論文の要旨

題目： Evaluation of Crack Repair Effectiveness and Thermal Insulation Performance in the Envelope for Enhanced Building Durability

(外気と接する建築部材の耐久性向上に資するひび割れ補修と断熱性能の評価)

氏名　李　雨彤 (LI YUTONG)

Background

In the realm of building construction, the building envelope assumes a critical role in safeguarding the building's interior from external environmental influences. The envelope enables the building to withstand natural forces such as wind, rain, sunlight, and temperature fluctuations. Consequently, the building envelope is also the part of the building that is most susceptible to deterioration. Over the past few decades, the construction industry has witnessed a transition from a focus on “building and storage” to “maintenance and renovation”. In this context, the assessment of the building envelope's durability has emerged as an imperative undertaking. First and foremost, the physical properties of concrete make cracking an inevitable challenge in concrete structures. The presence of cracks engenders structural vulnerability and expedites the deterioration process. Hence, the effective repair of cracks assumes paramount significance in extending the lifespan of buildings. Additionally, space cooling constitutes a significant contributor to climate change owing to its substantial energy consumption and the prevalent utilization of refrigerants possessing notable global warming potential. Accordingly, a meticulously designed and constructed envelope system, encompassing insulation and minimizing heat transfer and energy consumption, presents itself as a viable solution. For the above reasons, this paper conducts a study on the evaluation of crack repair effectiveness and insulation performance.

Purposes and contents

The first purpose of this paper is to establish crack movement simulation experiments to evaluate the durability of the repair. One of the reasons that may affect the durability of a crack repair is the crack movement. Crack movement is the change in crack width caused by the change in ambient temperature. Crack movement occurs every day, and it repeatedly affects the repair area, eventually causing repair failure. Starting with the most harmful through-thickness cracks, this paper investigated and measured crack movements in actual buildings. For recurring specific crack movement patterns, simulations were performed in the laboratory. Experimental methods for evaluating the durability of crack repair against crack movement were proposed.

The second purpose of this paper is to evaluate the resistance of common repair solutions to crack movement to help establish a more appropriate solution selection system. The crack repair methods evaluated in this paper include injection method, U-groove routing and sealing method, and surface coating method. The materials covered mainly include epoxy resins, polymer cements, and waterproof coatings. The experimental methods used are the crack movement reproduction experimental method and the crack bending-like movement fatigue test method proposed in the previous item. In the reproduction experiments, the ability of different repair solutions to suppress crack movement was discussed by comparing the data before and after repair. The durability of the various repair solutions was compared within a limited test time. Numerical simulations of the physical properties of the repair materials that may affect the crack movement patterns were also performed in conjunction with the finite element method. In fatigue tests, the repair effectiveness was discussed around the specimen damage forms, damage rates, and strain levels with varying ambient temperature and amplitude of movement.

The third purpose of this paper is to establish a simple insulation performance evaluation method and a prediction formula for heat-flow density. The existing insulation performance evaluation method has the problems of difficult to control equipment and long testing time. Also, the professional indicators are not conducive to homeowner communication. For this reason, this chapter designed a simple test method to evaluate the insulation performance of building components. To demonstrate the effectiveness of the heat-flow sensor, it was used in both static and dynamic heat transfer experiments. When the boundary conditions are the same, a larger absolute value of the heat-flow sensor means better insulation performance. This makes it possible for anyone to evaluate the thermal insulation performance. In addition, to further enhance the communication efficiency, the indoor temperature increment was used as an evaluation index in this paper. A relationship equation between heat-flow density and time was proposed. Using this method, in the field, the indoor temperature increment for a long period of time can be roughly predicted from the heat flow measurement for a short period of time. In addition, the insulation performance of 14 experimental specimens was evaluated, including self-developed and commercial insulation materials and construction methods.

Conclusions

A discussion of available data from actual buildings revealed that the daily movement of through-thickness cracks is proportional to the temperature gradient of the wall cross-section and inversely proportional to the constraint strength, whereas no significant relationship exists with the initial crack width. The through-thickness crack undergoes a daily bending-like movement that is a combination of temperature and mechanical load deterioration. In the laboratory, the bending-like movement can be reproduced in an asymmetric restraint scheme. The advantage of the reproduction experimental method is that both temperature and mechanical deterioration can be applied. For the other fatigue test method proposed in this paper, it is also possible to simulate the bending-like movement. The advantage is the adjustable test period and movement amplitude.

The movement pattern of cracks after repair may change under different repair solutions. The ambient temperature can also have an effect on the post-repair movement pattern. The reason may be the different coefficients of thermal expansion and Young's modulus of the materials. From the results of the experiments, as an injection material, hard epoxy resin is more suitable for repairing small movement cracks, soft epoxy resin is more suitable for repairing in low temperature environment, and polymer cement may not be suitable for repairing cracks with movement. For the U-groove routing and sealing method, durability can be ensured as long as the flexible epoxy resin used can follow the deformation at the crack and ensure sufficient bond strength. In addition, the water-based acrylic waterproofing coating used in this paper can be used to repair cracks at a wide range of temperatures, but it should be used in conjunction with a crack bridging layer when the crack movement is large.

The results of static and dynamic heat transfer experiments showed that heat-flow sensors can be used to quantitatively evaluate the thermal insulation performance. This paper established a simplified equation for the variation of heat-flow density with time. The results of this equation for the temperature increment in the indoor space agree well with the experimental results. In a simulation of a full-size building model, buildings with small roof U values were found to be effective in improving the indoor thermal environment, especially during the first few hours when the cooling equipment was turned off. At the 6th hour, the average indoor temperature increment of the building with insulated roof panels was reduced by about 48%.