Effect of grout material on stress wave monitoring in damaged concrete structures

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1. Abstract Injection of grout material is conventionally used for repair of structures. One of the evaluation techniques for the grout performance employs stress wave propagation. However, due to properties mis-match of the materials, the knowledge of the stiffening rate of grout should be known. In this case ultrasonic monitoring of grout and porous concrete specimens impregnated with grout is performed to highlight the influence of the injection material in the concrete ultrasonic characteristics. The subject is also investigated with multiple scattering theory to explain the observed behavior.

2. Introduction Repairing techniques and in-situ monitoring are steadily gaining the attention in civil engineering. One common repair method is the injection of grout [1] into a pattern of boreholes drilled on the structure. However, the evaluation of its performance is not an easy task. Ultrasonic measurements after the injection compared to prior ones revealed increase of velocity in the case of a concrete bridge pier repaired with inorganic agent with rapid setting time [2]. However, in a number of other cases, velocity after repair with grout decreased e.g. [3], making explanation difficult. Even if the defects are not completely eliminated, the velocity is not supposed to be negatively affected, according to common knowledge. Therefore, it is understood that the knowledge of grout properties at the time of monitoring is of paramount importance in interpretation of the monitoring results. In the present work, an ultrasonic monitoring series of hydration of grout material is performed, while additionally, in order to evaluate the influence of grout in the wave propagation parameters of a structure, porous concrete specimens were impregnated with grout and ultrasonically interrogated at different ages.

3. Experiment Two prism (100x100x400mm^3) specimens of 'quick setting and hardening grout' were casted with w/c=0.5 and cured at 5^{o}C. Fig.1 shows the average pulse velocity vs age curve as well as the best fit exponential curve. The material exhibited high rate of hydration and after the age of 10 days no considerable increase was shown. As to the porous specimens, their porosity was approximately 35% while one of them, with code name L contained lightweight aggregates. They were impregnated with a grout of w/c=2 with the use of vacuum chamber. One specimen was cured in an environmental chamber at 5^{o}C while the other two in 20^{o}C, in order to investigate the influence of different temperature. A high voltage pulser (Kaihatsu NSPG-53D) was employed for pulse generation and transmission, while propagated signals were detected with 60kHz resonant sensor, PAC R6 and recorded with a Mistras 2001. The pulse velocity of porous concrete according to the time after grouting is depicted in Fig.2. The velocities at the age of 0 days were measured before impregnation. As seen here and explained in detail in [4] all specimens exhibited lower velocity just after grouting in a percentage of 5% to 13%. After that, the specimens held at ambient temperature exhibited slight increasing rate and specifically for specimens L (lightweight) and N2 (normal) the velocity increased above the before impregnation level at the age of 5 and 14days respectively. However, pulse velocity of specimen N1, held at 5^{o}C even at the age of 14days was about 6% lower than the initial. This is considered to be due to the low rate of grout hydration imposed by the low temperature. In addition the lightweight specimen exhibited the highest velocity increase, more likely due to its low mechanical properties. The grout after some days acquired sufficient stiffness to reinforce the specimen and increase the velocity. In contrast, normal weight specimens were not reinforced that much, since the elastic modulus of grout compared to theirs is still much lower.

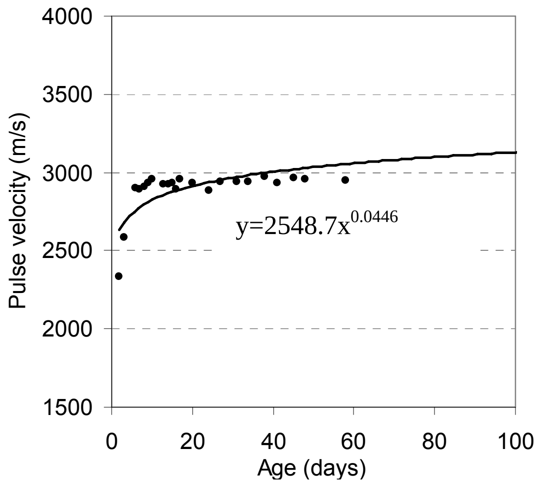

Figure 1. Pulse velocity of grout specimens vs age

Pulse velocity, concrete, grout, hydration, scattering
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4. Theoretical investigation Wave propagation in non homogeneous materials like concrete is governed to a great degree by scattering [5]. In this case the multiple scattering theory of Waterman and Truell [6] was used. The detailed procedure can be found in [4]. The cases considered were that of a material with 10%: i) air voids, resembling the damaged case ii) soft scatterers of elasticity modulus, E=6GPa to account for the early stage of grout hydration after repair and iii) harder scatterer of 26GPa, corresponding to the final velocity calculated by the exponential curve of Fig.1 for the age of 1 year. The diameter of scatterer was assumed 20mm and the elastic modulus of the matrix material, namely concrete was considered 45GPa. In Fig.3 the phase velocity of the band of 0-30kHz is depicted for all cases. It is obvious that the porous state velocity is higher throughout the band of interest than the material impregnated with soft grout (scatterer with E=6GPa). However, allowing the grout to harden the velocity is expected to increase to levels above the initial, (see porous concrete) since the modulus of grout increases to about 26GPa.

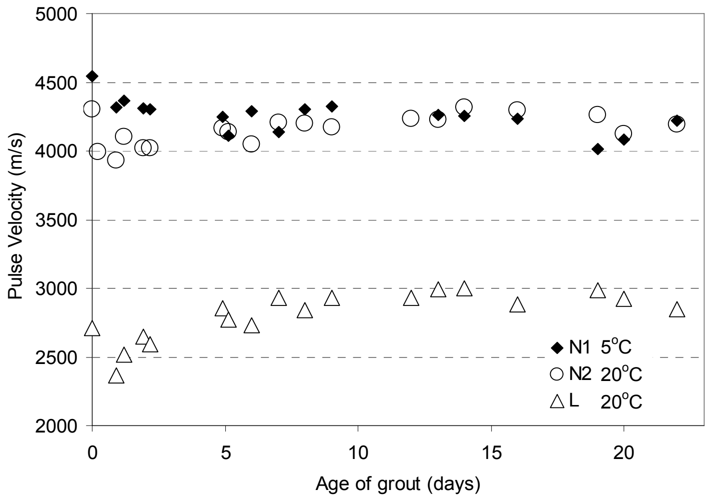

Figure 2. Pulse velocity of grouted concrete vs age of grout

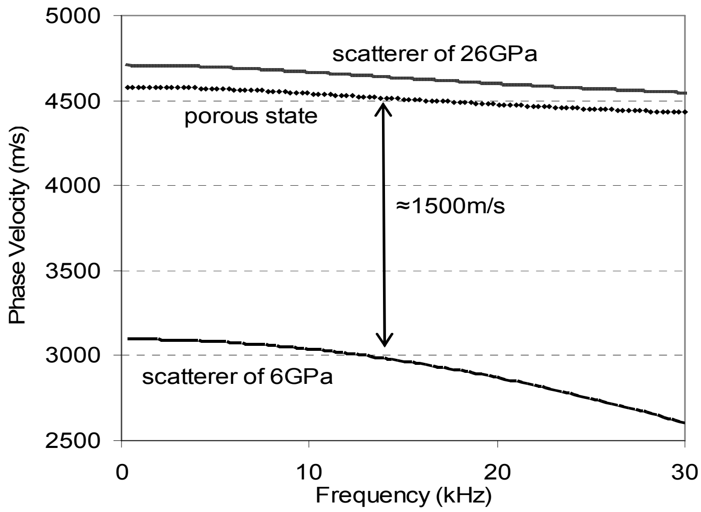

Figure 3. Theoretical velocity curves vs frequency

5. Conclusions In the present paper, the effect of grouting injection in concrete ultrasonic characteristics is addressed. Due to hydration reaction after mixing, grout has a time dependent effect on the velocity response of the whole structure. Ultrasonic experiments were conducted on specimens of grout material typically used in practical applications, to have an estimation of its elastic constants at any age. Additionally, porous specimens were impregnated with grout and held at different conditions in order to measure their response at different ages of grout. Results reveal that at early stages of grout hydration, while it has not yet developed sufficient stiffness, it is expected the velocity values to reduce compared to before grouting, according also to the environmental conditions. This is also investigated by means of multiple scattering theory which highlights that the properties of the scatterer are crucial for the total response; low elasticity is responsible for decrease of velocity, while hard scatterer elevates the total velocity response.

[References]

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