In-Situ Rock Testing for the Design of the Lai Chau RCC Dam

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Abstract

For the design of the foundation level and stability assessment of concrete dams three criteria with respect to the rock-mass are important to establish as soon as possible for a safe and economic dam design; the rock shear strength parameters, concrete-rock shear strength parameters and modulus of deformation. In this respect timely in-situ testing carried out according to international standard is considered best practice.

The Lai Chau dam is situated in northern Vietnam and is the upper most dam in a cascade of hydropower dams along the Song Da. The site geology is of a composite granitoid intrusive body of grano-diorite, quartz-diorite and diorite, which has been syn-tectonically intruded and extensively tectonised post intrusion. In the technical design stage dam foundation levels are initially defined based on weathering. Vietnamese weathering classification systems describe 5 weathered weathering Vietnamese weathering classification systems describes 5 weathered grades from IA1 (completely weathered rock) through to IIB (fresh rock).

For the Lai Chau Project two exploratory adits; HN-1 (length: 260 m) and HN-2 (length: 200 m) were carried out at the proposed dam axis in the left and right abutments respectively. The rock mass of the weathering grade IIA (slightly weathered) was considered the most appropriate foundation material. However, tests were also carried out in rock masses of weathering grade IB (moderately weathered) and IIB (fresh).

A comprehensive in-situ testing program (rock-rock shear and concrete-rock shear tests and modulus tests) was performed in the rock-mass on the various weathering grades to establish the parameters associated with the identified weathering grades. On the basis of these tests an optimized foundation design was possible with foundation in IIA in the river section and in IB on the upper parts of the abutments. As a result excavation and RCC volume could at design stage be minimized.

Keywords: In-Situ Testing, Dam Foundation, Design Parameters.

1. Introduction

The dam for the Lai Chau HPP (under construction) is the most upstream of a cascade system on the Song Da within Vietnam (see Fig.1 for location). Downstream the Son La dam (2012) and the Hoa Binh dam (1994) have already been constructed. The completion of the Lai Chau HPP will result in a total installed power capacity of 5'520 MW on the Song Da mainstream. For the Lai Chau dam an RCC (roller compacted concrete) gravity type dam was chosen as the most economic. The maximum dam height is131 m. The original dam design called for a maximum height of 137 m. A higher quality rock mass in the river section allowed for excavation to be stopped 6 m higher. The installed power capacity is 1'200 MW with 3 Francis turbines. Construction of the Lai Chau dam started in 2011 and is due to be completed in 2015.

Site investigations for the damproject from feasibility stage (2004) through to detail design stage are extensive and beyond the scope of this paper but include; extensive surface geological mapping (1:25.000 to 1:2000 scale maps covering the study area), some 9'484 m of boreholes with approximately 4'180 in-hole tests and a large laboratory testing schedule. As part of the investigations,during the technical design stage in 2009, exploratory aditsin the left and right abutments at the proposed dam axis were excavated. These large scale excavations enabled a better characterization of the rock-mass weathering and appropriate placement of the test positions. In-situ shear and modulus tests were carried out within the identified weathering classes (principally in the weathering grades IB and IIA) to evaluate the shear strength parameters and the deformation modulus of the rock-mass classes.

2. Geology

2.1 Regional Stratigraphy

The dam site is in an area of high to medium mountainous relief, dissected by the Song Da, with peak elevation generally between 1000 and 2000m a.s.l. At the dam area the Song Da cuts down to an elevation of 185 m a.s.l. The geological history is long and complex. The regional geology is presented in Fig. 1. The oldest rocks present are the Nam Cuoi Formation, a marine clastic sequence of Silurian-Devonian age. The Carboniferous-Permian is represented by the Nam Kha A Formation, a basaltic to rhyolite volcanic sequence and the Song Da Formation, a marine clastic sequence of conglomerates, sandstones, shale and limestone. Clastic sequences of the Nam Man Formation and the Suoi Bang Formation represents sedimentation during Triassic times. The Jurassic is represented by the Nam Po Formation a sequence of sandstones and shale. During the Cretaceous the Nam Ma Formation, a terrestrial sequence of thickly bedded conglomerates and gritstones were deposited.

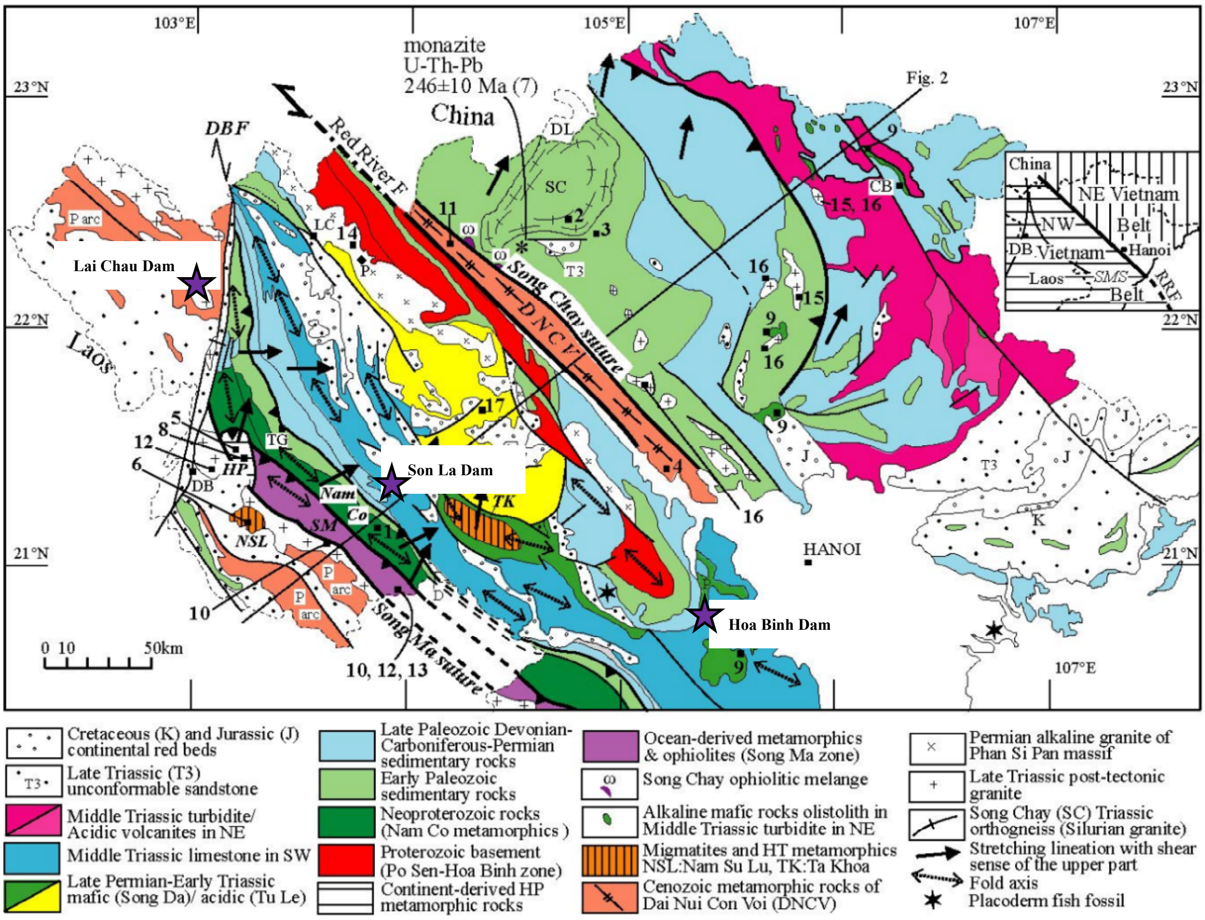

Fig.1. Regional geology indicating positions of the Hoa Binh, Son La and Lai Chau dams.

2.2 Intrusive Geology

During Permo-Triassic times, the above described stratigraphic sequences have been intruded into by the Dien Bien Complex. This intrusive complex is recognized as being intruded in two main phases; a first phase of gabbro,gabbro-diorite and diorite can be observed, with a second phase, which saw the intrusion of diorite, granodiorite and biotite-granite.

2.3 Structural Geology

The structure of North Vietnam is dominated by important transform faults, which act as a tectonic release mechanism related to the continued closure and up-rise of the Himalayan mountain chain. The faults zones are NW-SE trending steeply dipping to sub-vertical strike-slip fault zones, which result in high regional seismicity.Northern Vietnam straddles the Song Ma suture, which defines the boundary of the South China Terrane to the northeast and the Indochina Terrane to the southwest.

The Song Ma and the Song Da sutures are recognized as being formed in Paleozoic and Mesozoic age respectively (Metcalfe 1996), with subduction to the southwest. Large scale folding, thrusting and nappe formation is indicative of continent-continent collision rather than arc-continent collision. The terrestrial Song Da Formation probably represents a rift basin sequence during Permo-Triassic times (Tran 1979, Hutchinson 1989a, b). The major faults are herein described; The Dien Bien Phu – Lai Chau Fault (grade I) is the most important fault regionally (15 km from the dam site) and displaces dextrally the Song Ma Suture and the Triassic granitoid intrusions. These granitoid intrusions are seen to the north of the fault at Lai Chau and to the south of it at Dien Bien Phu. Since approximately 5 Ma the fault has been reactivated with sinistral displacement and relatively strong seismic activity recording events of approximately 5 on the Richter scale.The Upper Song Da Fault (grade II) is long, extending from Chinese territory along the left bank of the Song Da towards the Dien Bien Phu – Lai Chau Fault.A fan of numerous un-named grade III to grade IV faults extends from the Upper Song Da fault and cut across the Song Da.

2.4 Site Geology

The geology at site is that of a composite granitoid intrusive body, dominated by granodiorite, diorite and subordinate granite. Field relationships indicate that the igneous body was intruded as a late syn-tectonic intrusion with continued supra-crustal ‘brittle’ deformation. The igneous body is dissected extensively by faults of grade IV and below (according to Vietnamese standard, Table 1). The rock-mass ranges from massive sound rock with few discontinuities to poor rock quality with closely spaced discontinuities.

Table 1 Classification of tectonic discontinuities (TCVN 4253-86)

Class	Type	Length /Scale	Fault width
I, II	Large Faults, boundary of tectonic plates and blocks	10’s to 100’s km	10’s m
III	Medium Faults, block boundary	km to 10’s km	5 – 10 m
IV	Small Fault, intact- block boundary	100’s m to km’s	0.5 – 2.5 m
V	Large Joint	100’s m	2.0 – 50 cm
VI	Medium Joints	10’s to 100’s m	Several mm
VII-VIII	Small Joints	< 10m	~1 mm

2.5 Site Weathering Classification

Of importance for the successful completion of any large dam construction project is an understanding of the rock-mass, and more precisely an understanding how processes such as weathering manifest themselves within the structure of the rock mass. Generally, the best way to achieve this is by the application of a site specific weathering classification system that addresses the genesis and structure of the rock mass. The rock-mass at LaiChau is not overly complex and in this respect the Vietnamese weathering classification of EVN regulationfor Hydropower projectshas been applied. The Vietnamese weathering classification system is compared with other internationally recognized classifications systems below (Table 2) to enable initial understanding. Typical weathering grades of the granitoid rock-mass at Lai Chau are shown below in Fig. 2. As with all visual and descriptive geological classification systems the boundaries of such classification systems are open to interpretation and the development of its application on site must be carefully considered.

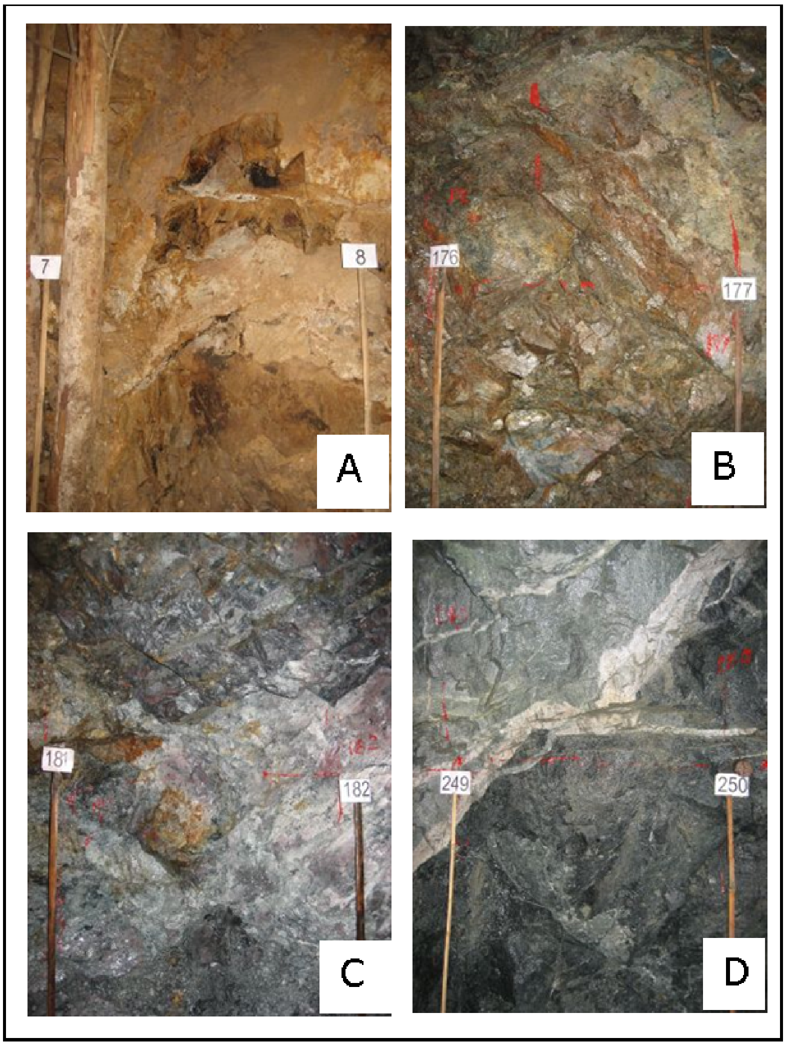

Fig. 2.Photographs of the Vietnamese weathering grade at Lai Chau; A: Photo of IA2 weathering class, B: Photo of IB weathering class, C: Photo of IIA weathering class, D: Photo of IIB weathering class

Table 2. Comparison of Rock Mass Classification Systems

EVN regulation for Hydropower projects		ISRM (1981)	Hoek-Brown GSI		Bieniawski
Zone	Description	Weathering. Grade	Rock Mass Structure	Joint Surface Conditions	Rock Mass Rating RMR
IA1	Completely weathered rock, decomposed to soil	W5	Soil	-	-
IA2	Highly weathered and highly fractured rock	W4	Disintegrated, heavily broken rock mass	Poor to very poor, highly weathered surface	Very poor < 21
IB	Highly fractured rock, moderately weathered	W3	Very blocky / disturbed / folded / faulted	Poor to fair, moderately to highly weathered	Poor 21 - 40
IIA	De-stressed and fractured rock, fresh	W2	Blocky, partially disturbed	Good, slightly weathered	Fair 41 - 60
IIB	Intact rock, fresh, weakly to moderately fractured	W1	Blocky, well interlocked, undisturbed	Very good, un-weathered	Good 61 - 80

3. Exploratory Adits

Prior to mass excavation for the dam to design foundation level, access to the rock-mass for the execution of in-situ tests is normally by the construction of exploratory tunnels or adits. It is best practice for concrete dam construction to characterize the rock-masses for the left abutment, right abutment and river section separately. At Lai Chau two such exploratory adits HN1 and HN2 were excavated in the left and right abutments respectively at the proposed dam axis.

The left bank exploratory adit HN1 was excavated to a total length of 260 m. The following zones have been found: From chainage 0 – 1.55 m: soil of completely weathered zone of IA1, from 1.55 to 8.96 m: highlyweathered rock zone of IA2, from 8.96 to 177.7 m: moderatelyweathered rock zone of IB, from 177.7 to 217.7 m: slightly weathered rock zone of IIA, from 217.7 to 260 m: fresh rock (IIB).

Theright bank exploratory adit HN2 was excavated to a total length of 200 m. The following zones have been found: From chainage 0.0 – 5.1 m a colluvium soil layer, from 5.1 to 31.2 m: soil of the completely weathered zone of IA1, from 31.2 to 31.7m: highly weathered rock zone of IA2, from 31.7 to 88.0 m:moderatelyweathered rock zone of IB, from 88 to 166.35 m: slightly weathered rock zone of IIA, from 166.35 to 200 m: fresh rock (IIB).

3.1 Rock Mass Shear Strength Tests

Rock mass shear tests have been carried out after the ASTM D4554 – 90test method for the in-situ determination of shear strength testing. Each test block was formed by lines of contiguous drill holes (Ø 60 mm)to create a square block of nominal dimension 0.7x0.7x0.35 m. Fig.3a shows the typical test arrangement of the test set-up. Nine test series, each of five individual tests were carried out with normal stresses of between 0.5 - 3.3 MPa, which reflect the loads of the proposed RCC dam. The loads and displacements were measured for peak and post peakto evaluate residual values.After execution of the test the failure surface on the blocks was inspected and mapped(Fig. 3b) to assist in interpretation.

The test positions were located according to weathering class; two tests have been carried out on rocks of weathering class IB, one each in HN1 and HN2. Four test series have been carried out on weathering class IIA, two each in HN1 and HN2. Two test series have been carried out on weathering class IIB, also one each in HN1 and HN2. In adit HN1 one test series on tectonized material was carried out. Both peak and post peak (residual) strengths were calculated from the test measurements. The combined test results from HN1 and HN2 are shown graphically for class IIB and IIA in Fig.. 5. The separated results of left abutment and right abutment results from the test series in weathering rock mass IIA are shown graphically in Fig.6.

Fig.3a: typical test arrangement

Fig.3b. Inspection of sheared surface after testing

3.2 Rock /Concrete Shear Strength Tests

Five series, each of three individual tests have been carried out in the various rock weathering classes in HN1. One test series has been carried out on tectonized material. In HN2 four test series have been carried out in the various rock weathering grades. Normal loads of 1.0 to 3.0 MPa have been applied to reflect loading from the dam. The rock/ concrete shear test procedure is similar to that for the rock-mass shear tests. A cleaned rock surface is prepared and a concrete test block is formed on the surface/rock blocks.

3.3 Modulus Tests

The in-situ modulus for the rock mass was estimated using a rigid plate loading method afterASTM D 4394 – 84. A total of 16 tests were carried out in the various rock mass weathering classes. The typical test arrangement is shown below in Fig.4. The borehole diameter for the fixed measurement anchor positions was 56 mm; the anchors were set at 0.3, 1.0, 2.0 and 3.5 m depth within the boreholes. Loading was applied across a 710 mm diameter loading plate at six stages from 1.0 to 3.5 MPa to reflect the loading conditions of the RCC dam. .

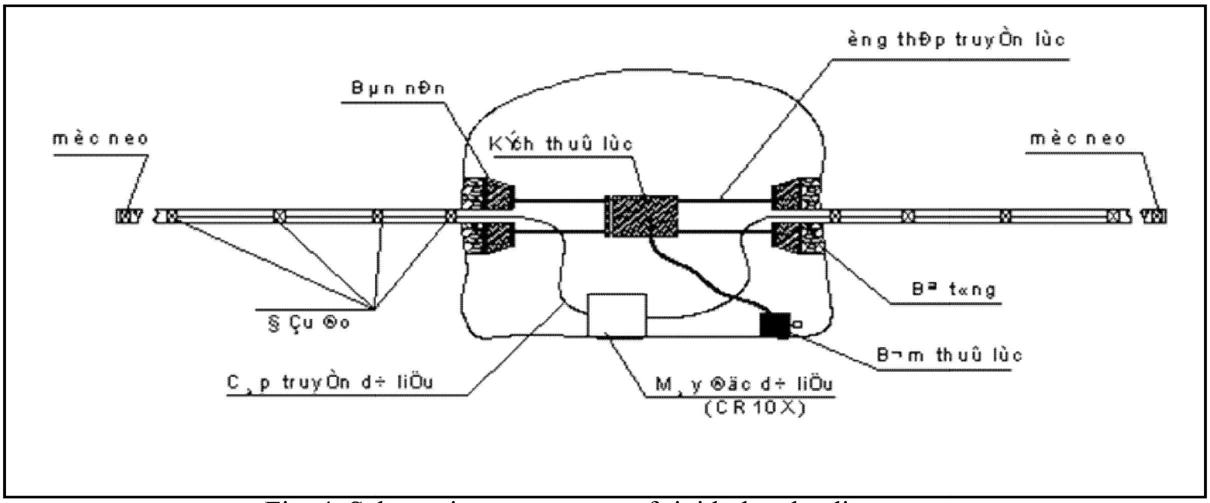

Fig. 4. Schematic arrangement of rigid plate loading test

4. Results

4.1 Rock-Rock shear strength

The calculation procedure of normal and shear stresses derived from applied test loads are included in ASTM D4554 – 90. All test data (peak and residual) for the rock-rock shear strength is shown together for the weathering classes IIA and IIB in Fig.5.A greater variation is seen for rock class IIA. In Fig. 6 the peak and the residual rock-rock shear strength results for HN1(left abutment) and HN2 (right abutment) are shown separately and the data scatter is greatly reduced. The derived shear parameters in the left and the rightabutments for class IIA are, despite similar weathering classes, different. Higher calculated friction angles and apparent cohesions are derived for the right abutment. Data for IB is not shown.

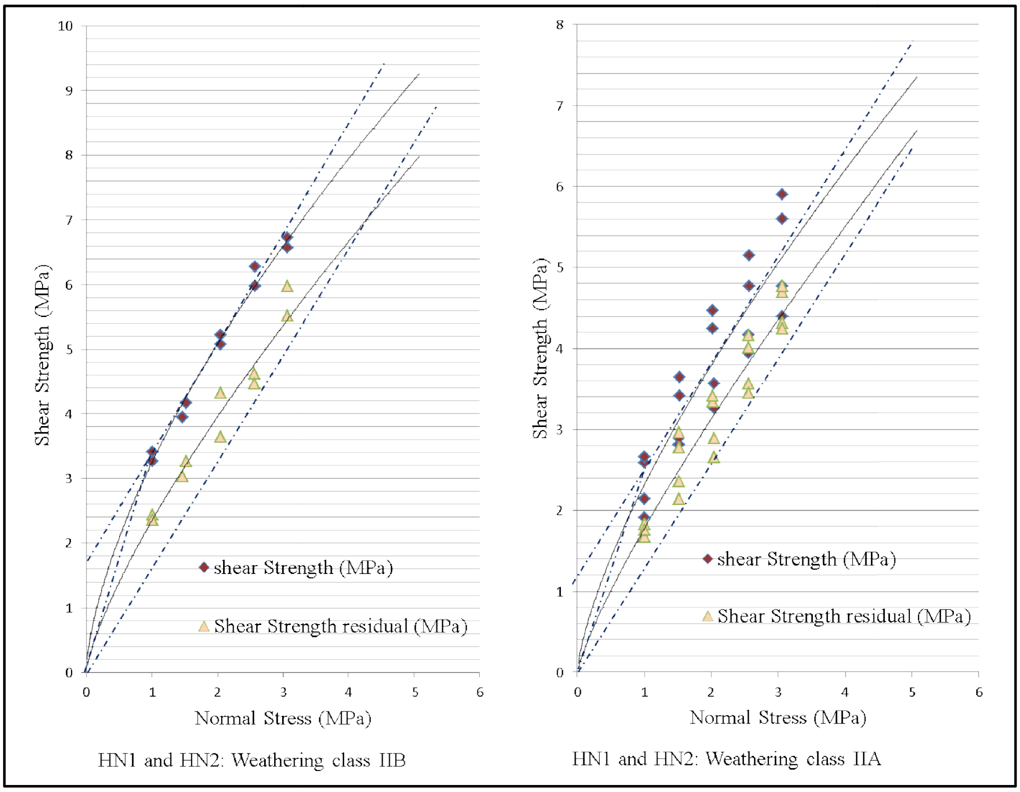

Fig. 5. Peak and residual shear strengths for class IIA and class IIB

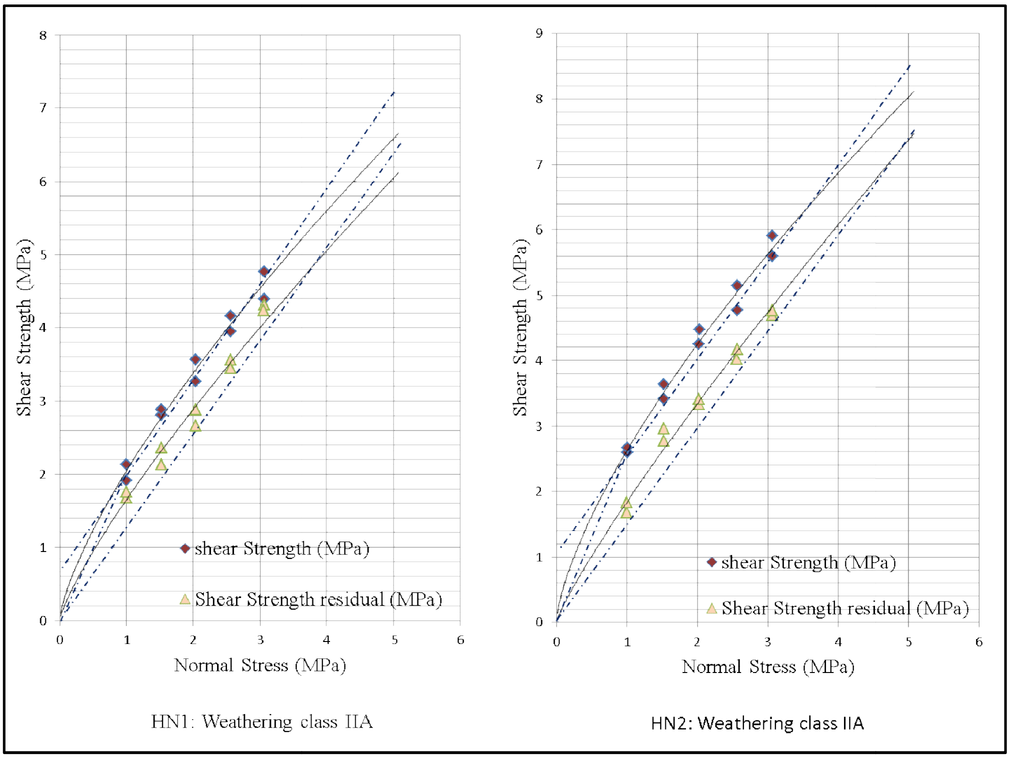

Fig.6. Peak and residual shear strengths for class IIA separated into left bank (left diagram) and right bank (right diagram).

Table 3. lower bound design values

Weathering Class	Mohr-Coulomb Parameters			
	Peak		Residual	
	φ(°)	C (MPa)	φ (°)	C (MPa)
Class IB	47.0	0.67	45.0	0
Class IIA	48.7	0.92	45.4	0
Class IIB	58.7	1.53	50.9	0

Based on the test results lower bound values could be evaluated (Table 3). The selection of these values was assessed with comparison from rock mass classification systems (GSI and RMR).

4.2 Rock-Concrete shear strength

Calculation procedures of the normal and shear stresses for the rock-concrete tests are as for rock-rock tests. Consideration of the results from the rock-concrete shear tests differ from the rock-rock shear strength as the rock-concrete shear strength parameters are highly dependent upon the roughness of the formed rock surface and of the concrete-rock bond strength. The in-situ tests, however, indicated designconcrete-rock peak friction angle of 45° with apparent cohesion of 0.69 MPa. The residual friction angle was also 45°.

4.3 Rock-Mass Modulus

Calculation procedures are shown in ASTM 4394 – 84. Some of the modulus testing results are shown illustratively below. Fig. 7a demonstrates the effect of blast disturbance on the results. Fig. 7b and Fig. 7c indicate that beyond d=2.0, the effect of blasting becomes significantly reduced. Significantly, Fig. 7b and Fig. 7c demonstrate a marked contrast in deformation modulus values between left and right abutment class IIA material. From class IIB the test results from HN1 and HN2 were very similar, with a range of 21-24 GPa at d=3.5 from HN1 and a range of 23-25 GPa at d=3.5 from HN2.

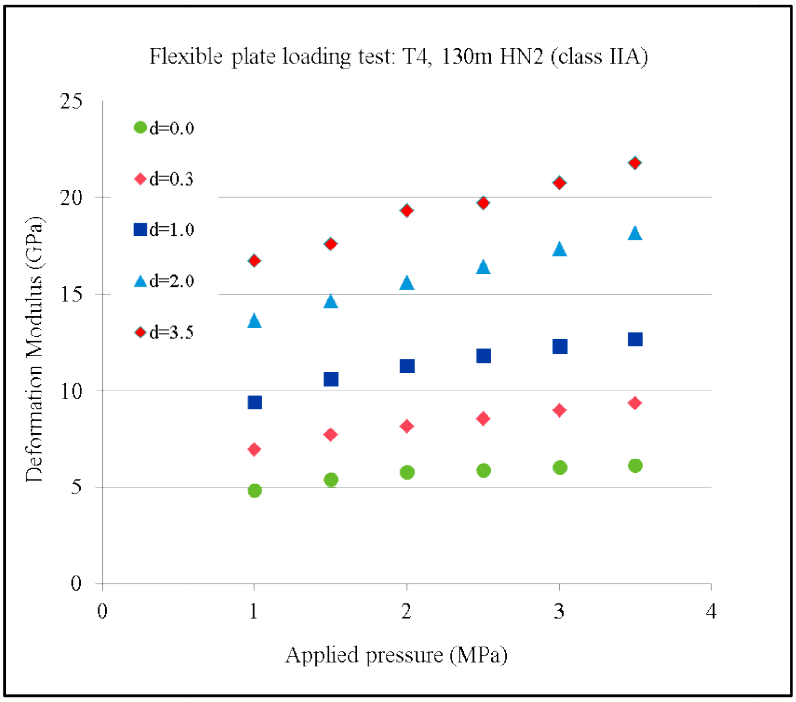

Fig. 7a. Rigid plate loading test: test T4 at 130m HN2 (class IIA)

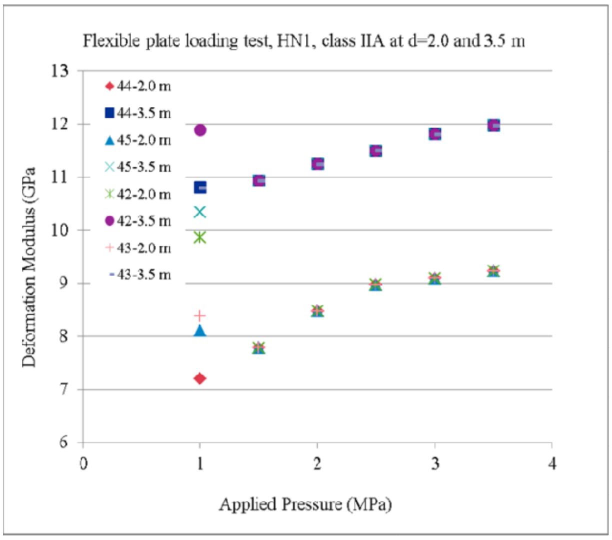

Fig. 7b. Rigid plate loading tests in HN1 on class IIA for d=2.0 and 3.5 m

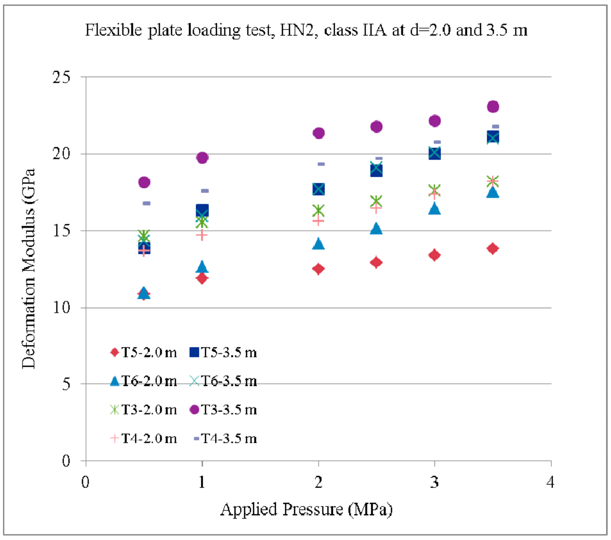

Fig. 7c. Rigid plate loading tests in HN2 on class IIA for d=2.0 and 3.5 m

5. Interpretation

In reading this paper, it should be realized of course, that for the evaluation of dam stability the recognition and characterization of discontinuities and the potential for forming sliding blocks is arguably of greater importance. This consideration is however beyond the scope of this paper.

On the basis of the in-situ test results, lower bound Mohr-Coulomb parameters could be selected.Numerical stability analysis for the dam could be carried out and on the basis of this the dam foundation level could be defined in class IIA rock mass, with the left and right abutments above elevation 265 m a.s.l. founded in class IB material.

The derived Mohr-Coulomb Parameters and modulus values from the fresh (IIB) rock mass are similar in the left and right bank. The derived parameters in the slightly weathered rock-mass (IIA) differ significantly between the left and right abutment, despite being in the same weathering grade.

The in-situ test resultspresented above indicate that in fresh rock (IIB) both visual assessmentof weathering of the rock mass and the derivation of physical parameters using rock mass classification systems can be assessed reliably. However, within the range of slightly weathered to moderately weathered rock-masses,visual recognition criteria can be erroneous. The calculated best fit friction angles in the slightly weathered rock mass (IIA) material differed by 10% between HN1 and HN2, despite being in similar rock masses of equal weathering grade. The rock mass classification system used at design stage (GSI and RMR) was not capable of discerning the difference between left and right abutment. The design parameters could be chosen to account for the lower parameters seen in the left abutment.

6. Concluding Remarks

Dam foundation levels generally are based on engineering judgment. This judgment should be based on a balanced combination of as many sources of information as possible.

For numerical analysis, the selection of design parameters will always have inherent risk, due to rock-mass variability. Therefore, for the design of concrete dams the selection of design parameters must always be lower bound values, derived by assessment of all data available. These estimates should, however, also be realistic to approximate the design foundation level and not be overly conservative.

Both the use of rock-mass classifications, laboratory and in-situ testing and where confidence is lacking sensitivity analysis in combination must be maintained as best practice for selecting parameters.

Rock-mass classifications are very useful for developing parameters at feasibility stage, but assumptions interpretational variation incorporated within the various rock-mass classification systems are not always capable of picking up differences that may affect the design of a concrete dam.

Acknowledgements

Thanks are given to EVN for permission to publish this paper and many thanks to Helmut Stahl and Marco Conrad for review of the paper.

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