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The Use of Reclaimed Water in the Compaction of Granular Materials

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ABSTRACT

With increasing concerns about sustainability issues combined with the lake of water resources, using the reclaimed water for the compaction of the granular materials that are used as a part of the pavement structure has become essential. The reclai med water is derived from the treatment process of the water obtained from the sewage system or industry process. The use of reclaimed water is currently getting more popular in several fields such as irrigations, compaction, and construction. The main objective of this paper is to examine the effect of using the reclaimed water on the characteristics of granular material specially the maximum dry density and the California bearing ratio. Two different types of types of crushed stone base course materials have been used in this study. The first one is crushed lime stone base course materials, while the second is crushed dolomite base course materials . The two types of materials have been examined using the potable water and the reclaimed water. The results indicated that the reclaimed water can be used effectively in the compaction of unbounded road materials. In some cases the use of the reclaimed water improved the California bearing ratio for the compacted materials.

Keywords:
Granular materials, Compacti on, California Bearing Ratio, Reclaimed water

BACKGROUND ON CHARACTERISTICS AND USES OF RECYCLED WATER

With the current water shortage in Middle East, there is a need as well as opportunities to look for alternative sources of water for use in industry. Several reports have suggested there is a need to use water more efficiently by reusing wastewater (1).

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Typical industrial use of recycled water includes wash down, dust control on construction sites and quarries, boiler feed, process water, industrial cooling and mining as well as a broad range of other uses. Generally, the water quality requirements for industrial purposes are determined by the needs of the process being supplied. Recycled water used for construction purposes may only be used for soil compaction, during grading operation, consolidation and compaction of backfill in trenches for non-potable water, sanitary sewer, storm drain, gas and electric pipelines (2). California Health Law CHL related to Recycled Water, Title 22 (2001) Article 3, Part b Uses of Recycled Water states "Recycled water used for the following uses should be at least disinfected secondary treated recycled water": Industrial boiler feed, non-structural fire fighting, soil compaction, mixing concrete, dust control, and cleaning roads, sidewalks.

In 2005, the Queensland Water Recycling Guidelines (2) specify four classes of recycled water, with A being the cleanest and D the dirtiest, based on microbiological characteristics and other physical properties as shown in Table (1). The use of categories of recycled water has advantages in providing a more easily recognizable system for consumers and producers of recycled water.

This is supplemented by a quantitative health risk assessment for class A+, thus five classes of recycled water exist as shown in Table (2) (Manual for Recycled Water Agreements in Queensland, 2005b). These classes provide an indication of the level of the treatment processes used and the human health risks associated with its use (2).

Alternatively, the National Guidelines for Water Recycling (2006) do not specify classes of water quality but allow a 'fit for purpose' approach to be used based on the contaminant levels present in the recycled water (3).

Table (1) recommended water quality specification for class A -D recycled water (2).

Class	E. coli (median) cfu/100ml	BOD5 mg/L (median)	Turbidity NTU 95% ile (max.)	SS, mg/L (median)	TDS, mg/L or EC, µS/cm (medians) TDS/EC	pH
A	<10	20	2 (5)	5	1000/1600	6-8.5
B	<100	20	-	30	1000/1600	6-8.5
C	<1000	20	-	30	1000/1600	6-8.5
D	<10,1000	-	-	-	1000/1600	6-8.5

Table (2) description of the five classes of recycles water (2).

Class of recycled water	Description
Class A+	No pathogens should be detectable. Safe for many uses other than those involving human consumption.
Class A	Very low levels of microbiological indicators. Safe for most end users, including those that could involve occasional human contact.
Class B and Class C	Only to be used with appropriate control measures in place.
Class D	Has the lowest microbiological quality with very limited number of

	recommended uses.

Table (4) provides a list of other water quality characteristics that can be import ant in determining the suitability for particular end uses of recycled water. This list is intended to provide a starting point for discussions between suppliers and customers concerning the recycled water quality and, where necessary, be a guide for furth er testing of the recycled water.

Table (4) characteristics of recycled water from sewage treatment plants relevant to sustainable use of recycled water (2)

Recycled water use or system configuration	Recycled water quality characteristics	Potential environmental operational or productivity impacts
Irrigation of crops/ grasses (all types)	Total Dissolved Salts (TDS)1 or Electrical Conductivity (EC) Sodium Adsorption Radio (SAR)2 Boron Chloride pH, water hardness Nutrients Nitrate ($N0_3$-)	Soil structure and soil fertility Stalinisation of soil and groundwater Damage to plant growth Damage to foliage Corrosion/fouling of pipes & fittings Bioclogging of irrigation equipment Eutrophication from mutrient en
Long distribution system and/or retention times	Biochemical oxygen demand (BOD)/ or suspended solids/turbidity	Odour problems, biofilm (slime) growth in pipes and storage tanks
Recycled water stored in lagoons	Nutrients	Algal blooms in storages
Significant trade waste inputs	Heavy materials Pesticides and stable organic compounds	Acute toxicity to some plants Accumulation of toxicants in food chain
Pasture irrigation, cattle shed washdown	Helminthes	Tapeworm infection in livestock
Environmental purposes (for example wetlands)3	Nutrients BOD Temperature, Chlorine, Ammonia	Algal growth Oxygen depletion in receiving waters, leading to death of aquatic organisms Harmful to fish and other organisms
Recreational purposes-ornamental water bodies and passive recreation (no swimming or boating)	Aesthetics Nutrients	Clarity, colour, oil and grease, debris Algal growth & blooms affecting aesthetics and biological health

1- TDS is a measure of the inorganic and dissolved salts such as sodium, calcium, magnesium, iron, chloride, sulphates, bicarbonate, nitrates and phosphates

2- SAR is the rate of sodium ions (Na_+) relative to calcium (Ca_+) and magnesium ions (Mg_+) in the soil solution. SAR indicates the potential for sodium to accumulate in the soil.

3- Recycled water characteristics important for environmental and recrea tional purposes are highly site specific receiving water quality (environmental values)

Table (5) presents suggested wastewater treatment processes, reclaimed water quality, monitoring, and setback distances for various types of water reuse. Attention is drawn to Construction Use and Industrial Reuse. The USEPA and California documents form the basis for most Australian publications and guidelines (4).

Table (5) Suggested Guidelines for Water Reuse (4)

Type of reuse	Treatment	Reclaimed water quality[2]	Reclaimed water monitoring	Comments
Construction use Soil compaction, Dust control, Washing aggregate making concrete	• Secondary[4] • Disinfection[6]	• ≤ 30 mg/l BOD[7] • ≤ 30 mg/l TSS • ≤ 200 fecal coli/100 ml[9,13,14] • 1 mg/l Cl_2 residual (minimum) [11]	• BOD – weakly • TSS – daily • Coliform - Daily • Cl_2 industrial - continuous	• Worker contact with reclaimed water should be minimized • A higher level of disinfection, e.g., to achieve ≤ 14 fecal coli/100 ml, should be provided when frequent work with reclaimed water is likely

Footnotes

1- These guidelines are based on water reclamation and reuse practices in the U.S., and they are especially directed at states that have not developed their own regulations or guidelines. While the guidelines should be useful in many areas outside the U.S local conditions may limit the applicability of the guidelines in some countries.

2- Unless otherwise noted, recommended quality limits apply to the reclaimed water at the point of discharge from the treatment facility.

3- Setback distances are recommended to protect potable water supply sources from contamination and to protect humans from unreasonable health risks due to exposure to reclaimed water.

4- Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contractors, and may include stabilization pond systems. Secondary treatment should produce effluent in which both the BOD and TSS do not exceed 30 mg/l.

5- Filtration means the passing of wastewater through natural undisturbed soils or filter media such as sand and/or anthracite, filter cloth, or the passing of wastewater through microfilters or other membrane processes.

6- Disinfection means the destruction, inactivation, or removal of pathogenic microorganisms by chemical, physical, or biological means. Disinfection may be accomplished by chlorination, UV radiation, ozonation, other chemical disinfectants, membrane processes, or other processes. The use of chlorine as defining the level of disinfection does not preclude the use of other disinfection processes as an acceptable means of providing disinfection for reclaimed water.

7- As determined from the 5-day BOD test.

8- The recommended turbidity limit should be met prior to disinfection. The average turbidity should be based on a 24-hour time period. The turbidity should not exceed 5 NTU at any time. If TSS is used in lieu of turbidity, the TSS should not exceed 5 mg/l.

9- Unless otherwise noted, recommended coliform limits are median values determined from the bacteriological results of the last 7 days for which analyses have been completed. Either the membrane filter or fermentation tube technique may be used.

10- The number of fecal coliform organisms should not exceed 14/100 ml in any sample.

11- Total chlorine residual should be met after a minimum contact time of 30 minutes.

12- It is advisable to fully characterize the microbiological quality of the reclaimed water prior to implementation of a reuse program.

13- The number of fecal coliform organisms should not exceed 800/100 ml in any sample.

14- Some stabilization pond systems may be able to meet this coliform limit without disinfection.

15- Commercially processed food crops are those that, prior to sale to the public or others, have undergone chemical or physical processing sufficient to destroy pathogens.

16- Advanced wastewater treatment processes include chemical clarification, carbon adsorption, reverse osmosis and other membrane processes, air stripping, ultrafiltration, and ion exchange.

17- Monitoring should include inorganic and organic compounds or classes of compounds, that are known or suspected to be toxic, carcinogenic, teratogenic, or mutagenic and are not included in the drinking water standards.

HAZARD OF RECYCLED WATER IN ROAD CONSTRUCTION

Technical Note 53 (2) identifies the risk of using recycled water for road construction and maintenance as:

- human health risks of workers and public (These are relatively well known -pathogens);
- engineering risk to road infrastructure such as pavements and structures (limited available information about associated risks - soluble salts, organics, sugars, fats and oils); and
- environmental risk to natural environment such as flora, fauna and watercourses
  - (Environmental risks are well understood in theory, however specific dose/response data are not available for all permutations of recycled water entering the natural environment – nutrient levels and dissolved oxygen)

Table (6) outlines the requirements that must be achieved in areas of risk described

Above (2).

Risk Area	Performance Targets
Human Health	No workers (including contractors) or members of the public will experience ill health effects from the use of recycled water in road related activities
Engineering	The use of recycled water does not lead to premature aging or distress (for example a reduced design life) or increasing maintenance costs of road pavements and structures.
Environment	No environmental harm is caused from use of recycled water in road related activities.

RESEARCH OBJECTIVES

There was a lake of published literature on using recycled water in construction activities such as soil compaction, pavement construction, dust suppression and concrete mixing even though in most guidelines these uses are described as potential options. Moreover, Current road construction, for instant, did not take the arrangement of reclaimed water pipeline into account formerly, which makes it inaccessible to built up any pipeline for the distribution of reclaimed water now (5).

Therefore, this paper focuses on examining the effect of using the reclaimed water on the characteristics of granular material specially the maximum dry density and the California bearing ratio.

To achieve the desired research objectives, two different types of types of crushed stone base course materials have been used in this study. The first one is crushed lime stone base course materials, while the second is crushed dolomite base course materials. The two types of materials have been examined using the potable water and the reclaimed water obtained from El-Birka sewage treatment plant. Table (7) shows the results of the chemical analysis performed on the used reclaimed water.

Table (7) the results of the chemical analysis performed on the used reclaimed water

E. coli cfu/100ml	3100
BOD5 mg/L	18
SS, mg/L	27
TDS, mg/L or EC, µS/cm TDS/EC	1480
pH value	7.4

Comparing characteristics of the used reclaimed water (displayed in Table 7), with the classes of reclaimed water in Table (2), it is found that the used reclaimed water is fulfilling the requirement of class C of reclaimed water.

A set of laboratory experiments is done on the examined unbounded road base course materials to examine the using of reclaimed water on both material compactions as well as California Bearing Ration CBR after soaking. Also, the CBR tests are repeated after one and two weeks to investigate the variation in material strength with time. For each performed test a control test, using potable water, is done to compare the obtained results with the control result.

The following part of the papers shows the laboratory experiments done on the examined base course materials. Table (8) shows the obtained laboratory tests performed on the examined unbounded road base course using potable water as control tests and using the reclaimed water.

Table (8) shows the executed laboratory tests on the examined road base course materials*.

Test	Used water	
	Potable water (control samples)	Reclaimed water

	1	2	1	2
Disintegration (%)	1.08	0.66	1.79	0.79
Absorption (%)	9.6	1.7	9.7	1.9
Maximum dry density (gm/cm3)	2.145	2.226	2.132	2.218
Optimum water content (%)	8.9	7.4	9.4	7.8
CBR after soaking (%)	63	83	59	81
Retest of CB after one week	62	80	60	78
Retest of CBR after two weeks	60	78	58	77
Average CBR	61.67	80.33	59	78.67

1- crushed lime stone base course material

2- crushed dolomite base course material

* all performed laboratory experiments are executed in road laboratory, public works department, faculty of engineering, Ain Shams University.

Figure (1) shows the CBR results of the examined crushed lime stone base course material and Figure (2) shows the variation in CBR values of examined crushed lime stone base course compared with the control tests (done using potable water).

Similarly, Figure (3) shows the CBR results of the examined crushed dolomite base course material and Figure (4) shows the variation in CBR values of examined crushed dolomite base course compared with the control tests (done using potable water)

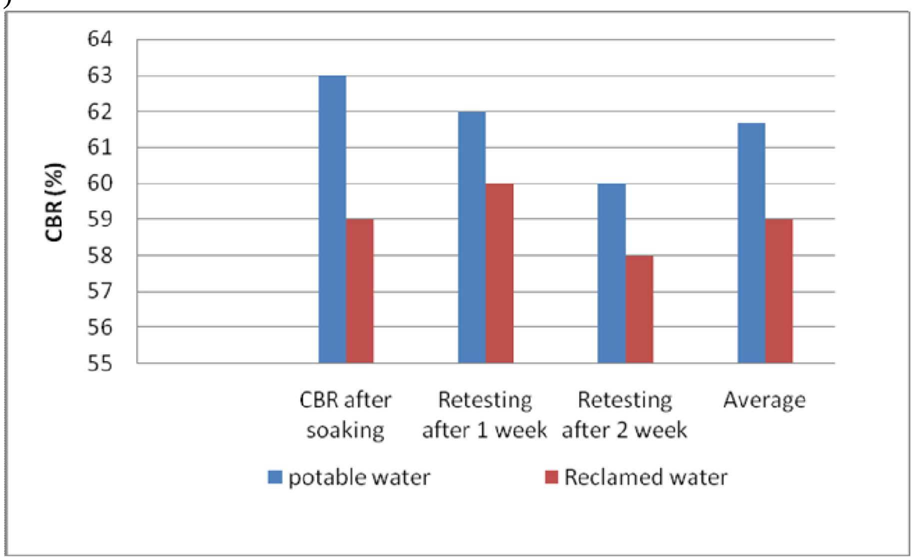

Figure (1) CBR results of the examined crushed lime stone base course material

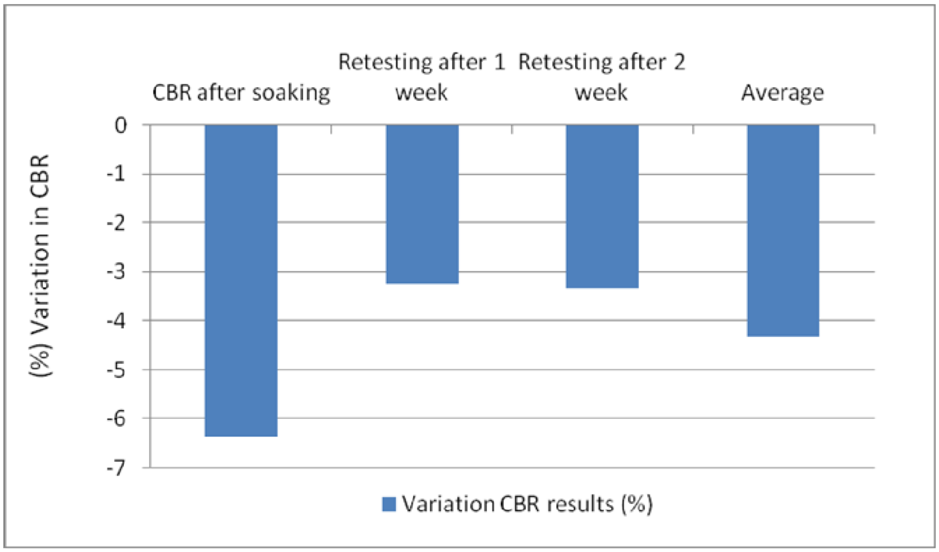

Figure (2) shows the variation in CBR values of examined crushed lime stone base course compared with the control tests (done using potable water)

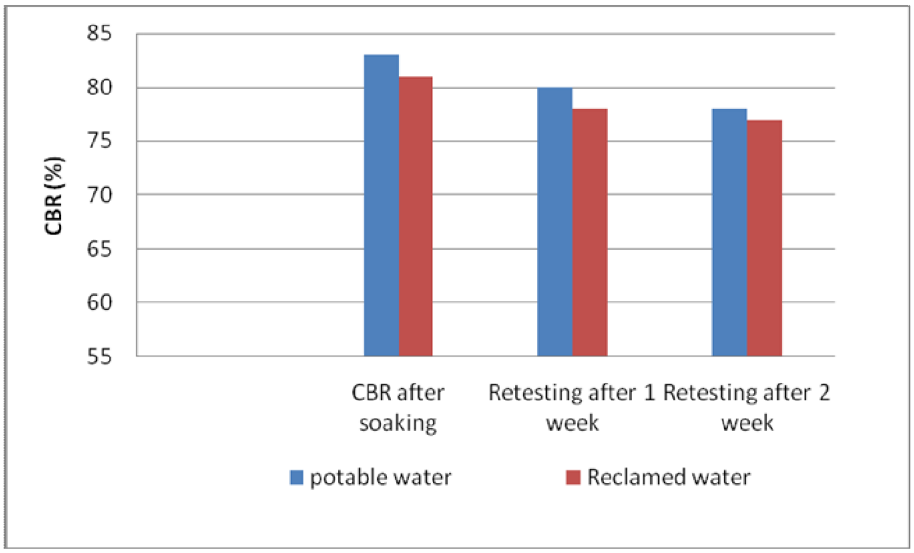

Figure (3) CBR results of the examined crushed dolomite base course material

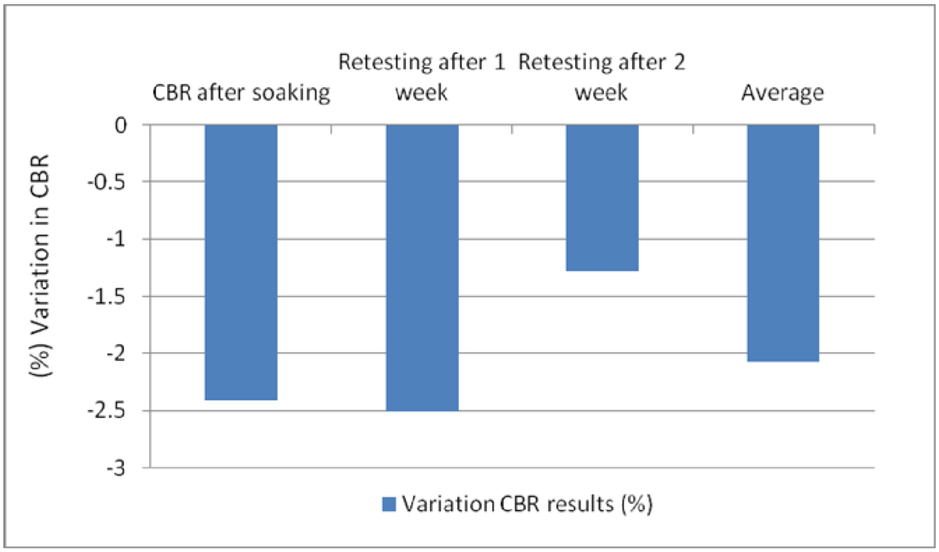

Figure (4) shows the variation in CBR values of examined crus hed dolomite base course compared with the control tests (done using potable water)

INTERPRETATIONS OF RESULTS

From Table (8) the following results are found:

- Disintegration in percentage of examined unbounded base course materials using reclaimed water is slightly higher than disintegration in percentage using potable water (control tests)
- Absorption in percentage of examined unbounded road base course materials is approximately equal to the absorption in percentage using potable water (control test)
- No significant changes in the maximum dry densities obtained using modified proctor test on examined unbounded road base course materials if compared with the control samples (done using potable water). Nevertheless, the optimum water content using reclaimed water is slightly higher than that obtained using potable water (control samples).
- The obtained CBR using reclaimed water is slightly lower than the CBR using potable water (control tests). Also, the repeated CBR after one and two weeks are slightly lower than the obtained repeated CBR result using potable water (control testes).

Figure (1) shows the CBR results of unbounded crushed lime stone base course material using reclaimed water and the control results (using potable water). As mentioned, the CBR results using reclaimed water is slightly lower than control tests. Figure (2) shows these variations, which vary from -2.3% to -6.3%

Similarly, Figure (3) shows the CBR results of unbounded crushed dolomite base course material using reclaimed water and the control results (using potable water). As mentioned, the CBR results using reclaimed water is slightly lower than control tests. Figure (4) shows these variations, which vary from –1.2% to –2.4

Also, an important conclusion could be extracted from the results as the variation (reduction) in CBR values of examined unbounded crushed dolomite road base course materials is much lower than the reduction in CBR values of examined unbounded crushed lime stone base course materials. Therefore, reclaimed water is much recommended to be used in compaction of unbounded dolomite base course materials.

CONCLUSIONS AND RECOMMENDATIONS

From the results the following conclusions and recommendations can be extracted:

- Two different types of unbounded base course materials are examined using reclaimed water obtained from El-Berka sewage treatment plant.
- The chemical analysis performed on the used reclaimed water showed that it fulfilled the requirements of class C reclaimed water.
- The results shows that reclaimed water can be used in compaction of unbounded road base course materials. However, it is much recommended to use it with unbounded crushed dolomite road base course materials as the variation (reduction) in CBR compared with the results using potable water (control tests) is not significant.
- It is recommended to implement a test section in an under construction road project using reclaimed water in compaction possess of unbounded materials to verify the applicability and encourage switching to reclaimed water in road construction.

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