

NUMERICAL INVESTIGATION ON RAINFALL NOISE INTRUSION AND
PREDICTION OF RAIN NOISE FOR DIFFERENT COMPOSITE ROOF
CONSTRUCTIONS.


LEE SHE JIE

A project report submitted in partial
fulfillment of the requirements for the award of
the Degree of Bachelor Mechanical Engineering (Structure & Material)

Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

March 2008

“I hereby declared that this thesis is my own work except the ideas and summaries
which I have clarified their sources”

Signature: 

Author : Lee She Jie

Date : 16/6/08

Specially dedicated to my family, friends and companion

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude and appreciation to my supervisor, Mr. Lee Yuk Choi in my Universiti Teknikal Malaysia Melaka (UTeM) for his tremendous help, advice and unending guidance to me until the completion of my Project Sarjana Muda. He has given me considerable freedom and shown patience as I pursued the idea development in this project. Thanks again to him for His willingness to support the ideas forwarded in this project was a motivation for me to perform better.

The second person I want to thanks is to Mr Muhammad Haziq Lim who is my computer software supervisor. Without his help and guidance, I was unable to finish this project on time.

Nevertheless, thanks to UTeM library to provide the sufficient information for me to study for the roof structure and material. I also want to appreciate the librarian to give me guidance and show their cooperation for me. The infrastructure like library and CC really helped me in finding the journals, and related revision books. The study would not have been possible without their help.

Final thanks go to my family and friends especially Shirley for her spirited encourage and word processing, as well as for their patience and encouragement.

ABSTRACT

This thesis is focused on the numerical investigation on rainfall noise prediction for different composite roof construction for different rainfall rates, velocity and droplet size. Based from the previous reviewed on the 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 rate and rainfall velocity that impacting on the roof panel and then transmitted into a reverberant room condition an empirical constant was proposed which allows the sound intensity level to be estimated. Theoretical studies were based on the concept and mechanism of noise generation on different composite roof installed and roofing material layers construction in an acoustic reverberation room. Basically, the composite roof were laminate the roofing materials to form a single layer of composite but as for roof construction, most of the time that consisted a bare roof and composite roof with different noise control options such that its effect on noise and vibration generated could be determined. Based on the theoretical for semi-empirical equation and the transmission loss, a new numerical prediction is formulated to predict the sound intensity level due to a range of composite roof layer. This numerical prediction was compared with previous works for purpose validation and it was found that the numerical prediction was quite accurate in terms of minimal error. The characteristics of the composite roof materials especially the density and the thickness may influence the transmission loss value. As the density and the thickness increased of the roof material being selected, more sound transmission loss will be obtained and therefore reduced the noise generated inside a room.

ABSTRAK

Tesis ini fokus atas pengajian mekanisme generasi bunyi ke atas bumbung komposit dipasang pada sebuah bilik gema ujian akustik. Mengikut kajian teori sebelum ini, kaedah separuh empirik formula digunakan untuk meramal aras kebisingan hujan berdasarkan kepada beberapa binaan bumbung komposit. Berdasarkan kepada anggapan saiz titisan, curahan hujan dan halaju titisan hujan, pemalar empirik bunyi binaan bumbung berkenaan dikemukakan untuk membolehkan aras keamatan bunyi dianggarkan. Seperti yang diketahui umum, kebisingan dijana oleh hentaman hujan ke atas bumbung adalah disebabkan oleh hentaman getaran secara rawak. Sebagaimana kita tahu, komposit dihasilkan daripada percantuman lapisan bahan material. Dengan ketebalan dan densiti yang sedia ada dalam sifat-sifat tersendiri, maka dapat menghasilkan kesan mengurangkan kebisingan apabila melalui komposit tersebut. Tidak dapat dinafikan bahawa jika ketebalan dan densiti sesuatu bahan itu adalah tinggi, maka tahap mengurangkan kebisingan juga akan tinggi. Persamaan empirikal berdasarkan kepada teori dapat dirumuskan bagi mendapatkan hubungan di antara kebisingan dan getaran ke atas bumbung komposit terhadap frekuensi pusat jalur oktaf sepertiga. Ikhtiar juga dibuat untuk mengesahkan pengaruh redaman ke atas radiasi kuasa bunyi dari bumbung dapat mengurangkan aras halaju getaran. Kaedah separuh empirik kemudian akan diprogramkan ke dalam database software komputer untuk dapatkan keputusan janaan bunyi dalam bilik gema. komposit dihasilkan daripada cantuman beberapa lapis bahan

TABLE OF CONTENTS

CHAPTER	CONTENTS	PAGE
	COVER PAGE	
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xii
	LIST OF EQUATIONS	xv
CHAPTER 1	INTRODUCTION	1
	1.1 Overview	1
	1.2 Objectives of the Project	2
	1.3 Scopes of the Project	3
	1.4 Problem Statement	3
CHAPTER 2	LITERATURE REVIEW	5
	2.1 Background	5
	2.2 Rainfall Characteristics	5
	2.3 Rain Impact noise on roof	9
CHAPTER 3	THEORY	12
	3.1 Noise Prediction on roof	12

3.2	Transmission Loss for Composite Roof	14
3.2.1	Resonant Frequency	16
3.2.2	Region II: Mass-Controlled Region	17
3.2.3	Region III: Damping- Controlled Region	18
3.3	Composite Roof with Air Space	20
3.4	Two-Layer Laminate	22
3.5	Steady-State Sound Level in a Room	24
3.5.1	Average Absorption Coefficient	25
3.5.2	Sound level in a reverberant room	26
3.6	Sound Power and Sound Intensity	28
3.7	Sound Power Level and Sound Pressure Level	28
3.8	The Prediction of the rainfall	29
CHAPTER 4	METHODOLOGY	31
4.1	Test Samples	32
4.1.1	Roof 1	32
4.1.2	Roof System 2	33
4.1.3	Roof System 3	34
4.1.4	Roof System 4	35
4.1.5	Roof System 5	36
4.2	The Database	37
4.3	Visual Basic	38
4.3.1	A typical session in Microsoft Visual Basic	39
4.3.2.	The Use of Visual Basic in this Project	40
CHAPTER 5	RESULTS AND DISCUSSION	42
5.1	Roof 1	42
5.2	Roof system 2	44
5.3	Roof system 3	47
5.4	Roof system 4 and 5	50
5.5	Numerical Prediction Comparison for Roof	53
5.6	Numerical Prediction Comparison for Roof System 2	54
5.7	Numerical Prediction Comparison for Roof	

	System 3	57
5.8	Numerical Prediction Comparison for Roof System 4	58
5.9	Numerical Prediction Comparison for Roof System 5	60
CHAPTER 6	CONCLUSION	62
6.1.	Suggestion and Recommendation for the future work	63
	REFERENCES	64
	APPENDIX A	66

LIST OF TABLES

TABLE NO.	TITLE	PAGE
3.1	Transmission Loss Values	15
3.2	Values of the plateau Height (TL_p) and Plateau Width (Δf_p) for the approximate method of calculation of the transmission Loss for Panels.	15
3.3	Subjective Acoustic Characteristics of Rooms.	26
3.4	Regime of the roof system 2 to 5	29
5.1	Roof 1(Bare Roof); $v = 9.11$ m/s	53
5.2	Roof 1(Bare Roof) ; $v = 9.11$ m/s	53
5.3	Roof system 2; $D=5.5$ mm $v = 9.23$ m/s	54
5.4	Roof system 2; $D=5.5$ mm $v = 9.23$ m/s	55
5.5	Roof system 2; $D=4.5$ mm $v = 9.11$ m/s	56
5.6	Roof system 2; $D=4.5$ mm $v = 9.11$ m/s	56
5.7	Roof system 3; $D=5.5$ mm $v = 9.23$ m/s	57
5.8	Roof system 3; $D=5.5$ mm $v = 9.23$ m/s	58

5.9	Roof system 4; $D=4.0$ mm $v = 8.9$ m/s	59
5.10	Roof system 4; $D=4.0$ mm $v = 8.9$ m/s	59
5.11	Roof system 5; $D=4.0$ mm $v = 8.9$ m/s	60
5.12	Roof system 5; $D=4.0$ mm $v = 8.9$ m/s	61

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
3.1	Schematic of the approximate loss of a panel.	19
3.2	Composite material with an air space between the two panels	20
3.3	Two-ply laminated panels	22
3.4	The reverberant and the direct sound fields.	25
4.1	Typical section of roof 1	32
4.2	Typical section of roof system 2	33
4.3	Typical section of roof system 3	34
4.4	Typical section of roof system 4	35
4.5	Typical section of roof system 5	36
4.6	The sample of the database output	38
5.1	Numerical Prediction in sound intensity levels at drop diameter 4.5 mm at different rainfall rates for bare roof (roof).	43
5.2	Numerical Prediction in sound intensity levels at drop diameter 5.5 mm at different rainfall rates for bare roof (roof 1).	43

5.3	Numerical Prediction in sound intensity levels at drop diameter 5.5 mm at different rainfall rates for roof system 2.	44
5.4	Numerical Prediction in sound intensity levels at drop diameter 4.5 mm at different rainfall rates for roof system 2.	45
5.5	Comparison of sound intensity levels at drop diameter 4.5 mm, flow rate 65 mm/hr between roof 1 and roof system 2.	46
5.6	Numerical Prediction in sound intensity levels at drop diameter 5.5 mm at different rainfall rates for roof system 3.	47
5.7	Numerical Prediction in sound intensity levels at drop diameter 4.5 mm at different rainfall rates for roof system 3.	48
5.8	Comparison of sound intensity levels at drop diameter 4.5 mm, flow rate 292 mm/hr between roof system 2 and roof system 3.	49
5.9	Numerical Prediction in sound intensity levels at drop diameter 4.0 mm with different rainfall rates for roof 4.	50
5.10	Numerical Prediction in sound intensity levels at drop diameter 4.0 mm with different rainfall rates for roof system 5.	51
5.11	Comparison sound intensity levels at drop diameter 4.0 mm, flow rate 200 mm/hr between roof system 4 and roof system 5.	52
5.12	Comparison sound intensity levels between Numerical Prediction and Experiment Data at drop diameter 5.5 mm, flow rate 292 mm/hr	54
5.13	Comparison sound intensity levels between Numerical Prediction and Experiment Data at drop diameter 4.5 mm, flow rate 292 mm/hr	55
5.14	Comparison sound intensity levels between Numerical Prediction and	

Experiment Data at drop diameter 5.5 mm, flow rate 219 mm/hr	57
5.15 Comparison sound intensity levels between Numerical Prediction and Experiment Data at drop diameter 4.0 mm, flow rate 100 mm/hr	58
5.16 Comparison sound intensity levels between Numerical Prediction and Experiment Data at drop diameter 4.0 mm, flow rate 105 mm/hr	60

LIST OF EQUATIONS

EQUATION NO.	FORMULA	PAGE
(3.1)	$S.I.L_A = 46 + 10 \log_{10} \left(\frac{Q}{Q_0} \right)$	12
(3.2)	$S.I.L_A = 45 \log \left(\frac{D}{D_0} \right)$	12
(3.3)	$S.I.L_A = 45 \log \left(\frac{v}{v_0} \right)$	13
(3.4)	$S.I.L_A = 10 \log_{10} \left(\frac{N}{N_0} \right) + 45 \log \left(\frac{v}{v_0} \right) + 45 \log \left(\frac{D}{D_0} \right) + C$	13
(3.5)	$\frac{N}{N_0} = \frac{QD_0^3}{Q_0D^3}$	13
(3.6)	$S.I.L_A = 10 \log \left(\frac{Q}{Q_0} \right) + 45 \log \left(\frac{v}{v_0} \right) + 15 \log \left(\frac{D}{D_0} \right) + C$	13
(3.7)	$S.I.L_A = 10 \log \left(\frac{Q}{Q_0} \right) + 45 \log \left(\frac{v}{v_0} \right) + 15 \log \left(\frac{D}{D_0} \right) + C + \text{delta } C$	14
(3.8)	$S.I.L_A = 10 \log \left(\frac{Q}{Q_0} \right) + 45 \log \left(\frac{v}{v_0} \right) + 15 \log \left(\frac{D}{D_0} \right) + 10 \log \left(\frac{\eta}{\eta_0} \right) + C$	14

$$(3.9) \quad f_{mn} = \left(\frac{\pi}{4\sqrt{3}} \right) c_L h \left(\left(\frac{m}{a} \right)^2 + \left(\frac{n}{b} \right)^2 \right) \quad 16$$

$$(3.10) \quad c_L = \sqrt{\frac{E}{\rho_w (1 - \sigma^2)}} \quad 16$$

$$(3.11) \quad f_{11} = \left(\frac{\pi}{4\sqrt{3}} \right) c_L h \left(\left(\frac{1}{a} \right)^2 + \left(\frac{1}{b} \right)^2 \right) \quad 16$$

$$(3.12) \quad f_{11} = \frac{10.2 c_L h}{\pi \sqrt{3} D^2} \quad 17$$

$$(3.13) \quad f_{11} = \frac{5.25 c_L h}{\pi \sqrt{3} D^2} \quad 17$$

$$(3.14) \quad \frac{1}{a_m} = 1 + \left(\frac{\pi f \rho_w h}{\rho_1 c_1} \right)^2 \quad 17$$

$$(3.15) \quad M_s = \rho_w h \quad 17$$

$$(3.16) \quad TL_n = 10 \log_{10} \frac{1}{a_m} \quad 18$$

$$(3.17) \quad TL = TL_n - 5 \quad 18$$

$$(3.18) \quad TL = TL_n(f_c) + 10 \log_{10}(\eta) + 33.22 \log \left(\frac{f}{f_c} \right) - 5.7 \quad 19$$

$$(3.19) \quad TL_n(f_c) = 10 \log_{10} 1 + \left(\frac{\pi f_c M_s}{\rho_1 c_1} \right)^2 \quad 19$$

$$(3.20) \quad \frac{\rho c}{\pi(M_{s1} + M_{s2})} < f < f_0 \quad 20$$

$$(3.21) \quad f_0 = \left(\frac{c}{2\pi} \right) \sqrt{\left(\frac{\rho}{d} \right) \left(\frac{1}{M_{s1}} + \frac{1}{M_{s2}} \right)} \quad 20$$

$$(3.22) \quad TL = 20 \log_{10} (M_{s1} + M_{s2}) + 20 \log_{10} f - 47.3 \quad 21$$

$$(3.23) \quad F_0 < f < \left(\frac{c}{2\pi d} \right) \quad 21$$

$$(3.24) \quad TL = TL_1 + TL_2 + 20 \log_{10} \left(\frac{4\pi f d}{c} \right) \quad 21$$

$$(3.25) \quad TL = TL_1 + TL_2 + 10 \log_{10} \left(\frac{4}{1 + \frac{2}{\alpha}} \right) \quad 21$$

$$(3.26) \quad X = \frac{E_1 h_1^2 - E_2 h_2^2}{2E_1 h_1 + E_2 h_2} \quad 22$$

$$(3.27) \quad TL = 10 \log_{10} \left(1 + \left(\frac{\pi f M_s}{p_0 c} \right)^2 \right) - 5 \quad 23$$

$$(3.28) \quad M_s = \rho_1 h_1 + \rho_2 h_2 \quad 23$$

$$(3.29) \quad f_c = \left(\frac{c^2}{2\pi} \right) \sqrt{\left(\frac{M_s}{B} \right)} \quad 23$$

$$(3.30) \quad B = \frac{E_1 h_1^3}{12(1 - \sigma_1^2)} \left(1 + 3 \left(1 - \frac{2X}{h_1} \right)^2 \right) + \frac{E_2 h_2^3}{12(1 - \sigma_2^2)} \left(1 + 3 \left(1 - \frac{2X}{h_2} \right)^2 \right) \quad 23$$

$$(3.31) \quad \eta = \frac{(\eta_1 E_1 h_1 + \eta_2 E_2 h_2)(h_1 + h_2)^2}{E_1 h_1^3 \left(1 + 3 \left(1 - \frac{2X}{h_1}\right)^2\right) + E_2 h_2^3 \left(1 + 3 \left(1 - \frac{2X}{h_2}\right)^2\right)} \quad 24$$

$$(3.32) \quad \bar{\alpha} = \frac{\sum \alpha_j S_j}{S_0} \quad 25$$

$$(3.33) \quad \frac{4W}{4} = \frac{P^2}{\rho_0 c} \quad 26$$

$$(3.34) \quad R = \frac{\bar{\alpha} S_0}{1 - \bar{\alpha}} \quad 26$$

$$(3.35) \quad L_p = L_w + 10 \log_{10} \left(\frac{4}{R} + \frac{Q}{4\pi r^2} \right) + 10 \log_{10} \frac{(\rho_0 c W_{ref})}{P^2_{ref}} \quad 27$$

$$(3.36) \quad L_p = L_w + 10 \log_{10} \left(\frac{4}{R} + \frac{Q}{4\pi r^2} \right) + 0.1 \quad 27$$

$$(3.37) \quad \text{Intensity, } I = \frac{\text{Soundpower } W}{4\pi r^2} \quad 28$$

$$(3.38) \quad \text{Intensity, } I = \frac{W}{2\pi r^2} \quad 28$$

$$(3.39) \quad \text{Sound power level, } \text{PWL} = 10 \log_{10} w + 120 \quad 28$$

$$(3.40) \quad \text{SPL} = \text{PWL} - 20 \log_{10} r - 11 \quad 29$$

$$(3.41) \quad \text{SPL} = \text{PWL} - 20 \log_{10} r - 8 \quad 29$$

$$(3.42) \quad T_L = 10 \log (1 + 0.8709 \text{Ms}^2) - 5 \quad 29$$

$$(3.43) \quad T_L = T_{L1} + T_{L2} + 20 \log (4.5242x) \quad 30$$

$$(3.44) \text{ S.I.L}_A = 10 \log \left(\frac{Q}{Q_0} \right) + 45 \log \left(\frac{v}{v_0} \right) + 15 \log \left(\frac{D}{D_0} \right) \\ - 10 \log (1+0.8709\text{Ms}^2) - 5 \quad 30$$

$$(3.45) \text{ S.I.L}_A = 10 \log Q + 45 \log v + 15 \log D - 10 \log (1+0.8709\text{Ms}^2) - 5 \quad 30$$

CHAPTER I

INTRODUCTION

This chapter will introduce the overview and the objective of this project. Besides that, it also includes some problem statement and the scope of this project.

1.1 Overview

In the beginning of this project, it will start with an introduction to the basic concepts and theory of sound. It is important for the engineer to understand the nomenclature and physical principles involved in rain noise transmission of rain impact through metal roofing in order to suggest a rational procedure for rain noise reduction. Furthermore, this project will also examine the alternative method for predicting the noise generated by the raindrop on the metal roofing. This information is required in the design stage of any rain noise control project. Information about the specification and characteristic of the roof material can allow the design of equipment that is quieter in operation through adjustment of the raindrop speed or some other parameter.

A study of the rain noise control techniques applicable to rooms will be made by using conventional method to overcome rain impact noise fairly straight forward. These procedures include the use of acoustic treatment of the walls of the room and the use the multilayer of material to make as the roof will reduce the impact force. It is important to

determine if acoustic treatment of the metal roofing will be effective or if the offending noise source must be enclosed to reduce the rain noise to an acceptable level.

Concern about problem of noise in the workplace and in the living space has escalated since the amendment of the Walsh-Healy Act of 1969. This act created the first set of nationwide occupational noise regulations (Occupational Safety and Healthy Administration, 1983). In the design of many appliances, such as dishwashers, the designer must be concerned about the noise generated by the appliance in operation. It is important that noise control be addressed in the design stage for many mechanical devices. Lack of proper acoustic treatment in offices, apartment, and classrooms may interfere with the effective functioning of the people in the rooms. Even though the rain noise is not dangerous and not particularly annoying, if the person cannot communicate effectively, then the rain noise is undesirable

1.2 Objectives of the project

This project is to analyze the rainfall noise level when it impacting on the surface of the roof system and transmit through the different material layers to a reverberant room. The main objectives in this project are as following:-

Investigate impact noise on lightweight composite roof

- Predict the relationship between impact noise sound level on selected roofing inside a room subjected to composite roof construction at different rainfall rate.
- Study and identify the method used in programming to generate the result numerically.

1.3 Scopes of the project

This project will investigate the rainfall noise drop on the construction of the material roof layers analysis. The scopes that generally cover in this project are as following:-:

- Familiarize the use of any software package as a tool (Visual Basic)
- Numerical simulation of rainfall noise generated by rainfall on roof structures via programming based.
- Prediction of sound pressure / intensity level generated by rainfall on different composite roofs.
- Validation with available analytical or experimental works possible at all stages.

1.4 Problem Statement

Nowadays, global warming affect the rain fall rate unstable in certain area of the world. Especially those countries near the tropical rain fall zone. This rain fall may cause the building always face the sound pollution problem during heavy rain. This rain fall noise is affected by high rain impact noise free drop on the metal roof layer and the metal roof material resonates randomly and generates the high level of noise into the room. This noise pollution may lead the communication is difficult to proceed and productivity performance can be affected also.

As an example, Malaysia is one of the country locate in the tropical zone, therefore the rainfall rate is estimated to be 180 to 220 mm/hr, in which the rainfall rate

is quite critical. In the certain area of Malaysia such as the city of Kuala Lumpur, most of the building or tower 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. Lack of proper acoustic treatment in offices, apartment, and classrooms may interfere with the effective functioning of the people in the building.

To overcome this noise pollution during the heavy rain fall, most the roof constructor will design the roof with select high density and thicker roof material so that the noise levels may be reduce. Adding the multiple layers or the composite roof material can reduce resonate of the sound intensity levels. As the high density material can produce a good transmission loss therefore more of the material's engineer are try to develop on this composite engineer material to increase their transmission characteristic of the roof material so that it can perform better solution to solute the rain fall noise pollution problem during the heavy rain.

CHAPTER II

LITERATURE REVIEW

This chapter will introduce a lot of literatures that have been studied and reviewed as a reference which are intimately relative with this project. The construction of the roof system directly influence the rainfall noise level from the out side of the room transmits into the roof layers and finally transmits into the reverberant room.

2.1 Background

A lot of studies had been done by researcher are related to prediction of rainfall drops for different composite roof constructions. However, it is only reviewed fewer studies which were focus on investigate on roof construction system. Although the roof layers construction is different for every country, but the conceptual to calculate the transmission of the rainfall noise through these layers are always same.

According to J.McLoughlin, D. J. Saunder & R.D Ford (1993) conclude that lightweight steel and aluminium roof cladding systems are commonly used in large 'shed' type constructions where cost is often more important than noise considerations. However, the use of these systems in more noise-sensitive environments such as schools, office buildings, conference halls and leisure centres has increased the interest in their acoustic performance. In addition to providing adequate insulation between