Research on Red-Bed Soft Rock Engineering Properties and Foundation Appraisal of Construction Engineering in Guangzhou

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Abstract. Based on the methods of geological drilling, literature research, induction and statistics, the site investigation of an old industrial park reconstruction project in Haizhu District of Guangzhou city was completed. The landform, formation lithology, structure and hydrogeological characteristics were systematically identified. Combined with indoor test and in-situ test, the variation rules of physical and mechanical parameters of argillaceous siltstone with different weathering degrees in the site were analyzed, and the evaluation results were given. The engineering suitability and the foundation stability are evaluated. The results showed that the weathering of soft rock makes the statistical standard values of compression coefficient, compression modulus, direct fast shear cohesion and internal friction angle of rock and soil decrease. Under the saturated state, the average value of strongly weathered argillaceous siltstone is 1.51 MPa, and that of moderately weathered argillaceous siltstone is 6.2 MPa. The strength of soft rock is low after softening with water, and the differential weathering of rock mass is strong. There are great differences in rock strength, local differences between fully and strongly weathered rock surfaces, and great changes in thickness. The weathering is extremely heterogeneous, in which the influence of structure, lithology, fissures and groundwater played a key role. The foundation is generally in a stable state, and the site is suitable for the construction of the project. The research results can provide reference for similar geotechnical engineering investigation and design.

1. Introduction
The red bed soft rock is widely distributed in China with large exposed area, especially in the south where there is abundant rainfall, rapid engineering construction and strong human activities. Under the condition of rainfall, the red bed soft rock is easy to cause the softening of soft rock, resulting in slope landslide, collapse, ground collapse, foundation pit deformation and other major engineering disasters. Therefore, the determination of Engineering softening characteristics of soft rock is an important research topic[1-4]. Researchers at home and abroad have carried out laboratory tests, numerical simulation and corresponding theoretical research on softening mechanism of red bed soft rock[5-9]. However, due to the complex composition of soft rock, different diagenetic mechanism and many influencing factors of weathering, it is still a difficult problem to accurately analyze the influence of weathering on softening characteristics of soft rock[10]. Based on the comprehensive analysis of engineering geological field surveying and mapping, drilling exposure and test results, the engineering
characteristics of soft rock and the foundation stability of the site under different weathering actions are analyzed, which can provide reference for the investigation and design of similar projects.

2. Project overview
The project is a reconstruction project of an industrial park in Haizhu District, Guangzhou. The total land area of the project is about 29944.98 square meters, and the total construction area of the reconstruction is about 52219.5 square meters. It is a 2-6-storey frame structure, and most of the first floor of the house is used as workshop and warehouse. It is planned to be upgraded to a commercial entity integrating incubator, acceleration platform, headquarters office and ecological leisure format with accelerated gathering of high-end industrial talents and resources. The site is located on the river side of Shiliugang river. It was originally an industrial park. The site has been artificially hardened. The overall terrain is relatively flat, belonging to the flood plain geomorphic unit. The highest elevation of the site is 8.5m and the lowest is 6.5m.

- Geological structure. According to the bedrock geological map and relevant regional geological data, the site is located in the southeast of Guangzhou fault depression. The regional structural faults mainly include the NW trending Tianhe Beiting fault and the nearly EW trending Guangsan fault. The Tianhe Beiting fault is located in the east of the site, about 500m away, and the Guangsan fault is located in the north of the site, about 600m away Fault structure trace. The exposed bedrock of the site is mainly clastic rock of BAIHEDONG formation (K1b) of Lower Cretaceous system, and the lithology is mainly argillaceous siltstone and silty mudstone. The quaternary system is mainly composed of alluvial silty clay (clay), local silt, fine sand and coarse sand, as well as alluvial silty clay, clay and silt. The overburden is mainly composed of Quaternary artificial fill, alluvium and residual soil, with thickness of about 14~21m.

- Hydrological conditions of the site. The groundwater in the site is divided into Quaternary loose rock pore water and bedrock fissure water according to the characteristics of water bearing medium, and can be divided into phreatic water and confined water according to the burial conditions. The measured initial groundwater level is 0.30~1.50m, and the buried depth of stable groundwater level is 0.50~1.20m. According to local experience, the annual variation range of groundwater level is generally 0.20m~2.00m.

- Typical drilling sequence of the site. The typical geological sequence revealed by the site survey drilling is 1 miscellaneous fill, 2-1 silt, 2-2 silty clay, 2-3 medium coarse sand, 3-1 muddy soil, 3-2 silty clay, 3-3 medium coarse sand, 4-1 silty clay (residual), 5-1 completely weathered argillaceous siltstone, 5-2 strongly weathered Argillaceous siltstone and 5-3 moderately weathered argillaceous siltstone.

3. Statistical analysis of soft rock parameters
The site investigation adopts comprehensive investigation method, which combines data collection, field drilling, sampling inspection, indoor test and in-situ test. The soft rocks such as argillaceous siltstone in the site are strongly weathered, and the weathering difference is obvious, and the buried depth of bedrock varies greatly. The weathered residual soil of the original rock is locally distributed, and the fully and strongly weathered rock is widely distributed. The thickness of the residual soil is relatively small and the development range is limited. The thickness of the fully and strongly weathered rock varies greatly. Affected by the stratum structure and groundwater, soft plastic cohesive soil is distributed at the rock soil interface in some sections, which has adverse effects on the selection and construction of pile foundation bearing stratum. Residual soil and completely and strongly weathered rock (half rock and half soil) have the bad characteristics of large void ratio, uneven soil quality, easy softening and disintegration after soaking.

3.1. Statistical analysis of soft rock indoor test
In order to obtain physical and mechanical properties of soft rock and weathered soil in the site, the samples of main rock and soil layers were taken. According to the requirements of relevant specifications,
the soil routine tests were carried out on the soil samples, and the natural uniaxial ultimate compressive strength tests were carried out on the rock samples. According to genetic type, lithology and state. The results are shown in table 1 and table 2.

### Table 1. Statistical table of rock strength.

| Layer                        | Test status    | Maximum value(MPa) | Minimum value(MPa) | Average value (MPa) |
|------------------------------|----------------|--------------------|--------------------|---------------------|
| Strongly weathered argillaceous siltstone | Saturated      | 1.74               | 1.27               | 1.51                |
| Moderately weathered argillaceous siltstone | Saturated      | 8.07               | 4.33               | 6.2                 |

### Table 2. Statistical Analysis of weathering sample parameters of soft rock.

| Layer                        | Project                          | Moisture content | Wet density | Void ratio | Liquid limit | Plastic limit | Plastic liquidity index | Compressibility Coefficient | Compressibility modulus | Direct quick shear | Cohesive power | Neimobucke corner | Plasticity index | Liquidity index | Compressive Modulus | Cohesion Power | Internal friction angle |
|------------------------------|----------------------------------|------------------|--------------|------------|--------------|---------------|-------------------------|-----------------------------|------------------------|-----------------|----------------|----------------|----------------|----------------|-------------------|-----------------|-------------------|
| Residual silty clay (bedrock weathering) | Maximum value                  | 40.50            | 2.02         | 1.13       | 46.40        | 28.90         | 17.50                   | 1.14                         | 0.62                  | 7.12            | 32.00          | 24.00          | 0.49            | 4.22             | 16.79             | 8.92             |
|                               | Minimum value                   | 11.80            | 1.75         | 0.54       | 21.30        | 13.30         | 8.00                    | 0.21                         | 0.23                  | 3.38            | 11.10          | 4.30           | 0.46            | 9.06             | 40.00             | 16.70            |
|                               | Average                         | 28.78            | 1.88         | 0.87       | 36.93        | 23.17         | 13.77                   | 0.50                         | 0.38                  | 5.37            | 23.30          | 14.22          | 0.49            | 4.22             | 16.79             | 8.92             |
|                               | Standard deviation              | 11.39            | 0.10         | 0.26       | 11.06        | 7.67          | 3.72                    | 0.37                         | 0.14                  | 1.39            | 7.89           | 6.42           | 0.49            | 4.22             | 16.79             | 8.92             |
|                               | Coefficient of variation        | 0.396            | 0.053        | 0.293      | 0.300        | 0.331         | 0.270                    | 0.742                        | 0.364                 | 0.259           | 0.339          | 0.452          | 0.49            | 4.22             | 16.79             | 8.92             |
|                               | Standard value                  | /                | /            | /          | /            | /              | /                       | /                            | /                     | /               | /              | /              | /               | /                | /                 | /                |
|                               | Maximum value                   | 38.60            | 2.06         | 1.09       | 50.20        | 32.80         | 18.10                   | 0.45                         | 0.46                  | 9.06            | 40.00          | 16.70          | 0.49            | 4.22             | 16.79             | 8.92             |
|                               | Minimum value                   | 14.80            | 1.70         | 0.54       | 26.90        | 14.50         | 11.10                   | 0.06                         | 0.20                  | 4.42            | 25.50          | 12.10          | 0.49            | 4.22             | 16.79             | 8.92             |
|                               | Average                         | 26.97            | 1.87         | 0.86       | 37.41        | 23.64         | 13.77                   | 0.27                         | 0.32                  | 6.11            | 30.96          | 14.93          | 0.49            | 4.22             | 16.79             | 8.92             |
|                               | Standard deviation              | 8.48             | 0.12         | 0.21       | 8.45         | 6.64          | 2.39                    | 0.14                         | 0.08                  | 1.34            | 5.16           | 1.63           | 0.49            | 4.22             | 16.79             | 8.92             |
| Fully weathering argillaceous siltstone | Coefficient of variation        | 0.315            | 0.063        | 0.247      | 0.226        | 0.281         | 0.174                   | 0.512                        | 0.258                 | 0.220           | 0.167          | 0.109          | 0.37            | 5.27             | 27.73             | 13.91            |
|                               | Standard value                  | /                | /            | /          | /            | /              | /                       | /                            | /                     | /               | /              | /              | /               | /                | /                 | /                |
|                               | Maximum value                   | 40.00            | 2.09         | 1.07       | 51.20        | 33.20         | 18.00                   | 0.38                         | 0.40                  | 9.69            | 47.00          | 20.20          | 0.40            | 9.69             | 47.00             | 20.20            |
|                               | Minimum value                   | 14.50            | 1.82         | 0.49       | 25.60        | 14.40         | 10.30                   | 0.08                         | 0.16                  | 5.14            | 23.10          | 10.90          | 0.16            | 5.14             | 23.10             | 10.90            |
|                               | Average value                   | 22.58            | 1.98         | 0.69       | 33.32        | 20.98         | 12.34                   | 0.20                         | 0.26                  | 6.82            | 34.83          | 16.30          | 0.26            | 6.82             | 34.83             | 16.30            |
|                               | Standard deviation              | 7.66             | 0.10         | 0.19       | 7.48         | 5.71          | 2.05                    | 0.10                         | 0.07                  | 1.46            | 7.34           | 3.05           | 0.10            | 1.46             | 7.34              | 3.05             |
|                               | Coefficient of variation        | 0.339            | 0.052        | 0.280      | 0.225        | 0.272         | 0.166                   | 0.521                        | 0.269                 | 0.214           | 0.211          | 0.187          | 0.30            | 6.01             | 30.8              | 14.6             |
|                               | Standard value                  | /                | /            | /          | /            | /              | /                       | /                            | /                     | /               | /              | /              | /               | /                | /                 | /                |

Combined with the analysis of the test data, the weathering of soft rock makes the indexes of core sample decrease greatly, and the statistical standard values of compression coefficient, compression modulus, cohesion of direct quick shear and internal friction angle decrease comprehensively. Under the saturated state of soft rock, the average value of strongly weathered argillaceous siltstone is 1.51 MPa, and that of moderately weathered argillaceous siltstone is 6.2 MPa, which indicates that soft rock is easy to soften when encountering water and should be paid attention to in engineering.

### 3.2. Statistical analysis of in situ testing of soft rock

Standard penetration test and other tests were carried out on the main rock and soil layers during the investigation. The blow counts of standard penetration test are measured blow counts, which are divided according to genetic type, lithology and state. Statistical results of test are shown in table 3.
Table 3. Statistical table of standard penetration test results.

| Layer                        | Project               | Number of samples | Maximum value (strike) | Minimum value (strike) | Average value (strike) | Standard deviation (strike) | Coefficient of variation | Correct coefficient | Standard value (strike) |
|------------------------------|-----------------------|-------------------|------------------------|------------------------|------------------------|-----------------------------|--------------------------|------------------------|------------------------|
| Residual silty clay          | Measured value        | 10                | 45                     | 15                     | 20.3                   | 9.166                       | 0.452                    | 0.736                  | 14.90                  |
| (weathered bedrock)          | Correction value      | 10                | 34.35                  | 11.45                  | 15.15                  | 6.980                       | 0.461                    | 0.730                  | 11.06                  |
| Fully weathered argillaceous siltstone | Measured value        | 16                | 55                     | 29                     | 39.5                   | 7.581                       | 0.192                    | 0.915                  | 36.10                  |
| Strongly weathered argillaceous siltstone | Correction value      | 16                | 39.05                  | 21.566                 | 28.98                  | 5.559                       | 0.192                    | 0.915                  | 26.51                  |

Table 4. Statistical table of borehole wave velocity test results.

| Layer                        | Density / degree of weathering | Minimum wave velocity (m/s) | Maximum wave velocity (m/s) | Average wave velocity (m/s) |
|------------------------------|--------------------------------|-------------------------------|-------------------------------|-----------------------------|
| Residual silty clay (bedrock weathering) | Hard plastic                  | 164.3                         | 178.2                         | 171.4                       |
| Argillaceous siltstone       | Fully weathering               | 317.6                         | 345.3                         | 330.7                       |
| Argillaceous siltstone       | Strong weathering              | 424.6                         | 441.6                         | 434.8                       |

According to the results of in-situ test, the average measured blow count of strongly weathered argillaceous siltstone is 59.60, the correction value is 42.63, the average measured blow count of fully weathered argillaceous siltstone is 36.10, the correction value is 26.51, and the average measured blow count of residual silty clay is 14.90, the correction value is 11.06. Among them, the standard deviation of residual silty clay is larger, which indicates that its weathering is the most uneven, followed by fully weathered argillaceous siltstone, and the standard deviation and coefficient of variation of strongly weathered argillaceous siltstone are the lowest, and the weathering is more uniform.

3.3. Analysis and design of geotechnical parameters

According to the above-mentioned geotechnical test and in-situ test results, combined with regional experience, the recommended values of geotechnical parameters such as bearing capacity characteristic value and compression modulus of each rock and soil layer are shown in table 5, which can provide reference for similar engineering investigation and design.

Table 5. Recommended values of geotechnical parameters.

| Layer                        | State               | Characteristic value of bearing capacity $f_{ak}$ (kPa) | Compression modulus $E_s$ (MPa) | Deformation modulus $E_0$ (MPa) |
|------------------------------|---------------------|--------------------------------------------------------|--------------------------------|---------------------------------|
| Residual silty clay (weathered bedrock) | Plastic            | 150                                                   | 4.0                            | /                               |
| Argillaceous siltstone       | Fully plastic       | 200                                                   | 5.0                            | /                               |
| Argillaceous siltstone       | Fully weathered     | 350                                                   | /                              | 40                              |
| Argillaceous siltstone       | Strongly weathered  | 450                                                   | /                              | 80                              |
| Argillaceous siltstone       | Moderately weathered| 1500                                                  | /                              | 200                             |

4. Analysis of engineering properties of soft rock in site area

4.1. Engineering property evaluation of soft rock weathered soil

The residual silty clay in the site area is formed by the weathering of argillaceous siltstone. Its state is plastic to hard plastic, mainly hard plastic. It has certain bearing capacity, general engineering
properties, and is easy to soften after immersion. It is not suitable to be used as foundation bearing stratum because it is distributed locally in the site.

The fully weathered argillaceous siltstone is distributed locally in the site, and its bedrock rock structure is basically destroyed. The rock core is mostly weathered in plastic soil shape, and some sections are in hard soil shape. The engineering property is very poor. It is a weak interlayer in the bedrock layer. It has continuous thickness of hard soil shape or half rock and half soil shape, and good bearing capacity.

4.2. Evaluation of engineering properties of soft rock and weathered rock
The core of strongly weathered argillaceous siltstone is hard soil, half rock and half soil with high bearing capacity. It can be used as the bearing layer of precast pile foundation and is a good foundation bearing layer for multi-storey and small high-rise buildings. However, it is easy to become soft and disintegrate when encountering water, and the bearing capacity is greatly reduced. Therefore, attention should be paid to the foundation design and construction.

The moderately and slightly weathered rock has good mechanical properties and is a good bearing stratum for buildings, but moderately weathered rock surface is relatively deep buried.

5. Uniformity and stability evaluation of foundation in site

5.1. Evaluation of foundation uniformity
The Quaternary overburden layer in the site area is mainly composed of artificial miscellaneous soil layer, land-based alluvial proluvial and residual soil, including silty clay, silt (silt soil), medium coarse sand, mainly composed of silty clay, silt (silt soil), medium coarse sand, showing the structure distribution of fine upper particles and coarse particles at the lower part, and the flow plastic soft silt soil layer is mixed in the middle. The medium coarse sand is distributed only in local areas, and the sand layer is lenticular or strip shaped. The distribution of weathered residual soil is small and the thickness is not changed much. The distribution of soft and hard interlaced layers makes the site uniformity worse.

Influenced by structure, lithology, fracture and groundwater, the rock mass has strong weathering effect, and the rock strength is different, the whole and strong weathered rock surface have a large local difference and a large thickness change. The long and short piles and the rock socketed depth should be considered in the design and construction of pile foundation.

5.2. Site stability evaluation
According to Appendix A of code for seismic design of buildings (GB 50011-2010), the site of the project is located in the area with seismic fortification intensity of 7 degrees, the design basic seismic acceleration value is 0.10g, and the design earthquake group is the first group. According to the code for seismic design of buildings (GB 50011-2010), the design characteristic period is 0.35s.
According to the time series and spatial distribution characteristics of regional seismicity, Guangzhou is located in the southeast coastal seismic belt. Most of the earthquakes occurred in history are medium and small-sized sensitive earthquakes with the maximum magnitude of $M_{\text{max}} = 4.34$ degree, and there is no disastrous strong earthquake record. There is no trace of fault structure in this survey. The terrain of the site is flat and open, and there are no adverse geological processes and geological disasters such as ground collapse and ground fissures. The site is basically stable, suitable for the construction of the project, and the suitability level can be determined as more suitable.

6. Conclusions
Through the geological analysis and stability evaluation of soft rock in site, the conclusions are drawn.

1) Combined with the analysis of geological drilling, no trace of landslide and active fault structure is found in the site, and the site is basically stable. If the appropriate foundation type is selected, it is suitable for the construction of the project.

2) The weathering of soft rock makes the statistical standard values of compression coefficient, compression modulus, direct fast shear cohesion and internal friction angle of core sample decrease. Under the saturated state of soft rock, the average value of strongly weathered argillaceous siltstone is $1.51\text{MPa}$, and that of moderately weathered argillaceous siltstone is $6.2\text{MPa}$, which indicates soft rock is easy to soften when encountering water.

3) Due to the influence of structure, lithology, fissure and underground water, the soft rock mass has strong differential weathering effect, the rock strength has great difference, the fully and strongly weathered rock surface has large local difference, and the thickness changes greatly. Therefore, the long and short piles and rock socketed depth should be considered in the design and construction of pile foundation.

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