Study on the material and structural test program of stones with bonded anchors for performance-based design

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How reliably can the material properties of masonry structures be estimated from core samples?

BACKGROUND

Fig. 1 Examples of damage (Kumamoto earthquake)

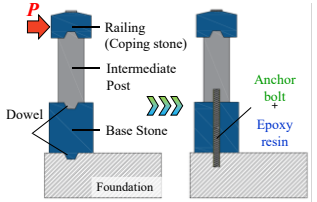

Fig. 2 Schematic illustration of bonded anchoring

[Masonry structures](#) (bridge, lantern, etc.)
- Long-term use
- Historic and aesthetic values
- Unique appearance

[Condition](#)
Deterioration
Damage due to natural disasters

✓ Masonry structures should be strengthened while preserving their original appearance.
→Bonded anchors can connect stones without changing their original appearances (Fig. 2).

[Performance-based design](#)
Design concept for verifying structural performance against required performance levels

[Challenges](#)
How many sampling cores are required to estimate each material properties ?

[Approach](#)
Experimental evaluation of material properties using sampling cores.

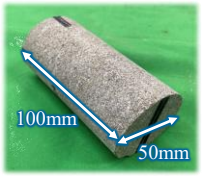

Fig. 3 A sampling core

METHOD

(1) Uniaxial compression test and measurement of nondestructive indicators
- ✓ Uniaxial compressive strength σ_c
- ✓ Young's modulus E
- ✓ Dry density ρ_d
- ✓ P-wave velocity V_P

(2) Brazilian test
- ✓ Tensile strength σ_t

(3) SCB test
- ✓ Fracture toughness

(Stress intensity factor K, Energy release rate G, Fracture energy G_F *etc.*)

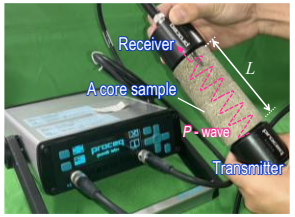

Fig.4 Measurement of P-wave velocity

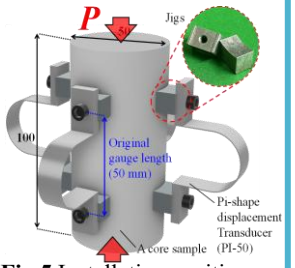

Fig.5 Installation positions of measuring instruments

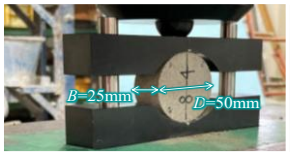

Fig.6 Brazilian test

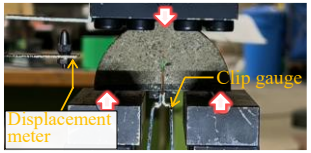

Fig.7 SCB test

KEYWORDS

Masonry structures, material properties, Performance-based design

RESULTS

- Database construction from core tests and literature survey
- Regression models using dry density ρ_d and P-wave velocity V_p
- Estimation of compressive strength σ_c and Young's modulus E

[Multiple regression equations](#)

$$E = \frac{1}{a}\rho_d^b \cdot V_p^c \quad (1) \qquad \sigma_c = \frac{1}{d}\rho_d^e \cdot V_p^f \quad (2) \qquad \sigma_c = gE \quad (3)$$

a (= 1,116.7 $kg^{0.533}MPa^{-1}s^{-1.571}m^{-0.027}$), b (= 0.5328), c (= 1.5710), d (= 0.6053), e (= 1.0810), f (= 0.0213 $kg^{-1}MPam^3$), g (= 0.0034)

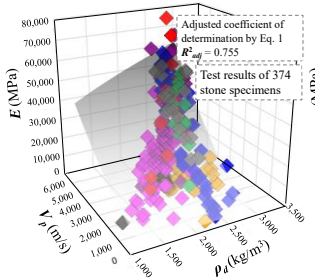

Fig.8 E - ρ_d - V_p relationship

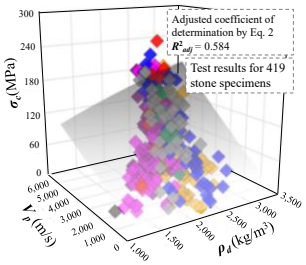

Fig.9 σ_c - ρ_d - V_p relationship

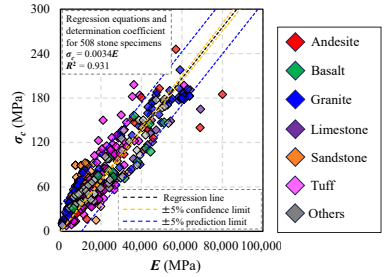

Fig. 10 σ_c - E relationship

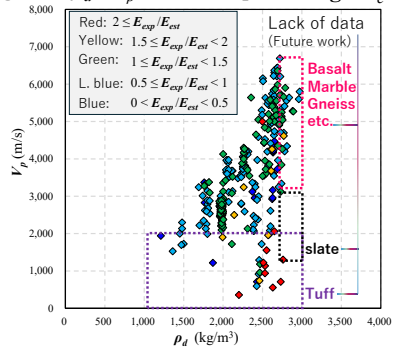

Fig.11 Estimation error of Eq. (1) in V_p - ρ_d plane

[Discussion](#)

- ✓ E and σ_c exhibited positive correlations with ρ_d and V_p.
- ✓ The estimation accuracy of σ_c was lower than E.
- ✓ The number of samples and estimation accuracy should be improved for tuff, slate, basalt, marble and so on

SUMMARY

- A material property database was constructed from sampling core tests and literature survey.
- Both E and σ_c showed positive correlations with ρ_d and V_p
- Noticeable deviations remained in σ_c estimation across stone types, indicating the need for further database expansion and additional parameters.