

Research Article

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Utilization of marble piece wastes as base materials

<https://doi.org/10.1515/geo-2020-0197>

received June 10, 2020; accepted September 23, 2020

Abstract: With the increasing population, the limited natural sources are decreasing and environmental pollution is increasing. In recent years, the increase in industrial wastes and the high cost of disposal methods of these wastes have necessitated the evaluation of industrial wastes in industrial businesses. Truck tires, blast furnace slag, fly ash, waste concrete, and dismantled asphalt coverings can be listed as industrial wastes. If these wastes are used, environmental pollution is reduced, and contributions are made to the country's economy. In this study, an evaluation of marble waste as base material was performed. In this scope of work, physical tests, a modified Proctor test, a dry/wet California bearing ratio test, and density of soil in place by the sand cone test were conducted. Also, X-ray diffraction, X-ray fluorescence, and mercury intrusion porosimetry analyses were performed on these marble waste. As a result, the physical and mechanical properties of marble waste were determined. In conclusion, marble waste has been found suitable as a base material according to the Technical Specifications of Turkish Highways.

Keywords: marble waste, modified Proctor test, California bearing ratio, field density test

1 Introduction

In recent years, the increase in industrial wastes and the high cost of disposal methods of these wastes have necessitated the utilization of industrial wastes in different business lines. One of the EU Sustainable Development

Strategy objectives is increasing the efficient use of natural resources and preventing waste generation by applying the concept of life cycle and promoting reuse and recycling [1]. The objectives of the EU waste management policy are to eliminate, reduce, and prevent pollution, to prevent the exploitation of nature and natural resources in a way that harms the ecological balance, to ensure their rational management, and, to use waste by quality standards [2]. Particularly in industrial production enterprises that produce large quantities, a large amount of waste is produced. Quarry waste is just one of them, and, usually generates significant amounts of natural stone waste. At the same time, this waste accounts for half of the complete stone extracted [3]. Marble wastes are often dumped in landfills because 40% of marble waste are small pieces and of low or zero economic value [4].

The amount of quarry waste that can be stored varies significantly, and open pits and quarries generate much more mine waste than an underground mine [5,6]. Therefore, released wastes cause pollution on the soil, toxic gases, and environmental pollution. To decrease the environmental impact of wastes, solid wastes are recycled for use in building construction or production of building materials [7]. In particular, the limited amount of natural aggregates required for road construction and the increase in transportation costs warrant the use of industrial wastes. Many wastes in the world are evaluated, and contribute to the economy is provided. Rice and wheat husks, peanut husks, cotton stalks, and vegetable wastes are used for cement boards, isolation boards, wall panels, building panels, bricks, and acid-resistant cement production.

Coal residues, steel slag, bauxite red sludge, and construction debris waste are used to produce bricks, blocks, tiles, cement, paint, fine and coarse aggregates, concrete, wood by-products, and ceramic products [6]. Wastes from mining and the iron, copper, zinc, gold, and aluminum industries are used to produce bricks. At the same time, both fine and coarse lightweight aggregates and tiles are made from waste gypsum, lime sludge, limestone waste, broken glass and ceramics, marble processing, and kiln dust wastes. Additionally, blocks, bricks,

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cement clinkers, gypsum fiber boards, and gypsum plaster are used in cement and supersulfate production. Also, hazardous wastes include galvanizing wastes, metallurgical residues, waste sludge, and waste treatment plants, and tannery wastes are used in the production of boards, brick, cement, ceramics, and tiles [8].

With the advances in technology, the rise and acceleration of housing construction have caused an ever-increasing use of marble. Therefore, to meet the increasing demand, the number of marble-processing plants in Turkey and throughout the world has increased, which has led to the rise of marble waste. In general, quarry waste is obtained during the crushing process of materials in crushers. Also, marble wastes are produced during the cutting of the marbles to produce regular geometric shapes. In recent years, with the rapid development in the construction sector, the use of marble in buildings has been continuously increasing, and the number of marble enterprises has been rising in parallel. Also, because of the use of marble in the form of slabs, marble blocks are cut into large plaques, increasing the marble waste. The use of quarry wastes such as marble waste as building materials prevents the reduction of natural rivers and mining materials [9]. Marble wastes in the quarry environment are in the form of slurry/powder and stones of irregular shape and size, which are dumped in open lands and along roads, which create a lot of environmental and health problems, as shown in Figure 1 [10–13]. Air pollution, water pollution, accidents due to dumping, accidents due to slippery roads, and loss of flora and fauna may be added as problems [13]. Waste rocks are stacked near to the quarry for associated with transport costs. During mining, a massive quantity of solid wastes is being generated as by-products. In this case, it is important to recycle and use such an enormous amount of waste in the production of construction materials. Also, transportation costs are reduced with the utilization of quarry waste in existing areas [14–16]. The aim of this study was to evaluate marble waste, which is an industrial waste. Therefore, cost expenses will be reduced with the region's evaluation process where the wastes are located.

The classification of superstructures according to the properties of the materials used in the road pavement layer consists of rigid and flexible structures according to their types and construction techniques. The choice of the pavement depends on the traffic, the soil, environmental conditions, and economic conditions. The rigid pavement is formed by coatings using cement concrete. In pavement, the role of concrete is to transmit traffic loads to the base and, at the same time, to prevent the base from deforming. Flexible pavement is called the

superstructure and is formed by using bitumen coatings. Flexible pavement transmits loads from traffic to substrates. The function of the base layer beneath the surface is to transfer vehicle loads to the subbase without exceeding the bearing capacity. The base layer is applied using granular material or stabilized material taken from the furnace and increases the load-bearing capacity of the pavement. The lower foundation layer's function is to create a working area for the construction of the bitumen-coated layers. The quality of granular materials used in this layer may be lower than that of the base layer [17,18]. At the same time, the subbase layer is the layer that spreads the loads from the traffic to the base and provides resistance against frost/water [19]. The subgrade is formed from compressed natural soil. It is the final stage of transmission of the pavement load and should have good drainage [20]. In short, the properties of the materials used in road construction must meet the specified criteria. When the existing road material does not meet the requirements, mechanical or chemical soil improvement methods are used. Improvements to the soil are usually made by the use of lime, cement, and so on. Also, with the increase in industrial wastes, various waste is used for soil improvement. These industrial wastes, such as blast furnace slag, fly ash, construction waste, dismantled asphalt pavement, and waste marble, can be used for road construction. Waste materials are commonly used as an alternative to nonrenewable resources.

Waste rock may be considered as materials for roads, building foundations, or cement factories, depending on its geotechnical and geochemical characteristics [5,21]. These materials are generally used in the transport infrastructure fields due to the enormous amount of material required [22–28]. It is important to split/fill the natural soil to the desired height along the highway route to ensure the safety, speed, and comfort required for motor vehicles. Unfortunately, unused wastes are refused and accumulated as mounds of marble waste close to extraction quarries [29]. Figure 2 shows the flow chart of reusing marble waste processes. The right column in Figure 2 illustrates the steps used in the procedure used to evaluate and use pieces of marble waste in this study.

Many quarry waste materials are being studied as sustainable materials [30–36]. Ilıcalı [37] researched the usability of Erdemir slag as an aggregate. For the compatibility of subbase and base layers, slag breaking and sieving as well as mixing with additional materials such as Portland cement, cement, lime, and asphalt cement were studied. The slag's chemical and physical properties were found to be suitable for the pavement layers. The mechanical properties of the mixtures were above the

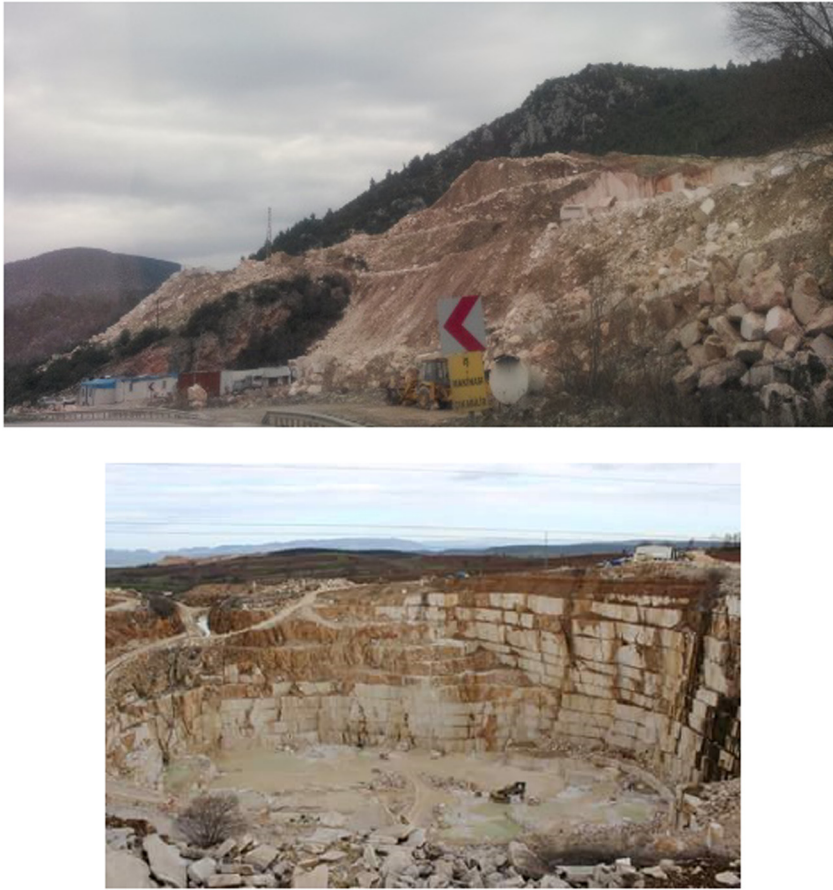


Figure 1: Marble waste dumped in open lands, Bilecik, Turkey.

desired values in the base and subbase layers. Ilıcalı also stated that it is economical to use Erdemir slag on the road superstructure at sites far from the quarries. Yılmaz et al. [38] examined the suitability of using the quarry material produced in the Seslidere quarry as pavement material on the İyidere–Çayeli route to the Black Sea Region. Los Angeles abrasion loss, peel strength, resistance to weathering (Na_2SO_4 freezing loss), brittleness, polishing value, flatness index, specific gravity, and absorption percentage values are stated to comply with the standards, which indicated that quarry material can be used as a pavement material. Barritt [39] reported that 5% of recycled materials are used in asphalt applications, 7% in concrete forms, 18% as subbase material, and 70% in the filler. Langer et al. [40] argued that due to the growing economy of countries, there would be a need for large amounts of natural aggregates. Researchers have stated that the use of recycled aggregates in roads, buildings, and asphalt pavement will reduce the need for natural aggregates. In another study, it has been stated that stone waste in different forms, which causes environmental pollution in recent years, can be used in the construction

industry as well as in other activities, such as paper-making, the ceramic industry (tiles), and the production of paint, plastics, polymers, glass, rubber, pharmaceuticals, textiles, soaps, wax, and agricultural fields [41]. Swamy and Das [42] have stated that some wastes can be used as sustainable road materials by using an appropriate technology. Estanqueiro [43] noted that recycled aggregates have significant environmental advantages over natural aggregates throughout the life cycle of concrete. Neves et al. [44] noted that the evaluation of recycled materials had ecological and economic contributions. Researchers have compacted the mixes prepared with natural and recycled materials in the field. Low compression deflectometer (FWD) tests were performed after compression, and it was found that the performance of layers prepared with recycled materials to be appropriate. Kim et al. [45] examined the frost sensitivity of aggregates from recycled materials. As a result, it has been observed that recycled aggregates have higher frost sensitivity and better mechanical properties than those of natural aggregates. Ahmed et al. [46] reported that the solution is recovering because large amounts of wastes in marble and

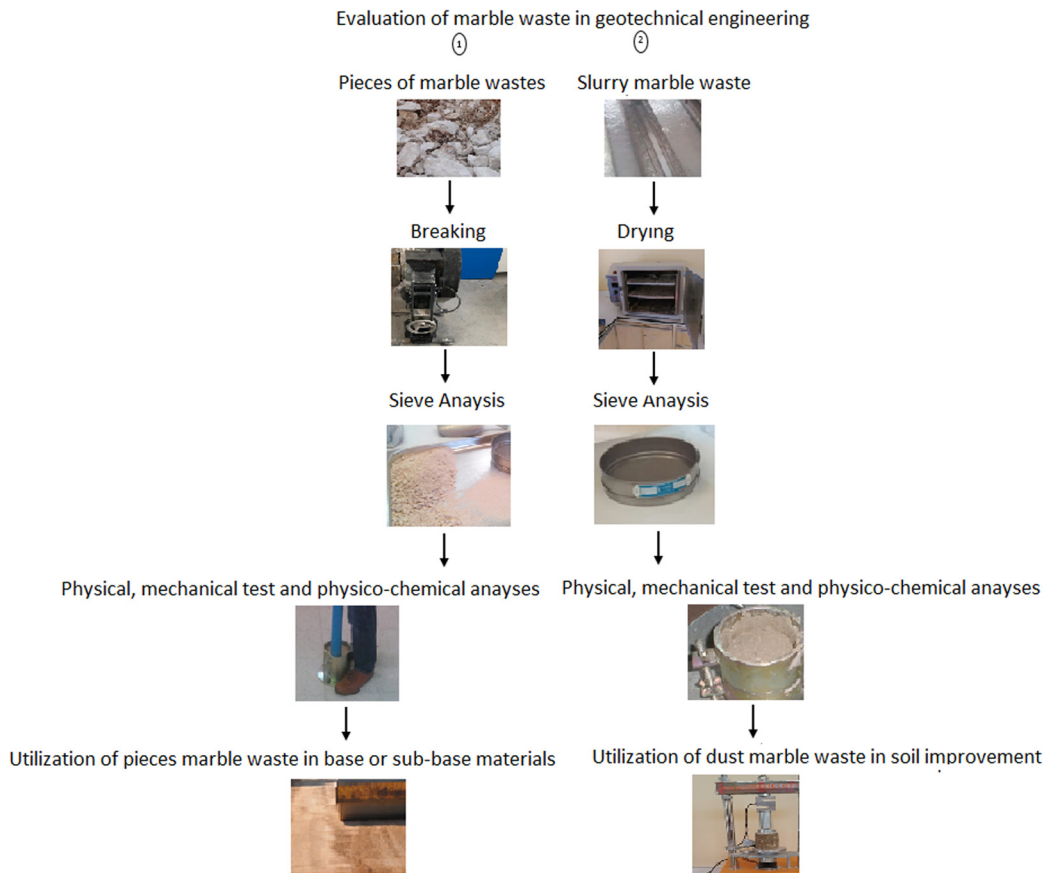


Figure 2: Flow chart of reusing marble waste processes.

granite quarries cause environmental problems. In particular in road and dam construction and as railway ballast, concrete and asphalt mixtures were investigated as aggregates. The researchers conducted modified Proctor and CBR experiments for their usability as the base material and suggested that they could ultimately be used as base and subbase materials in road construction. In another study, it was stated that marble wastes could be used in different construction works in different sizes [47].

Berwal et al. [48] gave information on the use of recycled waste from different countries such as the United Kingdom, the Netherlands, Belgium, Japan, and the USA. The researchers also used recycled aggregate as a subbase material and said it was appropriate. As a result, they said that savings could be achieved using recycled aggregates [49–51]. Abukhattala [52] reported that using recycled materials in the best way means building better roads and protecting natural resources. In Europe, studies on the utilization of quarry waste are carried out. However, in some countries, waste assessment is not sufficiently provided due to insufficient

information and updated legislation [53]. Gautam et al. [54] examined the use of Kota stone mine wastes instead of the aggregate used in the granular substrate. Kota quarry waste was manually separated into aggregates of the desired size and evaluated in terms of physical and mechanical parameters according to the specification. It was found that Kota quarry and slurry waste could be used as a granular substrate in flexible coating. In recent years, waste management through recycling of wastes has attracted much attraction and contributes to the economies [55–65].

The characteristic that distinguishes marble wastes from other wastes such as fly ash, marble dust, and ceramic waste is its use as a direct aggregate. However, other wastes are used by mixing them to the soil. Generally, mixtures of different percentages are prepared, and mixtures which meet the desired criteria are used. The direct use of wastes provides advantages in the process and the use of machinery/equipment fuel. This study examined the percentage CBR value of large pieces of marble waste according to the criteria of the Technical Specifications of Turkish Highways (TSTH) suitability [66].

2 Marble waste

In the geological process of the formation of Earth's crust, the materials formed as a result of the metamorphism of rocks, such as limestone and dolomite, are crystallized again under elevated temperatures and pressures and became marble. Marble is a metamorphic crystalline rock, and it contains predominantly crystalline grains of calcite, dolomite, or serpentine [67]. Pure marble is translucent and white and can take different colors through various chemical and physical that occur within it [68]. Commercially, it covers many kinds of rocks that are durable when polished. Marble wastes can be divided into those from quarries and enterprises. Natural conditions found in quarries, such as faults, cracks, and slits, can make it nearly impossible for blocks to be obtained. This leads to the emergence of waste materials. Another type is marble dust wastes that are encountered in sedimentation ponds.

Marble wastes used in this study were obtained from marble quarries and processing plants in Bilecik. Marble quarries are located in 3 different regions in Bilecik Province (Figure 3) [69], and marble wastes were obtained from these quarries (Figure 4). Marble wastes are concentrated along a line, including the Central district, Gölpazarı district, and Yenipazar district, and they take these names. To be a reference for future studies, sampling was made at least from three points. The marble wastes in these three regions were sampled and evaluated for usability as the base material in road pavement by performing the tests specified in the TSTH. The average diameters of marble wastes from quarries are 75 to 100 mm, formed into aggregates in the 0–25 mm diameter range by a mini crusher.

The physicochemical properties of the marble wastes used in this study were determined by X-ray diffraction (XRD), X-ray fluorescence (XRF), and mercury intrusion porosimetry (MIP) analyses. XRD analysis is a qualitative analysis that gives us information about the mineral contents or solid particles of a specific shape. XRD is one of the basic techniques used in the phase analysis of solid and powdered materials. XRD analysis provided data on the morphology of the material, the amount of phase, crystal size, changes in structure, crystal orientation, and atom positions with XRD. Mineralogical analyses of the marble wastes were carried out by using an X-ray diffractometer (Empyrean, Panalytical) using a $\text{CuK}\alpha$ radiation source ($\lambda = 1.5405 \text{ \AA}$). Also, the measurement conditions were 45 kV and 40 mA, and scanning speed was $2^\circ/\text{dk}$. XRD graphs of marble samples are given in Figure

5. Calcite is the main mineral determined by the XRD analysis of the Center, Gölpazarı, and Yenipazar marble samples. Also, XRF analysis was performed to determine the chemical content percentages on the marble wastes using an XRF unit (Panalytical, AXIOS). The measurement conditions were 40 kV and 60 mA, and the measurement environment was 99.999% purity He. The data obtained from the XRF experiment are given in Table 1. The table shows the presence of a high concentration of Ca. The MIP is a commonly used technique for determining powder and bulk pore size and size distribution. In recent years, mercury porosimetry has been widely used to determine the pore diameter distribution of soils. This study used Micromeritics, AUTOPORE IV 9510, and low pressure is 50 psi, and high pressure is 60,000 psi. An increment intrusion–pore size diameter curve, according to the MIP results, is given in Figure 6. In the marble parts of the three regions, the pores are concentrated between 0.003–0.005 mm and 45–150 mm.

3 Method

This study performed physical tests, the modified Proctor test, the dry/wet strength CBR test, and on-site unit weight of waste marble using the sand cone method. For each mixture, at least three samples were tested to ensure the reproducibility of the data.

3.1 Physical tests

Materials that make up the base layer are divided into fine and coarse aggregates. Coarse aggregates, gravel, are defined as natural aggregates that do not have a specific shape and size [66]. This material can be used to provide the physical properties to the specifications for shallow traffic volume or on roads of low bearing (Table 2). According to AASHTO T-19 [70], values of loose unit weight less than $1,100 \text{ kg/m}^3$ are undesirable for this aggregate. Table 3 shows the limit costs necessary for the thin part of the material to be used in making a foundation after passing through a 2.00 mm sieve [66].

In this study, mixtures were prepared according to Type-C grading of the granular base material of TSTH. The sieve analysis test, frost resistance test in coarse aggregates with MgSO_4 , Los Angeles wear test, flatness

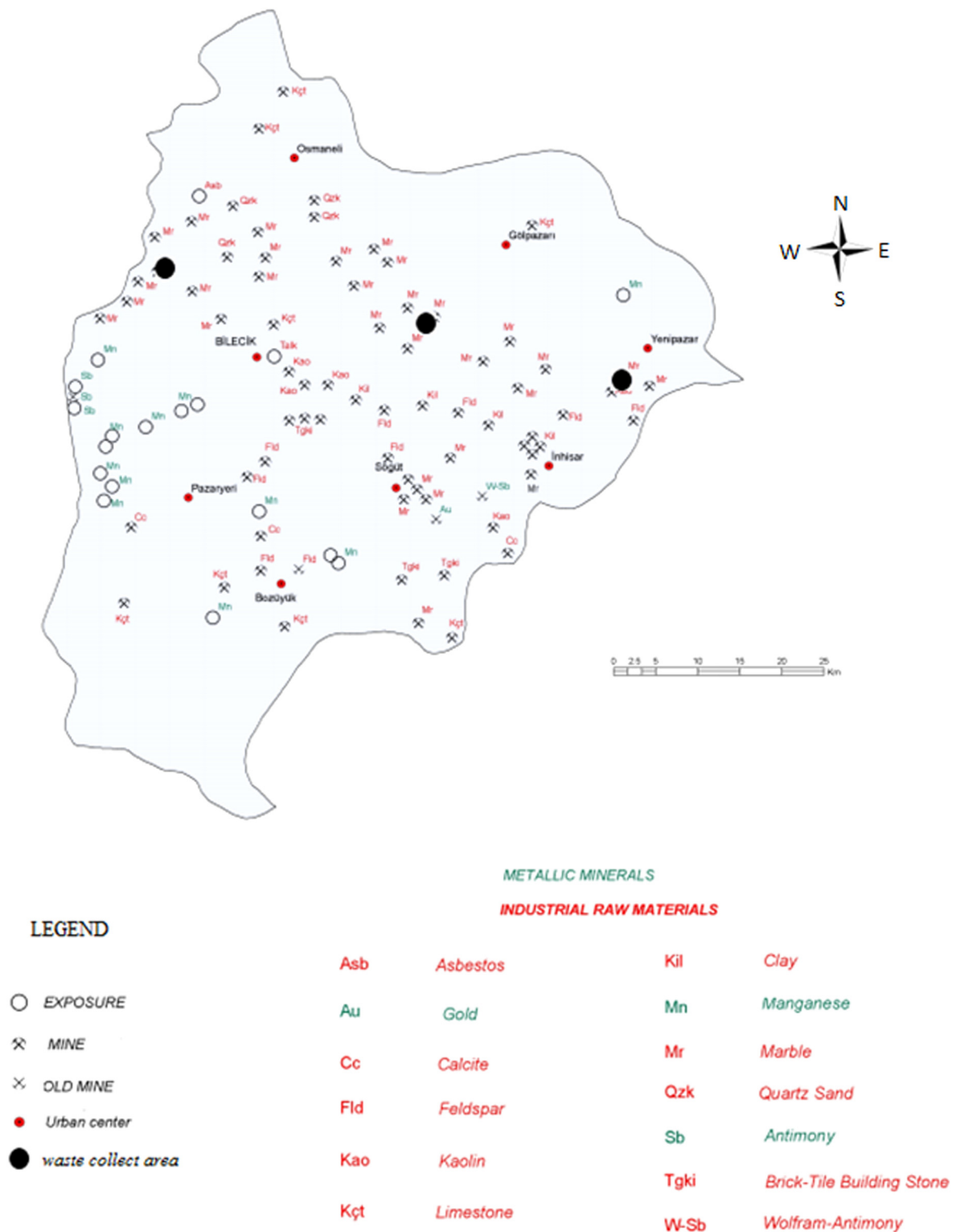


Figure 3: The location of the points on the map where the samples were taken [69].

index, organic matter detection test, and water absorption test were performed. In fine aggregates, the liquid limit, plastic limit, determination of the organic matter, and methylene blue tests were applied. The grain distribution

curve was adjusted according to specification values. The modified Proctor test, dry/wet California bearing ratio (CBR) test, and on-site unit weight test using the sand cone method were performed on samples.



Figure 4: Waste collection area.

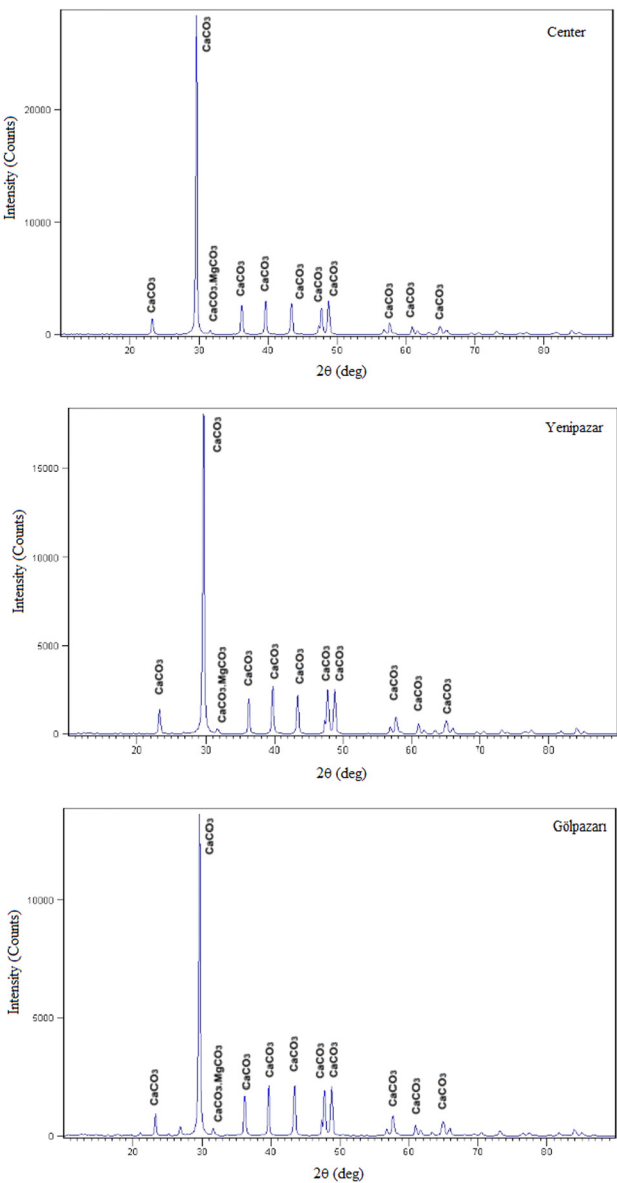


Figure 5: XRD analysis results of marble samples.

Table 1: XRF analysis results

Component	Center sample (%)	Gölpazarı sample (%)	Yenipazar sample (%)
O	4.872	5.217	—
Na ₂ O	—	0.041	0.046
MgO	0.093	0.081	0.102
Al ₂ O ₃	0.083	0.652	0.115
SiO ₂	0.296	1.052	0.288
P ₂ O ₅	0.275	0.287	0.271
SO ₃	0.009	0.011	0.008
Cl	0.009	0.021	0.010
K ₂ O	0.011	0.160	0.058
CaO	94.229	91.329	98.735
TiO ₂	—	0.198	—
MnO ₂	—	0.026	0.034
Fe ₂ O ₃	0.086	0.865	0.167
NiO	—	0.013	0.016
ZnO	—	0.017	0.012
SrO	0.036	0.026	0.133
ZrO ₂	—	0.005	—
LOI	0.001	0	0.005

Furthermore, X-ray diffraction (XRD), XRF, and mercury porosimetry (MIP) analyses were performed on these wastes. Marble waste samples were taken from İlyasbey village of the Merkez district, Şahinler village of the Gölpazarı district and Kuşça village of the Yenipazar district. These samples were prepared by the gradation (0–25 mm), and road pavement base material physical tests according to the TSTH were performed on the samples.

Using the freeze–thaw test with magnesium sulfate (MgSO₄), the aggregates are were found to be resistant against weather effects or freezing effects. With the Los Angeles experiment, the deterioration in the standard gradation of the mineral aggregate is determined as a result of the abrasion factors that the aggregates will be exposed to. The flatness index test is based on defining aggregate particles whose thickness is less than 0.6 of their nominal size as flat. The organic matter experiment with NaOH does not give a quantitative result and is an observational experiment. The test determined whether the aggregate samples contain organic matter or not. Clay lumps test is conducted for the approximate determination of clay lumps and friable particles in aggregates. With the water absorption test, the water accumulation capacity on the surfaces of the aggregate grains is determined. The plasticity of the material is determined by the consistency test (Atterberg consistency). The methylene blue test is performed to determine the pollution rate of the aggregates.

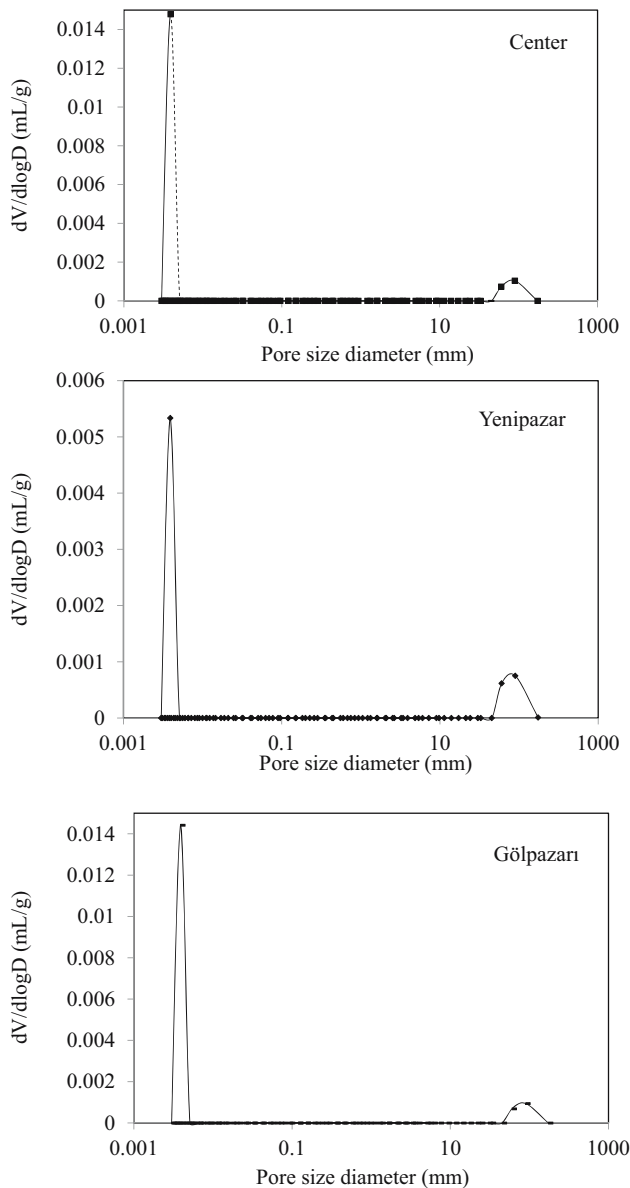


Figure 6: Pore size distribution of marbles measured by MIP.

Table 2: The physical properties of coarse aggregate [37]

Name of the experiment	Criterion	Standard
Weather resistance test (MgSO ₄), %	≤20	TS EN 1367-2
Fragmentation resistance (Los Angeles), %	≤35	TS EN 1097-2
Clay lumps and friable particles, %	≤1.0	ASTM C-142
Flatness index, %	≤25	TS EN 933-3
Organic matter, (3% NaOH)	Negative	TS EN 1744-1
Water absorption, %	≤3.0	TS EN 1097-6

Table 3: The physical properties of the fine aggregate [37]

Name of the experiment	Criterion	Standard
Liquid limit, %	NP	TS 1900-1 AASHTO T89
Plastice index, %	NP	TS 1900-1 AASHTO T90
Organic matter, %3 NaOH	Negative	TS EN 1744-1
Methylene blue, g/kg	≤3.0	TS EN 933-9

3.2 Modified proctor test

This test is an assay for determining the water content, which gives the maximum dry unit volume weight on soil compacted by a particular method. The mechanical setup provided by the 4.53 kg rammer falling freely from 457 mm was used for this experiment. The dry unit-volume weight (ρ_k) was obtained from a series of experiments, and the corresponding water content (w) values were recorded. In this study, a modified Proctor test was performed according to TSE1900-1 [71].

3.3 CBR TEST

The CBR test determines the bearing capacity. This test is a mechanical strength test that compares the bearing capacity of a material with that of a well-graded crushed stone. This ratio is expressed as a percentage. The CBR sample is prepared at the optimum water content and maximum dry density or any other density at which the test is required by the modified Proctor's method. The experiment was conducted on dry and wet CBRs to determine the lowest bearing capacity. The voids are filled with water, in other words, to determine the influence of the natural conditions on a sample in the field. The sample was soaked in water for 4 days, during which time the sample was provided with weights representing the estimated load that would generally come upon it. It was checked whether these materials swell in water. No swelling was observed in light aggregates. After four days, the sample was removed from the water and placed under normal conditions. The free waters in the structure were kept until drained and then the CBR test was performed.

Then, the load values (kg) corresponding to the required sinking values (mm) were recorded at the pressures given by the standard (kg/cm²). Horizontal axis

penetration and vertical axis pressure values were recorded. Pressure–penetration curves were obtained from these values. As a result of the necessary corrections, the CBR values were found with the corrected pressure value corresponding to the penetrations of 2.54 mm (0.1 in.) and 5.08 mm (0.2 in.). CBR values were calculated multiplied by 100 after the corrected pressure value at the penetration of 2.54 mm (0.1 in.) to a standard pressure of 70.31 kg/cm^2 . The fixed pressure value at 5.08 mm (0.2 in.) penetration is compared to the standard pressure value of 105.46 kg/cm^2 . The CBR test is an important test to determine the transport properties of fillers/base or subbase materials. In this study, the CBR test was performed according to the TSE 1900-2 [72] standard.

3.4 Field density test using the sand cone method

In this study, the sand cone method was used to control compaction in the field. The sand cone method used in the soil compaction test was carried out according to the TSE 1900-1 [71] standard. Maximum dry unit volume weight values obtained from laboratory and field were compared, and a ratio was obtained. The ratio obtained is required to be 98%. If the calculated rate is equal to this value, compression is accepted. If it is below this value, compression should be continued. For the control of this ratio to be calculated, the natural unit volume weight (ρ_n) of the testing terrain and the maximum dry density of the territory are found by determining the water content. In the field, the base plate is carefully placed by removing the loose part that is not fully compressed. The base plate is placed on the prepared soil and fixed to the soil by nailing through four-sided holes. A 15-cm-deep cylindrical hole is made in the middle of the base plate. The weight of the soil sample extracted from the pit is weighed in a bag and recorded so that the water content remains the same. The unit weight cone filled with sand is placed on the soil-mounted base plate with the mouth closed. The predetermined test sand is filled into the cylindrical hole of the cone. Sand starts to flow when opening the switch. The switch is closed when the sand flow is complete. The excess sand is taken into the bag, and its weight is noted. Thus, the sand filling the pit and that remaining in the cone are calculated. The volume of the material taken from the hole is calculated using the unit weight of the sand used in the experiment and the volume of the sand cone.

4 Results and discussions

4.1 Physical test results

The experiments according to the TSTH standards of the materials necessary for laying the road were carried out on waste marble samples obtained from marble quarries located in the Central district, Gölpazarı district, and Yenipazar district. Figure 7 shows the sieve analysis experiments performed on marble waste samples. Results of the freeze–thaw test, the Los Angeles test, the flatness index test, the water absorption test, and the methylene blue test are given in Figure 8.

It is known that aggregates under the effects of weather for a long time undergo gradation deterioration due to freezing and thawing. Since gradation deterioration will cause deterioration of the road, aggregates are required to be resistant to frost and thawing. As a result of the freeze–thaw experiments in this study, the loss value against the effect of air, which is desired to be at most 20%, was calculated as 16.54% in the Central district sample, 13.46% in the Gölpazarı district sample, and 11.83% in the Yenipazar district sample. Since the degradation of the aggregates will cause segregation, the desired compression ratio is not achieved, and the road foundation exposed to traffic loads may collapse. Therefore, abrasion losses of aggregates to be used in road constructions must be within the specification limits. As a result of the Los Angeles experiments in this study, the maximum accepted loss is 35%, and it is 14.17 in the Central district sample, 11.51 in the Gölpazarı district, and 13.48 in the Yenipazar district sample. The aggregates used in road constructions are required to be crushed stones and not flat. Since aggregates exposed to traffic loads will be exposed to pressures from all directions, flat grains cannot provide the desired strength. Also, the compression of flat grains is not at the desired level. As a result of the flatness tests conducted in this study, a maximum of 25% is required, and the compression was 20.87 in the Central district sample, 14.52 in the Gölpazarı district, and 11.94 in the Yenipazar district sample. It is necessary to know the rate of organic matter in aggregate samples. Since aggregates containing organic matter can lead to chemical reactions in the structure they are part of, which can cause deformations.

For this reason, the amount of organic matter is not desired. These organic materials were not found in the three marble waste samples considered in the experiment. As a result of the clay pellet experiment conducted

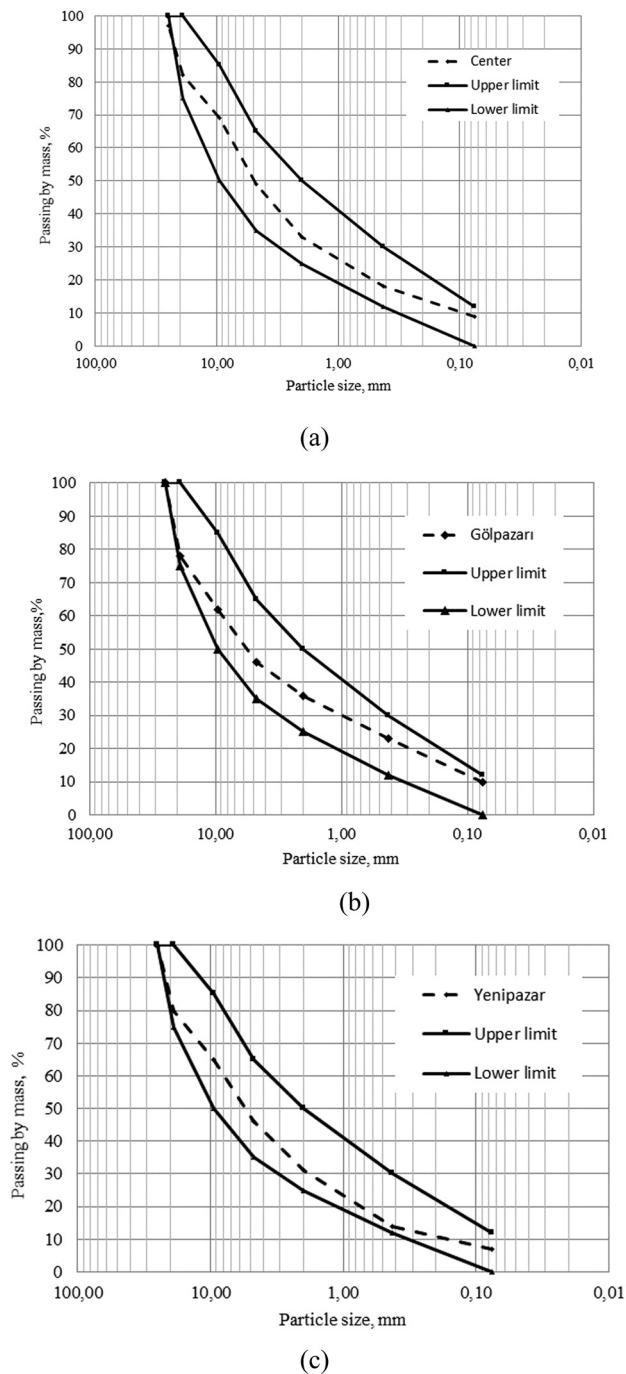


Figure 7: Grain size distribution of marble waste from the (a) Central, (b) Gölpazarı, and (c) Yenipazar districts.

in this study, no clay lumps were found in the three marble waste samples, which can be at most 1%.

Aggregates with a high water absorption capacity cause soil deterioration because of water stagnating in the foundation ground where they are located. Therefore, the water absorption capacity of the aggregates used in road foundation constructions should be below a threshold limit. As a

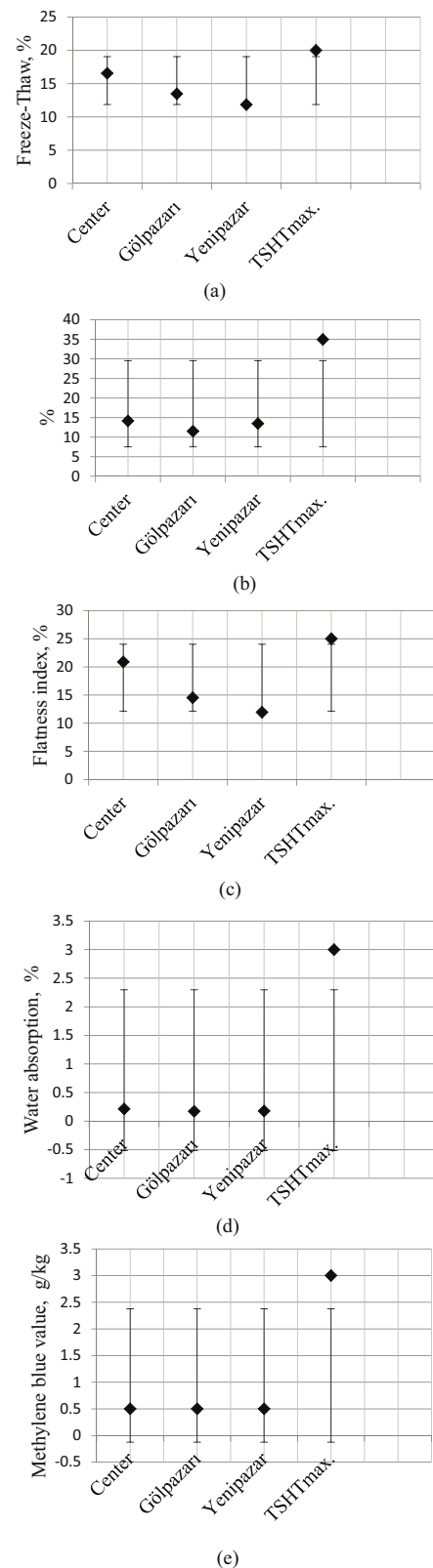


Figure 8: (a) The freeze–thaw test, (b) the Los Angeles test, (c) the flatness index test, (d) water absorption and (e) methylene blue test results.

result of the water absorption capacity in this study, a maximum of 3% is acceptable. It was obtained as 0.0214 in the sample of Central district, 0.0171 in the sample of Gölpazarı district, and 0.0177 in the sample of Yenipazar district. The liquid limit of the samples was found from the experiments performed with the Casagrande instrument, while the plasticity index was calculated based on the results of the liquid limit and plastic limit tests. Aggregates to be used to construct the foundation ground for roads are required to be nonplastic. This is because the plastic behavior of the fine aggregates in the foundation ground will cause deformations to the foundation ground since it will be intensively exposed to water. The consistency tests were carried out on the three marble wastes and, wastes are determined as non-plastic (NP) soils. The fine grain soil being plastic reduces the resistance of the road's foundation soil against traffic loads. As a result of the methylene blue tests carried out in this study, a maximum of 3% is acceptable. It was found as 0.5 in all three samples.

4.2 Modified proctor test

The dry unit volume weights and water contents of the soils were calculated using this test, which was performed by compressing soils with different percentages of water. The dry unit volume weights and water contents obtained according to the amounts of water added at different rates intersected. The maximum dry unit volume weight ($\rho_{k \max}$) and optimum water contents (w_{opt}) were calculated. The three samples were prepared according to the Highways Granular Foundation Layer standards, and tests were conducted according to the TS-1900-1 2006 standard. The modified Proctor test results are given in Table 4. According to experimental results, the Central district sample had the lowest optimum water content, while the Gölpazarı district sample's optimum water content was 24% higher, and the Yenipazar district sample's optimum water content was 17% higher. Maximum dry unit volume weights ($\rho_{k \max}$) and optimum water contents (w_{opt}) were found to be very close to each other.

4.3 CBR test

The CBR test provides the carrying ratio of soils using the correlation between the amount of load applied to the

Table 4: Modifiye Proctor experiment results

Material	$\rho_{d \max}$ (kN/m ³)	w_{opt} (%)
Center district	21.72	4.20
Gölpazarı district	21.62	5.20
Yenipazar district	21.53	4.90

($\rho_{d \max}$: maximum dry unit volume weight, and w_{opt} : optimum water contents).

soil and its penetration. According to the TSTH, the maximum dry unit volume weight found by the modified Proctor test must be 98% for the base material, and the wet CBR value is not less than 100%. For this purpose, the mixtures were first prepared in the maximum dry unit volume weight determined by the modified Proctor test. The samples were compressed again using a modified Proctor method. For the wet CBR test, the compressed samples were soaked in water for 4 days. Whether the materials would swell under the influence of water was also checked during this process. After soaking, whether the desired 100% value was reached was checked by performing the CBR test. For CBR 100% crushed stone curve in the TSTH, the penetration of 1.25 mm is 0.84 kN, penetration of 2.5 mm is 13.2 kN, and penetration of 5.0 mm is 20 kN. The results of the CBR test applied to dry and wet samples are given in Figure 9. All the CBR experiments conducted on the three samples show that the desired CBR 100% value has been reached according to the TSTH. Also, no swelling occurred in any sample during saturation for four days.

4.4 Field density test using the sand cone method

Field compaction was carried out with the help of cylinders (Figure 10). The compaction result depends on the type of compaction device, soil grain size distribution, water content, layer thickness, number of cylinder passes, and the passing speed of the compaction aid. In this study, the percentage of compaction was determined by the sand cone method. It was calculated the compaction percentages of the road fill, or base layers laid, in the field. A Mobile crusher was installed in the marble quarry in Ilyasbey, where the sample from the Central district was used. Thus, in large tonnages, marble waste was graded to

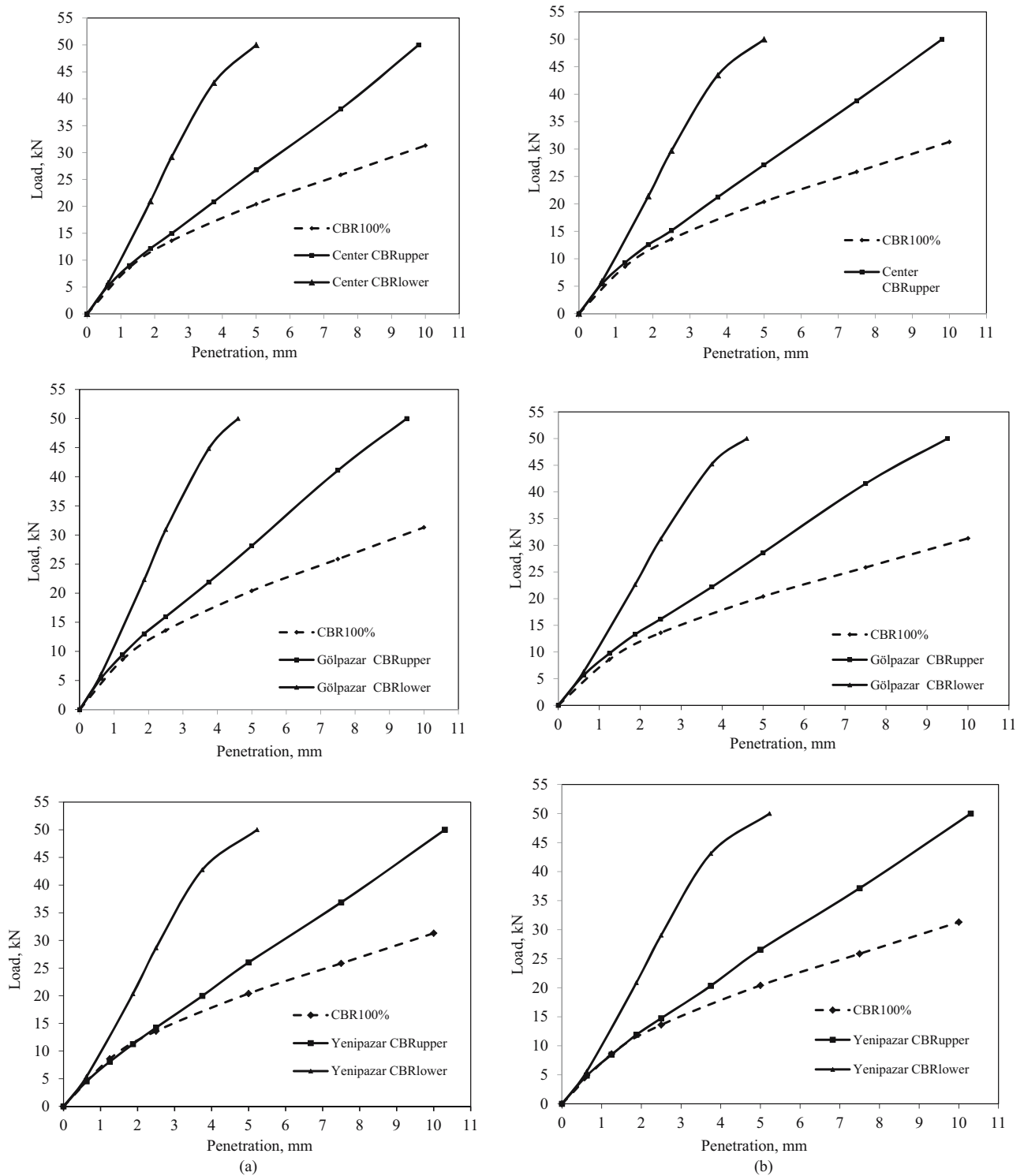


Figure 9: (a) Dry CBR curves and (b) wet CBR curves.

0–25 mm and laid as the primary material for the road. The samples of the marble wastes laid were compacted using cylinders; thus, the foundation of the road was produced. The sand cone test was carried out in three different

regions of the base production made with the Central district sample. The compaction percentages of the material were calculated as 99.2%, 99.6%, and 99.7%. They were appropriate according to the TSTH standards [16].



Figure 10: (a) Compaction of the base layer made of marble waste and (b) control by sand cone method on the base layer.

5 Conclusions

This study, conducted on the reuse of marble piece wastes, pointed out that marble waste generates environmental pollution and causes economic loss. A large amount of waste is generated with marble mining activity. In this

study, marble waste samples taken from the Central district, Gölpazarı district, and Yenipazar district of Bilecik Province, which have different characteristics as marble structures, were examined according to the TSTH standards as to whether or not their properties are within desired limits of base materials. The modified Proctor test,

dry/wet CBR test, and on site density of soil test by the sand cone method, and XRD, XRF, and MIP analyses were applied to three different marble wastes. The experimental results showed that the marble wastes are suitable to be used as base materials, and evaluations of the results obtained are presented below:

- XRD, XRF, and MIP analyses were performed on these wastes. Calcite is the main mineral determined by the XRD analysis of all three marble samples. The XRF analysis shows the presence of a high concentration of Ca. Also, according to the MIP analysis the pores are seen to be concentrated between 0.003–0.005 mm and 45–150 mm.
- Mixtures were prepared according to Type-C grading of the granular base material of TSTH. Firstly, the wastes were determined to be homogeneous in the range of 0–25 mm base material grading specified as Type-C by the sieve analysis test.
- Of the freeze–thaw test, the Los Angeles test, the flatness index test, the water absorption test, the methylene blue test, clay lumps test, organic matter test, and consistency test showed that these marble wastes are suitable as base material according to the TSTH.
- The modified Proctor tests were conducted on samples, and maximum dry unit volume weights ($\rho_{k\max}$) and optimum water contents (w_{opt}) were found to be very close to each other.
- The dry/wet CBR test were performed on samples, and CBR values were determined above 100%.
- In this study, marble waste was graded to be 0–25 mm and laid as the primary material for the road after the percentage of compaction was determined by the sand cone method. The sand cone test was conducted in the field for the compaction percentages of the road fill, or base layers laid. The compaction percentages of the samples were calculated as 99.2%, 99.6%, and 99.7%. Compaction percentages obtained were found to be appropriate according to the TSTH [16].

Based on the results of this study, a solution to the problems of environmental pollution and raw material supply can be found by evaluating the marble waste according to the regulations of each country. All over the world, studies on waste utilization should be encouraged within the scope of efficient and environmentally friendly use of resources, dissemination of recycling, and contributing to the economy.

Acknowledgments: This study has been produced from Gökhan Yakşe's master's thesis titled "Waste Marble Particles Evaluation as the Base Material."

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