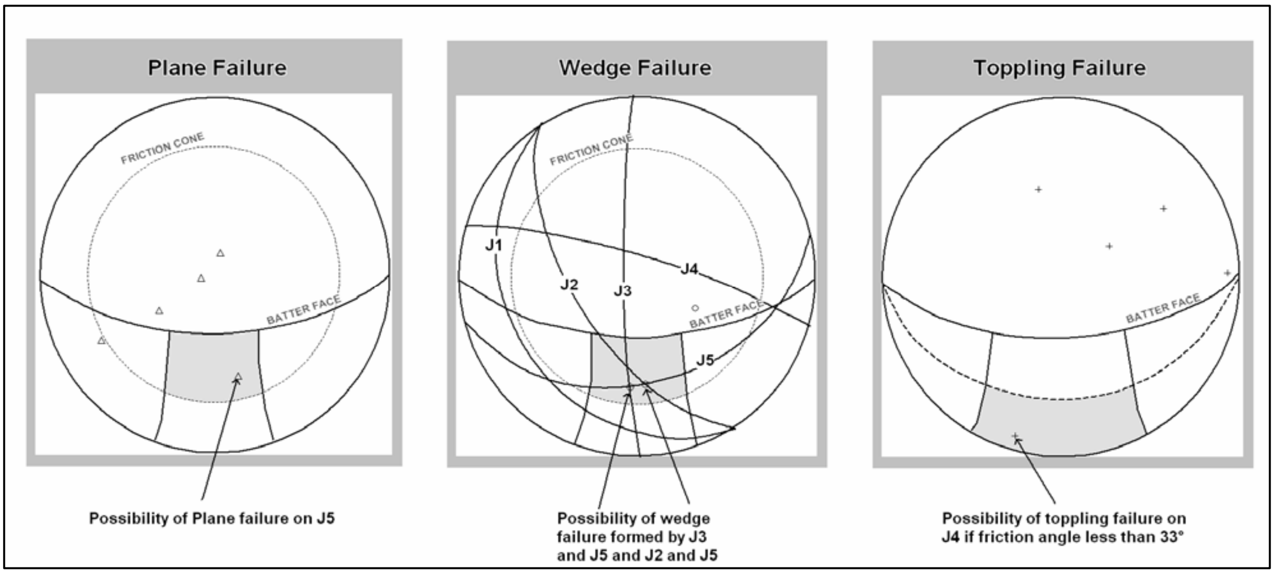


Figure 9 – Spillway South Slope Kinetic Analysis

Further structural geology and geotechnical engineering work is required to establish the spacing and continuity, and surface characteristics for the dominant structural features. This data is required before undertaking further geotechnical analysis of potential wedge features developed by these structures.

6.0 SUMMARY AND CONCLUSIONS

The meta-sedimentary rocks in the Traveston Crossing area consist of interbedded siltstones and mudstones. These appear to have been deposited in an accretionary wedge setting, resulting in a chaotic melange in which bedding is not persistent over more than short distances. The rocks are highly silicified.

There are folds, faults and joints in the mapped area. Bedding is difficult to find and follow and it is considered that there may be more folds that were not mapped. Jointing is neither widespread nor penetrative. Three common orientations were noted and joints are typically of limited persistence, parting and interconnectedness.

The orientation and nature of structure observed from the downhole geophysical logs (including sheared and crushed zones, joints and bedding contacts) confirms the observations during mapping that the rocks at the site appear to have been subjected to one or more tectonically induced disruptions.

Five geological domains have been modelled with four southeast striking lithological boundaries. Based on the relatively widely spaced boreholes across the flood plain, it could be considered that the southwest dipping shears (the dominant structural feature) could develop into persistent structures potentially forming intersecting planes defining wedge blocks plunging from 15º to 50º to the southeast.

The structures observed in the vicinity of the site are not considered likely to result in major seepage paths beneath the dam wall, principally because of the chaotic, discontinuous nature of sediments laid down in an accretionary wedge and also because of the post-depositional silicification. This has been largely confirmed by the relatively low Lugeon values recorded in water pressure testing in investigation boreholes.

Further work is required to confirm the nature and orientation of the structures observed in the proposed spillway channel excavation.

7.0 ACKNOWLEDGEMENTS

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8.0 REFERENCES

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