CHAPTER X

SUMMARY AND CONCLUSIONS

The present exploration to determine the geomechanical aspects of the Chiew Larn diversion tunnel was performed during the initial phases of the construction project, followed by an observation during and after the excavation of the diversion tunnel. The rock index properties were firstly determined to evaluate the significant geologic features for tunnelling. After that the observation provided a mean to relate the rock index properties to the diversion tunnel, portal slopes, and foundation stability.

In the study, it was found that, the Chiew Larn diversion tunnel, portal slopes and main dam foundation area are underlain by massive bedded pebbly graywackes and subarkosic sandstones with significatly different textures.

Two quantitative X-ray diffraction analyses were carried out on mudshales which associate the graywackes. The results showed that the rocks compose mainly of quartz and illite with small quantities of chlorite, feldspar, and rare mixed-layer minerals.

The structural geologic study disclosed four sets of joints and faults with the orientation N20°W-N30°E/84°E, N70°E-S55°E/50°-74°S, S20°W/70°-90°W, and N70°W/60°-80°N. The further detailed study on the degree of crushed rock fragments or cavities and calcite crystals coated along the joints or forming veinlets was done such that the characteristics can be correlated with the observable rock-mass behavior variations.

The groundwater flow was noted to concentrate along a limited number of narrow jointed zones in the diversion tunnel. The natural groundwater influx volumes were observed to be in the order of 700-1,200 cc/min, then drop to 100-200 cc/min in three days.

The density of the rock types in the study area was one of the most fundamental physical properties that received the attention. The mean dry, saturated, natural-dry and bulk densities of the pebbly graywackes are 2.68, 2.71, 2.70 and 2.67 gm/cc respectively while those of the subarkosic sandstones are significantly lower, 2.63, 2.68, 2.65, and 2.61 gm/cc respectively. The mudshales mean densities at the dry, saturated, natural-dry and bulk conditions are 2.56, 2.65, 2.63, and 2.50 gm/cc. The mean values of water content and absorption of pebbly graywackes are 0.48 % and 0.64 %, and of subarkosic sandstones 0.33 % and 1.015 %.

The laboratory-determined mean porosity of the weathered pebbly graywackes in 2.58 %, appreciably higher than that of the fresh pebbly graywackes and subarkosic sandstones which are 0.97 % and 1.24 % respectively.

The physical durability of the pebbly graywackes from the diversion tunnel area was determined in a 5-cycle slake durability test to have a mean index value 99.40 % (2-cycles).

The dispersion of the results of the unconfined compression tests is as usually occurred, consequently the average strength values were 64.51 and 144.32 MPa for the pebbly graywackes and subarkosic sandstones respectively.

The tensile strength is considered using 2 easily-performed test methods. The average value of the Brazilian tensile strength of the pebbly graywackes and subarkosic sandstones are 10.43 and 17.48 MPa respectively. The average axial, diametrical and irregular lump point-load strengths of pebbly graywacks are 4.26, 3.71 and 3.76 MPa, respectively. The variation in Brazilian tensile strength was observed to be greater than that derived in the point - load tests.

For the natural-dry samples to be direct-shear tested, the average peak and residual static friction angle (ϕ) are 55.67° and 34° respectively while the average cohesion (c_p) is 15.33 MPa The average saturated condition internal friction angle was 52.17°, cohesion (c_p) is 14.00 MPa.

The Schmidt hammer hardness testis a simple and guick method to be performed, and its result is crude however acceptable for an estimation. The jointed pebbly graywacks and subarksose possess the Schmidt number values of 43.18 and 45.90 in average, respectively.

The pebbly graywackes were studied for a suitability as an aggregate. The test results are : mean Los Angeles abrassion hardness 28.04 %, uniformity factor 0.22, and average sulphate soundness value 0.55 %, uniformity and curvature coefficient of aggregate grading 4.01 and 1.52 respectively, aggregate crushing value 20.61, void ratio 1.34.

The laboratory-measured P-wave velocities of the subarkosic sandstones collected as dry, natural-dry and saturated have the average values of 4420, 4530, and 4540 m/sec, of the pebbly graywackes, 4410, 4480, and 4485 m/sec. The shear velocities of subarkosic sandstones in the aforementioned three conditions are 2460, 2500 and 2430 m/sec, of the pebbly graywackes, 2510, 2525 and 2480 m/sec.

The rock mass rating values application to the diversion tunnel using Bieniawski's (1979) classification were in the range of 25.00-92.50 (poor to very good rock) and the Q-system yielded Q values between 0.04 and 32.80 (extremely poor to good rock).

The movement in three sections of extensometers in the diversion tunnel where shear zones and/of other major discontinuities appeared were in the range of 0.20-13.95 mm.

From the slope stability analysis of the upstream and downstream cut portal slopes were found that their factor of safety varies from 0.49 to 1.34. The in-situ rating was applied to the slope in these areas is varies from very poor to good.

An estimation of the modulus of deformation on the basis of the Geomechanics Classification for foundation was noted to be 3.40×10^4 MPa in average.

The mentioned characteristics of the rocks and rock mass, thus, guide to the following conclusions.

1. The uniaxial compressive strength of the average pebbly graywacke and subarkose specimens are moderately strong to strong, and strong to very strong, respectively, though a substantial varia-

tion occurs in some specimen. This may be caused by the variation in the textural fabric and composition of the rock, clay minerals inclusions and by the abundant flaws, fractures, and weak bands.

2. The tensile strengths recieved in both the Brazilian and point-load tests are decisively affected by the orientation of the cleavage planes to the loading axis, the development of fissures, grain sizes of quartz and clay minerals, and the weathering degree and formation of the secondary minerals.

3. The direct shear test results indicate a general tendency for both the cohesion and the basic friction angle of the saturated samples to be lower than those of the dry samples, although a few instances the reverse was found to be true. It is considered that the pebbly graywackes exhibit an antifrictional characteristics. As the basic friction angle of the saturated rock is greater than that of the dry one, it thus indicate that a greater strength of the dry rock than that of the saturated one are controlled by the existance of clay minerals or iron compounds.

4. The saturated specimens in sonic velocity tests usually lead to a rise in the P-wave velocities. On the other hand, transverse wave velocities (V_s) remains almost constant in all specimens regardless of the different degrees of saturation. Although the sandstones were different from the pebbly graywackes to subarkosic sandstones, there is a relationship between the velocity and porosity that the velocity of propagation decreases when the porosity of the rocks increases.

5. It was found that the values of the elastic constant obtained by a static method are lower than those obtained by a dynamic method. The difference in the constants so determined varies from 0 to 65%. The difference was explained as being due to the pressence of cleavages, cracks, clacite veinlets or cavities, with the static yielding being affected by deformation of cleavages and crackes and the dynamic measurements being less influenced by these factors.

6. The properties of hardness, compressive strength, and modulus of elasticity which were determined by the Schmidt rebound hammer test are easily and accurately obtainable as by other various testing methods.

7. The rock aggregates made up with the pebbly graywacke have an inferior engineering characteristics. Thus the requirement of the construction materials for the dam construction, especially the materials used as coarese filter, rock fill, rip rap and aggregates for cement concrete, still exist.

8. The deformation displacement in most of the tunnel walls was in the range of 0.05 - 7.5 mm indicating the normal movements not effecting the tunnel stability.

9. The assessment of rock mass using both rock-mass classification methods indicated that the quality of rock mass along the diversion tunnel are good in average (Class II). In the cases of extremely poor to poor rock conditions, such as, at the shear zones or faults, the Q-system method is more effective than the Geomechanics Classification.

10. The preliminary graphic analyses of the slope stability indicated that the possible failure in the more competent sandstone sequence at the upstream and downstream portals would be in the form of wedge and planar failures as controlled by the pre-existing discontinuities in the rock mass. Generally, these slopes stands up stable by the internal friction locking of its discontinuity surfaces. They will instead become unstable and failure occur when the discontinuity surfaces are lubricated by the in-filled water with a help from the water pressure increase which will further open the existing.