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Wind Effect on Vibration and Scattering Behavior of Japanese Roofing Tile

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Abstract

A series of wind tunnel tests were conducted on the vibration and scattering behavior of full-size models of tiles widely used as roofing materials on Japanese wooden dwellings. This study has investigated the nature and source of such movement with the aim of providing better insight into the mechanism. The result of these measurements indicates that a basic mechanism can be developed that will lead to flow-induced vibration of the roofing tiles. The values of the oscillation frequencies relate to the values of natural frequencies of the vibration.

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1. Introduction

The wind load on a roofing element is created by the difference in the external and internal pressure. The net wind load is generally determined by the building flow field, wind gustiness, and element flow field [1], [2]. While these parameters directly influence the external pressure distribution on the roofing element, the

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internal pressure development, depending indirectly on these parameters, is governed by a dynamic response that varies in the roofing elements. The pressure distribution on the external roof surface and the internal pressure are well known from previous investigations [3], [4]. The element wind load may differ significantly from the load derived by the external pressure distribution. The internal pressure is governed by the wind permeability of the surface, which is determined by openings such as gaps between tiles and venting devices as well as the resistance from equilibrating flow through and underneath the wind permeable surface [5].

Flow-induced vibration of roofing tiles generally appears immediately before their scattering. The flow-induced vibration (aeroelastic instability) of structures is an important phenomenon for the following two reasons: (1) Strong lateral, self-excited oscillations can develop at a certain wind velocity (onset velocity) as a result of the lateral aerodynamic force component, and (2) the tendency to these vibrations affects the behavior of the structure below the onset velocity as it produces a negative aerodynamic damping, which can considerably reduce the total damping available to the structure [6]. The investigation of flow-induced vibration of roofing tiles prior to the scattering has attracted little attention. This study investigates the nature and source of the vibration and scattering behavior of these tiles with the aim of providing a clearer insight into the mechanism, and this paper presents the initial results of studies into the wind-inducing device for the tiles.

Using wind tunnel tests, a study was conducted to clarify the behavior of the roofing tile vibration and the primary factors that affect the scattering. The results indicate that the vibration mechanism behaves in a manner consistent with that of a self-excited system, and the surface flow creates reasonable uplifting moments only for wind directions roughly perpendicular to the eaves.

Nomenclature

P	pitch angle
Q	flow angle
U	upstream flow velocity
X	streamwise coordinate
Y	transverse coordinate
Z	perpendicular coordinate to surface of roofing tile

2. Test Facility and Analysis Procedure

The schematic diagram in Fig. 1 illustrates the general layout of the test facility used in this investigation. The experiments were conducted in an open-circuit wind tunnel that was driven by an axial-flow fan. The nozzle of the wind tunnel had a 500 mm × 1,300 mm cross section. The maximum velocity of flow from the nozzle was about 50.0 m/s. The streamwise turbulence intensity of the flow was about 10% of that generated by the grids. The turbulence intensity of the flow condition is in the same order as the turbulence intensity of approached wind flow experienced in practice.

Twenty-five roofing tiles were set up in five lines by five rows on a pitched roof in the downstream flow from the wind tunnel (Fig. 1 (a)). The roofing tiles were composed of clay, and each weighed about 2.8 kg. The vibrations of the roofing tiles were measured by a Laser Doppler Vibrometry (LDV, OMETRON VS1000) and an accelerometer (ONO SOKKI NP-3560), and the practical natural frequencies of the roofing tiles were analyzed by the impulse force hammer test method. The vibration velocity could be measured up to 1,000 mm/s by the 1 mW LDV, and the vibration frequency range was from dc to 50 kHz. Each roofing tile was equipped with an accelerometer, as shown in Fig. 1 (b). The accelerometer was used to measure the dynamic behavior in three directions; X, Y, and Z axis of tiles; and weighed about 5.0 g. The experiment to measure vibration frequencies of the tiles was generally performed by the accelerometer. Unfortunately, the vibration