# The Effects of Unstable Fault Zones on Design Parameters of Tunnels (The Case of Erzurum Kırık Tunnel)

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## 1.ABSTRACT

The Kırık Tunnel in Erzurum is an important route in the highway network designed to connect the northern and southern regions of Turkey. The tunnel, planned to be 7 km long, 10 m high and 7 m wide, passes through a geologically complex region. Preliminary investigations have revealed that the tunnel route is predominantly composed of clayey limestone and marl succession with variable slopes and orientations. During the tunnel construction works, a cave-in occurred during excavation after the water flow and a fault zone containing sandy-gravelly and organic matter was encountered at the 1+825.70 km section of the tunnel. The discovery of the crushed zone due to faulting necessitated a change in the tunnel design and it was decided to apply the back analysis method to understand the collapse mechanism. The deformation data affecting the tunnel were obtained with the help of load cells and back analysis was performed to determine the parameters of the collapse material from this deformation value at the time of collapse. Rock mass classifications were made using the parameters obtained from field and laboratory observations. As a result, with the help of Rocscience RS2, the collapse in the Kırık Tunnel was analyzed by finite element method and back analysis was performed. During the back analysis, the lateral vertical stress pressure acting on the faulted weak zone had to be re-evaluated. The k value changes in the numerical calculation model were examined from the existing approach methods and the comparison of these methods depending on the deformations in tunnel construction was given within the scope of the study. As a result of these data, new design parameters were found and grouting and support recommendations were given to overcome the stability problems in the tunnel. Accordingly, the lateral vertical stress ratio was taken as 1.6, which is normally 0.4, and the lateral pressure in the tunnel was determined as higher than the vertical pressure. With the new parameters, the unstable zone in the tunnel was theoretically crossed without any problems.


## 2.INTRODUCTION

The region where the Kirik Tunnel was built is located between the provinces of Erzurum and Ispir in northeastern Turkey. The collapse that occurred on August 4, 2022, in the under-construction Kırık Tunnel which diverges approximately northward from the D925 (Erzurum–Pazaryolu) highway, 3 km east of an active fault zone, and is designed to connect Erzurum to the İspir district beneath the Mescit Mountains has been investigated. This incident has been utilized in a back-analysis to better understand the significance of the horizontal-to-vertical stress ratio in weak rock masses. Given the presence of an active fault zone in the vicinity, it is believed that tectonic activity may have contributed to variations in in-situ stress conditions, potentially exacerbating the failure mechanism.

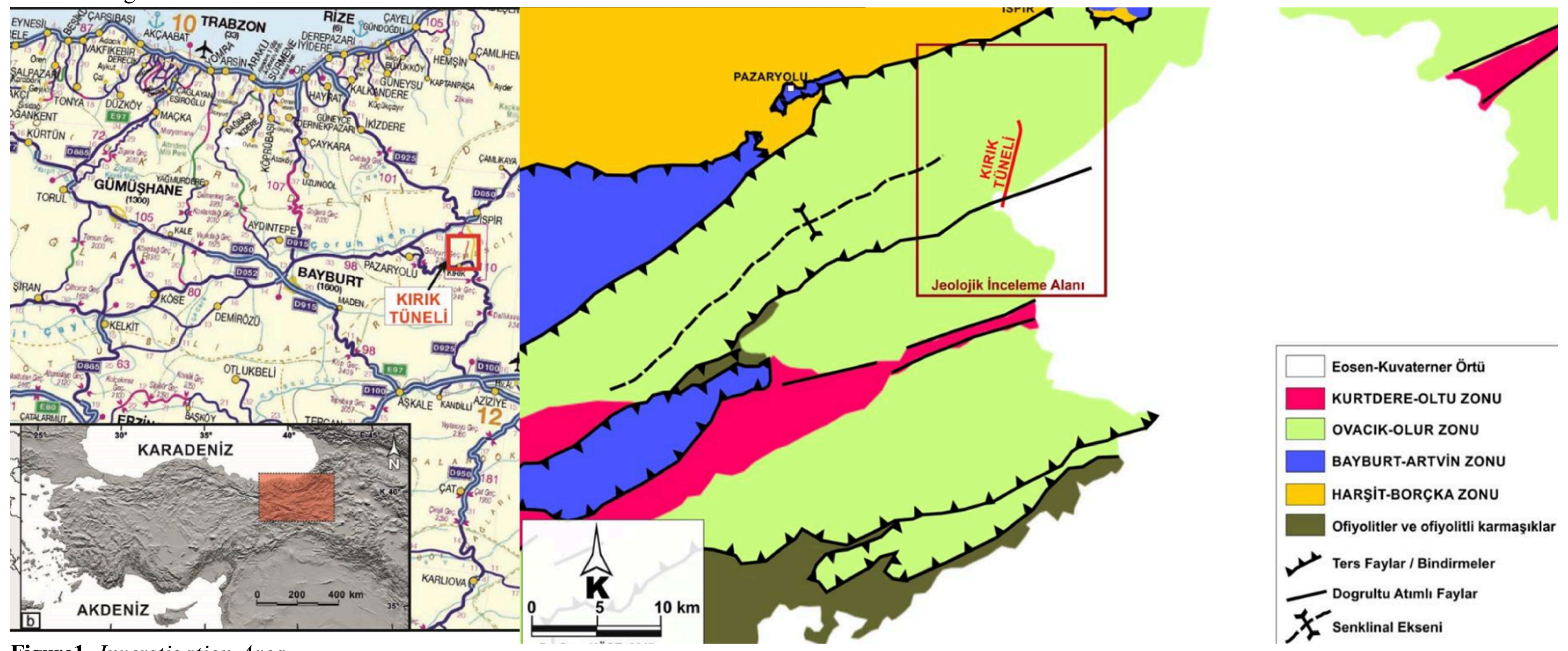



**Figure1.** *Inverstigation Area*

The study included field, laboratory and office studies. In field studies, geological and morphological observations were made along the route of the tunnel and samples of cave-in materials and water were collected. In laboratory studies, index and strength tests were performed also rock mass classifications (e.g. RMR, Q, GSI) were calculated from these data. In office studies, back analysis methods were used to design support systems. Main focus of this project is the importance of determining a accurate "k" value for geological numarical analysis.

This study conducted in two horizontal vertical stress ratio options. In the beginning of this study Sheorey (1994)'s prompt has been used as the result of the that we did not recognised the fault system's effect on the "k" value. When we discover the shear zone from the logs, we decided to update the value of horizontal vertical stress ratio.

**Figure 2.** *Recent Photo Of Right Tube (Cave in Occured Here km:1+825.00)*

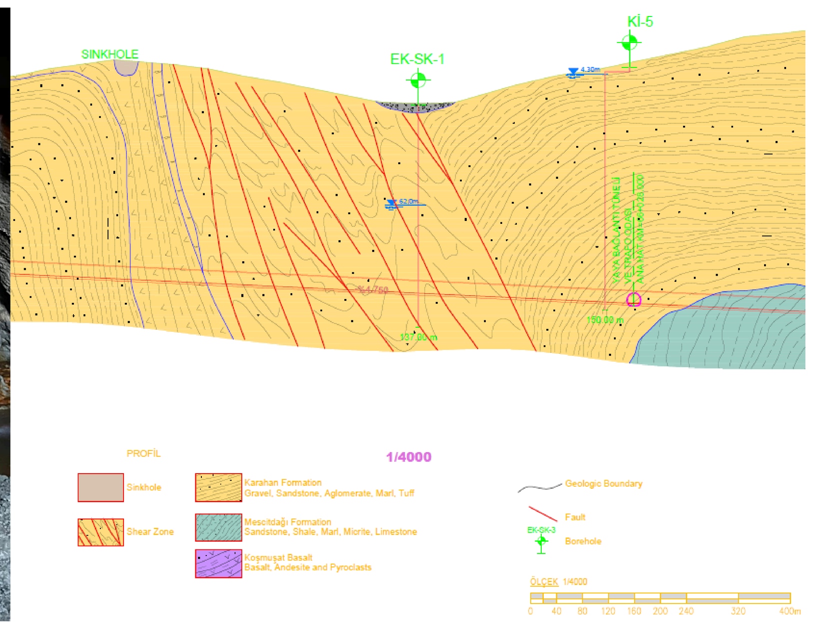



**Figure 3.** *Cross Section of Shear Zone*

**Figure 4.** *Water Income And Support System Deformations*

**Figure 5.** *Construction Site*

## 3.DESIGN PARAMETERS

In order to determine the design parameters, rock mass classifications RMR, Q, GSI classifications, which are the most critical points in tunnel design, were made. Following these classifications, the ÖNORM-NATM support class was determined with the Q and RMR classification values. As a result, the support systems recommended for the support class determined as "C3 Very Stressed" were taken into consideration while establishing the calculation model.

**Table 1.** *Design Parameters*

| Uniaxial Compressive Strength, rmUCS (MPa) | Rock Material Constant, mi | Geological Strength Index, GSI | Elastic Modulus, Ei (MPa) | Cohesion, c (kPa) | Unit Weight, γ (kN/m³) | Internal Friction Angle, Ø (°) | Rock Mass Rating, RMR | Deformation Modulus, Em (MPa) | Q Classification |
|---|---|---|---|---|---|---|---|---|---|
| 2.10 | 7 | 28 | 855 | 0.095 | 19.99 | 17.05 | 14 | 0.33 | 0.01 |

Uniaxial compression tests performed on core samples in this section of the tunnel average value; 2.1 MPa, average rock unit volume weight; 19.99 kN/m3, minimum value of modulus of elasticity; 0.86 GPa material constant mi=7. In addition, considering that the tunnel excavation technique to be opened is mechanical excavation and/or drilling- blasting and the fractured structure of the unit, the exfoliation factor was taken as (D) = 0.0 (for unexploded rock) and 0.5. The thickness of the cover in the collapse zone was also determined as approximately hmax=127.00 m. In addition to these design parameters, residual GSI and Horizontal Vertical Stress Ratio "k" values were determined. These values were found by calibrating field observations and abacs and the most appropriate approach method was decided.

Within the scope of the study, it was considered that the horizontal vertical stress ratio of the tunnel should be greater than or equal to 1 due to the development of a crushed zone due to faulting and the deformation values measured in the left and right shoulder regions of the tunnel are greater than or equal to the vertical axis of the tunnel.

The approach proposed by Jethwa (1984) was used to mathematically prove this situation observed in the field and to determine whether there is a squeezing mechanism

**Equation 1.** *Jethwa (1984)*

$$Nc = \frac{\sigma_{cm}}{p_0} = \frac{\sigma_{cm}}{\gamma \cdot h} \qquad \sigma_{cm} = \sigma_{ci} \cdot \left(\frac{GSI - 10}{40}\right)^2 \qquad Nc = \frac{0.42525}{19.99 \cdot 127} = \frac{0.42525}{2538.73} = 0.1675$$

This equation introduces a dimensionless coefficient denoted as Nc, which serves as the basis for categorizing the degree of squeezing in rock masses into four distinct classes: severe, moderate, mild, and no squeezing. In this formulation, $p_0$ represents the in-situ stress, which is a function of the unit weight of the overburden material (γ) and the depth of overburden (h). This classification provides a practical approach for anticipating deformation behavior in weak and squeezing ground conditions, particularly in tunnel engineering applications. Furthermore Hoek and Marison suggested given equation for squeezing behavior. As the result of that equations very severe squeezing problems and plastic cave ins are expected.

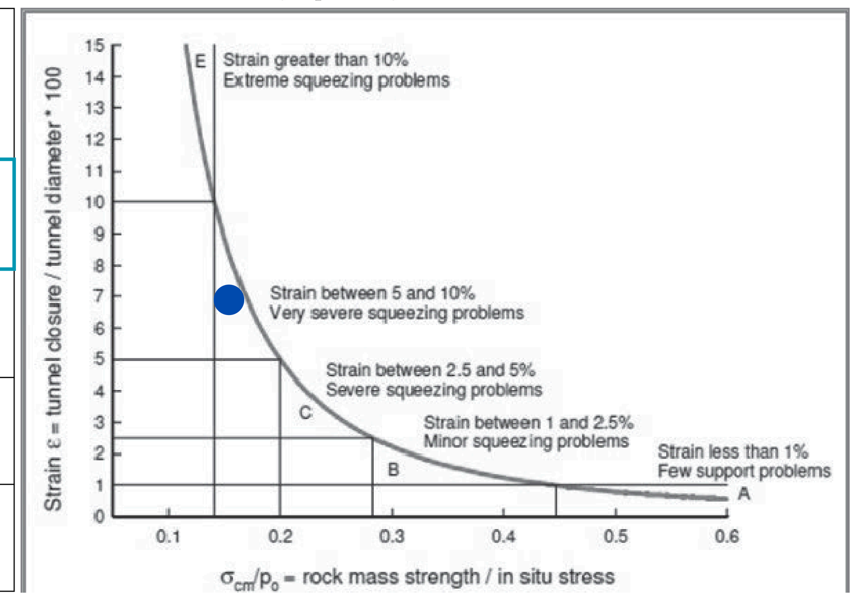
**Equation 2.** *Equation Describing Squeezing Behavior in the Absence of Support Hoek & Marison (2000)*

$$\varepsilon = 0.2 * (\sigma_{cm}/p_0)^{-2}$$

**Table 2.** *Classification Of Squeeze Levels*

| Squeezing Degree (Nc) | Range | Description |
|---|---|---|
| High | < 0.4 | Significant Squeezing |
| Medium | 0.4 - 0.8 | Moderate Squeezing |
| Light | 0.8 - 2 | Light Squeezing |
| No Squeezing | > 2 | No Squeezing |

**Table 3.** *Table Describing Squeezing Behavior*




## 4. GEOLOGICAL NUMERICAL MODEL

A geological computational model was developed based on borehole data and design parameters. This model was employed in a back-analysis to determine the horizontal-to-vertical in-situ stress ratio (k-ratio). The parameters of the potentially unstable zone were defined using borehole core data, with particular attention to a crushed zone characterized by agglomeratic material, which is interpreted as a shear-induced breccia associated with faulting.

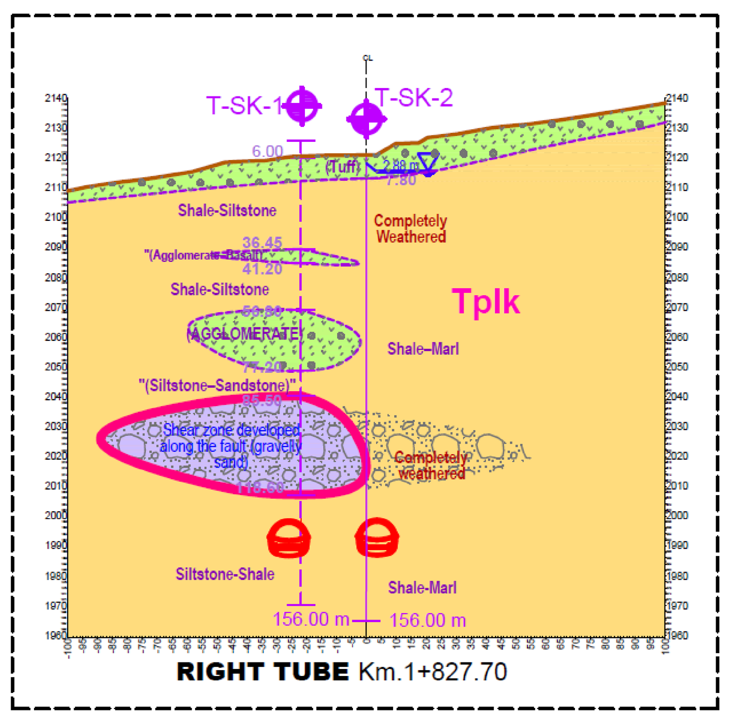



**Figure 6.** *Geological Model*

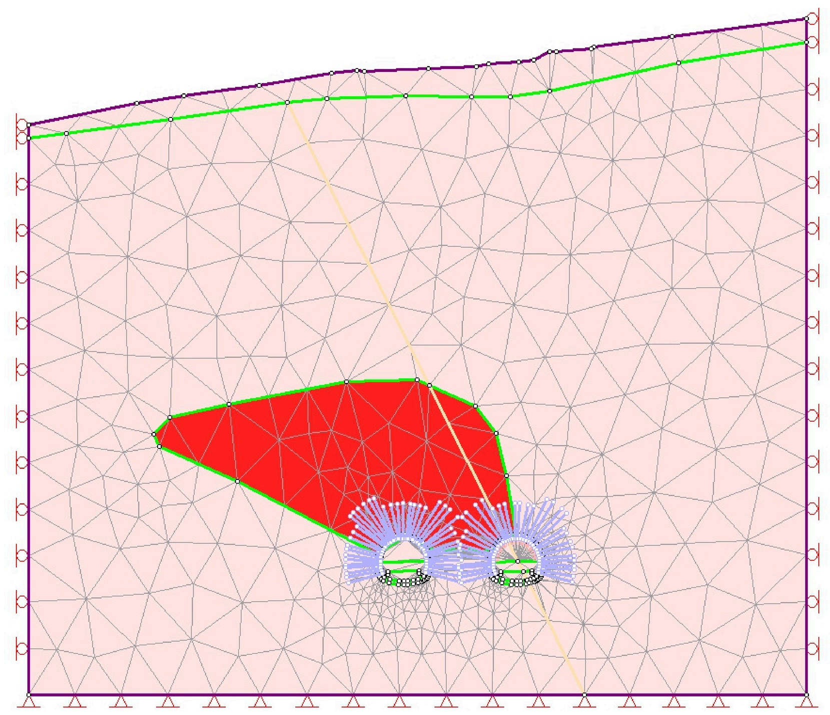


**Figure 7.** *Numerical Model*

## 5.BACK ANALYSIS

In this study, a back analysis approach was employed to determine the most representative lateral earth pressure coefficient (k) for a tunnel section undergoing deformation. Field data obtained from load cells during collapse conditions were used as a benchmark. By iteratively calibrating numerical models, the k value that reproduced deformation patterns consistent with the observed collapse behavior was selected. Once the numerical model aligned with field observations, the corresponding deformation values at this k level were extracted for further evaluation.

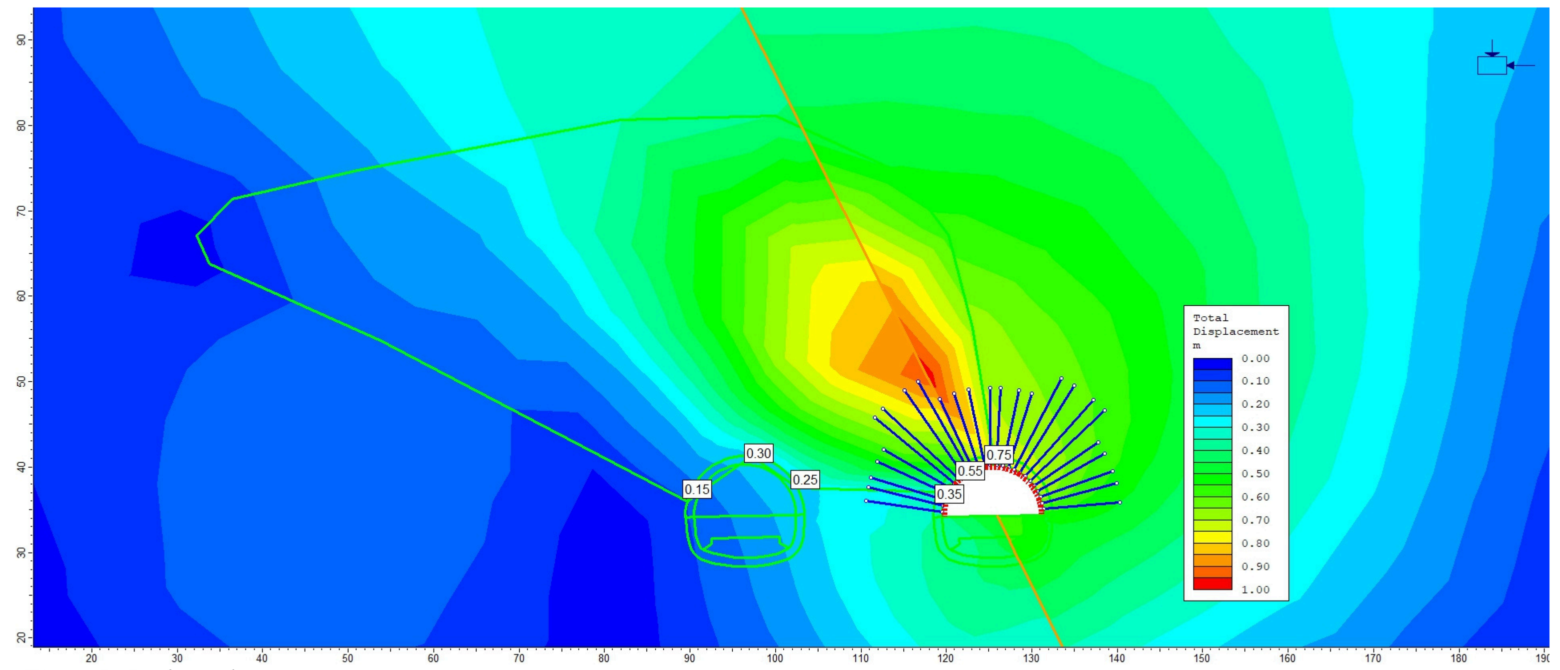



**Figure 8.** *Back Analysis*

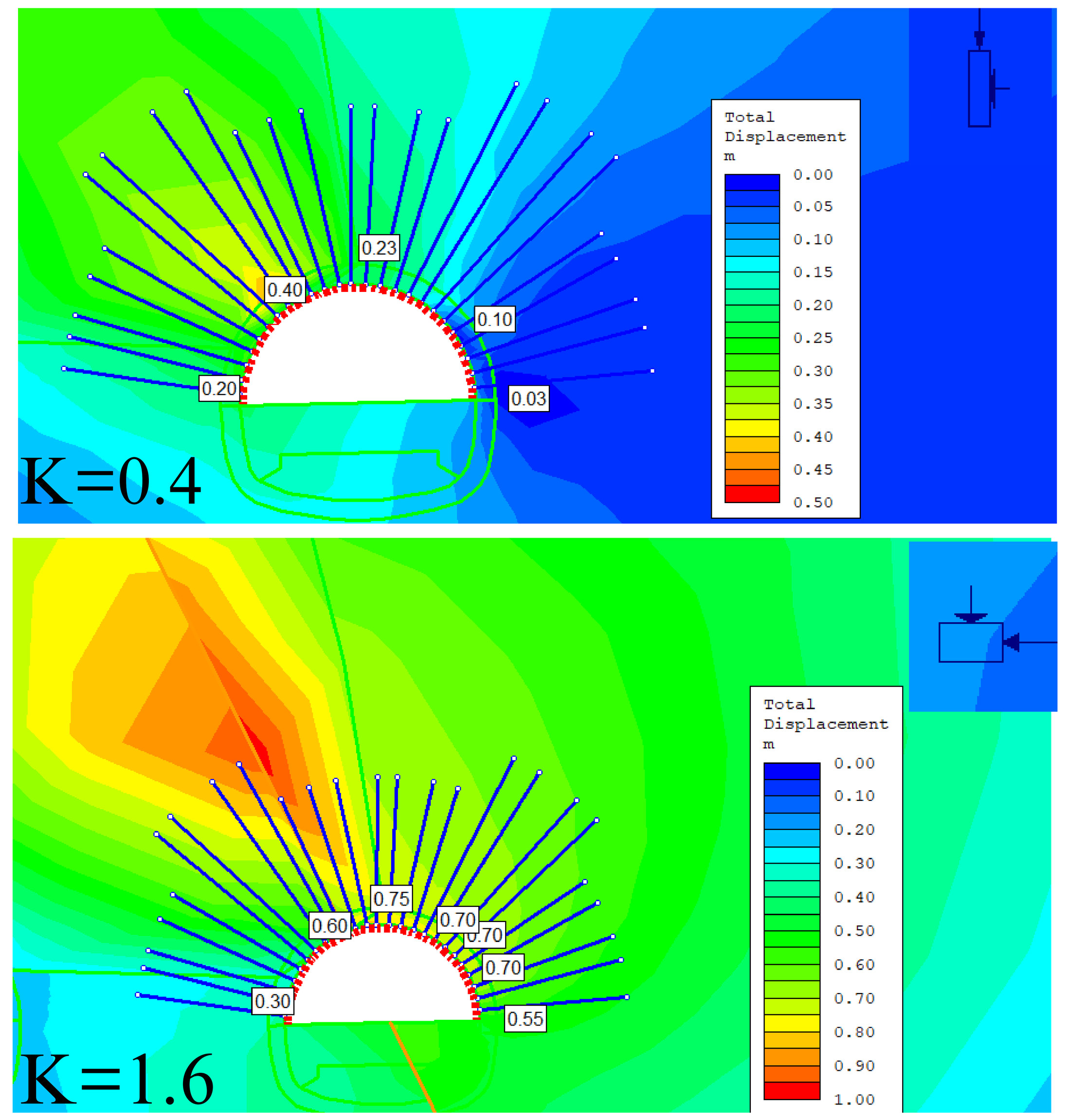



**Figure 9.** *Comparison Of Horizontal Vertical Stress Ratio Effect On The Displacement Values*

## 6.CONLUSION

The results obtained in this study are listed below.

Field observations (Geology and Hydrogeology) should be well calibrated with office studies for consistency and applicability of geotechnical data in tunnels drilled in weak rock environments.

Unpredictable tunnels in weak rock environments geological In order to avoid such conditions, drilling studies should be emphasized and accurate parameters should be tried to be reached with on-site experiments.

The compression mechanism in the tunnel was identified and a new support system was proposed. Although C4 classification is not applied in highway tunnels in Turkey, a stable environment can be created in the tunnel and deformation can be minimized with C4 support proposals in the region where the stability problems of Kırık Tunnel are experienced

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