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# Improvement of Forest Road Gravel Surfacing Quality by Nano-polymer CBR PLUS

**Majid Lotfalian, Aidin Parsakhoo, Amir Savadkoohi**

***Abstract***

*In this study, CBR PLUS was used on gravel roads to reduce erosion and consequently maintenance costs of forest road network. Nano-polymer CBR PLUS with weight percentages of 0.25, 0.50, 0.75 and 1.00% in water were added to the surfacing materials of a forest road in Nekachoob Company of Iran. A comparative soil chemical and mechanical test for untreated and treated soil was carried out to observe variations in results. The results showed that by increasing the percentage of CBR PLUS, the soil fine particles content decreased. In addition, with increasing the CBR PLUS content, a decrease of the liquid limits was observed in soil. Soil treated with CBR PLUS, resulted in improvement of soil dry density and California bearing capacity (CBR). Moreover, the amount of Calcium, Magnesium, Potassium ions increased with the increasing CBR PLUS. Finally, it was concluded that 1.00% of nano-polymer CBR PLUS acted better in comparison with lower concentration. However, it is suggested that higher levels of this substance should be evaluated in future studies.*

*Keywords: roadway, gravel surface, stabilizer, soil mechanical tests, nekachoob*

## 1. Introduction

Road network plays a major role in the movement of the country's people and goods. Most of the forest roads in the Hyrcanian zone have a gravel surface and the un-sieved materials of roadways consist of sandy to sandy clay loam soil material. Gravel is brought to the site from a quarry or stream bed. Sometimes, oversize stone or clay particles can be detected in stream materials. These poor materials of road surfaces are subject to erosion and degradation, which lead to sedimentation (Miller et al. 1998, Liu et al. 2009). The performance of a forest road depends on the quality of two layers including natural earth and improved surface layer (Inyang et al. 2007). Coarse-grained soils composed of a mixture of coarse and fine gravels with little or no fines are suitable for natural earth. Above the compacted natural earth, there is an improved layer with the thickness of 15–20 cm of well graded materials (Sessions 2007). The capacity of these layers to support the loads applied to the ground is defined as bearing capacity. A useful parameter for determining the strength of subgrade material is the California Bearing Ratio (CBR). CBR measurements in forest road/gravel road conditions are often carried out using the light falling weight deflectometer (LFWD), the dynamic cone penetrometer (DCP) and the conventional falling weight deflectometer (FWD) (Kaakkurivaara et al. 2015). It is crucial for forest engineers to develop gravel forest roads with a CBR value. The surface should be kept smooth and free from holes and ruts (Mishra 2012, Krishna et al. 2013). Clay in gravel road feels slippery and sticky when moist. Soil engineering properties in forest road construction depend on clay content. Plastic clays exhibit shrink/swell behavior with a change in moisture content (Sharma et al. 2008). Swelling of clays causes serious damages in the gravel surface of forest road especially during the harvesting operation (Azzam 2014).

Al-Rawas et al. (2005) used various stabilizers including lime, Portland cement and lime/cement mixtures to consolidate subgrade or base materials and concluded that lime shows the greatest improvement to compressibility CBR values and swelling. Nowadays, numerous types of nano-polymer particles/nano composites are used for soil stabilization in engineering operations. CBR PLUS is a unique cation reactive organic compound, which forms protective, oily layers on the surface of soil and clay particles. It reduces ion mobility and ion exchange and simultaneously makes the clay material hydrophobic by eliminating the adsorption of water. CBR PLUS has been successfully used on gravel roads to reduce maintenance costs (Petry and Little 2002). CBR PLUS is a concentrated liquid, of which 100 liters consolidate between 10,000 and 20,000 square meters of soil to a depth of 15 cm when diluted with water. Taherkhani et al. (2012) used CBR PLUS for improving physical and mechanical properties of different combinations of clay, sand and gravel. They concluded that the CBR PLUS decreases the plasticity index and permeability and increases the compressive strength and CBR of the combinations. The combination of 50% gravel, 30% sand and 20% of clay is found to attain the highest strength with the stabilizer (Piratheepan et al. 2010).

Unfortunately, despite of wide distribution of clay soils in Hyrcanian forest and their high destructive influence on road surface materials, no research has been conducted regarding improvement of such clay by nano-polymers. Therefore, finding of low cost nano-polymers and efficient concentration to stabilize these materials is important for the prosperity in forestry operations. CBR PLUS has the potential to increase the strength and durability of road construction materials. The aim of the present study was:

⇒ to investigate the effects of nano-polymer CBR PLUS on some physical and mechanical properties of road surface materials

⇒ to determine the optimum percentage of CBR PLUS for improving the quality of forest road gravel surface

⇒ to assess the effects of CBR PLUS on some chemical properties of runoff produced from road surface materials

## 2. Materials and methods

### 2.1 Study area

This study was conducted for forest roads in district one of Nekachoob forestry plan. This forest is located in the South-East of Neka city (from 36°28′55′′ to 36°36′55′′ North Latitude and from 53°20′15′′ to 53°35′00′′ East Longitude), Iran. The total length of forest road is 24 km with maximum bearing capacity of 45 tons. These roads are classified as secondary forest roads and used for the aims of forestry and wood transportation. The forest is located at an altitude of 140–600 m above sea level. The precipitation is 618 mm throughout the year. The climate of the region is mid moist and temperate. In this study, a segment of the road with a dimension of 50 meter × 4 meter and gravel surfacing depth of 0.15 meter was selected for treatments.

### 2.2 Data collection and measurements

In this study, the surfacing material was brought to the site from a stream bed to improve the surfacing quality of a forest road. Five macro plots with dimensions of 2×3 meters were established in longitudinal slope direction of the road. One of these macro plots was untreated and others were treated by CBR PLUS nano-polymer with weight percentages of 0.25, 0.50, 0.75 and 1.00% in relation to the weight of water, in

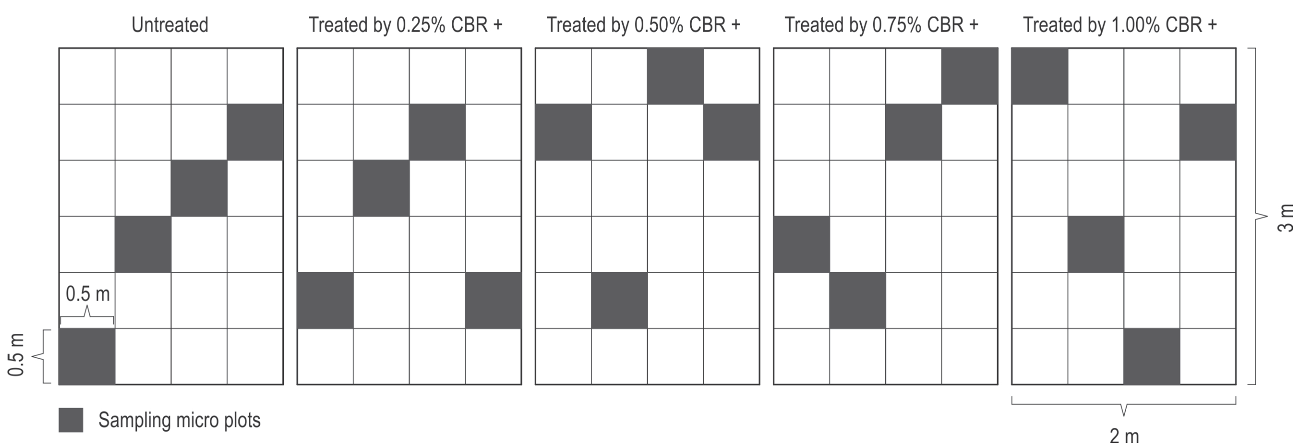


**Fig. 1** Schematic of sampling design in study area

which CBR PLUS was solved. In this study, the technical performance of CBR PLUS nano-polymer showed lower concentration, because CBR PLUS nano-polymer is still considerably more expensive than the conventional methods and a small increase in concentration can enormously increase overall costs when considering the total length of road network. Besides, the biological effects of this nano-polymer have not yet been recognized. Each macro plot was divided into 24 micro plots with dimensions of 0.5×0.5 meters and then four of them were randomly selected for soil analysis (Fig. 1). After two weeks from the treatment time, 48 kg of the surfacing material was collected from the selected micro plots to investigate the variations in mechanical status of materials. Soil mechanic test, including Atterberg limits (liquid limit, plastic limit and index), moisture, density AASHTO (Proctor compaction) and CBR, was carried out in the laboratory.

Sieve Analysis: Dry and wet sieve analysis of the soil was performed in the laboratory. The sieve sizes were 0.075, 0.15, 0.60, 2.00, 2.36, 4.00 and 8.00 mm. The particle size distribution was obtained from records of the weight of soil particles retained on each sieve and is usually shown as a graph of 'percentage passing by weight' as a function of particle size. The soil particles larger than 0.06 mm in diameter can be described as coarse and the smaller ones as fine particles.

Water content: Soil moisture was calculated using Equation (1):

$$W = \frac{W_1 - W_2}{W_2 - W_3} \times 100 \qquad (1)$$

Where:

$W_1$ weight of the can (g) + wet soil (g)

$W_2$ weight of the can (g) + dry soil (g)

$W_3$ weight of the empty can (g)

The tested soil samples were oven-dried at 105 °C for 24 hours.

Atterberg Limits: Liquid Limit (*LL*) was determined using Equation (2) (Atterberg 1911):

$$LL = W_{\mathrm{N}} \times \left(\frac{N}{25}\right)^{0.121} \qquad (2)$$

Where:

$N$ number of drops of the cup required to close the groove

$W$ soil moisture content (%) at which the groove is closed

The moisture content, as determined in Equation (1), when the soil sample is cracking, is the Plastic Limit (*PL*).

The Plasticity Index (*PI*) of the soil is the numerical difference between its liquid limit and its plastic limit (Equation 3, Atterberg 1911):

$$PI = LL - PL \qquad (3)$$

Standard Proctor test: To assess the amount of compaction and the water content required in the field, compaction test (Standard Proctor test) was done on the soil. The water content, at which the maximum dry density is attained, was obtained from the relationships provided by the test (Equation 4, Davidson and Gardiner 1949).

$$P_{\mathrm{d}} = \frac{P_{\mathrm{W}}}{\left(\frac{W}{100} + \frac{1}{G_{\mathrm{s}}}\right)} \qquad (4)$$

Where:

$P_{\mathrm{d}}$ dry density of the soil g/cm$^3$

$G_{\mathrm{s}}$ specific gravity of the soil being tested (assume 2.70 if not given)

$P_{\mathrm{W}}$ density of water in g/cm$^3$ (approximately 1 g/cm$^3$)

$W$ moisture content (%)

In the Proctor test, the soil was first air dried and then separated into samples. The water content of each sample was adjusted by adding water. The soil was then placed and compacted in the 4-inch-diameter Proctor compaction mould using 25 blows by a 5.5 lb standard hammer falling 12 inches. At the end, the sample was removed from the mould and the dry density and the water content of the sample were determined for each Proctor compaction test. Then, a curve was plotted for the dry density as a function of the water content. From this curve, the optimum water content to reach the maximum dry density can be obtained.

California Bearing Ratio (CBR): The CBR value of a soil is an index related to the strength of the soil (Equation 5, Yetimoglu et al. 2005).

$$Y_{\mathrm{d}} = \frac{Y_{\mathrm{t}}}{1 + W} \qquad (5)$$

Where:

$Y_{\mathrm{d}}$ equivalent dry unit weight of the soil

$Y_{\mathrm{t}}$ total unit weight

$W$ moisture content (%)

In the CBR test, soil samples were compacted using metal rammer to obtain unit weights both above and below the desired unit weight. After allowing the sample to take on water by soaking, or other specified treatment such as curing, each sample was subjected to penetration by a cylindrical rod. Stress versus penetration depth were plotted to determine the CBR for each specimen. The CBR at the specified density was determined from a graph of CBR versus dry unit weight.

Rainfall Simulation on treated plots: A portable single nozzle (nozzle code: Schlick r86510) rainfall simulator simulated rain with drop size of 3 mm for 20 min at the intensity of 32 mm/h. Water was rained from the nozzle mounted 2 m above the ground onto 20 micro plots of 0.5×0.5 meters bordered by a steel structure. Runoff water samples were collected by water gauge and then transmitted to the laboratory. The road was a secondary road and during the study, all road traffic was stopped for 30 days.

Measuring the runoff Calcium (Ca), Magnesium (Mg) and Potassium (K): Surface runoff suspension of each gauge was sampled by 0.3-L glass recipients. Immediately after the collection and after the settling of the sediment in the glass, a sample of the solution was removed for analysis of Ca, Mg and K contents. Ca was measured using the NaOH titration method. Mg was determined with atomic absorption spectrophotometer. The available K was determined by ammonium acetate extraction at pH 9.

Statistical package for social sciences (SPSS) were used for data analysis and least significant difference (LSD) was used for comparing averages.

## 3. Results

When making the surface layer of forest roads, it is not enough to apply individually the bearing capacity of clay materials, gravel and sand. State Standard Specifications (1996) recommended that the blend of different size aggregates should be 40–80% hard stone graded from 6 to 76 mm in diameter in the base and 19 mm aggregate for surface gravel (crushed stone) with 20–60% sand (less than 6 mm) and 8–15% fines. Greater amount of clay in the surfacing layer of forest road makes it prone to erosion and sensitive to freezing. For the purpose of this study, surfacing materials were used as follows: 42% of gravel, 37% of sand and 21% of silt and clay. Then, these combinations were stabilized with different percentages of nano-polymer CBR PLUS. As shown in Fig. 2, a certain procedure cannot be stated for the effects of CBR PLUS upon plastic limit and plastic index of soil. The liquid limit decreased 4% by increasing CBR PLUS (Table 2). The rate of soil dry density has increased by heightening CBR PLUS. Using different moisture contents from 4% to 9%, the dry unit weight measured at the end of each Proctor Test were plotted, and subsequently the maximum dry density and optimum water content for each CBR PLUS treatment were obtained. It was observed that, by adding CBR PLUS to the road surface materials, the maximum dry density changed significantly from 2.09 (control sample) to 2.17 g/cm$^3$ (1.00% CBR PLUS) (Table 2). The state at the peak is said to be that of 100% compaction at a particular compactive effort, the curve is usually of a hyperbolic form, when the points obtained from tests are smoothly joined. When water is added to dry soil, it helps in bringing the solid particles close by coating them with thin films

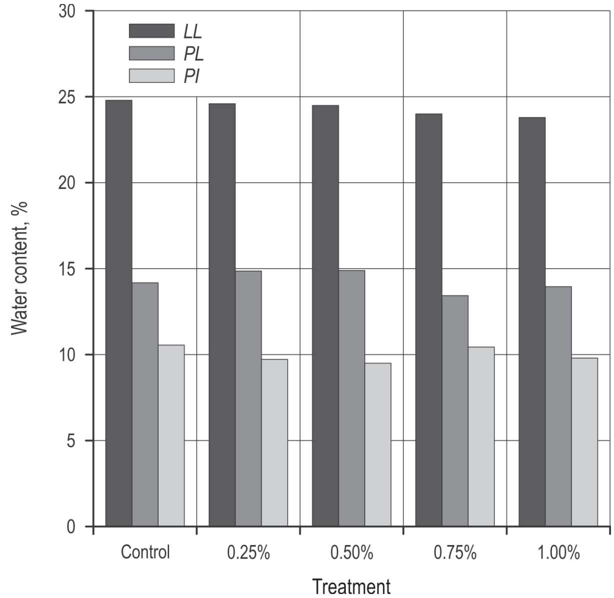


**Fig. 2** Effect of different percent of CBR PLUS on Atterberg limits including Plastic Index (*PI*), Plastic Limit (*PL*) and Liquid Limit (*LL*)

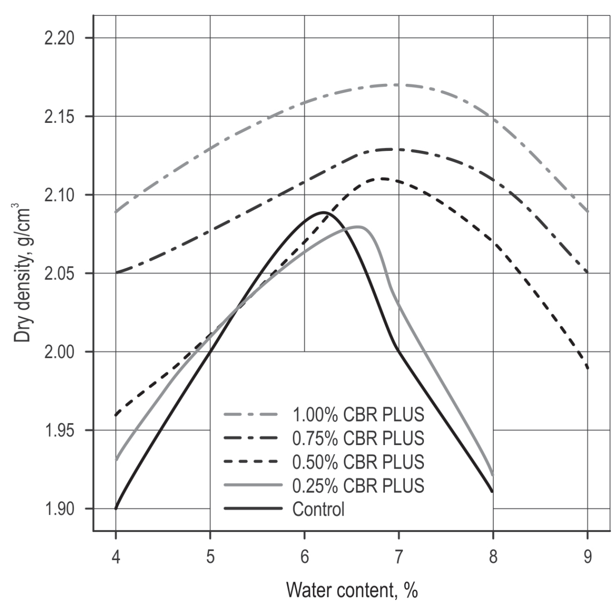


**Fig. 3** Dry density of materials treated by CBR PLUS in Proctor test

**Table 1** Weight distribution of particle size for GM (Silty gravel or silty gravel with sand based on unified soil classification system) materials treated by CBR PLUS at the depth of 0–20 cm

| Treatment | Fine particles, % | Coarse particles, % |
|---|---|---|
| Control | 28 | 72 |
| 0.25% CBR PLUS | 27 | 73 |
| 0.50% CBR PLUS | 22.9 | 77.1 |
| 0.75% CBR PLUS | 20.9 | 79.1 |
| 1.00% CBR PLUS | 19.9 | 80.1 |

of water. The peak of dry density was detected at water content of 7% (Fig. 3).

According to the grading curve of the treated and untreated samples, it can be concluded that by heightening the CBR PLUS from 0.25% to 1.00%, the amount of soil fine particles are reduced from 28% (control sample) to 27% (0.25% CBR PLUS) and then decreased by 8.1% when adding 1.00% CBR PLUS. The 1 percent treatment holds the least weight percent of fine particles and maximum weight percent of coarse particles compared to other treatments (Table 1). Particle size distribution analysis revealed that the materials treated by 1.00% CBR PLUS contained more sand and gravel size particles (>0.06 mm) as compared to materials treated with lower percentages of CBR PLUS. Indeed, considering the grain size distribution curves for 0.25%, CBR PLUS and control sample are poorly graded (Fig. 4).

Fig. 5 shows the California bearing ratio increased by increasing the CBR PLUS. It was observed that by adding CBR PLUS to the road surface materials, the CBR values changed significantly from 73% (control sample) to 78% (0.25% CBR PLUS) (Table 2). It was identified that the amount of runoff Calcium, Magnesium, Potassium in treated plots was higher than in untreated plots after rainfall simulation. The amount of these ions increased with the increase of the percentage of CBR PLUS (Table 3).

## 4. Discussion

The effect of using a new stabilization product, CBR PLUS, on gravel surfacing layer of forest road

**Table 2** Comparison of some mechanical properties of materials treated by different weight percentages of CBR PLUS

| Treatment | Dry density g/cm$^3$ | CBR, % | Plastic index, % | Liquid limit, % |
|---|---|---|---|---|
| Control | 1.98$^b$ | 73$^b$ | 10.55$^a$ | 24.79$^a$ |
| 0.25% CBR PLUS | 1.99$^b$ | 78$^{ab}$ | 9.72$^a$ | 24.59$^a$ |
| 0.50% CBR PLUS | 2.03$^{ab}$ | 82$^a$ | 9.50$^a$ | 24.49$^a$ |
| 0.75% CBR PLUS | 2.09$^a$ | 85$^a$ | 10.44$^a$ | 24.00$^b$ |
| 1.00% CBR PLUS | 2.13$^a$ | 88$^a$ | 9.80$^a$ | 23.79$^b$ |

Note: Different superscripts show significant difference at probability level of 5% based on LSD test

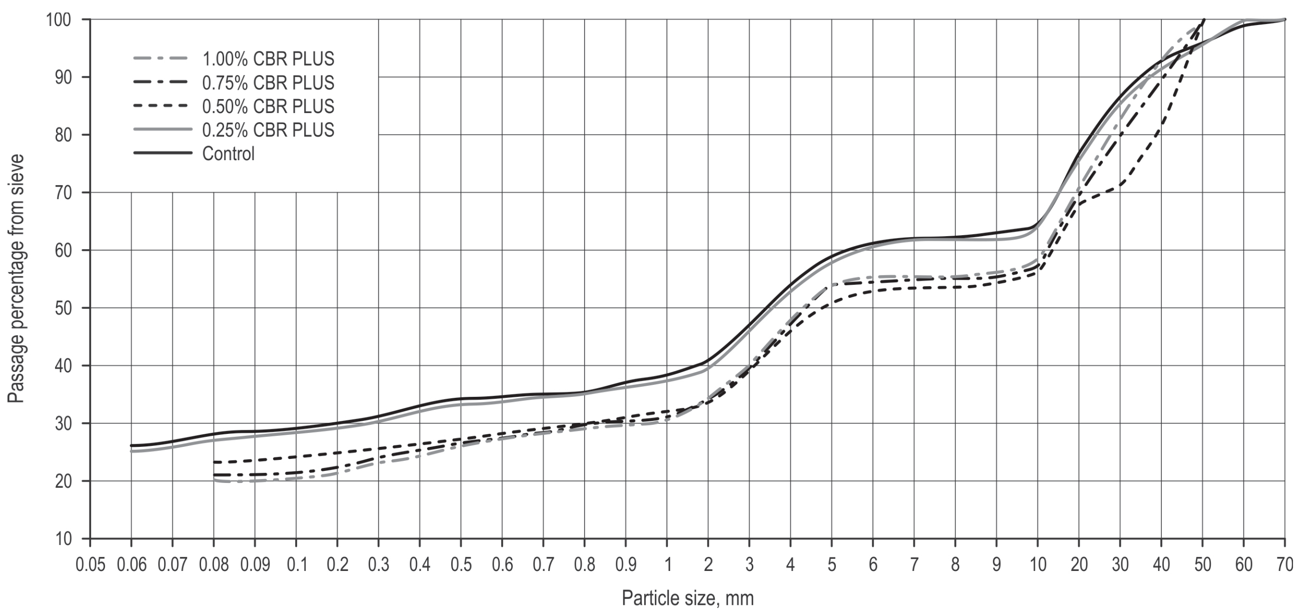


**Fig. 4** Curve of weight distribution of particle size for materials treated by different percentages of CBR PLUS

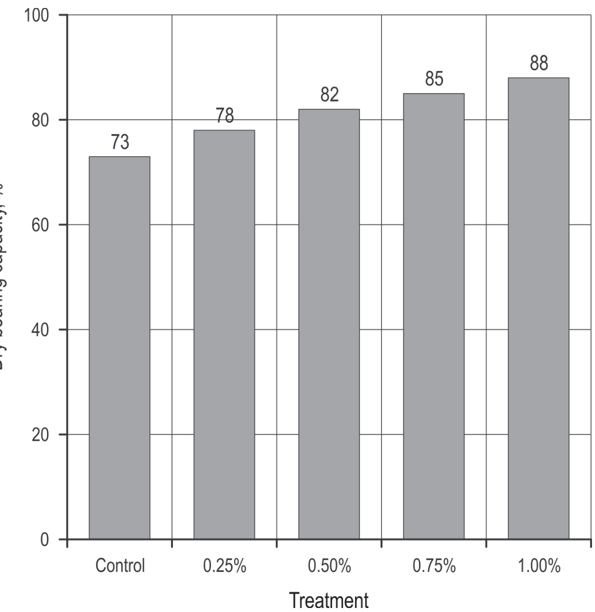


**Fig. 5** Variations of California bearing ratio (dry CBR) by increasing the percentage of CBR PLUS

was studied by conducting different experiments such as Atterberg's limits, Standard Proctor and California bearing ratio tests on soil mixed with different percentages of CBR PLUS: 0.25%, 0.50%, 0.75%, and 1.00%. In a study in Turkey, polymer was used as an additive for the improvement of a base road material (Kavak et al. 2010). Nanotechnology is one of the most active research areas dealing with civil engineering and construction materials. CBR PLUS is often applied in small quantities on the road surface by using a water tanker normally used for dust control.

Water is a natural destroyer of roads. CBR PLUS nanotechnology allows permanent waterproofing of soils and aggregate surfaces. In this study, the liquid limit decreased significantly (4%) by increasing CBR PLUS, which was in agreement with the findings of Taherkhani et al. (2012). They concluded that the CBR PLUS decreases the plasticity index and permeability of materials. In addition, Musavi et al. (2014) showed that the CBR PLUS decreased the liquid limit and plasticity index. The Atterberg liquid limit is the water content at which the body begins to flow, using a specific apparatus. High liquid limits indicate soils of high clay content and low bearing capacity. Therefore, when a soil liquid limit decreases, the soil mechanical resistance improves (Jianqiao et al. 2012).

The stabilization process of road surfacing materials by nano-polymer CBR PLUS requires more than two weeks, which is called supplementary period (Lahalih and Ahmed 1998). The density rate of dry soil increased by heightening CBR PLUS, which indicates that the shear resistance increased and soil infiltration decreased. Musavi et al. (2014) showed that the CBR PLUS can increase the optimum moisture and maximum dry density. We found that by heightening the CBR PLUS, the amount of soil fine particles reduced. The combination of 50% gravel, 30% sand and 20% of clay is found to attain the highest strength with the stabilizer (Piratheepan et al. 2010). Moreover, California bearing ratio increased by increasing the CBR PLUS and this is the indicator of high resistance and bearing capacity of materials. This finding was also observed by several other researchers (Taherkhani et al. 2012, Musavi et al. 2014). Increment in CBR value by nano-polymer CBR PLUS is helpful in reducing the quantity of gravel materials and consequently thickness of the surfacing layer of forest road.

In the present research, after rainfall simulation, it was identified that the amount of runoff Calcium, Magnesium and Potassiumin was higher in treated plots than in untreated plots. The amount of these ions increased with the increase of the percentage of CBR PLUS. It was proved that the clay particles cause absorption of metal ions (Velde 1995, Jain and Ram 1997). The metal ions, while absorbing a high amount of water, cause the decrease of soil resistance and increase of its volume. These ions are called water absorbents. CBR PLUS is a kind of product made from organic Solphonic Asid, which destructs water absorbents and breaks the absorbents-clay link (Yilmaz and Civelekoglu 2009, Taherkhani and Javanmard 2015). Then it would be replaced by absorbents and make the Clay hydroponic. This leads to the release of ions like Calcium, Magnesium and Potassium, heightening the resistance and bearing ratio of soil.

**Table 3** Amount of runoff Calcium, Magnesium, Potassium in treated and untreated plots (mg/Li)

| Variables | Control | 0.25% CBR PLUS | 0.50% CBR PLUS | 0.75% CBR PLUS | 1.00% CBR PLUS |
|---|---|---|---|---|---|
| Calcium | 120 | 145 | 172 | 196 | 224 |
| Magnesium | 13 | 17 | 21 | 25 | 29 |
| Potassium | 7 | 7 | 8 | 8 | 9 |

The conventional method of surfacing requires high maintenance costs. Road gravel surface making use of CBR PLUS may have a high initial cost but it has nearly no maintenance costs, which will have a positive effect on the road economy in a long-run. In this study, it was concluded that 1.00% of nano-polymer CBR PLUS acted better in relation to the weight of water, in which this material is solved, in comparison with other treatments. However, it is suggested that higher levels of this substance should be evaluated in future studies.

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