Influence Factors of the Slope Rockmass Deformation Characteristics based on in-situ tests

GUO Xifeng*, WU Xiangchao
Changjiang River Scientific Research Institute, Wuhan 430010, China

Corresponding E-mail: xifeng1984@126.com

Abstract: The Sanhekou reservoir arch dam (145m) is one of the highest in the world. It is founded on metamorphic sandstones and crystalline limestone. This work conducted an in-situ deformation test on various lithology and weathering degree rock developed in slope adits on dam abutment, under same loading paths and maximum pressure as that acting on the abutment rockmass. In the tests, factors of deformation behavior of slope rockmass were extracted and variation range of deformation parameters of different rockmass were evaluated. Results show that the three of factors (weathering degree, integrity degree and anisotropy) are the main ones influencing the deformation performance of slope rockmass.

Keywords: deformation; rockmass; weathering degree; integrity degree; anisotropic

1. Introduction

Engineering rockmass is a complex medium (Yu Zhenping, 2005). Its physical and mechanical properties are dominated by many factors (e.g. Li Weishu, 2006). From continuous engineering practice, people learned that there is not only randomness but also structural and regularity change in the space for the rockmass mechanical parameters (Zhang Qiangyong, 2008).

In order to provide estimate the rock deformation parameters for use in design of the arch dam and further research the rockmass deformation characteristics, this paper carried out in-situ plate loading deformation tests on dam abutment slope rockmass at dam site of Sanhekou hydraulic project. There were 42 test points performed in total. And then the rock mass mechanical parameters such as deformation modulus and elastic modulus were provided for different rockmass with weathering degree, which provide the basis for dam deformation checking. In particular, the influencing factors of the deformation characteristics of slope rockmass studied.

2. Geological Settings

The water diversion project from Han to Wei River, Shanxi Province, consists of two stage water source projects named as Huangjinxia and Sanhekou reservoirs and two tunnels (i.e. Huangsan and
Qinling tunnel) about 100km in total length. Sanhekou hydraulic project is located at the junction of Foping County Hanzhong City and Ningshan County, Ankang City in Shaanxi Province. The dam was a roller compacted concrete arch dam with a maximum height of 145m.

The dam site area bedrock under the Silurian the system Meiziya group the metamorphic sandstone paragraph (SmSS) metasandstone, crystalline limestone, marble and Indosinian local folder intrusive granitic pegmatite, quartzite veins. Metamorphic sandstones: light gray to taupe, ingredients mainly feldspar and quartz, minor mica and dark-colored mineral, blastopsammitic texture, bedded structure, local folders have banded distribution of the thin layer crystalline limestone which thickness is generally less than 3.0m. Crystalline limestone: light gray, dense and hard, ingredients mainly calcite and minor quartz, granular texture or fiber texture, massive structure, local folders have banded distribution of the thin layer metamorphic sandstone which thickness is generally less than 5.0m. Located in the upper arch dam line downstream of the mountain and the river bed, banded outcrop, ground outcrop width is generally 35 ～ 60m, maximum 180m.

3. Deformation Tests

The test procedure of plate loading tests are: ①Site Preparation, ②Description of the test Site Geology, ③Equipment installation and ④Loading Procedure, according to the Chinese code and ASTM D4394.
Theoretical basis of in-situ deformation tests using plate loading tests is Boussniesq formula, which can be deduced in a semi-infinite space medium with vertical load applied, the medium was required to be homogenous and isotropic. According to theoretical solution, rock type in the test zone is required to be approximately the same. For rigid bearing plate, take deformation measurements on the edge of the bearing plate at four equally spaced intervals. The average deflection on the bearing plate can be used for calculation. The formula is shown as Eq. (1) (reference: Chinese code SL264-2001 or ASTM D4394).

\[
E = \pi \cdot \frac{(1-\mu^2)pD}{W} = \frac{(1-\mu^2)P}{W \cdot D}
\]

where \(W\) = displacement in the direction of the applied load, \(p\) = pressure on the test, \(P\) = total load on the rigid plate (50.5cm for this site), \(D\) = diameter of the bearing plate, \(\mu\) = Poisson’s ratio, \(E\) = modulus of deformation or elasticity.

4. Test Results and Analysis

14 sets consisting of 42 deformation tests are conducted, the results are statistically analyzed as followings:

| Set number | Weathering degree | Loading direction | Statistics in group | Statistic by rock type |
|------------|-------------------|-------------------|---------------------|------------------------|
|            |                   |                   | Min(MPa) | Max(MPa) | n | avg | SD | CV | SV |
| PD25E1     | slightly-weathered | Horizontal        | 22.93     | 32.79    | 6 | 22.33 | 7.25 | 0.32 | 16.43 |
| PD25E2     | metamorphic sandstones | Horizontal        | 11.55     | 19.99    | 15 | 26.17 | 9.05 | 0.35 | 21.95 |
| PD24E1     | slightly-weathered | Horizontal        | 25.48     | 39.55    | 21.06 | 39.80 |
| PD20E1     | crystalline limestone | Vertical        | 9.16      | 33.91    | 12.23 | 16.45 |
| PD21E1     | horizontal        |                   |           |          |     |       |       |     |     |
| PD20E2     | weakly-weathered  | Vertical        | 6.96      | 17.58    | 6   | 12.58 | 3.88 | 0.31 | 9.36  |
| PD24E2     | crystalline limestone | Horizontal        | 9.79      | 14.72    | 13.61 | 21.33 |
| PD23E2     | horizontal        |                   |           |          | 14.63 | 27.22 |
| PD22E2     | weakly-weathered  | Vertical        | 7.16      | 10.10    | 3   | 8.63  | 1.47 | 0.17 | 8.63  |
| PD14E2     | pegmatite vein    | Horizontal        |           |          |     |       |       |     |     |

Note: n —— test quantity  avg —— average  SD —— standard deviation  CV —— coefficient of variation  SV —— standard value

For the deformation characteristics of the rockmass, there are many influencing factors, such as weathering degree, lithology, the full extent of the joints and fractures, groundwater richness and anisotropy and so on (Shi Anchi, 2008).

4.1 Weathering Degree
I set deformation test for every crystalline limestone rockmass with slightly weathered and weakly weathered were carried out at 5 adits such as PD22, PD23, PD24, PD20, PD2, the ratio of deformation modulus for crystalline limestone with different weathering degree will be seen in table 2. While considering there is not comparative test, metamorphic sandstone and pegmatite vein will not be analyzed like this.

**Tab.2 Ratio of deformation modulus for crystalline limestone with different weathering degree**

| Adit number | Weathering degree | Deformation modulus/GPa | Ratio |
|-------------|-------------------|--------------------------|-------|
| PD22        | E1 Slightly weathered | 30.14                    | 1.83  |
|             | E2 Weakly weathered | 16.49                    |       |
| PD23        | E1 Slightly weathered | 27.73                    | 2.17  |
|             | E2 Weakly weathered | 12.77                    |       |
| PD24        | E1 Slightly weathered | 32.88                    | 2.36  |
|             | E2 Weakly weathered | 13.96                    |       |
| PD20        | E1 Slightly weathered | 20.44                    | 1.48  |
|             | E2 Weakly weathered | 13.85                    |       |
| PD2         | E1 Slightly weathered | 19.64                    | 1.74  |
|             | E2 Weakly weathered | 11.31                    |       |

On the same test adit, the deformation modulus of slightly weathered is as 1.48~2.36 times as weakly weathered. Therefore, weathering degree is the main factor impacting the modulus difference of test points. The deformation modulus of slightly weathered rockmass is much higher than the weakly weathered rockmass for the same lithology.

4.2 Lithology

The appeared rocks in dam site are metamorphic sandstones, crystalline limestone and pegmatite vein. The rockmass of these tests classified 4 classes: including slightly weathered metamorphic sandstones, slightly weathered crystalline limestone, weakly weathered crystalline limestone and weakly weathered pegmatite vein according to lithology and weathering degree. As for rockmass structural complexity, there are very great differences of the behavior for the same rockmass class. According to the classified statistics of deformation parameters by lithology, weathering degree, and loading direction, see table 3.

**Tab.3 test results statistic by lithology**

| Lithology            | Weathering degree | Loading direction | Loading number | Deformation modulus/GPa range | average | Elastic modulus/GPa range | average |
|----------------------|-------------------|-------------------|----------------|-------------------------------|---------|---------------------------|---------|
| metamorphic sandstones| Slightly weathered| horizontal        | 6              | 11.55~32.79                  | 22.33   | 21.55~58.86               | 33.45   |
|                      |                   |                   |                |                               |         |                           |         |
| crystalline limestone| Slightly weathered| horizontal        | 15             | 9.16~39.80                   | 26.17   | 12.62~72.58               | 41.58   |
|                      |                   |                   |                |                               |         |                           |         |
|                      | Weakly weathered  | horizontal        | 12             | 9.79~27.22                   | 15.56   | 14.77~36.17               | 24.15   |
|                      |                   | vertical          | 6              | 6.96~17.58                   | 12.58   | 12.35~25.56               | 19.18   |
|                      |                   | in all            | 18             | 6.96~27.22                   | 14.57   | 12.35~36.17               | 22.49   |
| pegmatite vein       | Weakly weathered  | horizontal        | 3              | 7.16~10.10                   | 8.63    | 9.51~13.97                | 11.56   |
Metamorphic sandstones and crystalline limestone class are belong to harder-hardest rock, as for deformation modulus, average value of slightly weathered metamorphic sandstones is 22.33 GPa, average value of slightly weathered crystalline limestone is 26.17 GPa. This shows that there are differences between two lithology rockmass even though the same weathering degree. However, the average value of pegmatite vein is 8.63 GPa, which is lower than the crystalline limestone with the same weathering degree. Thus, capacity of resisting deformation is different for the rockmass with different lithology, which leads to the difference of deformation modulus.

4.3 Integrity Degree

Samples of crystalline limestone collected from left bank are divided into 2 sets, slightly weathered and weakly weathered, each with 5 and 6 sets of specimens respectively. Deformation test are performed on these specimen. The minimums of test result are on the low side due to poor integrity and fracture development and do not have a universal meaning.

However, the majorities of test results could represent the whole deformation characteristic of the rock. Table 3 shows the statistical analysis of test result of crystalline limestone collected from left bank. The maximum value of deformation modulus of 5 sets of 15 slightly weathered crystalline limestone specimens tested varies between 28.36 and 39.80GPa, and the average value is 34.51GPa. The maximum value of deformation modulus of 5 sets of 15 weakly weathered crystalline limestone specimens tested varies between 14.72 and 27.22GPa, and the average value is 18.67GPa.

Of the same lithology and with similar weathering degree, specimens collected from adits PD20 and PD2 show a lower value of deformation modulus than those collected from adits PD22 and PD23. The poor integrity, developed joints and fractures as well as abundant groundwater in areas PD20 and PD2 lead to this phenomenon.

4.4 Anisotropy

To know more about weakly weathered crystalline limestone, 1 set of horizontal and vertical deformation test are conducted in adits PD2 and PD20 respectively. Test results show: the value of horizontal deformation modulus is roughly equal to that of vertical, with horizontal deformation modulus varying between 9.79 and 27.22GPa, and vertical deformation modulus varying between 6.96 and 17.58GPa. However, the average value of horizontal deformation modulus is a little higher than that of vertical, with a horizontal versus vertical ratio of 1.237.

This is mainly because the tested rock mass has a low-angle dip and the structure plane is almost horizontal. When subjected to horizontal load, the structure plane does not play a dominant role, whereas the mineral grain and lattice deformed by pressure. However, the deformation is relatively small; hence, a high deformation modulus is recorded. When subjected to vertical load, the structure plane deformed substantially, hence, a low deformation modulus is recorded.

This point of view is proved once again in this test. The rock mass in this project has obvious structure plane and shows anisotropic characteristics in the test . Of the same lithology and with similar weathering degree, the deformation modulus of rock mass subjected to horizontal load is higher than that of rock mass subjected to vertical load.

5. Discussion

14 sets of 42 specimens are tested. Table 1 shows the statistical parameters of test results such as maximum and minimum of deformation modulus, and standard deviation and variable coefficient of deformation modulus of the same rock. Due to the large number of crystalline limestone specimens, statistics of frequency distribution of deformation parameters are conducted according to the weathering degree. Test results of deformation modulus of the same kind of rock are not in conformity
with standard normal distribution. This also reflects the influence to rock deformation feature imposed by a number of factors mentioned above. The rock of dam site is mainly composed of meta-sandstone and crystalline limestone, which exist in the form of thick layer with slightly weathering. The rock which is relatively intact and has few bedding planes boasts better capacity of deformation resistance and high deformation modulus (HE Ruping, 2007).

All test results vary to a larger extent: the deformation modulus varies between 7.16 and 39.80GPa, and the elasticity modulus varies between 9.51 and 72.58GPa. The maximum versus minimum ratio is 5.6 and 7.6 respectively. This is the result of influence by a number of factors, such as weathering degree, direction of loading, and rock mass structure, as well as distribution of fracture and its development.

Most pressure-deformation curves are linear. This demonstrates that no obvious bedding surfaces or influence of huge structure surface exist. Within test pressure range, the deformation shows elastic feature.

Test results show: deformation modulus of slightly-weathered metamorphic sandstones is between 11.55 and 32.79GPa, that of slightly-weathered crystalline limestone is between 9.16 and 39.80GPa, that of weakly-weathered crystalline limestone is between 6.96 and 27.22GPa, and that of weakly-weathered pegmatite vein is between 7.16 and 10.10GPa. Dam site is located in rock mass with high deformation modulus. The average value of deformation modulus of slightly-weathered rock mass is above 20GPa, whereas the average value of deformation modulus of weakly-weathered crystalline limestone is between 10 and 20GPa. With integrity, fresh rockmass boast a higher deformation modulus than similar integrity weakly-weathered rock mass. Similarly, slightly-weathered rockmass boast higher deformation modulus than weakly-weathered rock mass.

6. Conclusions

Dam site is located in rockmass with high deformation modulus. The average value of deformation modulus of slightly weathered rockmass is higher than 20GPa, whereas the average value of deformation modulus of weakly weathered crystalline limestone is between 10 and 20GPa. With integrity, fresh rockmass boast a higher deformation modulus than similar integrity weakly-weathered rock mass. Similarly, slightly-weathered rockmass boast higher deformation modulus than weakly-weathered rock mass.

Weathering degree, lithology, integrity, anisotropy are the main influencing factors of the deformation characteristics of slope rockmass

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