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JUDUL: A STUDY ON SIMULATED RAINFALL NOISE GENERATION AND PREDICTION OF RAIN NOISE FOR COMPOSITE ROOF CONSTRUCTIONS

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A STUDY ON SIMULATED RAINFALL NOISE GENERATION AND PREDICTION OF RAIN NOISE FOR COMPOSITE ROOF CONSTRUCTIONS

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A project report submitted in partial fulfillment of the requirements for the award of the Degree of Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
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NOVEMBER, 2004
"I hereby declared that this thesis is my own work except the ideas and summaries which I have clarified their sources".

Signature : ...........................................
Author : LEE YUK CHOI
Date : 8/11/2004
Specially dedicated to my family, friends and companion...
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ABSTRACT

Experimental studies were undertaken to investigate the mechanism of noise generation on composite roof installed in an acoustic reverberant test chamber. Noise studies were for simulated rainfall in a special test facility. Noise measurements included the normalized impact sound using an impact tapping machine. Tests were undertaken for several roof construction combinations— that included a bare roof and a composite roof with different noise control options such that its effect on noise and vibration generated could be determined. Sound power levels per unit of roof area (i.e. sound intensity) of all the roofing samples tested are presented. Results for the normalized impact sound pressure level in accordance to ISO 140-7: 1998 were also obtained for the roofing samples. Vibration measurements were also undertaken that included the vibration velocity response of the respective roofs under different rainfall impact excitation, and natural frequencies of the roofing sample (obtained from conventional impact bump tests).

Based on the experimental results and theoretical considerations, a semi-empirical equation was developed to predict the noise level due to rainfall for a range of composite roof construction. For an assumed rainfall droplet size, rainfall precipitation and rainfall droplets terminal (impact) velocity, an empirical constant for this particular roofing construction was proposed which allows the sound intensity level to be estimated. As commonly known, noise generated by rain impact on roof are caused by random vibration impact. An empirical equation based on theoretical and experimental work was formulated to establish the relationship between noise and vibration on the composite roof over one third octave center audio frequencies. Attempts were made to validate the influence of damping on the radiated sound power from the roof by virtue of reduced vibration velocity levels. A stiffer roofing construction also increases the flexural stiffness of the roof, thereby reducing the critical frequency. Vibration of the roof was found to decrease when the surface mass of the roof was increased, which result in a reduction of sound generated in the test room.
ABSTRAK


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LIST OF SYMBOLS

B' - Bending stiffness per unit width
A - Area of water droplet
C - Constant for bare roof
c - Sound velocity in the medium into which sound is radiated
C_D - Drag coefficient
c_L - Longitudinal wave velocity in plate
D - Drop diameter
dB - Decibels
delta C - Roof constant with treatment
D_f - Drag Force
E - Modulus Young
F - Force
f_c - Critical frequency
h - Thickness
I - Sound intensity
L_{p1} - Octave-band level or A-weighted level for first measurement
L_{pn} - Octave-band level or A-weighted level for the nth measurement
L_v - Vibratory velocity level
M_s - Surface mass
n - Total number of measurements
N(D)dD - Number of drops per unit volume
Q - Directivity factor
Q - Rainfall rate
r - Distance between source and receiver
R - Radius of droplets
R_c - Room constant
S - Surface area
SIL - Sound Intensity Level
SPL - Sound pressure level
SWL - Sound power level
t - Time
U - Plate perimeter
v - Average RMS velocity of radiating surface
V_T - Terminal velocity
\(\langle v^2 \rangle\) - Average mean square velocity
W - Sound power
Z - Driving point impedance

GREEK SYMBOL AND SPECIAL NOTATION

\(\rho\) - Density of the fluid medium
\(\lambda_c\) - Wavelength at critical frequency
\(\rho c\) - Acoustic impedance of the surrounding medium
\(\rho_m\) - Plate density
\(\sigma\) - Radiation efficiency
\(\rho_w\) - Density of water
\(\rho_a\) - Density of air
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CHAPTER I

INTRODUCTION

1.1 Overview

Educational institutions, commercial buildings, theatres and stadium which utilizes metal roofing are always faced the problem of rain impact noise during heavy rain. Classes, concert halls and performance are therefore affected by high rain impact noise. When it rains, the raindrops excite the metal roof panels through random impacting. As a result, the metal panels resonate and generate high level of noise, especially during heavy downpour. It has always been a design challenge to reduce rain impact noise particularly for metal roofs. At elevated sound levels, communication is difficult and productivity can be adversely affected. In offices, extraneous noise can be disturbing to jobs requiring concentration.

In recent years, various mitigating measures proposed for the reduction of noise transmission of rain impact through metal roofing. Boards for example were added to the basic metal roofing system to enhance its transmission loss properties. Using conventional method to overcome rain impact noise is fairly straightforward, by adding multiple layers of dense materials. It can reduce the impact but not the radiated noise. To construct such systems will result in additional structural bonding, which requires a stronger roof structure with increased construction costs. In addition, time which is always critical in building construction is required to build such extensive systems.
Current building practice tends to favour the construction of roof with lightweight roof construction. However, by using lightweight roof structures in buildings where speech communication is of great importance causes noise due to rainfall impact on roof to be an issue of concern. In Malaysia, the rainfall rate is estimated to be 180 to 220 mm/hr, in which the rainfall rate is quite critical.

1.2 Objectives of the project

This project investigated impact noise on lightweight composite roof, and the evaluation of how simulation of rainfall can be used for physical testing of sound insulating systems for metal roofs. The objectives were as follows:

1) To obtain experiment data for noise generated from impact on lightweight composite roof at different roofing treatment.

2) To predict the relationship between impact noise and vibration on selected roofing construction.

1.3 Scopes of the project

The scope of this work generally involved the following:

1) Literature review specifically on noise generated by rainfall on roof structures.

2) Experimental studies involving tests on composite roof with and without noise mitigation.

3) Formulating a semi-empirical equation for rain impact noise.

4) Correlation and prediction of noise generation from rain impact and vibration on roof.
CHAPTER II

LITERATURE REVIEW

Precipitation occurs when cloud particles, which grow in complex processes like condensation and aggregation, reach such a size that their falling velocity is larger than the upward wind speed in the air. Precipitation is called rain when its particles are liquid water at ground level. Apart from its complex formation in clouds, rain is basically a population of falling drops interacting with each other (collision, breakup) and with their environment.

2.1 Background

Although studies have been done on evaluating sound based on subjective perception and physical parameters, rainfall impact noise and particularly in buildings, only limited work had been done on roofing systems.

Tachibana, et al (1988) examined loudness evaluations of sounds transmitted through the walls. It was concluded that arithmetic mean values of the sound pressure level in octave bands have high correlation with loudness and this value is a good single number for rating the airborne sound insulation performance of walls.
Hammer and Nilsson (1999) investigated the floor impact noise generated by male and female walkers and a tapping machine of lightweight and heavy weight floors. They mentioned that there is a high correlation between subjective preference and a combination of Zwicker loudness and sharpness for tapping machine and male walker but not female walker.

Jeon (2000) and Jeon, et al (2002) presented the subjective evaluations of floor impact noise generated by tapping machine, bang machine, rubber ball and a walker. They developed a model for subjective loudness based on Zwicker loudness, unbiased annoyance and fluctuation strength and also using Auto Correlation Function / Inner-Aural Cross-Correlation Function) factors. As a result, it was found that Loudness, Unbiased Annoyance from Zwicker parameters showed high correlation with subjective evaluations of loudness concerning floor impact noises. In addition, it was revealed that jumping is similar to the ball. Real sound source implemented with jumping noise on upper floor has similar perceptual characteristics to heavyweight impact noise, especially the noise generated by the rubber ball.

Measurements on steel roofs using natural and simulated rainfall were conducted by P. Dubout (1969) and K.O. Ballagh (1990). Despite this, both performed their experiments in a very small test chamber which limited the lower frequency to be measured.

The noise generated by rain impact on metal roof had been recognized as the most irritating noise because of its speech interference and human annoyance because the end recipient of noise is the human ear. Hence, this study aims at evaluating impact noise on lightweight composite roof.

A general literature review on rain will first be presented. This would be followed by a review of the studies on rain impact noise on roofs.
2.2 Rainfall characteristics

H. Byers (1973) found that a typical spherical droplet of diameter 20 \( \mu \text{m} \) would fall at a terminal velocity of about 1 cm/s. Droplets falling at that slow rate would be suspended in the cloud long enough for growth processes to occur. If those droplets, totaling 5 cm\(^3\) of condensed water, are distributed uniformly, there is about one droplet per mm\(^3\) and the separation between droplets is about 1 mm, or 50 droplet diameters.

The minimum size of raindrops falling on the ground depends on vertical wind speeds in clouds. A drop of 1 mm can fall 40 km. Rain which consists of drops of 0.1 mm diameter, is called drizzle, and is produced by low layer clouds. Raindrops occur about in any shape up to approximately 7 mm after which they tend to break up. The faster velocity and the larger size of droplets would cause an increase in number of collisions per unit time and hence it grows at a constantly increasing rate. Then a droplet may eventually fall out of the cloud as raindrop. (Chuen-Yen Chow, 1979).

Droplets of diameters less than 0.3 mm are nearly perfect spheres at terminal velocity. Therefore for larger drops one cannot describe the shape by one length. This problem was solved by the definition of an equivalent diameter: the diameter of a sphere with the same volume as the deformed drop. Falling drops of (equivalent) diameters of 0.3 to 1 mm resemble oblate spheroids. Drops larger than 1 mm resemble oblate spheroids with flat bases.

The distribution of raindrops with size was the subject of various publications (example: A.C. Best, 1950 & Y. Shiotoku, 1975). However, the experimental studies often showed substantial variations in their data. It was commonly accepted that this underlying pattern suggested an exponential distribution of the rainwater with drop diameter as large number of individual measurements is averaged, as first proposed by Marshall and Palmer (1948).
The Marshall-Palmer distribution was chosen for this study because it is still the most commonly used distribution. Despite its shortcomings in describing short-period samples, it gives a good approximation for most rainfall scenarios (K.C. Young, 1975, R. List & J.R. Gillespie, 1976 & P.T. Willis, 1984).

The terminal velocity is the maximum vertical velocity which a drop reaches. It was also the velocity when the gravitational force equals the drag force or called constant velocity. The usual assumption that the vertical velocity approximately equals the terminal velocity is thus only valid in wind flow with zero vertical wind velocity. Generally this was a good approximation for the undisturbed wind flow far from obstacles; near buildings vertical wind velocity influences the drop velocity. Strictly speaking, the horizontal wind component could also influence the falling velocity because it can deform the shape of a raindrop and thus the drag.

R. Gunn and G.D. Kinzer (1949) conducted an experiment in laboratory and presented a table with terminal velocity data as a function of drop diameter. In Figure 1.1, the relation given by equation 2 was plotted, with terminal velocities calculated directly from the equation of motion. The latter method overestimates the terminal velocity of bigger drops (D>3mm), because the used of drag coefficient function does not take drop deformation into account.