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**Research Article**

# Temperature Analysis of Concrete Road Expansion

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**ABSTRACT**

This article is dedicated to analyzing the impact of climatic conditions on the operational characteristics of concrete roads, with a focus on thermal deformations that occur during their use. Concrete roads have clear advantages in terms of durability and load capacity; however, the thermal expansion and contraction of concrete, caused by seasonal temperature fluctuations, can lead to the formation of cracks and defects that reduce the physical and mechanical properties of the road surface. The article presents a portion of a comprehensive study conducted on the "Shymkent-Turkestan" highway, where concrete samples from various locations were analyzed. The methodology included measuring the geometric dimensions, density, and thermal deformations of the samples. The average density values of the samples from the three road sections were 2.27 g/cm³, 2.35 g/cm³, and 2.42 g/cm³ for locations 1, 2, and 3, respectively. Low coefficients of variation in all three locations characterize the high quality of the concrete in terms of homogeneity and its suitability for further investigation of thermal expansion and contraction. Based on the obtained values of the thermal analysis of concrete samples from the three locations, a correlation between thermal expansion and contraction with the material density was established. The increase in thermal expansion is negligible, with an increase in density of 3.4%, the thermal expansion increases by 0.7%. With a density increase of 6.6%, the thermal expansion is 3.7%. The increase in thermal contraction with a density increase of 3.4% is 0.7%. With a density increase of 6.6%, the thermal contraction is 3.2%. The study's results will help improve the design and operation of concrete roads, taking into account the specifics of local climatic conditions.

**Keywords:** concrete roads, thermal deformations, climatic conditions, thermal expansion, thermal contraction, concrete density, road surface cracks, density measurements, temperature fluctuations, thermal testing, geometric dimensions, expansion joints.

## INTRODUCTION

The construction of concrete roads is currently of great importance due to their undeniable advantages in terms of durability and high performance, such as significant load-bearing capacity. About 1.6 thousand kilometers of cement-concrete roads, including major highways, have been built in Kazakhstan. However, during the operation of concrete roads, certain issues arise related to the climatic conditions of the region, particularly thermal expansion of the concrete. In some sources, the authors attribute road surface deformations to the peculiarities of road base design [1], [2], [3], [4]. According to studies conducted by domestic scientists in the field, temperature changes have a significant impact on the durability and performance of cement concrete roads [5], [6]. When designing and constructing such roads, it is essential to consider the regional climate conditions to ensure their reliability and durability. Concrete, as a material, is subject to thermal expansion and contraction, which can lead to the formation of cracks and other defects on the road surface. Numerous scientific papers have been devoted to the study of concrete properties [7], [8], [9], [10]. These defects can substantially reduce the physical and mechanical properties of the roads, increasing maintenance and repair costs. Therefore, understanding and accounting for thermal deformations of concrete roads is a key aspect in their design. This article examines part of a comprehensive study on concrete roads, specifically focusing on assessing the impact of temperature conditions and regional climate on their performance. The research was conducted on a section of the "Shymkent-Turkestan" highway, where core samples were taken for analysis.

The aim of this study is to identify patterns of thermal expansion and contraction in concrete, which will help improve approaches to the design and operation of roads, taking into account the specifics of local climatic conditions. This article presents a portion of a comprehensive study on concrete roads, focusing on assessing the impact of temperature conditions and regional climate on road performance.

The research methodology included sampling concrete from various locations along the studied road section, measuring their geometric dimensions, density, and thermal deformations. The results of this research can be used to develop recommendations for designing expansion joints and improving the performance of concrete roads in different climate zones.

The thermal analysis of concrete road expansion is a key aspect of this study, aimed at optimizing road design and operation. This work examines the impact of temperature changes on the expansion and contraction levels of the road surface. Special attention is given to the effects of seasonal temperature fluctuations on concrete structures, their thermal stability, and durability.

## METHODOLOGY

The concrete testing was conducted on a section of the operating highway "Shymkent-Turkestan." To evaluate the thermal expansion of concrete, core samples were taken from various locations along the road section. To identify statistical patterns in the temperature analysis data, 6 samples were collected from each of the three locations. The cores were extracted from a 70 km section of the "Shymkent-Turkestan" road. Figure 1 shows the core sampling points.

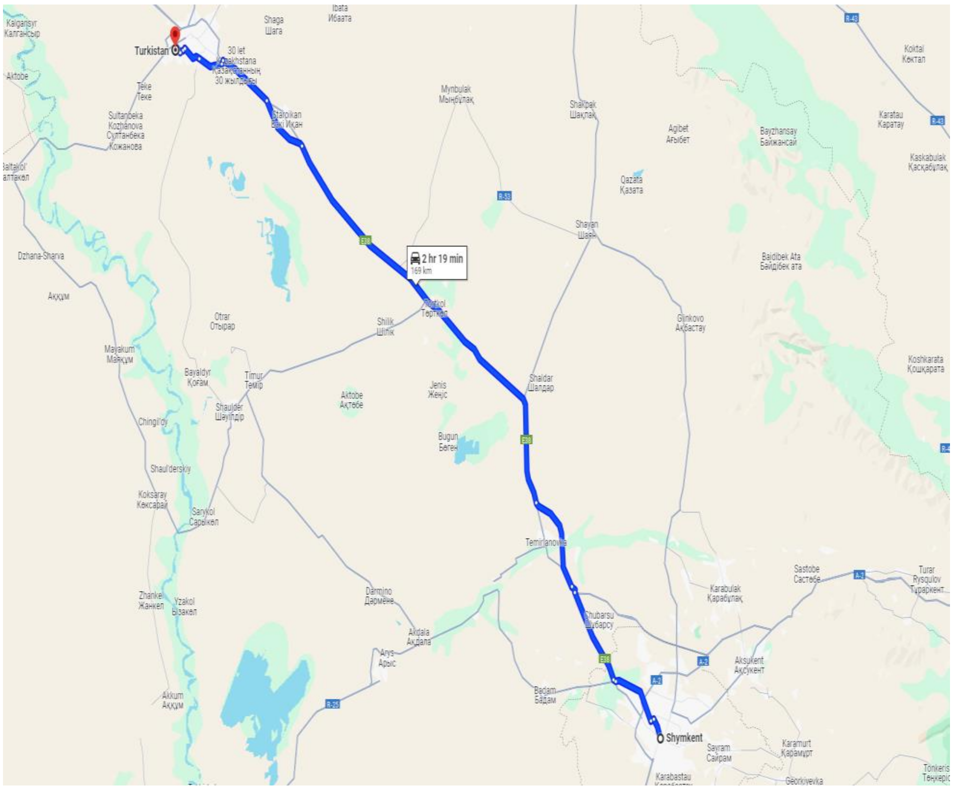



**Figure 1.** Location of Core Sampling Sites

**Research Sequence:**

- Drilling of 18 core samples from three locations along the road section.
- Measurement of the dimensions and density of the samples.
- Determination of thermal expansion of the samples using the heating method.
- Determination of thermal contraction of the samples using the cooling method.
- Processing and analysis of the results.

**Figure 2.** Core Sampling

The core samples were drilled using a diamond core drill with an internal diameter of 150 mm (Figure 2). The geometric dimensions of the samples were measured using a certified caliper. The density was determined by weighing the samples on certified scales. Heating and cooling were conducted using certified thermal chamber equipment (KTX), which allows for long-term exposure of samples within a temperature range from +180°C to -50°C (Figure 3). The tests were performed in a temperature range from +70°C to -30°C. The testing temperature regime was selected based on the regional climate characteristics, according to the results of monitoring road surface temperatures during the summer and winter periods [11].

**Figure 3**. Thermal Testing of Concrete Samples

To identify the samples, each was marked with a sequential number according to the sampling location:

- Location 1: samples $CS_1^1CS_1^1 – CS_1^6CS_1^6$;
- Location 2: samples $CS_2^1CS_2^1 – CS_2^6CS_2^6$;
- Location 3: samples $CS_3^1CS_3^1 – CS_3^6CS_3^6$;

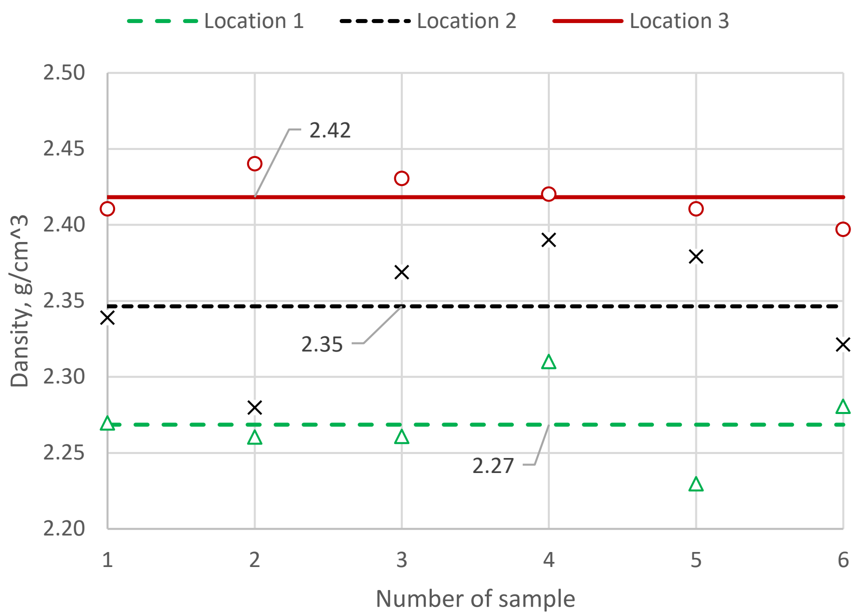
Where "CS" stands for concrete sample, the subscript denotes the location, and the superscript indicates the sample number.

## TEST RESULTS

Table 1 presents the measurements of geometric dimensions and mass of the collected concrete core samples. Figure 4A shows the results of individual and average density values by location, while Figure 4B illustrates the coefficients of variation for the individual values at each location.

**Table 1.** Measurement Results

| Sample Number | Height (cm) | Diameter (cm) | Volume (cm³) | Mass (g) |
|---|---|---|---|---|
| $CS_1^1$ | 4.43 | 14.3 | 711.1 | 1614 |
| $CS_1^2$ | 4.63 | 14.3 | 743.2 | 1680 |
| $CS_1^3$ | 4.45 | 14.3 | 714.3 | 1615 |
| $CS_1^4$ | 4.73 | 14.3 | 759.3 | 1754 |
| $CS_1^5$ | 4.54 | 14.3 | 728.8 | 1625 |
| $CS_1^6$ | 4.66 | 14.3 | 748.0 | 1706 |
| $CS_2^1$ | 4.73 | 14.3 | 759.3 | 1776 |
| $CS_2^2$ | 4.82 | 14.3 | 773.7 | 1764 |
| $CS_2^3$ | 4.71 | 14.3 | 756.1 | 1791 |
| $CS_2^4$ | 4.78 | 14.3 | 767.3 | 1834 |
| $CS_2^5$ | 4.65 | 14.3 | 746.4 | 1776 |
| $CS_2^6$ | 4.64 | 14.3 | 744.8 | 1729 |
| $CS_3^1$ | 4.98 | 14.3 | 799.4 | 1927 |
| $CS_3^2$ | 4.84 | 14.3 | 776.9 | 1896 |
| $CS_3^3$ | 4.99 | 14.3 | 801.0 | 1947 |
| $CS_3^4$ | 4.87 | 14.3 | 781.8 | 1892 |
| $CS_3^5$ | 4.98 | 14.3 | 799.4 | 1927 |
| $CS_3^6$ | 5.0 | 14.3 | 802.6 | 1924 |

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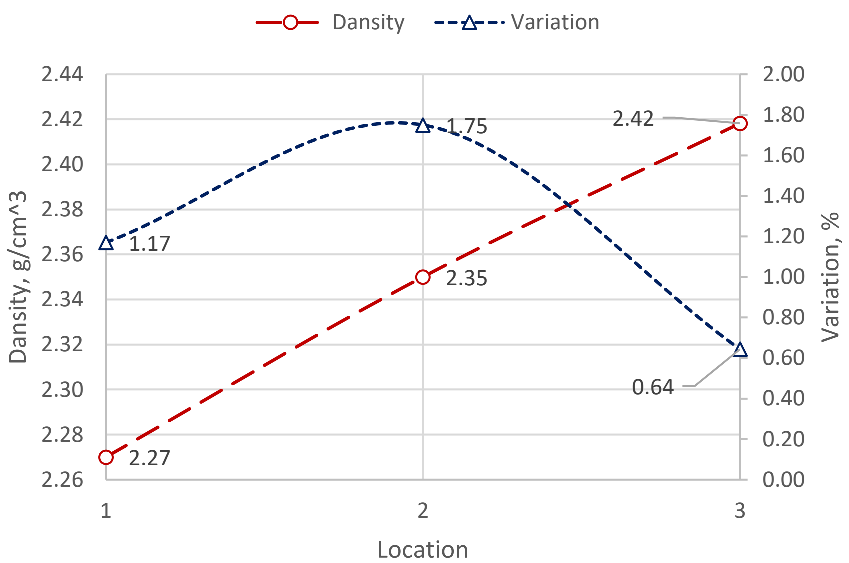


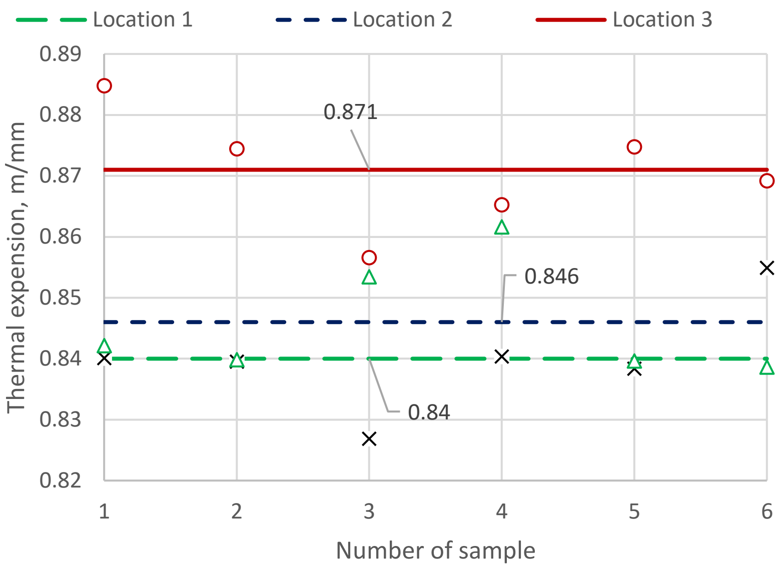

b)

**Figure 4.** Determination of Sample Densities

According to the test results, the density of concrete samples in Location 1 varies from 2.23 to 2.31 g/cm³, with an average value of 2.27 g/cm³. The coefficient of variation for the individual density values is 1.77. In Location 2, the densities range from 2.28 to 2.39 g/cm³, with an average of 2.35 g/cm³, and the coefficient of variation is 1.17. For Location 3, the density values range from 2.40 to 2.44 g/cm³, with an average density of 2.42 g/cm³ and a coefficient of variation of 0.64.

The lowest concrete density was observed in Location 1, and the highest in Location 3. The slight variation in density across different locations could be attributed to different batches of concrete used during road construction. Nevertheless, within each location, there is a high consistency in individual density values, as indicated by the low coefficients of variation. The low variation values across all three locations reflect the high quality of the concrete in terms of homogeneity, making the obtained density data suitable for subsequent thermal analysis.

Figure 5A shows the results of measuring the thermal expansion of concrete at a maximum sample heating temperature of +70°C. Figure 6A displays the thermal contraction at a minimum sample cooling temperature of -30°C. Figures 5A and 6A present the individual values of thermal expansion and contraction, while Figures 5B and 6B illustrate their average values by location along with the corresponding coefficients of variation.

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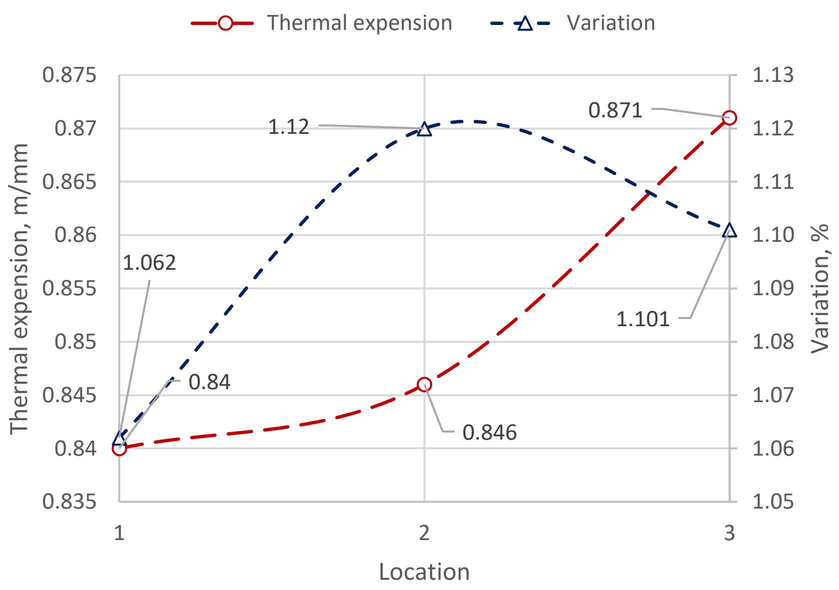
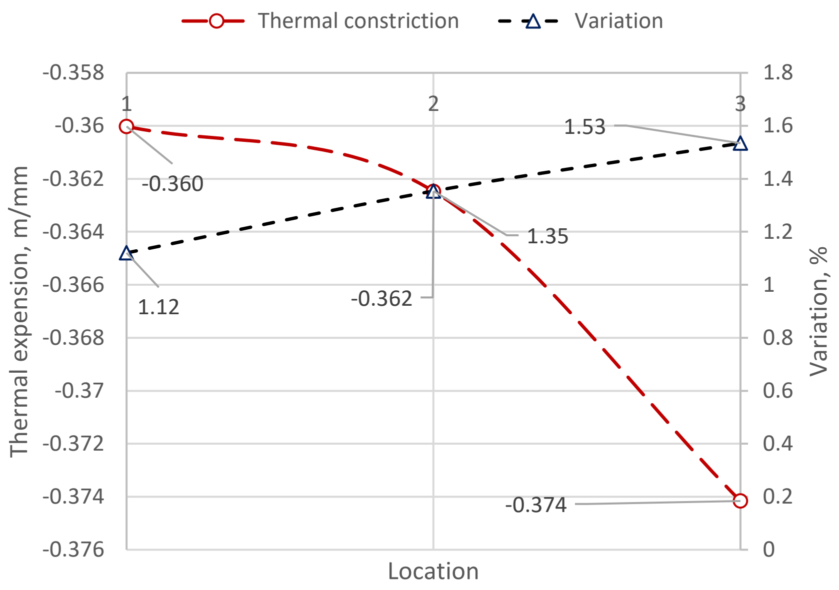



b)

**Figure 5**. Thermal Expansion of Samples

According to the research results, the maximum thermal expansion values of the samples in Location 1 range from 0.827 to 0.855 m/mm. The corresponding values for Location 2 range from 0.839 to 0.862 m/mm, and for Location 3, from 0.865 to 0.885 m/mm. The average thermal expansion values are 0.840 m/mm for Location 1, 0.846 m/mm for Location 2, and 0.871 m/mm for Location 3. The coefficients of variation in all three locations do not exceed 1.2%, indicating a close correlation between the individual values and a high degree of reliability in the obtained results.

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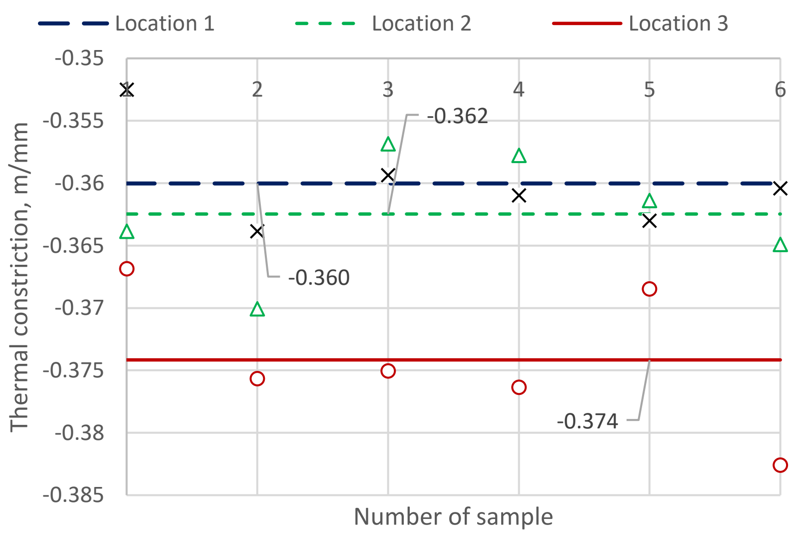



b)

**Figure 6.** Thermal Contraction of Samples

According to the research results, the maximum thermal contraction values of the samples in Location 1 range from -0.353 to -0.364 m/mm. The corresponding values for Location 2 range from -0.357 to -0.370 m/mm, and for Location 3, from -0.367 to -0.383 m/mm. The average thermal contraction values are -0.360 m/mm for Location 1, -0.362 m/mm for Location 2, and -0.374 m/mm for Location 3. The coefficients of variation in all three locations do not exceed 1.2%, indicating a close correlation between the individual values and a high degree of reliability in the obtained results.

The differences in thermal expansion and contraction across the various sampling locations are minimal; however, the maximum values for both thermal expansion and contraction are observed in Location 3, while the minimum values are found in Location 1. The deviations in thermal expansion values between Location 1 and Location 2 do not exceed 0.71%, between Location 2 and Location 3 do not exceed 2.87%, and between Location 1 and Location 3 do not exceed 3.56%. For thermal contraction, the deviations are as follows: Location 1 relative to Location 2 is 0.68%, Location 2 relative to Location 3 is 3.12%, and Location 1 relative to Location 3 is 3.78%.

Figure 7 shows a nomogram for the required width of the expansion joint depending on the distance between the joints.

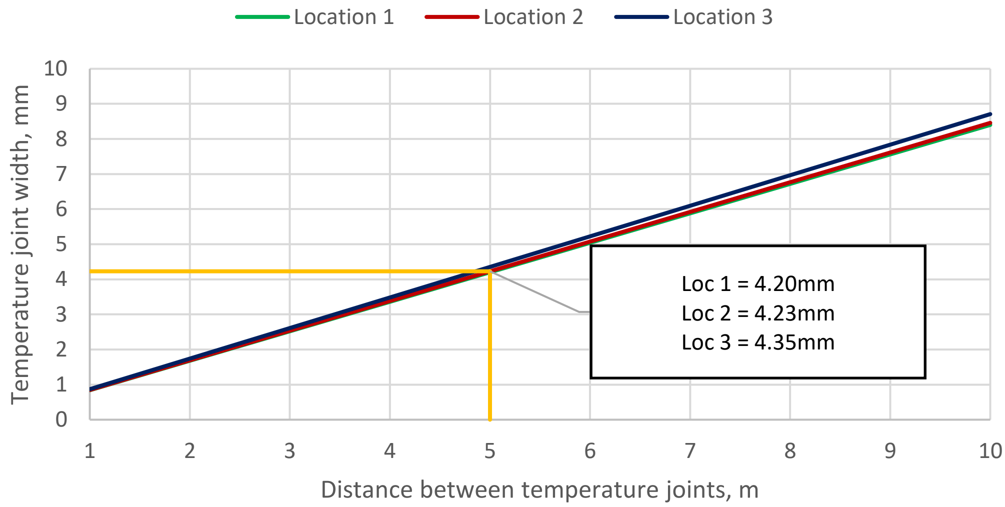
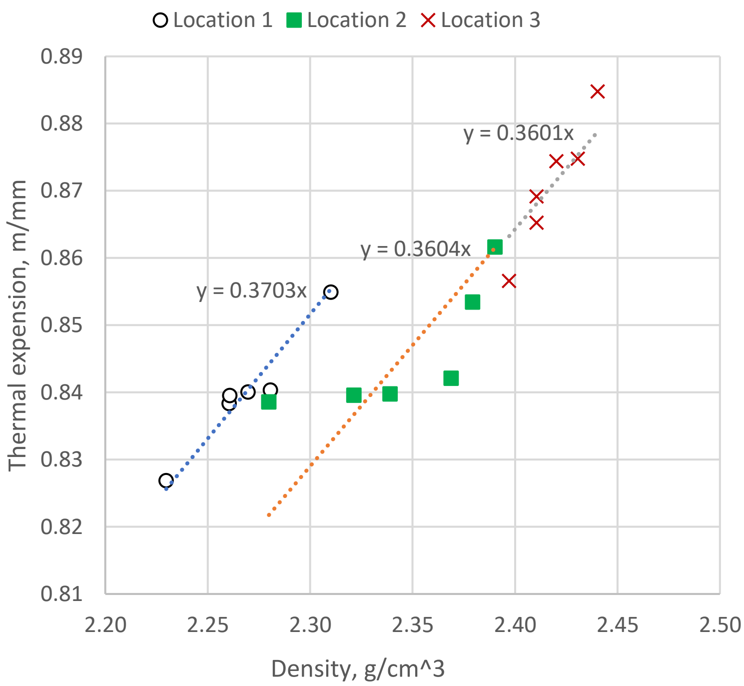



**Figure 7.** Dependence of Expansion Joint Width on Spacing

According to the nomogram, for the design solution involving joint spacing of 5 meters, the required expansion joint width is as follows: for Location 1, no less than 4.2 mm; for Location 2, no less than 4.23 mm; and for Location 3, no less than 4.35 mm. These requirements for thermal expansion are consistent with the actual implementation of the joints on the road section, where the joint width is 8 mm and the spacing is 5 meters [12].

Figure 8A shows the relationship between the thermal expansion of concrete and its density across the three locations. Figure 8B illustrates the same relationship for thermal contraction.

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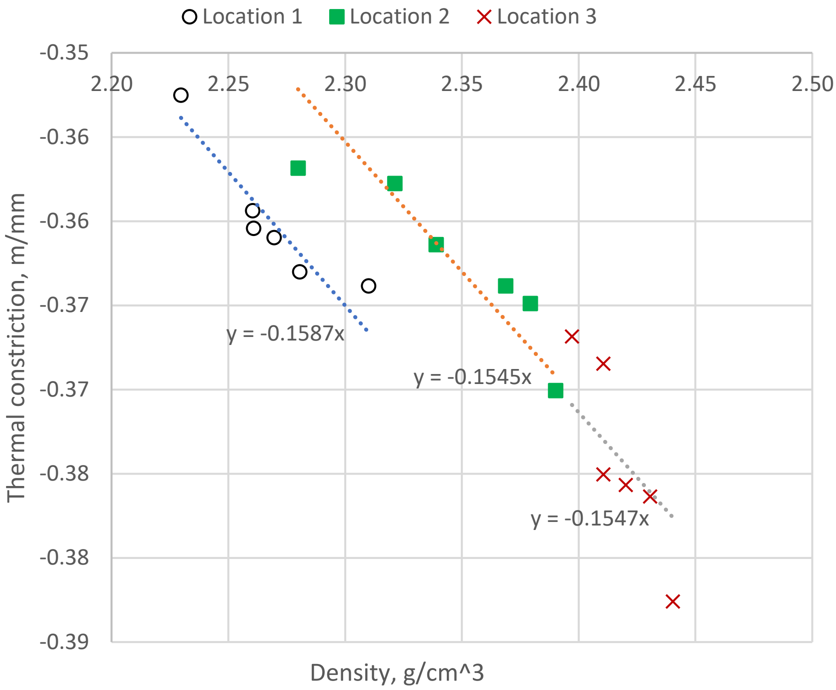


b)

**Figure 8.** Dependence of Thermal Expansion and Contraction on Concrete Density

According to the diagram, there is an observed increase in thermal expansion with higher material density. Similarly, thermal contraction also increases with higher density. The increase in thermal expansion is minimal; for a 3.4% increase in density, the thermal expansion increases by 0.7%, and for a 6.6% increase in density, the thermal expansion rises by 3.7%. The increase in thermal contraction for a 3.4% density increase is 0.7%, and for a 6.6% increase in density, the thermal contraction is 3.2%.

Overall, the increase in thermal expansion can be logically explained by the increase in material density per unit volume, which reduces the microporosity that acts as a buffer zone during thermal expansion [13]. The average relationship between thermal expansion and density for the tested concrete, as represented by linear functions on the diagram, can be expressed as:

$\rho=0.363\tau\_exp$

where ρ is the concrete density, and τ_exp is the thermal expansion of concrete at +70°C.

The average relationship between thermal contraction and density is expressed as:

$\rho=-0.156\tau\_con$

where ρ is the concrete density, and τ_con is the thermal contraction of concrete at -35°C.

## CONCLUSION

1. A thermal analysis was conducted on a test section of the "Shymkent-Turkestan" highway to evaluate the thermal expansion and contraction of concrete during both summer and winter periods.
2. The density tests of samples collected from three different locations along the road indicated a relatively small dispersion of individual values, both within and between locations. The dispersion of individual density values within each location did not exceed 1.8%, while the density difference between locations ranged from 3.4% to 6.6%. The high density of the results reflects the high quality of the concrete in terms of uniformity and makes the obtained density data suitable for subsequent thermal analysis.
3. The thermal expansion and contraction studies also demonstrated a high degree of convergence in individual values, both within and between locations. The error in individual values for thermal contraction within locations

ranged from 1.06% to 1.12%, and for thermal expansion from 1.12% to 1.53%. The low deviation from the mean indicates a high degree of reliability in the obtained results. Comparison of thermal expansion across different locations showed minimal variation, not exceeding 3.7%. For thermal contraction, the variation did not exceed 3.9%.

4. Based on the research results, a nomogram was developed to determine the required width of expansion joints based on their spacing. According to the nomogram, for a design solution with a joint spacing of 5 meters, the required expansion joint widths are: at least 4.2 mm for Location 1, 4.23 mm for Location 2, and 4.35 mm for Location 3. These thermal expansion requirements are consistent with the actual implementation of joints on the road section, where the joint width is 8 mm and the spacing is 5 meters.
5. Patterns of thermal expansion related to concrete density were obtained. The average relationship between thermal expansion and density for the tested concrete can be expressed as: $\rho=0.363\,\tau\_exp$ where $\rho$ is the concrete density, and $\tau\_exp$ is the thermal expansion of concrete at +70°C. The average relationship for thermal contraction is expressed as:
$\rho=-0.156\tau\_con$ where $\rho$ is the concrete density, and $\tau\_exp$ is the thermal contraction of concrete at -35°C. Overall, the increase in thermal expansion is logically explained by the increased material density per unit volume, leading to a reduction in microporosity, which acts as a buffer zone during thermal expansion.
6. Despite the high degree of convergence in the research results, further empirical studies are needed to accurately measure thermal expansion and contraction of concrete under these climatic conditions. However, the results obtained will be valuable for designing cement concrete roads, particularly for calculations and designing expansion joints.

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