Digital Solutions to Improve Workflows of 3D Ground Modelling

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ABSTRACT

3D ground modelling often starts with importing digitised ground investigation (GI) data into modelling software. This first step is very vital for further ground interpretation with meaningful result. Since the invention of digitised GI data, any data obtained on site can be electronically transferred by adopting the AGS format. To utilise any digital GI data for this purpose, engineering geologists must go through manual data clean up to suit the import format of modelling software. Otherwise, details will be lost such that risks could potentially be overlooked in the interpretation of the data. Aurecon has developed a new tool specifically to automate the manual process to restructure any AGS data, streamlining the process of 3D ground modelling. After any AGS files are processed by this tool, the likelihood of overlooking any details or important information has been greatly minimized. From our experience, the time saving between using this tool and manually processing digital data to build up a 3D ground model is often more than 50%. This paper will first discuss challenges of 3D ground modelling from AGS data, followed by discussion on preferred data structure for ground modelling and capabilities of the tool to overcome these challenges.

Keywords: 3D Ground Modelling, AGS, Digital workflow

1 Introduction

A well-established ground engineering design needs to be based on relevant and detailed ground model where most of the geotechnical risks are carefully determined and properly handled. Building up a detailed ground model involves cross-checking of different data and descriptions from ground investigation (GI) data, which may include grain size and type of soil material, strength and weathering grade of rocks, rock mass descriptions and characteristics of localized weak zones. The focus of each ground model may be very different depending on each project requirements. For example, the ground model for a cut-and-cover tunnel focuses on soil properties while the ground model for a deep rock tunnel focuses on rock mass characteristics.

At the start of every project, a new ground model needs to be developed to ensure that the ground model is serving the project's specific needs and that all project-specific GI data, or related archival GI data, are included. Depending on the scale of projects, hundreds or even thousands of GI data may be involved. Although GI data can be transferred in bulk in electronic format with the help of AGS data format, one cannot assume that the process of building up a ground model can be easily automated.

This is because only factual data collected from GI sites and laboratories is stored in AGS data. Without manual input from engineering geologists or geotechnical engineers, which involves checking and putting relevant data together and adding sensible interpretations, raw AGS data is far from having sufficient information required in building up a detailed ground model for any project. In large projects in which a large number of GI data is involved, it is often required for a team of engineering geologists or geotechnical engineers to work for a certain period (from days to weeks) to process all the data.

Therefore, in an attempt to reduce the time required in projects to work on repetitive tasks, a tool has been developed to semi-automatically process and refine AGS data for the need of a detailed ground model. The following section will explain in detail the challenges encountered when a detailed ground model is built from AGS data. The subsequent section will explore how these challenges can be overcome with the help of the tool. The benefits and future developments of the tool will be discussed in the final section.

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2 Common Challenges of Building Ground Model with AGS Data

Compared with building up a ground model based on the GI reports in hardcopies or pdf format, AGS data, which is saved in a format convenient for data storage and transfer, can save a huge amount of time for manual data input. Nevertheless, some challenges may be encountered when directly using the AGS data for ground modelling.

2.1 Reliance on Commercial Software

AGS data handling often relies on commercial software. AGS data is stored as a text file with specific format. It is almost like a combined csv file of all the groups. Although it can be opened with text-reading software, only a few commercial software can decode this specific format back to its spreadsheet-like format as designed. Though these pieces of commercial software allow reading, editing and visualizing of the data in different groups directly (Figure 1), no commercial software to-date enables query of data across different groups and restructuring of AGS data. These two tasks are often done out of commercial software and can only be done in spreadsheets which are output from the software. If performed manually, they could be extremely time-consuming tasks.

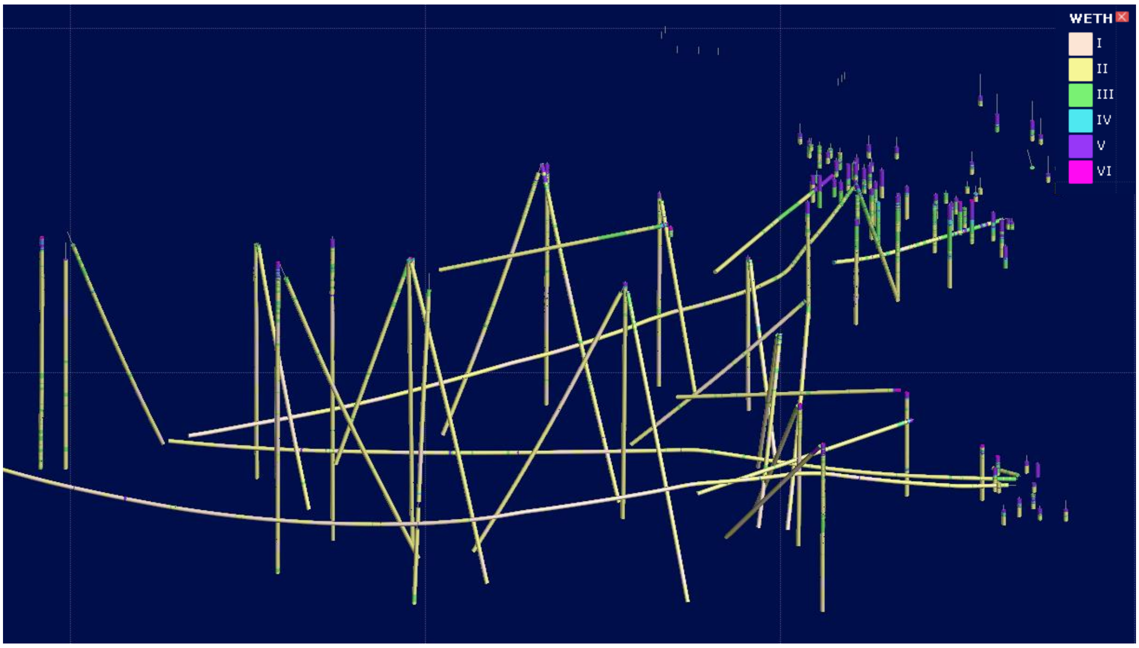

Figure 1: Raw AGS data visualized by commercial software, Leapfrog Works

2.2 Purpose as Electronic Transfer Format

The goal of AGS data format is to make electronical transfer and storage of ground investigation data possible (AGS, 2022; Caronna & Wade, 2005). AGS data format was introduced by the Association of Geotechnical and Geoenvironmental Specialists in 1991 to store GI data in digital format. This format stores data in Group Hierarchy, or a tree-like structure where a group on top is called parent group and groups below it is called child groups. Each group can have more than 1 child groups but at most 1 parent group. At the top of the hierarchy is PROJ group. Below PROJ group are LBSG and HOLE (which is renamed to LOCA in the latest (4th) version of AGS data format) groups which lab testing schedule and location details of each GI point respectively (see Figure 2 and Figure 3 for a better visualization of the structure).

This format is easy for any party using GI data (e.g., GI contractors, main contractor, consultant, etc.) as any data can be added or removed simply by editing a single group. It is also a great transfer format due to its small file size. It made transfer of more and more, if not all, GI data available since its introduction. However, when it comes to ground modelling when data from different groups should be read concurrently, problems may arise with data in different groups stored independently without relationship to other groups except their own parent group.

HOLE_ID	HOLE_TYPE	HOLE_NATE	HOLE_NATN	HOLE_GL	HOLE_FDEP	HOLE_STAR	HOLE_LOG	HOLE_REM	HOLE_LETT	HOLE_
BH1	W+RC	839956.27	828994.35	5.43	17.27	14/04/1999	K.M. To	1. Piezometer tip installed at 10.50m depth.		
BH2	W+RC	840083.86	829135.56	6.55	37.4	17/04/1999	K.M. To			
BH3	W+RC	840216.28	829280.88	4.91	27.48	22/04/1999	K.M. To	1. Piezometer tip installed at 21.45m depth.		
BH4	W+RC	840230.82	829195.83	6.31	22.82	9/4/1999	K.M. To	1. Piezometer tip installed at 16.10m depth.		
BH5	W+RC	840660.75	829638.92	5.54	37.16	21/04/1999	K.M. To	1. Piezometer tip installed at 25.00m depth.		
BH6	W+RC	840753.76	829649.59	4.99	46.06	12/4/1999	K.M. To			
TP1	TP	839921.45	828956.41	4.1	2.3	12/4/1999	K.M. To			
TP2	TP	840026.09	829073.55	5.63	2.4	12/4/1999	K.M. To			
TP3	TP	840115.37	829094.16	6.11	2.2	20/04/1999	K.M. To			
TP4	TP	840148.59	829203.17	6.78	1.2	15/04/1999	K.M. To			
TP5	TP	840217.7	829267.36	5.07	2	14/04/1999	K.M. To			
TP6	TP	840277.51	829222.71	5.78	1.3	15/04/1999	K.M. To			
TP7	TP	840387.15	829287.28	6.24	1.6	15/04/1999	K.M. To			
TP8	TP	840384.65	829381.94	5.77	2.1	3/5/1999	K.M. To			
TP9	TP	840474.73	829340.17	7	2	17/04/1999	K.M. To			
TP10	TP	840469.68	829496.15	6.24	2.1	5/5/1999	K.M. To			
TP11	TP	840566.68	829402.48	7.39	2	16/04/1999	K.M. To			
TP13	TP	840671	829475.05	5.78	2	16/04/1999	K.M. To			
TP14	TP	840816.46	829690.73	7.41	2.3	12/4/1999	K.M. To			
TP15	TP	840897.38	829793.95	8.41	2.3	13/04/1999	K.M. To			
TP16	TP	840988.85	829972.06	5.99	2.3	14/04/1999	K.M. To			
TP17	TP	841044.39	830096.51	5.67	2.3	13/04/1999	K.M. To			

PROJ | HOLE | HDIA | PTIM | SAMP | GEOL | DETL | FRAC | CORE | ISPT | PREF | POBS | WETH | IDEN

Figure 2: Example of structure of AGS file (converted to Excel spreadsheet by commercial software gINT)

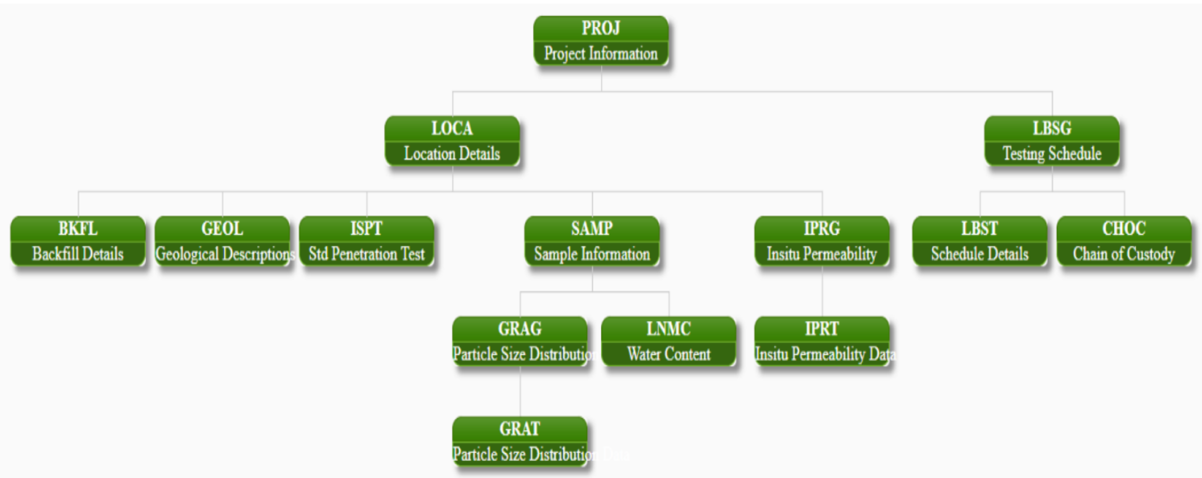

Figure 3: Structure of AGS data (from AGS, 2022)

2.3 Loss of Detailed Variations in Ground Conditions in Grouped Data

Raw AGS data alone does not directly show the detailed variations in ground conditions, due to its grouped structure. Detailed ground conditions may be described in numerous types of data, which may be continuous qualitative descriptions like field geological descriptions, continuous numeric data like coring information (core recovery, RQD etc.), discrete descriptions at certain depths like stratum detail descriptions, or discrete data at certain depths like field or lab test data.

Every type of data is stored in individual groups. Groups commonly used in ground modelling in Hong Kong include:

- DETL: Stratum Detail Descriptions
- FRAC: Fracture Spacing
- GEOL: Field Geological Descriptions
- WETH: Weathering Grade
- CORE: Coring Information

Interpretation of ground conditions cannot rely on any single group alone. For example, in the interpretation of engineering rockhead, other than reading the WETH group, the geologist must also check the CORE group for TCR and GEOL and DETL groups for descriptions to ensure all requirements for rockhead as described in the Code of Practice of Foundations are met.

2.4 Laborious Cross-group Analysis

Analyzing AGS data across numerous groups is a laborious process, because data are often stored in different intervals across different groups and querying capabilities are lost (Caronna & Wade, 2005).

Data in each group are often stored in depth intervals and only depths where there are changes in that particular group is recorded. As a result, the depth intervals often do not match with each other. In the example shown in Figure 4, main geological descriptions are stored in a large interval between 541.48m and 546.45m. RQD is stored in slightly smaller intervals: 541.30m – 542.85m, 542.85m – 544.38m etc. Weathering grade and fracture index are stored in smaller, yet completely different intervals. Detailed descriptions are then added in specific intervals.

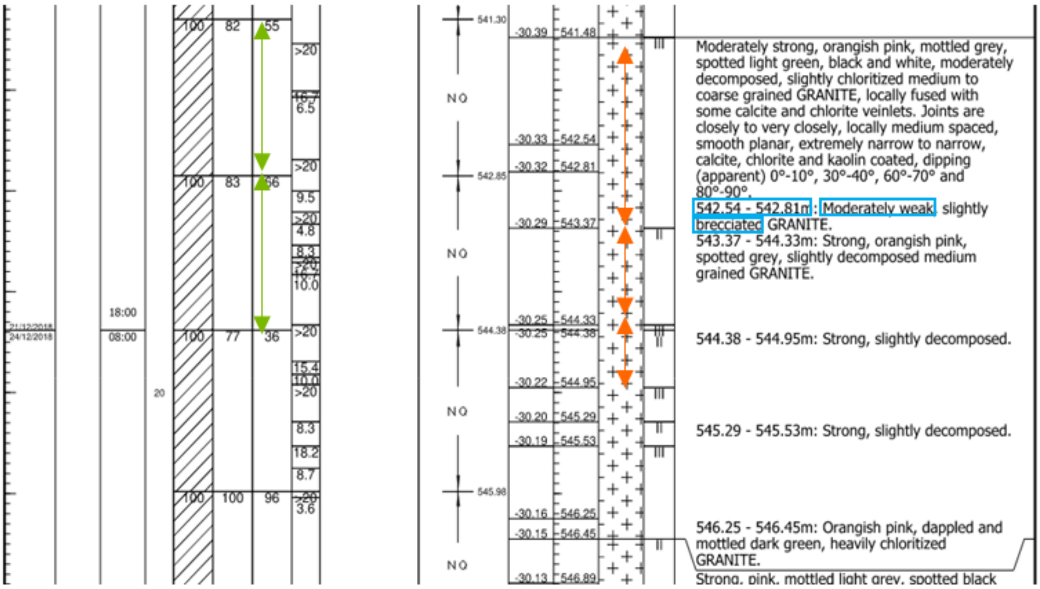

Figure 4: Example of common borehole log where data are stored in different intervals

If data in two or more different groups are to be compared, the intervals must be combined and broken down to smaller intervals. For example, if one wishes to find out the SPT-N value of different soil type (e.g., fill, marine deposits, alluvium, etc.) and grain size (e.g., sand, silt, clay, etc.), one may first transfer ISPT group data and the descriptions in GEOL group into an Excel spreadsheet. The soil type and grain size of each SPT test may be correlated manually by either reading the GEOL group descriptions one by one, or by combining data in both groups into a single table and then matching the soil types and grain size of each test at once. This process may still be easy if only few boreholes are involved and only data from two groups are to be correlated. If data from more than 2 groups are to be compared or combined, though not impossible, a large amount of repetitive data lookup and/or copy-pasting is required.

2.5 Overlooked Risk of Directly Imported AGS

Building up a ground model with AGS data directly may lead to geotechnical risks being potentially missed by overlooking data in other groups. As data are stored in different intervals in different groups, no one single group is comprehensive enough to reflect all the detailed changes of ground conditions. Whenever ground conditions are to be characterized by using data stored in more than one groups, correlating and combining the data is inevitable. If only selected groups are assessed, potential geotechnical risks represented in other unassessed groups may be overlooked.

For example, if only the WETH group is directly used for finding the engineering rockhead, localized weak materials described in DETL group and the presence of the description of corestone, which should not be considered as engineering rockhead, will highly likely be missed. And occasionally, in depths much below the engineering rockhead where mostly Grade II or Grade III rock is present, if only weathering grade is checked, localized weak zone or fault materials, which may be described in DETL or GEOL groups, will likely be missed, unless detailed manual checking is done on borehole logs or excel spreadsheets.

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3 Preferred Data Structure for Ground Modelling

For the purpose of developing a database for a comprehensive ground model, it is suggested to further process the AGS data by restructuring the Group Hierarchy structure. One single depth-related table (instead of separated groups) should be constructed to allow easier correlation of depth-related data across different groups. Depth intervals from all groups, which should be considered in the detailed ground model, shall be taken and broken down to merge data from all groups. Qualitative descriptions, such as field geological descriptions and stratum detail descriptions, should be included. Key descriptions, such as rock and soil types and soil grain size, should be extracted as well.

Important geological features, such as fault zones, shear zones and corestone zones, should then be extracted from descriptions. Continuous numeric data such as TCR, RQD, fracture index and weathering grade, should also be populated. Other depth-dependent data such as field test and lab test data, standpipe and piezometer installation records, can then be correlated with geological descriptions and coring information to enhance the efficiency of data interpretation. Subsequently, further interpretation of ground conditions (such as fault zones, weak seams) can also be added into this detailed database. With such database structure, any GI data can be correlated and interpreted with ease. Interpretations can also be visualized and related to factual data easily.

4 Capabilities of "AGS Processor"

With the aim of using AGS format data for ground modelling more efficiently, the authors developed a number of excel spreadsheets with complicated equations to process the AGS data. However, the authors soon realised that such excel spreadsheets are not user-friendly at all and this approach cannot support to process large amount of GI information. As a result, a python-based tool called AGS Processor (Figure 5 has been developed to solve the aforementioned problems. It aims at transforming AGS data files to a format ready for development of a detailed ground model.

4.1 Data Reconstruction

Similar to commercial software, this AGS Processor can read and parse (decode) AGS files. Excel files output from commercial software gINT can also be read. The widely adopted modified AGS 3rd version (AGS3) data format for Hong Kong industry can be read, checked and inspected. The Combine function allows the user to restructure AGS data from various groups, such as GEOL, CORE, DETL, FRAC and WETH, into a single depth-correlated table as suggested in Section 3. Depth intervals from all the groups are combined and data from all groups are automatically populated into the combined table (Figure 5).

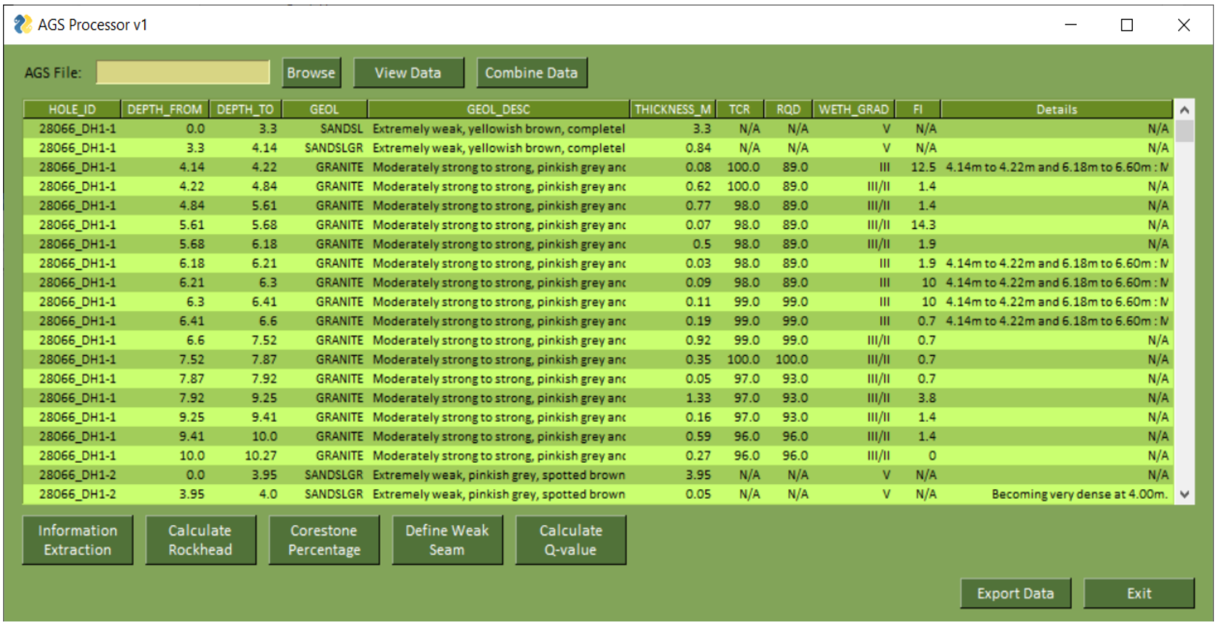

Figure 5: Preliminary Interface of AGS Processor, showing reconstructed AGS data

4.2 Information Extraction and Matching

To enhance the efficiency to cross-check the information and minimize the potential risks of missing important information in the geological descriptions (GEOL) and detailed descriptions (DETL), one of the functions of AGS Processor is to automatically extract and combine information from geological descriptions and detailed descriptions. Key descriptions, such as soil type and grainsize (e.g., marine clay, alluvial sand etc.) are extracted from geological descriptions and automatically matched. Other soil-related data, such as field test and lab test data, can then be matched with the corresponding soil type and grain size directly. For example, given a list of SPT data in the list of boreholes in the combined table, the soil types and grain sizes can be matched automatically. All the SPT data can then be sorted and plotted for evaluation directly. Another example of using this function is the packer test results can be matched with the RQD and fracture index (FI) which are stored in different group of the AGS data automatically for ease of review and further analysis.

Detailed descriptions are also checked. For instance, in rock portion, descriptions are also automatically checked in GEOL and DETL groups to locate any weak materials by searching for key words such as *moderately weak*, *weak*, *extremely weak*, or *no recovery*. Important geological descriptions such as *corestone*, *fault*, *fault gauge*, *fault breccia* can also be automatically located (Figure 6).

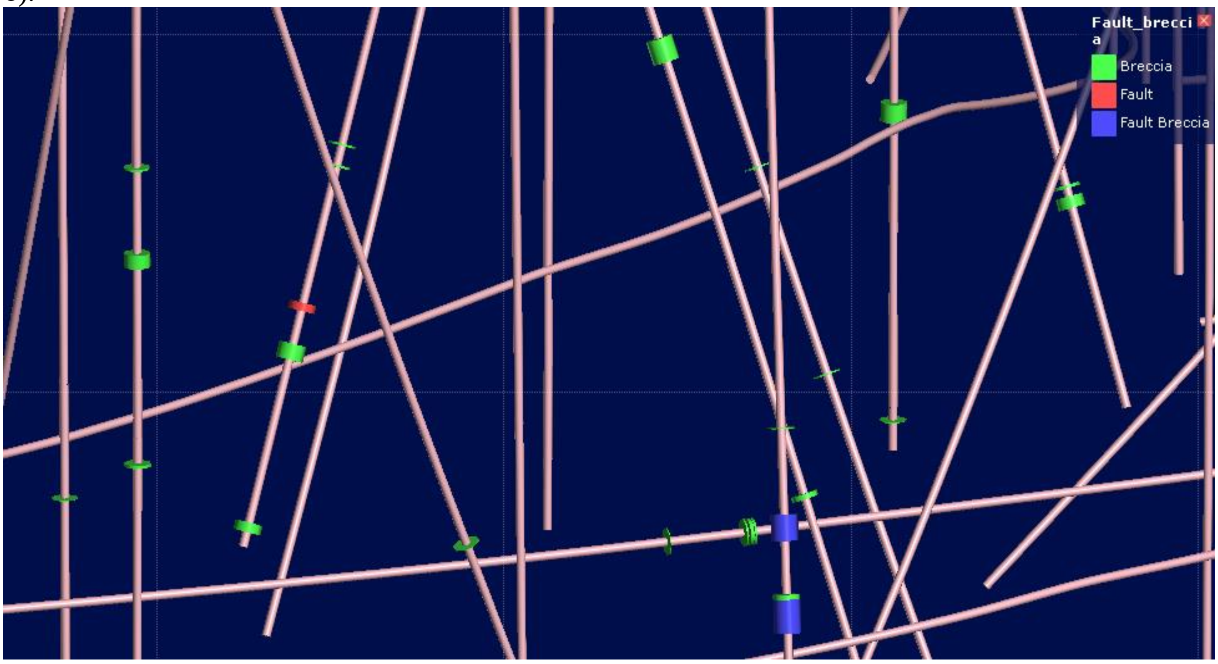

Figure 6: Example of "fault" (red), "breccia" (green) and "fault breccia" (blue) extracted from AGS Processor

4.3 Characterization of Ground Conditions

4.3.1 Engineering Rockhead

AGS Processor can also characterize ground conditions in different ways. The function of “Calculate Rockhead” can determine the depth of engineering rockhead of any boreholes. Conditions defining engineering rockhead can be specified and changed according to project requirements if needed. It is understood that some of the cases of determining the engineering rockhead can be complicated (even for manual interpretation) and this automatic function may not be able to determine the engineering rockhead for these complicated cases with 100% accuracy. Therefore, every calculated rockhead point will be further classified as either simple or complicated case. The user will be given alerts when complicated cases are encountered. For example, the user will be notified when corestone exists above rockhead, and when weak materials exist below rockhead.

Once the engineering rockhead has been determined based on user-defined conditions, the function of “Corestone Percentage” can then be used to calculate the percentage of rock above rockhead to estimate the percentage of corestones intercepted at each borehole.

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4.3.2 Zones of Weakness

AGS Processor can also help the users to characterize rock mass conditions by looking for the zones of weakness in the rock mass. After engineering rockhead has been defined, all weak materials below the engineering rockhead can be extracted and characterized. Depending on project requirements, for example in Geotechnical Baseline Reports or definitions defined by the users, the weak seams can be defined with editable parameters (e.g., weathering grade, RQD, FI, etc.), hence thicknesses of all the weak seams can be automatically calculated. Identified weak seams can then be grouped and characterized into wider zones of weakness based on criteria defined by the user such as width of widest seam, maximum separation, accumulated length along the borehole and density (Figure 7). Localized zones of weakness encountered at each borehole can then be outlined with a consistent definition with much less manual input and subsequently the users can interpret the zone of weaknesses located in the site area. The users can also do the interpretation with different trials using various definitions of weak seams and zones of weakness. This function is particularly useful when the zones of weaknesses are not discrete, and the weak materials shown in the boreholes distributed dispersedly in the site area.

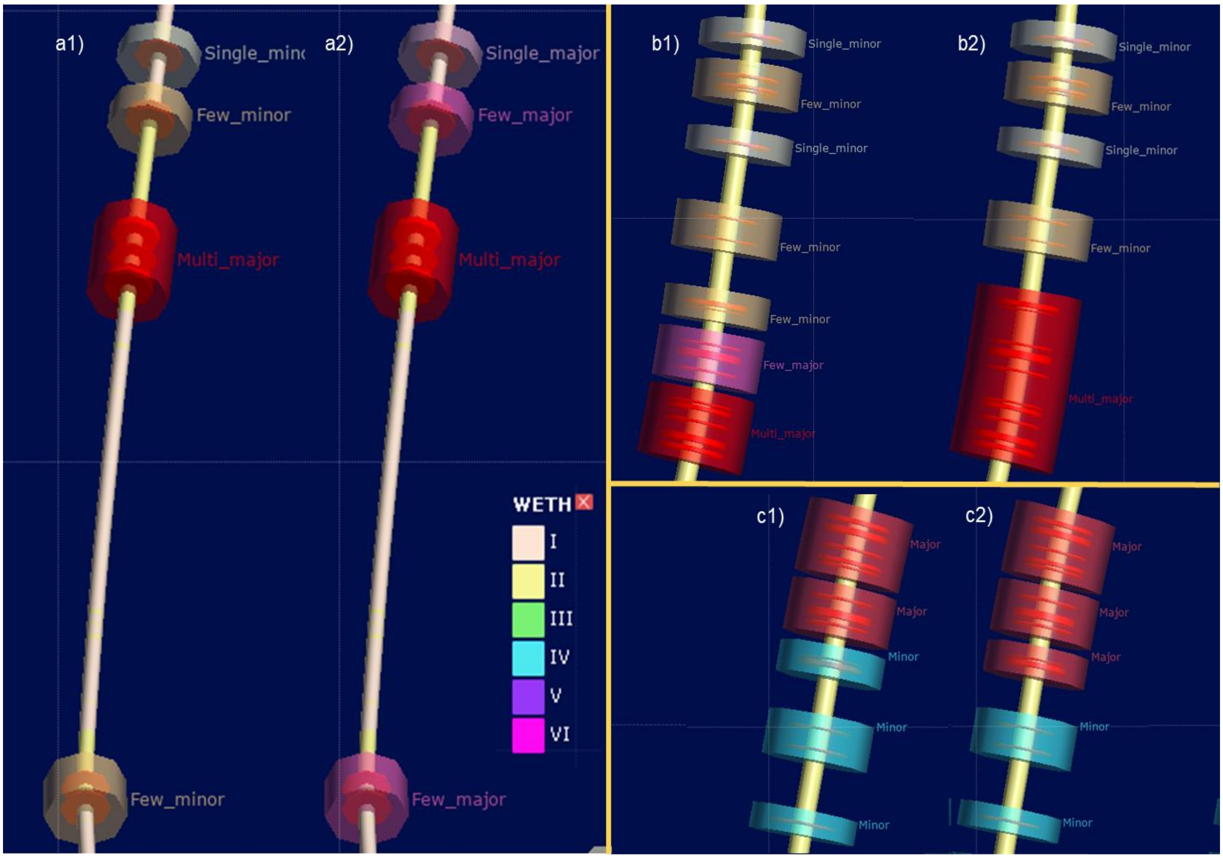

Figure 7 Example of zones of weakness extracted by AGS Processor: (a) classifying as major zone of weakness by width of widest seam (a1)>500mm or (a2)>350mm; (b) changing definition of zones by maximum separation of (b1)2m or (b2)3m between seams; (c) classifying as major/minor weak zone with density (c1)>0.2 or (c2)>0.15. Weak seams are denoted smaller red discs. Weathering grade is displayed at the background.

4.3.3 Rock Mass Quality

Rock mass quality such as the NGI-Q method is based on six parameters each defining different characteristics of the rock mass, and it can also be calculated from the reconstructed database (Figure 8). According to the authors' experience on site, parameter Jn can be estimated by numerical correlation with RQD or other correlation. Rock joint friction parameters, Jr and Ja, can be estimated from extracted rock joint descriptions based on RQD, Jn, Jr and Ja; the application of Jw and SRF as defined by the user, Q-value for each interval of the boreholes can then be calculated effectively from the reconstructed data for subsequent manual interpretation for estimating the rock mass quality of the site area. The rock mass quality using other rock mass classification systems such as GSI and RMR can also be calculated.

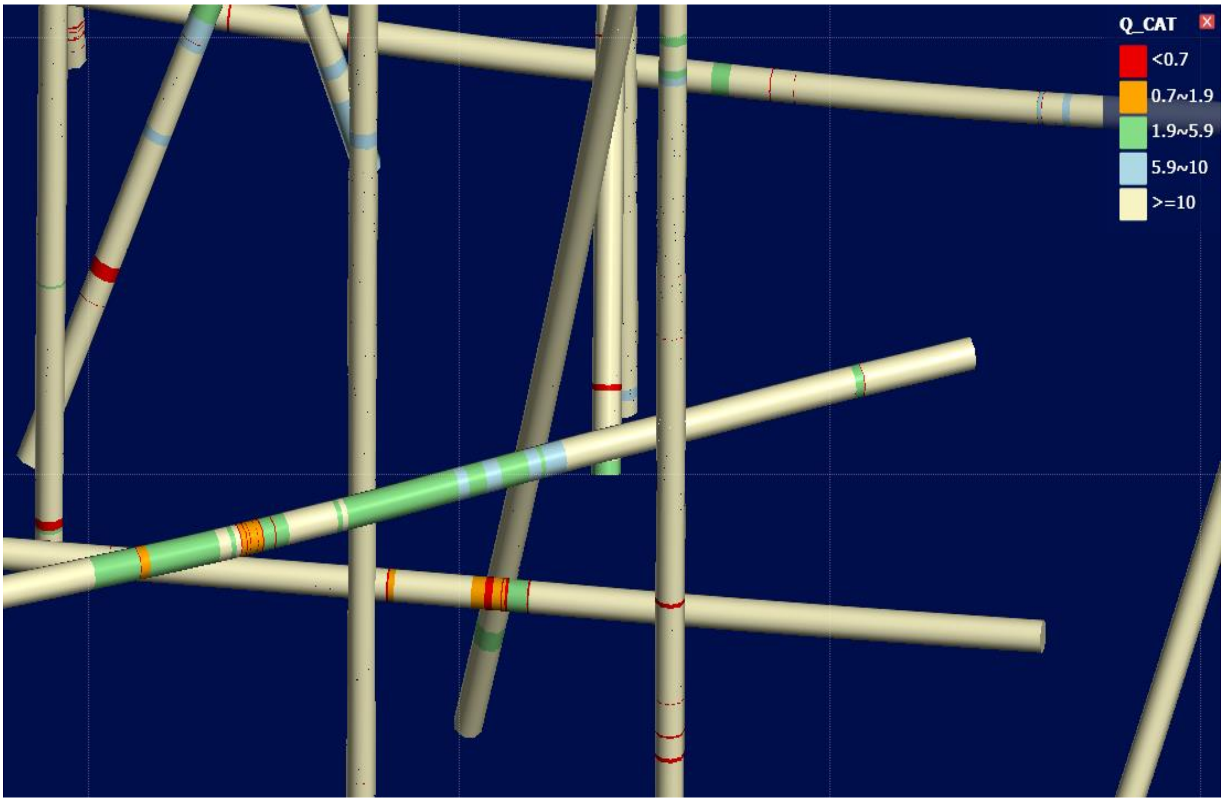

Figure 8 Example of NGI-Q values calculated by AGS Processor

4.4 Data Export

Processed data can be exported in a few ways. For the convenience of viewing all raw data and further processing, the combined database, instead of separated in groups, can be exported as a unified spreadsheet. Selected columns can then be imported to commercial ground modelling software such as Leapfrog to create 3D ground model. Since all the data are combined, data from different groups, including all details can be visualized, correlated and interpreted conveniently in 3D view. Data can also be transformed into AutoCAD or Civil 3D format for drafting or exported to ArcGIS platforms (ArcMap, ArcGIS Pro and ArcScene) for further spatial analysis.

5 Discussion

As a partially automated means of data preparation, AGS Processor brings significant benefits in the process of building up a detailed ground model. Most routine and repetitive manual processing and restructuring of data has been replaced by AGS Processor. From the experience of projects, it is estimated that more than 50% of time can be saved in the entire process of ground modelling (Figure 9). AGS Processor can especially enhance the efficiency in the steps of data reconstruction, information extraction and matching for different test results and corresponding geological information, calculation of engineering rockhead and interpretation of zones of weakness. More resources can then be redirected to evaluating and mitigating the risks of ground conditions. This can bring great savings, in terms of human resources, to ground engineering teams. This is especially useful during tendering or proposal of large underground projects where vast amount of GI data has to be processed to build a ground model as detailed as possible in a short time.

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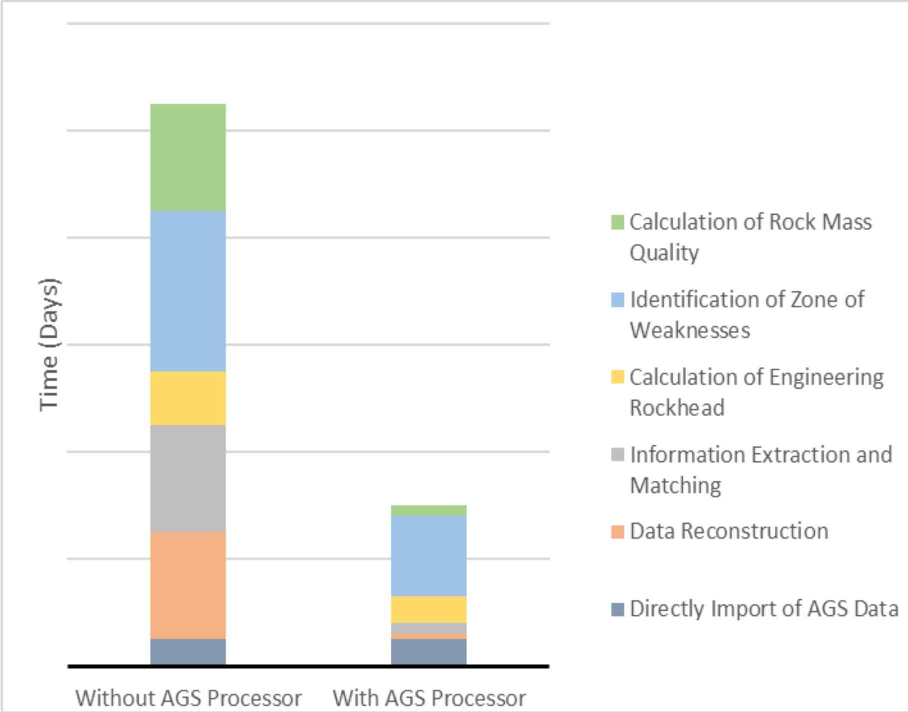

Figure 9: Estimated time savings of AGS Processor based on a recent cavern project (may differ among different projects)

It should be noted that although data processing can be automated, human interpretation and judgement should not be replaced (Gibbons & Kirk, 2019). The ground conditions, underlying risks and concerns for each site or project may not be the same. One method of characterization of data may not be directly applied to the other project or site. Though AGS Processor may help on characterizing ground conditions from raw data, detailed interpretations should always be led by experienced engineering geologists in order to prevent overlooking of risks.

Other than variation in ground conditions and identification of features critical to stability such as faults, a robust ground model may also include more extensive information such as groundwater monitoring data and other field and lab test data such as Borehole Televiewer Survey data. Unfortunately, these data are not always included in the AGS files in Hong Kong practice. Once these data are more broadly available in the industry, more functions and processes will be developed for AGS Processor, providing additional values to the detailed ground model.

6 Conclusion

AGS data format is a highly convenient data format for data storage and transfer. Yet building up a very simple ground model by directly importing and visualizing AGS data, such as showing RQD and weathering grade, may be fast and simple, but often cannot provide sufficient ground information for any meaningful engineering purposes. A more detailed ground model, such as one that includes descriptions of localized zones of weakness and rock mass characteristics, is usually required especially in the detailed design and construction stages.

As AGS data format was designed for efficient storage and transfer of GI data, challenges may arise when building detailed ground model with AGS format data due to its reliance on commercial software and its grouped structure. Detailed variations in ground conditions and risks may be easily overlooked unless additional manual efforts are paid in restructuring the data.

To suit the needs of building detailed ground models, AGS Processor can help as a semi-automated means of restructuring AGS format data and help to enhance the efficiency of ground modelling using its functions of information extraction and characterization of ground conditions. Based on our experience, it is estimated that over 50% of time can be saved in the entire process of preparing ground modelling for engineering purpose.

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