Creep deformation calculation method on sandstone rock foundation settlement of nuclear island

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Abstract: Most nuclear island built its foundation on the bed rock. Generally the bearing capacity of these bed rocks is very high and the settlements of these buildings are very small. But in some cases we should consider the nonlinear part of the bed rock deformation when the bedrock is sandstone, Siltstone and Shale etc. under the foundation. Because these Metamorphic deformations are mostly creep deformation. This article analyzed settlements of a nuclear island’s foundation which are much greater than it were being designed. The deformation of sandstone is very large when with high load on top of it. Long time of deformation can bring many problems in nuclear power plant, such as pipe tolerance, building connection problem, cable connection problem and can make damage of them. Compared observed dates and a calculation result by using FEM software. And here gives a simple calculation method on nuclear island foundation settlement on sandstone.

1. INTRODUCTION
Generally, nuclear island is located on hard rock as its foundation and the buildings will generate very little settlement which general are scope in several millimeters. But in this case the settlement exceeds the design value a lot. It’s worth to be researched and make progress on our calculation method.

2. Site Information and Nuclear Island Location
According to the genetic and morphological characteristics, this site is divided into the coastal hilly topography, coastal geomorphology and man-made geomorphologic units. On the South and East are the intertidal zone, and the north is a pool. Stratum is Quaternary accumulation layer, the Silurian sedimentary rock. The Quaternary strata are mainly marine sand, silt, clay gravel and slope residual pebbly silt clay; the Lower Silurian Liantan Group Fifth group is fragments sedimentary rocks.
Figure 2-1 nuclear island geological section
Locations of two Reactor Building (1RX and 2RX) are indicated in Figure 2-1. The following picture reveals the site area of folding, rock bedded, changeable dip and varied morphological change.

Table 2-1. Geotechnical Parameters

| Zone          | Level                  | Deformation Modulus E (Average) GPa |
|---------------|------------------------|-------------------------------------|
| Nuclear island| Strong weathered layer | 0.61                                |
| 1RX           | -0.50~ -29.0m IIIY     | 2.73                                |
|               | -29.0~ -81.0m IIY      | 7.34                                |
| 2RX           | -0.50~ -20.0m          | 1.10                                |
|               | -20.0~ -34.0m          | 2.73                                |
|               | -34.0~ -81.0m IIH      | 7.34                                |

3. Settlement Calculations by Numerical Method
Built the FEM model of the nuclear island through FEM analysis software and input Geotechnical Parameters and calculated through liner method.
The finite element software is used to model the building and the foundation, and the settlement is calculated according to the parameters of the geological survey report. The calculation is carried out in 2 models, model1 is assumed the ground mater to be homogeneous and isotropic, and the material properties are selected the medium weathered sandstone. Model2 is considered the strong weathered layer, still isotropic materials. Under the static load action, the maximum settlement of the foundation in the 2 models separately is 7.71mm (see Figure 3-2), 7.91mm (see Figure 3-4).

![Figure 3-1 MODEL1 – Nuclear Island FEM](image1)

![Figure 3-2 MODEL1 Settlement Result](image2)
4. Settlement Calculations by Algebraic Method

Use two methods to estimate foundation settlement here. The first method is based on the calculation method recommended by the Chinese code, Technical Code for Tall Building Box Foundations and Raft Foundation (JGJ6-99) [3].

\[ S = \rho b \sum_{i=1}^{n} \frac{\delta_i - \delta_i^*}{E_i} \] ........................(4-1)

Where:
S: final settlement of the foundation;
Pk: the average pressure based on long-term combination effect at the bottom of the foundation;
δi, δi-1: delta i, delta i-1 respectively based on ratio of length to width L/b and the distance between soil layer i bottom and foundation bottom; between soil layer i-1 bottom and foundation bottom, according to the "Technical Code for Tall Building Box Foundations and Raft Foundation" (JGJ6-99), in Appendix B table B;
E0i: deformation modulus of the layer i;
b: foundation width;
η: correction factor;
The second method is more simple calculation formula. The calculated results from the second methods are larger than the calculated values of the first method.

\[
S = \frac{\pi r^2 p_k(1-\mu^2)}{2\eta E} \quad \text{(4-2)}
\]

Where:
S: final settlement of the foundation;
pk: the average pressure based on long-term combination effect at the bottom of the foundation;
r: foundation radius
E: deformation modulus;
µ: poisson ratio;
After two analytical formulas, the maximum settlements of the RX buildings are both less than 7mm, which is less than the result of the finite element calculation.

5. Observed Dates of Foundation Settlement
The observation of settlement of the plant starts when the power plant was built. The maximum settlement of the plant reached 31mm after 2 years, 26.88mm on RX building. Settlement data see figure below.

| Number(mm) | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | average |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|
| settlement | 15.81 | 17.01 | 17.89 | 18.44 | 18.15 | 17.24 | 16.89 | 16.58 | 15.95 | 15.73 | 14.93 | 14.77 | 16.616 |

| Number(mm) | 201 | 202 | 203 | 204 | 205 | 206 | 207 | 208 | 209 | 210 | 211 | 212 | average |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|
| settlement | 23.05 | 21.62 | 21.23 | 21.45 | 23.24 | 22.19 | 23.4 | 24.84 | 26.88 | 25.58 | 25.59 | 24.42 | 23.624 |

Figure 5-1 Observe point layout

6. Analysis of The Difference Between The Observed Dates and The Calculation Result
The article [1] attributed the reason which caused most of the settlement to the soil rebound after excavation. But the total weight of nuclear island itself is less than the weight of the excavated rock. It’s not likely cause such large settlement. Secondly, from the geological section map(Figure 2-1) shows
that the unload weigh of 1RX is much larger 1RX building should cause more rebound when the foundation pit be excavated. But the article [1] gives the 2RX rebound value much larger.

The reason for such a large settlement should lay in several aspects;

1. Bedding structure is the mainly feature for sedimentary rock, accompanied by interlayer faults and argillation weak structural plane development. Its characteristic shows a strong anisotropy, the engineering properties of rock are mainly controlled by the strata layout and strata combination layout. In this case, the strata bedrock is with steep inclination angle, the creep slip between structural plane inevitable under nuclear island weight action. And different structural planes don’t work together to resist the pressure on it. Meanwhile, due to the low strength argillation weak structural plane and other weak structural plane, the shear strength to constraint on the foundation to prevent settlement reduced. All these reason make settlement larger. See figure Figure 6-1, it’s a example of creep slip between layers in sedimentary rock. Layers of limestone and shale have obvious creep slip.

2. The existence of strong weathered interlayer in the strata has a great contribution to the settlement in 2RX building. From comparison settlement of 1RX and 2RX, settlement in 2RX building foundation is 7mm average larger than 1RX’s because there is a larger strong weathered layer under 2RX building foundation.

3. Given the duration could be as long as 20 years to reach its stable settlement for granite bedrock foundation at nuclear island site. In this case it’s only 2 years to reach such a large deformation, so it still need fairly long time to reach its stable settlement.

7. Improved Formula to Evaluate Total Settlement Method

Based on the analysis above and the observation dates, it is hoped that the final settlement of the steep inclination sandstone strata can be estimated by a more accurate method. Modify the average elastic modulus by sum elastic modulus in area proportion of sandstone, argillaceous sandstone and silty sandstone one by one; and add the creep slip coefficient η to consider shear constraint decrease influence by low strength argillation weak structural plane and other weak structural plane and the steep inclination angle changed the stress distribution under foundation raft, which makes the stress dispersion angle to narrow. By comparing the different shapes of stress dispersion under foundations and consider the large creep deformation in 2 years, get the η value should be at least more than 2 in this case.
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