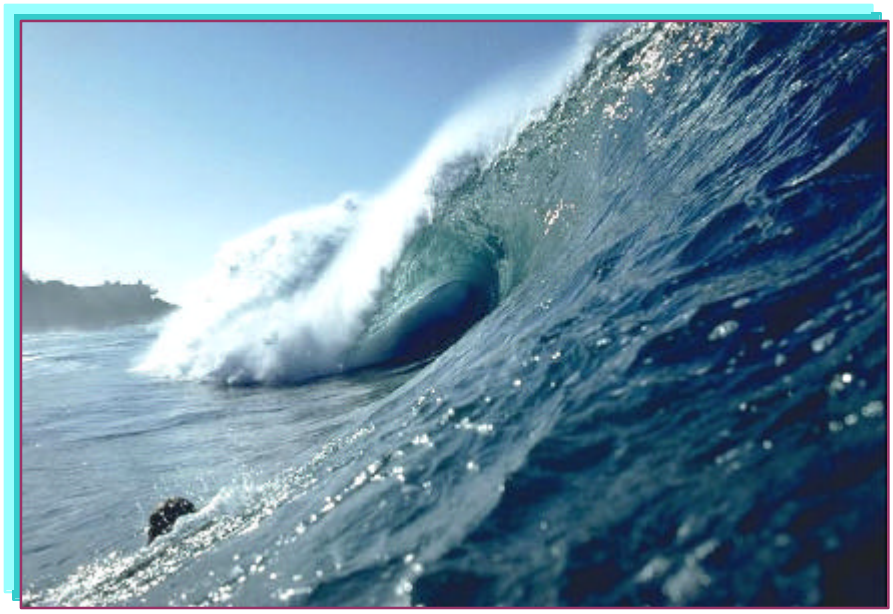
ASSESSMENT OF DREDGED CORAL RUBBLE

FOR CONSTRUCTION IN THE

FEDERATED STATES OF MICRONESIA



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Assessment of dredged coral rubble for construction in the Federated States of Micronesia[1]

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ABSTRACT: This paper presents the results of engineering-geological assessment of dredged coral reef rubble from Pohnpei Island, FSM for construction. Over 51 dredge sites were mapped. Disturbed samples were collected from dredge sites and assessed from petrography, composition, granulometry, Atterberg limits, water absorption, porosity, void ratio, dry and wet densities and unconfined compressive strength following American Society for Testing Material guidelines. More than 70 % of dredged rubble are abraded and angular sand and gravel, consisting of coral, foraminifera tests and Mollusc shells, with water absorption of 3-30 %; porosity of 6-23 %; void ratio of 0.06-0.30; dry and wet density of 1.88-2.50 kg/m^3 and 2.06-2.70 kg/m^3 respectively, with unconfined compressive strength less than 75 MPa. This suggests that this aggregate can be highly susceptible to failure under heavy static and dynamic loads, both in-situ and at fill and reclamation sites.

1 INTRODUCTION

Coasts in the Pacific Island Countries (PICs) are used for a variety of purposes, ranging from social and recreational to industrial activities. The relatively large ocean and maritime space in each of the PICs makes development impossible without some influence (positive or negative) on the coast and shorefront. For this reason, shorefront and coastline development must be pursued in a carefully planned manner, so as to minimise negative impact of development activities.

One of the main uses of coasts in PICs and in the Federated States of Micronesia (FSM) is coral reef dredging and mining of marine aggregate. This includes a mixture of carbonate sand, gravel, cobble and boulder, which comprise dead coral skeletons, live coral heads and massive coral skeleton, e.g. *Montstrea spp*. Coral reef mining has for many years, been the main source of construction aggregate for the building industry in PICs. Reef carbonates are used in four major activities. These are, for fill and land reclamation in wetlands; housing and tourism development; construction of coastal protection structures (like seawalls, groynes, revetments, breakwaters, gabion baskets and bio-engineering protection), promenades and infrastructure facilities (like coastal roads); and construction of industrial facilities and construction of residential buildings.

In coral reef and atoll environments, like those in FSM, mining of reef carbonates and extraction from storm ridge deposits, carbonate sandbanks, coral heads, reef rubble and reef sands and gravel is a multi-million dollar economic activity. Marine carbonates are mined from reef crests, back-reefs and lagoons, in water usually less than 10 m deep. Common species of corals, which are mined, are *Montastrea spp*., in addition to *Acropora spp*., and *Porites spp*. Finely abraded gravel and sand are mined from shallow lagoons, in commercial quantities. These finer materials contain

many branching corals, especially *Acropora spp.*, Mollusca, benthic foraminifera, *Halimeda spp.*, *Rhodophyta spp*. and Echinoderm test fragments.

Mining satisfies the demand for building aggregate, especially for domestic housing, which has evolved from the traditional thatched and palm dwellings, to concrete and mortar structures. In addition, much aggregate is required for the commercial building industry, and for construction of critical facilities, like airports, roadways and bridges. With changing societal trends in the region, which show departure from traditional (bures and canoe houses) building to concrete and mortar structures, and the demand for new homes, constructed facilities and civil infrastructure, there is an ever growing increase in the demand for building aggregate. Consequently, there has been a corresponding increase in dredging and mining of coral reef ecosystems to satisfy this demand in the construction industry. However, reef carbonates can be subject to early and premature engineering failure if they are of low quality, subject to large loads and not improved in engineered facilities. These can lead to premature failures, increase failure frequency of structures and increase risk associated with constructed facilities. This paper examines the geotechnics of modern reef carbonate and its implications for use as engineering construction material, with examples from, Pohnpei Island, FSM (Figure 1).

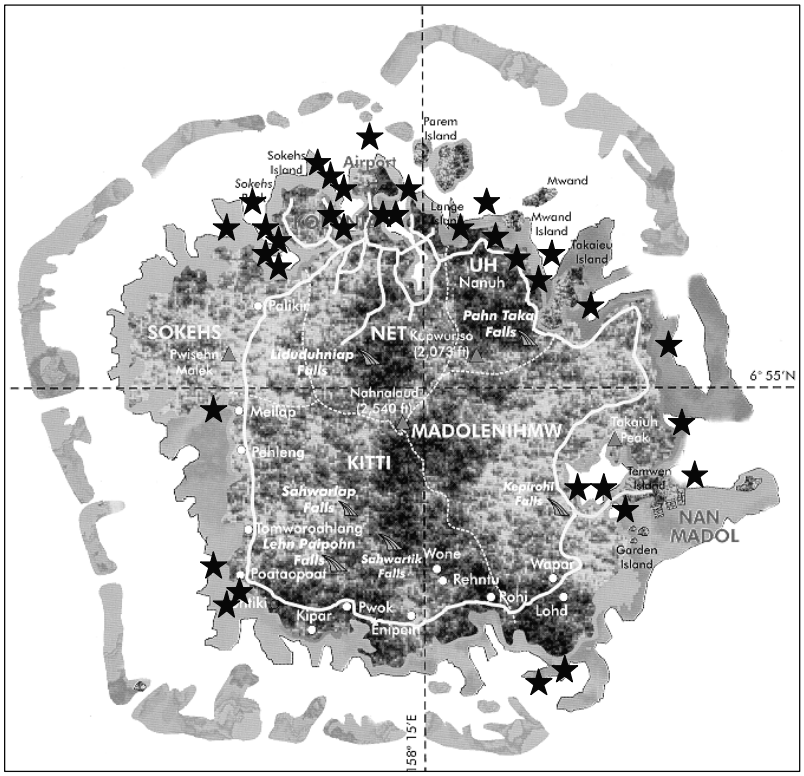


Figure 1. Map of Pohnpei, FSM showing dredge sites (stars).

2 METHODOLOGY

Major dredging sites were mapped on Pohnpei Island, FSM. Twenty samples of dredged material were collected and tested in the laboratory for composition, granulometry, dry and wet density, porosity, water absorption, void ratio and unconfined compressive strength following American Society for Testing material (ASTM (1999) guidelines. Site investigations were also conducted at 60 sites, to examine field aggregate geotechnical properties. The data was then used to assess the suitability of the sampled reef carbonates for engineering construction.

3 RESULTS

Most dredging and reef mining of aggregates take place in water depths of less than 10 m, and in many cases between 5-10 m. These are back-reef lagoons. Most excavation takes place by using hydraulic back hoe and dragline excavators. Figure 1 shows major extraction sites, which number fifty-one, of which forty-seven are dredge sites, with fourteen active areas. These sites represent dredging activities over the past two decades. Dredge material from these sites has several common characteristics. Twenty samples show that 50-70 % of this aggregate is made up of coral skeleton, especially branching *Acropora spp.* and *Porites spp.* corals. These aggregate are light grey to white, non-plastic, angular, poorly graded, abraded and pitted with cavities. They consist of 50-70 % gravel particles, with mixtures of carbonate, skeletal sands and less than 10 % oolitic particles. Gravel fragments contain calcareous algae encrustation and spirulid worm tubes. Samples can be classified as ASTM (1999) GP class or poorly-graded gravel and gravel-sand mixture, with little or no fines. Carbonate gravel is a major component of dredged aggregate and consists largely of coral fragments, Molluscs skeleton, echinoderm tests and Crustacean skeletons. *Halimeda spp*. and benthic macro-foraminifera tests are significant constituents of dredged sands in shallow lagoons and comprise up to 80 % of dredged lagoon sands. These particles are typically flat and with high aspect and low surface area/volume ratios, and are usually coarse sand to fine gravel with nominal particle diameter between 0.50-4.00 mm. These flaky particles are very porous, with high void ratios and are light, with specific gravity of less than 2.60.

Particles are un-cemented and not re-crystallised. Branching coral fragments are cylindrical, while massive species are generally composed of rounded to sub-rounded particles. Boulders are usually sub-rounded massive coral species, but sometimes branching and irregular *Acropora spp.* These are denser. Carbonate mud is a minor fraction of dredged material, usually less than 15 % of the bulk material. Table 1 presents some laboratory test data on coral gravel particles from dredged sediments, while Figures 2-6 present relationships between various geotechnical characteristics. From these data, samples have high water absorption, averaging 7.89 %, but can be up to 29 % in porous particles, with a corresponding high porosity and void ratio, averaging 12.81 % and 0.15 respectively, which cause dry and wet densities to show similar trends. Dry density tends to decrease with increase in void ratio and porosity, while wet density show a similar trend when examined in relation to water absorption (Figures 3-5). Wet densities of fragments averaged 2,420 kg/m^3, but some samples had densities as low as 2,060 kg/m^3. Few samples had relatively high dry densities, owing to their high porosity and void ratio. Those more dense samples had dry densities approaching that of the mineral calcite, about 2,700 kg/m^3 e.g. PA/K13 (Table 1). Water absorption and porosity show similar trends, except for sample PA/K 9 (Figure 2), while wet densities mimic dry density (Figure 6).

4 DISCUSSION

Modern reef carbonates from Pohnpei, FSM are of high porosity and void ratio, low dry and wet density, with low specific gravity (less than 2.60) are of low compressive and impact strength. If used to construct concrete and rigid structures, or as engineering fill and pavement base courses, they can performs poorly and fail under static or dynamic loads. In areas of high seismicity, like the Southwest Pacific (Maharaj (2001), engineered sites built with this material are highly susceptible to structural collapse under large-magnitude cyclic earthquake loads and strain. These material are also highly susceptible to grain crushing and decrease in void ratio or structural collapse, under isotropic consolidation and shear, due to the high aspect ratio and flakiness of most particles (Maharaj (1995). These can result in differential foundation settlement under structural and/or "live" load.

Marine aggregates also contain harmful magnesium, chloride and sulphate ions (in high concentrations in tropical seawater). These ions can cause chemical reactions with cement and steel (if unwashed and used in steel-reinforced concrete); especially where concrete is mixed using Portland cement (ASTM Type-I designation). Chloride ions also decrease the passivity of steel in

concrete, and increases the susceptibility of steel-reinforcing bars (rebars) to corrosion, in steel-reinforced concrete (Geological Society of London (1991). This type of corrosion of rebars cause swelling of the outer corroded films of rebars, by as much as 400 %. Such swelling results in high tensile stresses in cast concrete, which cracks, because of its low tensile strength. Tension cracks produced by this process cause further ingress of moisture and cause further oxidation of rebars and additional cracking. In addition, sulphate ions also react with calcium-rich cement and leads to precipitation of an expansive sulphate called ettringite and magnesium silicate hydrates. These also lead to swelling within the concrete and tensile stresses, also causing cracking and spalling. Chemical reactions like those described above, in this high pH (11-14) and moisture-rich environment can result in deterioration of cement-aggregate and steel-aggregate-cement binding reactions in concrete. This can ultimately lead to spalling of concrete and collapse of the concrete structures. Steel-reinforced concrete cast with these aggregates, usually show ferrous oxide and hydroxide staining (Maharaj (2001), due to rapid oxidation of the steel, on cracking of the concrete, and due to chemical attack by chloride ions usually present in these aggregate.

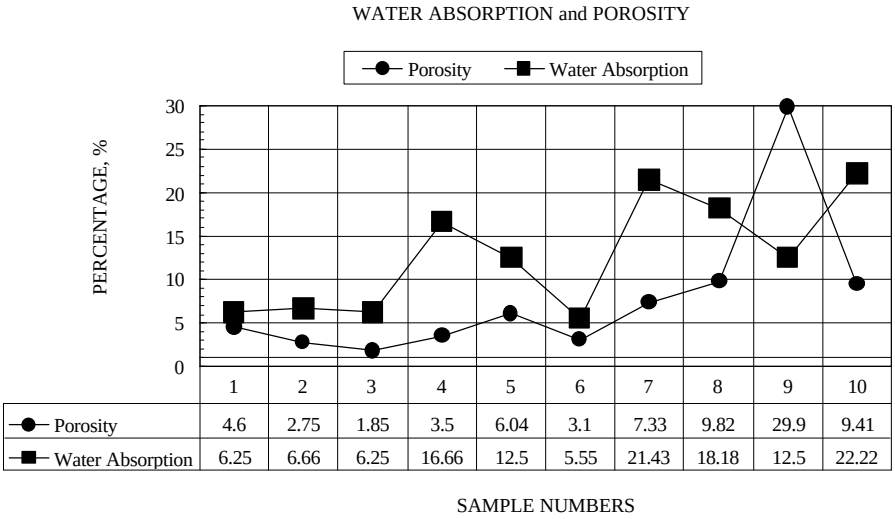
Table 1. Some geotechnical properties of dredged coral gravel.

Sample Number	Water Absorption, %	Porosity, %	Void Ratio, e	Dry Density, kg/m^3	Wet Density, kg/m^3
PA/K 1	4.6	6.25	0.06	2270	2370
PA/K 2	2.75	6.66	0.07	2420	2490
PA/K 3	1.85	6.25	0.06	2700	2750
PA/K 4	3.5	16.66	0.2	2350	2430
PA/K 5	6.04	12.5	0.14	2270	2410
PA/K 6	3.1	5.55	0.06	2510	2580
PA/K 7	7.33	21.43	0.27	2140	2300
PA/K 8	9.82	18.18	0.22	2040	2360
PA/K 9	29.9	12.5	0.14	1920	2500
PA/K 10	9.41	22.22	0.28	1880	2060
PA/K 11	4.62	6.23	0.06	2260	2360
PA/K 12	4.6	6.67	0.07	2420	2480
PA/K 13	1.83	6.3	0.06	2710	2750
PA/K 14	3.51	16.5	0.2	2330	2430
PA/K 15	6.04	12.52	0.14	2300	2400
PA/K 16	3.11	5.6	0.06	2500	2570
PA/K 17	7.32	21.33	0.27	2420	2310
PA/K 18	9.39	18.18	0.22	2040	2350
PA/K 19	29.7	12.6	0.14	1910	2540
PA/K 20	9.44	22.12	0.28	1850	2040
Average	7.893	12.8125	0.15	2262	2424

5 CONCLUSIONS

Reefs represent a major source of aggregate for the construction engineering industry in PICs like FSM. Aggregates in these areas are almost entirely reef carbonates, with more than 50-70 % coral gravel, skeletal sands and minor amounts of fines. These constituents are angular, with high aspect ratios, with high void ratios and porosity and of low densities. They also contain sea salts from seawater, notable chloride and sulphates. Consequently, they are of generally low quality for the construction industry. Where they must be used in construction, due to the unavailability of alternative sources of geomaterial or engineered composites, this aggregate must be initially

washed to remove sea salt, and will require additives to improve its strength depending on the desired engineering application. In addition, amendments to and modifications of design criteria need to be prescribed and made to improve on the (inherent low) quality of this aggregate when used in critical engineering structures and facilities. This will facilitate the optimum performance of constructed facilities built with these aggregates and therefore, reduce the risk and likelihood of their failure through engineering time.



	1	2	3	4	5	6	7	8	9	10
Porosity	4.6	2.75	1.85	3.5	6.04	3.1	7.33	9.82	29.9	9.41
Water Absorption	6.25	6.66	6.25	16.66	12.5	5.55	21.43	18.18	12.5	22.22

Figure 2. Graphical plot of water absorption and porosity for coral gravel samples.

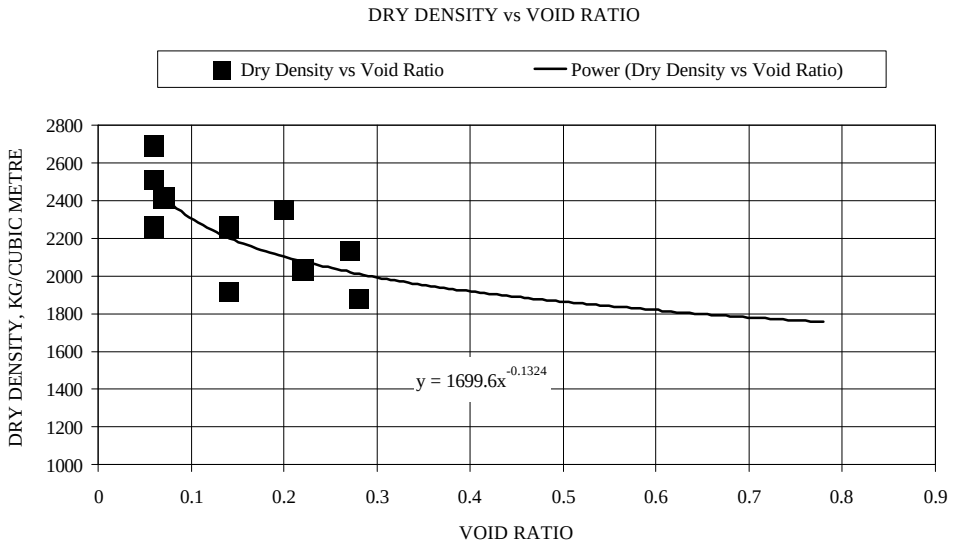


Figure 3. Graphical plot of dry density vs void ratio for coral gravel samples.

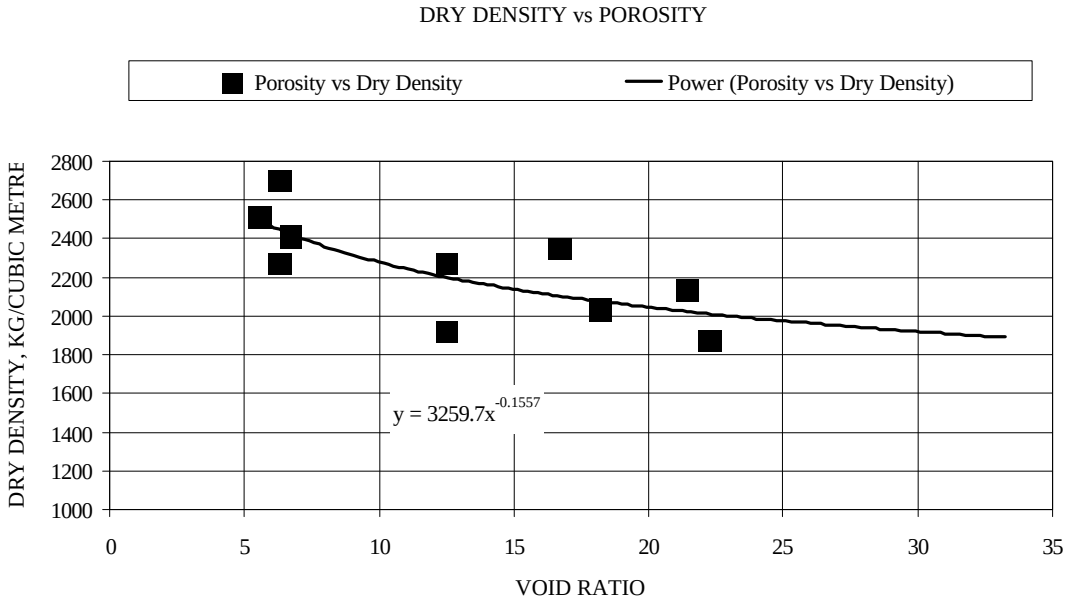


Figure 4. Graphical plot of dry density vs porosity for coral gravel samples.

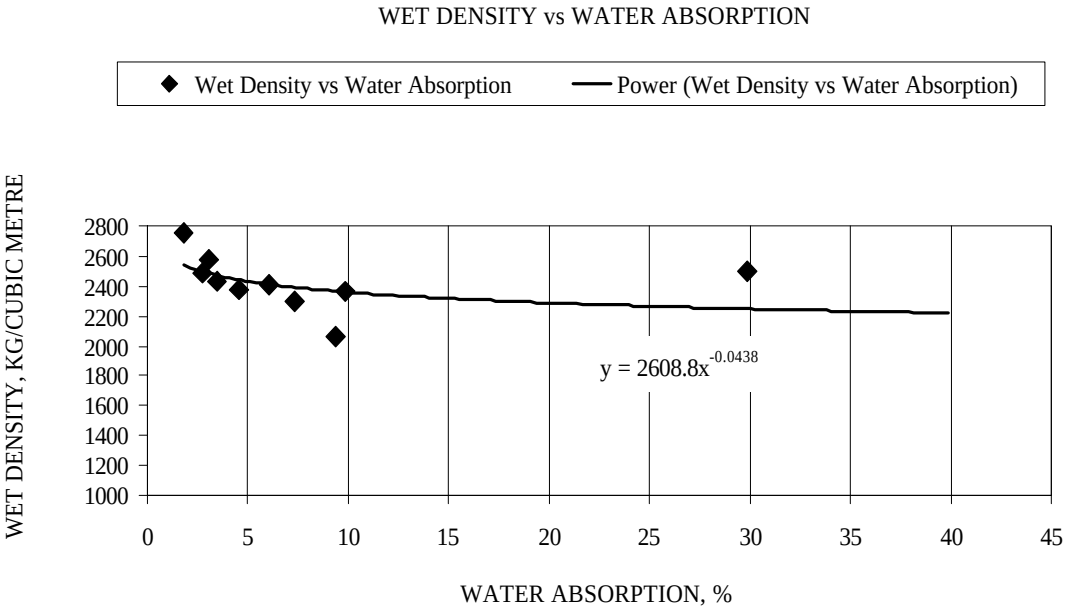
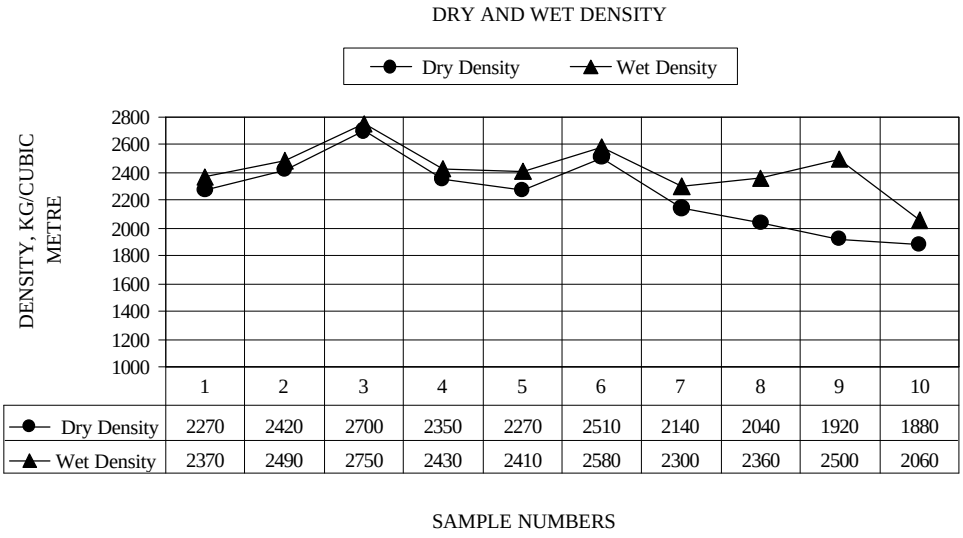


Figure 5. Graphical plot of wet density vs water absorption for coral gravel samples.



	1	2	3	4	5	6	7	8	9	10
Dry Density	2270	2420	2700	2350	2270	2510	2140	2040	1920	1880
Wet Density	2370	2490	2750	2430	2410	2580	2300	2360	2500	2060

Figure 6. Graphical plot of dry density and wet density for coral gravel samples.

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6 REFERENCES

ASTM. 2000. *Annual Book of ASTM Standards. Soil and Rock (I), Vol. 04.08, CD-ROM*. ASTM, Philadelphia.

Geological Society of London. 1991. Geomaterials in Construction. *Quarterly Journal of Engineering Geology, 24*, p. 1 - 168.

Maharaj, R. J. 2001. Monitoring and control of coral reef dredging in Pacific Small Island Developing States (SIDS): environmental and engineering implications. In J. Dobson (ed.) *Dredging For Prosperity*. Kuala Lumpur: WODCON, EADA.

Maharaj, R. J. 1995. Grain crushing and particle size reduction in response to isotropic loading and shear. Paper presented at the *Graduate School of Earth and Environmental Science and Department of Applied Geophysics*, Kyoto University, Japan, p. 1 - 20.