The 2020 World Congress on
The 2020 Structures Congress (Structures20)
25-28, August, 2020, GECE, Seoul, Korea

Evaluation of reinforced Granite stones with Titanium bars

*Fahimeh Yavartanoo[1], Thomas Kang[2], Tae-Uk Ha[3], Woo-Young Lim[4], and Sung-Gul Hong[5]

[1], [2], [5] Department of Architecture & Architectural Engineering, Seoul National University, Seoul, Korea
[2] tkang@snu.ac.kr
[3] Division of Safety and Disaster Prevention, National Research Institute of Cultural Heritage, Daejeon, Korea
[4] Department of Architectural Engineering, Wonkwang University, Iksan, Korea

ABSTRACT

Historical structures are of great importance in transmitting cultural values. In order to suggest a proper technique for preservation or retrofitting of historical structures, understanding their mechanical behavior through experimental investigations is necessary. In Korea, one of the most common and accessible used materials in historical construction is natural Granite stone. In this study, reinforcing by Titanium bars and epoxy resins as adhesive was suggested to enhance the mechanical behavior of jointed natural Granite stones. The material properties of Granite stone used in Mireuksaji stone pagoda, such as compressive and tensile strengths, were investigated from quarries close to the site. Material tests for Granite and Titanium bars were done based on the method presented in KS F 2405 (2010), KS F 2423 (2006), etc. Behavior of the bond was examined by conducting several pull-out tests, and results indicated that, if enough embedding length is provided, bond behavior will be satisfactory.

1. INTRODUCTION

One of the desirable methods in retrofitting fractured stone and broken material of historical structures is to join the deteriorated part of stone by reinforcing bars including the application of adhesives and grouts, as well as mechanical pinning repairs. This method allows for force distribution between the joint components with more reliability. Despite the simplicity of the concept, the mechanics of how the system behaves are complex. Hence, proper consideration should be taken into account to obtain desirable

---

[1] Graduate Student
[2] Professor
[3] Researcher
[4] Assistant Professor
[5] Professor

behavior in practice. This technique is similar to anchorage design in reinforced concrete structures in current design code provisions. A similar evaluation methodology has been employed by Modena and Cecchinato (1985) in studying the structural behavior of limestone lintels strengthened with stainless steel bars. Granite stones were widely used in Korean historical structures. In this study, the behavior of jointed Granite segments with epoxy and Titanium bars were investigated. Material properties of stone and Titanium bar were explored. Then, effective fixation length according to the diameter of the metal bars was examined through a series of pull-out tests.

2. MATERIAL PROPERTIES TESTS

2.1 Granite

Compressive strength of Granite stone was measured based on the specimens presented in KS F 2405 (Concrete Compressive Strength Test Method) and KS L 5105 (Compressive Strength Test Method of Hydraulic Cement Mortar) for three cylindrical specimens. The experimental equipment was a 2,000 kN UTM (Universal Testing Machine). The average values of 130 MPa for compressive strength were obtained which is around four to five times larger than common structural concrete compressive strength.

The tensile strength of the Granite material for four specimens was obtained following KS F 2423 (Test Method of Splitting Tensile Strength of Concrete). However, unlike normal concrete, Granite specimens were produced by cutting the shape. The average ultimate load and tensile strength of the specimens are 171.28 kN and 6.7 MPa respectively. Similar to observation on compressive strength, Granite has a quite larger tensile strength in comparison with common structural concrete.

2.2 Titanium

Two specimens having a 16 mm diameter were prepared according to KS B 0801 (Metal Material Tensile Test Specimen) standard (Korean Standard) to investigate the tensile strength of the Titanium. Tests were carried out using 2,000 kN UTM by method KS B 0802 (Metal Material Tensile Test Specimen) (Korean Standard). The yield point was determined by using the offset method (0.2 %). In Table. 1, P_u is ultimate load, F_y and F_u are yield and tensile strength, respectively, and E is the Modulus of Elasticity.

Table. 1 Results of Titanium test

Specimen	P_u (kN)	F_y (MPa)	F_u (MPa)	E (GPa)
T1	93.9	368.0	446.9	71.3
T2	92.0	358.8	457.3	69.9
Average	92.9	363.4	452.1	70.6

Although Titanium has a lower modulus of elasticity than mild steel and stainless steel, it has quite larger strength and smaller density, thermal conductivity and coefficient of thermal expansion. These characteristics make Titanium an effective and superior material for use in the rehabilitation works.

3. PULL-OUT TESTS AND BOND PROPERTIES

Given the cultural significance of Mireuksaji stone pagoda, effective development length of reinforcing bars placed in the stone structure should be determined correctly due to inevitable damage to the base material. Nine specimens were produced with variation in bar diameter (8, 12, and 16 mm) and embedment length. In each case, a Granite block having a size of 150 mm × 150 mm × 300 mm was prepared. Each specimen was embedded into a hole cored in the Granite and filled with an epoxy resin (Poong Rim Industry's L-30 product). Upon curing, specimens were placed in a steel case (jig), where pulling force was applied to the bar using a 2,000 kN UTM.

Based on the hypothesis for the bond, the tensile force of the bar, T, and shear stress at the bond interface is in the balance. The equation for obtaining effective development length can be summarized in Eq. (1).

$$T = A_t f_t = \mu \pi D l \tag{1}$$

Where f_t is the tensile strength of the bar, μ is the epoxy resin adhesive strength (12 MPa), and D, A_t, and l are the bar diameter, cross-section, and effective length, respectively. By manipulating the equation, the theoretical value of effective development length (l_{dt}) can be calculated as the ratio of $A_t f_t l/(\mu \pi D)$. Hence, the theoretical value of l_d for the bars with diameter of 8, 12, and 16 mm are about 61, 91, and 122 mm, respectively. Here, pull-out tests were carried out with three values of l (50, 100, and 150 mm) to examine the theoretical length. Fig. 1 displays the condition of specimens with a 16 mm diameter bar at the end of the test. Based on the results, for the case that l was larger than l_d, the bond behaved very well, and the specimen reached its desired ultimate capacity, i.e. yielding of the bar. While in other cases, tests were terminated mainly by crushing the block and pulling out of the bar.

P3 (l = 150 mm) P6 (l = 100 mm) P9 (l = 50 mm)

Fig. 1 Condition of specimens with 16 mm diameter bar at the end of the loading

A similar pattern was observed for all the other specimens, except the P4. Specimens P1 to P5 satisfied development length determined and showed favorable failure modes (i.e., Titanium bar yielding). Specimen P4 had local Granite fracture, which however occurred after a certain degree of bar yielding. While the specimens P6, P7, P8 and P9 with the embedded length shorter than the calculated development length failed in a brittle manner. The P6, P7, and P9 experienced complete pull-out failure without yielding, and P7 had local fracture of the Granite stone right after bar yielding (Table. 2). Therefore, effective development length determined for each cross-section can be used for future restoration.

Table. 2 Summary of pull-out test results

Specimen	Ultimate load (kN)	Ultimate stress (MPa)	Effective development length (mm)		Failure mechanism		
			Predicted	Provided	Granite	Bar yielding	Pull-out
P1	29.7	591.2	60.9	150	-	✓	-
P2	51.8	458.3	91.3	150	-	✓	-
P3	83.4	415.0	121.8	150	-	✓	-
P4	29.2	581.8	60.9	100	(local)	✓	-
P5	52.6	465.6	91.3	100	-	✓	-
P6	80.4	400.3	121.8	100	✓	-	✓
P7	29.9	595.8	60.9	50	(local)	-	✓
P8	51.3	454.2	91.3	50	✓	-	✓
P9	52.2	259.9	121.8	50	✓	-	✓

CONCLUSION

In this study, the behavior of jointed Granite segments reinforced with Titanium bars was investigated experimentally and compared with the sound stone. The material experiments were carried out to understand the material properties of Granite and Titanium bar. In order to investigate the bond behavior made by the epoxy resin to attach the metal rod and the Granite, a series of pull-out experiment was conducted to estimate the effective fixation length. This can help us to use a proper length of bars for restoration works.

REFERENCES

KS B 0802 (2003), Method of Tensile Test for Metallic Materials, Korea Industrial Standard, Korean Standards Association, Seoul, Korea. (in Korean)

KS B 0801 (2007), Test Pieces for Tensile Test for Metallic Materials, Korea Industrial Standard, Korean Standards Association, Seoul, Korea. (in Korean)

KS F 2405 (2010), Concrete Compressive Strength Test Method, Korea Industrial Standard, Korean Standards Association, Seoul, Korea. (in Korean)

KS F 2423 (2006), Split Tensile Strength Test Method of Concrete, Korea Industrial Standard, Korean Standards Association, Seoul, Korea. (in Korean)

KS L 5105 (2007), Compressive Strength Test Method for Hydraulic Cement Mortar, Korea Industrial Standard, Korean Standards Association, Seoul, Korea. (in Korean)

Modena, C, and Cechinato, P (1985), "Experimental investigation of bond of stainless steel bars for stone reinforcement," In *Proceeding of the 5th International Congress on Deterioration and Conservation of Stone*, Lausanne: Presses Polytechniques, Romandes, 949-58.