$$L = 10\log(10^{L_{sb}/10} - 10^{L_{b/10}}) \quad (1)$$

L: The adjusted sound pressure level (dB)

L_b : The sound pressure level of the background noise (dB)

L_{sb} : The mix sound pressure level of floor impact sound and the background noise (dB)

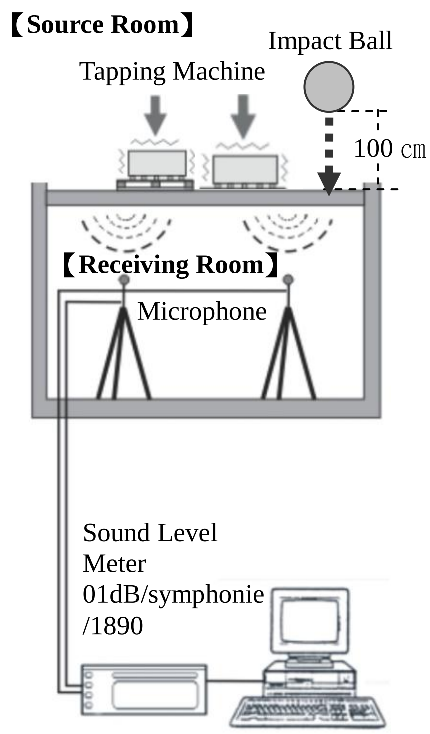
Diagram of testing setting	Pictures of the field experiment	
	 The impact ball height standard	 Tapping machine
	 Locations of microphone	 Computer and sound level meter

Fig. 3. The experiment settings

Table 2. The background information and testing locations of these condominiums

Condo NO.	Construction	Space Numbers
A	Reinforced Concrete	A1
B	Reinforced Concrete	B1, B2
C	Reinforced Concrete	C1, C2
D	Steel Construction	D1, D2,
E	Steel Construction	E1, E2
F	Steel Reinforced Concrete	F1, F2, F3, F4, F5
G	Steel Reinforced Concrete	G1, G2,G3, G4, G5
H	Steel Reinforced Concrete	H1, H2, H3, H4, H5
I	Reinforced Concrete	I1, I2, I3, I4

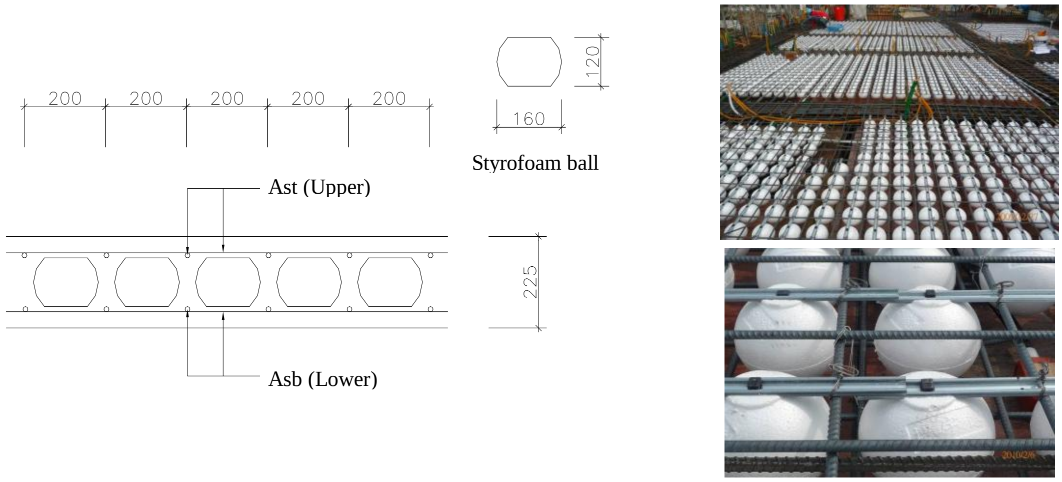
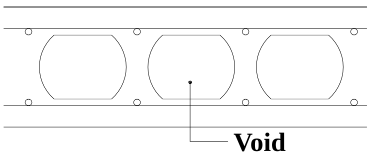
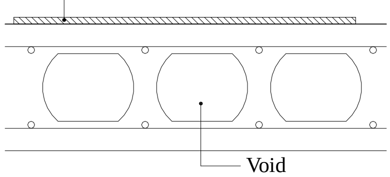
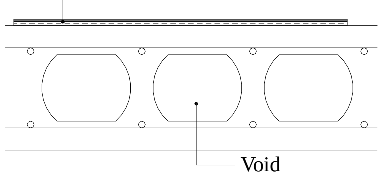


Fig. 4. The diagram and pictures of the void slab

Table 3. The information of the void slab

Size of Styrofoam Ball (mm)	Thickness of Slab (mm)	Ast (Upper Steel)	Asb (Lower Steel)
160	225	Long: 1-#4@20 Short: 1-#4@20	Long: 1-#4@20 Short: 1-#4@20

Table 4. The covering materials installation diagram

Control group	Material alteration		Experimental group
 Void slab	Wood		 Covering material (wood); Void slab
	Teak	t =12mm (with 12mm plywood)	
	Carpet		 Covering materials (carpet); Void slab
	Carpet	t=5mm	

RESULTS

The void slab without the covering materials of Condo A and Condo B. The testing results of the heavy and light floor impact sound of every testing rooms show in Table 5, Fig. 5, Fig. 6, Fig. 7, and Fig. 8. The L level of the heavy floor impact sound for both buildings is around 39 to 47, which shows better performance compared to the results of the light floor impact sound.

The void slab with the covering materials. The testing results of the covering materials show in Table 6, Table 8, Fig. 9, and Fig. 10. The results show that the carpet presents better performance than the wood in both buildings.

Table 5. The testing results of the floor impact sound

Condo NO.		**L (Heavy)**	**L Level (Heavy)**	$L_{n,w}$	**L (Light)**	**L Level (Light)**	$L_{n,w}$
A	A1	41	45	39	72	75	70
B	B1	44	45	44	73	75	72
	B2	48	50	47	74	75	73

Table 6. The testing results of the covering materials

Materials	**A1_Teak**	**A1_Carpet**	**B1_Teak**	**B1_Carpet**
Tested，$L_{n,w}$	55	49	64	53
Decreased value，ΔL_w	15	21	8	19

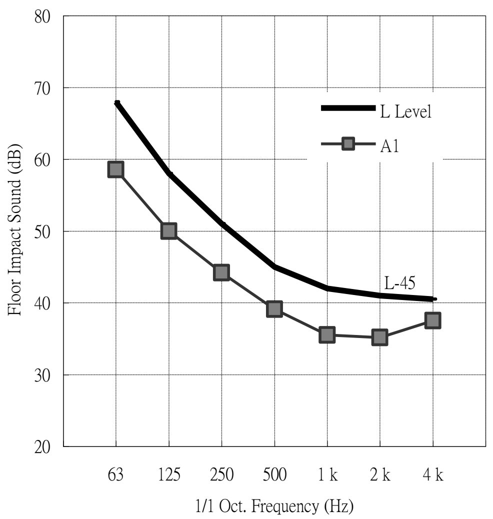


Fig. 5 The testing result of Condo A (Heavy)

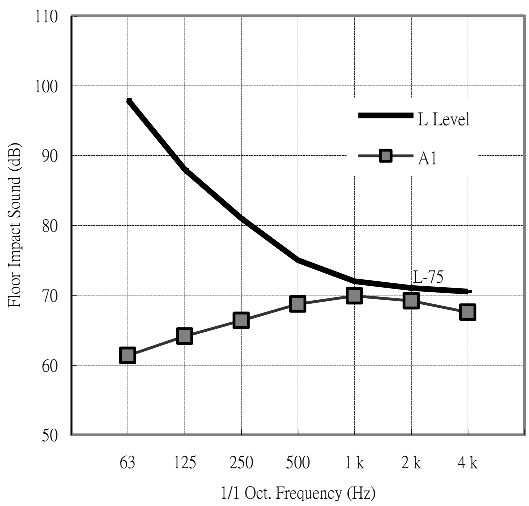


Fig. 6 The testing result of Condo A (Light)

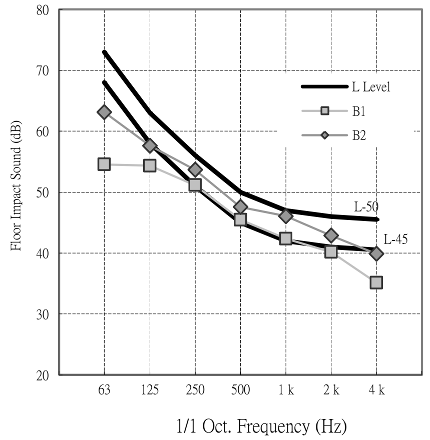


Fig. 7 The testing result of Condo B (Heavy)

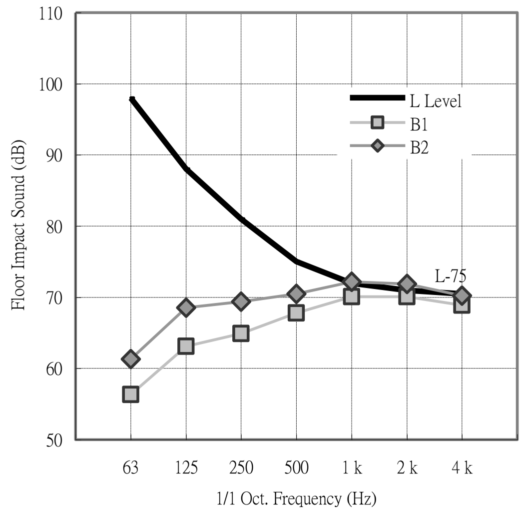


Fig.8 The testing result of Condo B (Light)

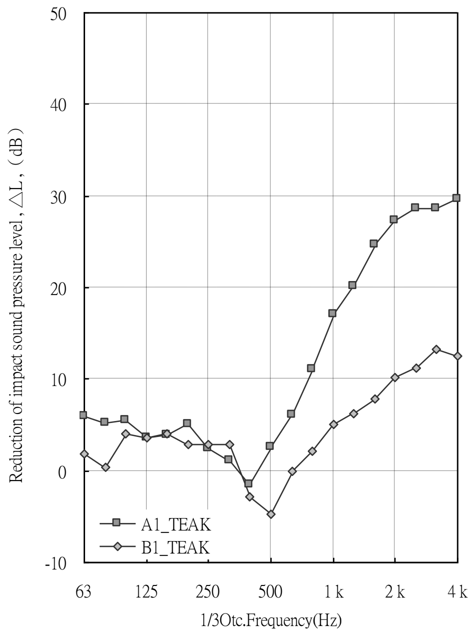


Fig. 9 The testing result of Teak

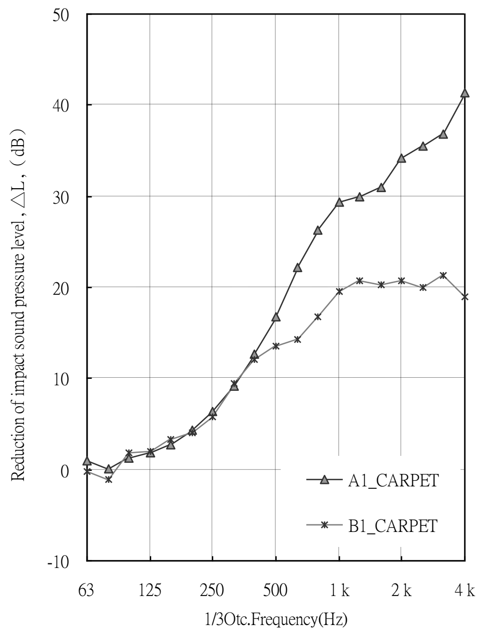


Fig. 10 The testing result of Carpet

CONCLUSIONS

As the life pattern changes and the population increases, high-rise building has been a popular housing choice. The floor impact sound is a significant problem of high-rise building, which is gradually being emphasized. The void slab, used to be used in huge span building, is very common in housing building. Therefore, the floor impact sound effect of the void slab in housing building should be taken into consideration seriously regarding the citizens living quality. This study followed the ISO 140-7 and 140-8 to experiment the performance of the bare void slab and the covering materials over the slab for discussing the possibility of material application on the void slab.

According to the results, the performance of the heavy floor impact sound, tested on the bare void slab, is quite effective, which the level is about *L*-45. However, the performance of the light floor impact sound is about *L*-75. The result shows that the void slab is effective regarding the heavy floor impact sound with insignificant influence regarding the light floor impact sound improvement. Also, regarding the covering materials, the testing results show that the carpet provides better floor impact sound insulation than the teak wood.

Therefore, through the experiments, this study could conclude that the void slab presents good effective performance for heavy floor impact sound. However, the void slab should be applied with covering materials to demonstrate efficient improvement toward the light floor impact sound, and the performance varies from materials. The void slab covered with carpet is the best combination according to the study. This conclusion would offer the interior design reference for decreasing the noise pollution, and expect to reach the better living quality in the future.

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第四版勞工聽力保護計畫指引編撰與宣導成效評估

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摘要：為改善及宣導勞工於職場中因為噪音暴露而引起的聽力損失問題，勞工安全衛生研究所於 2002 年彙整勞工安全衛生相關法規規定、國家標準、國內外文獻等編撰「勞工聽力保護計畫指引(第三版)」一冊，內容主要包含噪音作業場所調查與測定、噪音工程控制、勞工暴露時間管理、聽力特殊健康(體格)檢查及其管理、防音防護具選用與佩戴、勞工教育訓練、資料建立與保存等執行要項，供雇主、勞安衛人員及勞工參酌。但隨著時間及產業結構之演變，其內容及適用性有重新檢視之必要，亦須配合近年來修訂的安衛法規同步介紹與修正，以及進一步提出能夠提升勞工聽力保護計畫指引重要性及適用性的方法。2012 年編撰之第四版勞工聽力保護計畫指引內容的本質與視野，將超越符合目前法令的最低要求，其目的並非只是重申法令，而是要傳達一個良好的聽力保護計畫應具有的特質。新版勞工聽力保護計畫指引經宣導與推廣後，可以促使事業單位知曉並推行整合性聽力保護計畫之各項工作，落實自主管理，增進勞工的作業環境並且維護勞工聽力的健康。

關鍵詞：噪音；勞工聽力保護計畫

一、前言

在業界，噪音為一項主要的健康危害因子，不僅造成溝通干擾，亦會產生心理方面的煩躁不安、緊張壓力等問題，過度的暴露更會導致聽力受損。由噪音所引起的聽力損失(noise-induced hearing loss, NIHL)可分為傳音性聽力損失(conductive hearing loss)與感音性聽力損失(sensori-neural hearing loss)兩類。傳音性聽力損失是由外傷(如爆炸、打靶等突發性噪音造成之耳膜破裂)或疾病導致；感音性聽力損失則是由於長期暴露於噪音環境下，因內耳的毛細胞或柯式器等構造受損，導致聽力閾值升高而產生無法恢復的永久性聽力損失。以往因噪音引起的健康效應較緩慢且不易察覺，使得勞、資雙方容易因此而忽略了噪音產生的危害，待勞工發現聽力功能減退時，多已發生嚴重且無法恢復的聽力障礙，影響勞工的生活品質。

但許多調查結果發現，即使已制定了詳盡的法規，在國內、外依然有許多產業其勞工的噪音暴露依然不易控制。歐盟 2005 年調查資料包括受僱者、自營作業者，結果顯示工作時的危害因子，若以接觸危害因子時間佔工作時間 25%以上之各項因子比例來看，以噪音(30.0%)最高，其次為高溫(24.9%)、振動(24.2%)、低溫作業(22.0%)、二手菸(20.1%)等[1]。日本 2006 年勞動環境調查顯示[2]，勞動者中有 42.8%覺得被噪音困擾，25.1%覺得有異味，11.3%覺得很熱，9.4%有採光照明問題，8.8%覺得很冷。勞工安全衛生研究所從 1995 年開始至 2007 年間，每 3 年進行一次『工作環境安全衛生狀況認知調查』，根據調查結果顯示[3]，在工作場所中遭受的危害因子，勞工認為「噪音太大」的比例持續佔據危害因子的前三強，每期報告中勞工認為職場主要的危害因子，噪音所占的比例分別為 23.4%、40.4%、50.3%、46.3%、43.8%，勞工認為需要改善的安全衛生問題中，亦以空氣太髒、環境太熱或太冷、以及聲音太大三個項目最高。因此，噪音問題已是職場環境中，最普遍、最嚴重之職場健康危害因子之一。世界各國亦均有噪音相關法令，規範噪音暴露之大小與相對的容許暴露時間，其目的即在確保勞工的聽力在工作場所或一般大眾生活環境不會因過度的聲響而受到傷害或

干擾。

政府單位亦以勞動檢查的方式對事業單位進行監督，依 2012 年勞動檢查方針，各檢查單位應優先實施噪音專案檢查，以預防職業疾病發生。依 2007 年勞動檢查年報總計檢查事業單位 382 場次，初查 253 場次，複查 129 場次，事業單位違反勞工安全衛生法的主要項目是未採取適當的噪音的預防設備 187 件、未實施測定 115 件、未提供防護具 14 件、未實施健康檢查 2 件。綜合上述調查及檢查結果，督促事業單位之環境測定與改善設施確實施行仍有很大的進步空間，但勞工對於工作場所中潛在的噪音危害因子，其認知已逐漸提高，但是對於降低勞工的噪音暴露及免於聽力損失的風險，政府機關仍應持續加強及努力。

政府為了保護勞工免於聽力受損之苦，已制定相關的聽力保護法規，在勞工安全衛生相關法規中要求雇主應主動保護勞工避免因噪音所引起之健康危害，包含採取工程控制、減少勞工噪音暴露時間、使勞工噪音暴露工作日八小時日時量平均音壓值不得超過 90dBA；當勞工工作日八小時日時量平均音壓級超過 85dBA 時，雇主應使勞工佩戴有效之耳塞、耳罩等防音防護具。除此之外，法規亦對噪音作業場所調查與測定、聽力特殊健康(體格)檢查及管理、勞工教育訓練、資料建立與保存、職業性聽力損失之補償亦有詳細的規範，期望能給予勞工最周詳的保護，並達到勞、資雙贏的目的。

針對勞工於作業現場的噪音暴露管理，勞工安全衛生研究所已針對此一問題編撰「勞工聽力保護計畫指引」乙書，供事業單位勞工安全衛生管理人員參考運用。現行之勞工聽力保護計畫指引(第三版)於 2002 年編撰完成[4]，但是隨著時間及產業結構之演變，其內容及適用性有重新檢視之必要，近年來亦有相當多的安衛法規內容已經修改，皆須於新版的勞工聽力保護計畫指引中同步介紹與修正。另外，勞工聽力保護計畫指引中對於職業場所中已經存在的噪音作業環境提出相關改善程序與建議，推行多年成果業界普遍知悉本指引，但是仍未被普遍使用來改善噪音作業環境，故有必要提出能夠提升勞工聽力保護計畫指引重要性及適用性的方法。

二、第四版勞工聽力保護計畫指引修正內容綱要

自從勞工安全衛生研究所在 10 餘年前首次出版「勞工聽力保護計畫指引」，經多年推廣已有相當的認知與成效。但 10 餘年來國內職場環境的變異，與國內、外相關研究新的發現[5-9]，目前版本實有修編的必要，以因應職場多元性與新危害的出現。一個好的聽力保護計畫基本上最少應有目前版本之 7 個要項：1.噪音作業場所調查與測定；2.噪音工程控制；3.勞工暴露時間管理；4.聽力特殊健康(體格)檢查及其管理；5.防音防護具選用及佩戴；6.勞工教育訓練；7.資料建立與保存。

除了以上 7 個要項，新版的聽力保護計畫指引應考量評估計畫執行成效，納入第 8 個要項，即增加計畫稽核與改善的章節。所有聽力保護計畫要項均為職場聽力保護的重要事項，增加 1 個要項特別強調評鑑過程，以確保實施的成效。新版本將由管理階層、計畫執行者以及受影響勞工觀點編撰內容，並概述各種類相關參與者的權責。

本次新版勞工聽力保護計畫配合勞工安全衛生相關法規修正，並參照國外勞工聽力保護計畫之指引於各章節加入檢核事項，以便於讀者與執行者於實務中執行；並配合目前聽力損失相關研究，新增多項可能造成聽力損失之危險因子等資料。

(一) 在法規部分，於各節開頭加入法規重點概述使讀者易於瞭解，歸納相關法規之重點，便於相關條文之搜尋。

(二) 在噪音作業場所調查與測定方面，增加噪音作業場所勞工噪音暴露調查，以及將測定策略改為整合性暴露評估，亦依法規規定增加含採樣策略之作業環境測定計畫，以實務範例解釋相似暴露群(similar exposure group, SEG)概念及建立方法。

(三) 在噪音工程控制方面，新增探討歐盟 CE 標章(CE Marking)與噪音控制之相關性及參考文獻，並增加實務案例說明噪音控制之流程、檢討與評估。

(四) 在勞工暴露時間管理方面，增加實務上減少勞工暴露時間之方法案例分析。

(五) 在聽力特殊健康(體格)檢查方面，除了更新「民國 100 年第一梯次勞工特殊體格及健康檢查指定醫療機構名單」與新增民國九十八年聽力師法相關法規資料，更詳細說明分級管理之依據與標準。此外，亦針對職業性聽力損失職業病的認定基準與補償機制做說明。

(六) 於防音防護具使用時機與選用、佩戴方面，新增防音防護具之種類，及更新耳塞的佩戴方法及注意事項、說明暫時以防音防護具為聽力保護主軸的必要措施。

(七) 在勞工教育訓練方面，新增勞工教育訓練之整體概念，並透過訂定、執行、評價教育訓練計畫與範例，使訓練人員實施有效的勞工教育訓練。

(八) 在資料建立與保存方面，依據新修訂法規，修改保存資料之紀錄項目。

(九) 在聽力保護計畫績效評估方面，參考美國 NIOSH(National Institute for Occupational Safety and Health)聽力相關資料，建議強化聽力保護計畫年度查核項目。新增 P-D-C-A 的觀念，以及新增內稽、外稽的觀念，評估計畫完整性及品質。另外，說明第三版勞工聽力保護計畫附贈的光碟「勞工聽力損失風險評估計軟體」內容，並以圖示加上舉例說明教導讀者如何使用此光碟。

三、勞工聽力保護計畫指引研習成效

為宣導「第四版勞工聽力保護計畫指引」內容重點與重要性，強化勞工安全衛生管理人員執行勞工聽力保護計畫之能力，協助執行聽力健康檢查相關醫護人員了解勞工健康保護規則細項，以及了解噪音作業場所事業單位推動勞工聽力保護計畫之現況，勞工安全衛生研究所與中華民國音響學會至 2012 年 8 月 22 日止，共同辦理四場次之「第四版勞工聽力保護計畫指引宣導增能研習會」(圖 1)，以協助及促進噪音作業場所之事業單位推動勞工聽力保護計畫，進而提升勞工聽力健康。研習會參與對象以：1.高噪音作業場所勞工安全衛生相關人員、2.執行聽力健康檢查相關醫護人員為主，利用問卷調查其對勞工聽力保護計畫內容的了解、實際推動狀況、推動困難、實施聽力保護計畫之需求及實際應用情形、滿意度等資料，以了解「勞工聽力保護計畫指引」推廣與應用現況。

四場次研習會共有 453 人出席，回收有效問卷 387 份，參與人員方面，以女性居多佔 59.7%，而年齡以 30~39 歲(52.5%)最多，所屬區域分別為北區 18.6%，中區 39.8%，南區 41.6%；依公司行業類型分類以製造業(76%)最多，其次為其他(12.3%)及醫療服務業(8.1%)；主要參加者以勞工安全/衛生管理師、勞工安全衛生管理員約 51.7%最多；而參加人員之平均在職年資為 7.87 年，在職服務 5 年以上占 48.0%。

2012 年 7 月 31 日 台北場

2012 年 7 月 24 日 台中場

2012 年 8 月 07 日 台南場

2012 年 8 月 22 日 台中場

圖 1 第四版勞工聽力保護計畫指引宣導增能研習會辦理情形

3.1 研習前

本次參與人員在本次研習參加前，在「對於勞工聽力保護計畫指引之認知情形」方面，總分為 10 分，其平均得分為 4.98 分，其中以「對於 2011 頒布「勞工健康保護規則」修訂健康分級管理的認識」(6.24 分)與「有關「聽力特殊健康檢查及其管理」內容及增修部分的認識」(5.91 分)等特殊健康(體格)檢查項目最為了解，其次為「有關「保存資料之記錄項目」的認識」(5.95 分)、「有關「勞工聽力保護相關資料之建立、保存」內容及增修部分的認識」(5.85 分)、「有關「防音防護具選用與佩戴」內容及增修部分的認識」(5.80 分)；而認知程度較差之項目為「對於「歐盟 CE 標章」的認識」(2.72 分)，其次為「了解利用歐盟 CE 標章，採購低噪音設備對噪音控制之助益」(2.87 分)，如表 1 所示。

在「對於勞工聽力保護計畫指引之信心情形」方面，總分為 10 分，其平均得分為 5.17 分，其中以「對於未來執行有關「勞工聽力保護相關資料之建立、保存」的信心」(5.71 分)最為了解，其次為「對於未來執行有關「聽力特殊健康檢查及其管理」的信心」的認識」(5.69 分)、「對於未來執行有關「防音防護具選用與佩戴」的信心」(5.66 分)、「對於未來執行有關「勞工教育訓練」的信心」(5.49 分)；而信心程度較差之項目為「對於未來執行有關「噪音工程控制」的信心」(3.99 分)，如表 2 所示。

表 1 研習前、後對於勞工聽力保護計畫指引認知情形

題目內容	平均得分		增加分數
	前	後	
1. 有關「勞工聽力保護相關法規」內容及增修部分的認識	5.15	7.84	2.69
2. 有關「噪音作業場所調查與測定」內容及增修部分的認識	5.20	8.03	2.83
3. 對於「相似暴露群(SEG)」概念的認識	4.34	7.09	2.76
4. 有關「噪音工程控制」內容及增修部分的認識	4.42	7.74	3.33
5. 對於「歐盟 CE 標章」的認識	2.72	7.38	4.66
6.了解利用歐盟 CE 標章，採購低噪音設備對噪音控制之助益	2.87	7.49	4.62
7. 有關「勞工暴露時間管理」之內容及增修部分的認識	5.24	8.06	2.82
8. 有關「防音防護具選用與佩戴」內容及增修部分的認識	5.80	8.16	2.36
9. 對警告聲響在噪音場所防音防護具使用的處理	5.25	7.95	2.70
10. 有關「聽力特殊健康檢查及其管理」內容及增修部分的認識	5.91	8.21	2.30
11. 對於 2011 頒布「勞工健康保護規則」修訂健康分級管理的認識	6.24	8.42	2.19
12. 對於噪音性聽力損失職業病的認定基準的認識	5.41	8.14	2.73
13. 有關「勞工教育訓練」內容及增修部分的認識	5.47	7.85	2.38
14. 有關「勞工聽力保護相關資料之建立、保存」內容及增修部分的認識	5.85	8.17	2.32
15. 有關「保存資料之記錄項目」的認識	5.95	8.22	2.27
16. 有關「聽力保護計畫績效評估」內容及增修部分的認識	5.07	7.99	2.92
17. 對於應用「P-D-C-A 的觀念」在聽力保護計畫的認識	5.39	7.97	2.58
整體認知程度	4.98	7.74	2.76

3.2 研習後

本次參與人員在參加本次研習之後，在「對於勞工聽力保護計畫指引之認知情形」方面，其平均得分為 7.74 分，其中以「對於「歐盟 CE 標章」的認識」(增加 4.66 分)與「了解利用歐盟 CE 標章，採購低噪音設備對噪音控制之助益」(增加 4.62 分)、「有關「噪音工程控制」內容及增修部分的認識」等噪音工程控制項目了解較多；而整體認知得分之提升也介於 7.09 至 8.42 分，如表 1 所示。

在研習課程後，在「對於勞工聽力保護計畫指引之信心情形」方面，其平均得分為 7.53 分，其中以「對於未來執行有關「噪音工程控制」的信心」(增加 2.90 分)了解最多，其次為「對於未來應用「第四版勞工聽力保護計畫指引」的信心」(增加 2.83 分)；雖然在研習後「對於未來執行有關「噪音工程控制」的信心」(6.90)仍較低，但整體信心得分之提升也介於 6.90 至 7.98 分，如表 2 所示。以上在研習會前、後之認知與信心程度之前、後平均得分皆達統計上顯著差異。

表 2 研習前、後對於執行勞工聽力保護計畫信心情形

題目內容	平均得分		增加分數
	前	後	
1. 對於未來運用有關「勞工聽力保護相關法規」的信心	5.31	7.52	2.21
2. 對於未來執行有關「噪音作業場所調查與測定」的信心	5.30	7.47	2.17
3. 對於未來執行有關「噪音工程控制」的信心	3.99	6.90	2.90
4. 對於未來執行有關「勞工暴露時間管理」的信心	5.19	7.69	2.49
5. 對於未來執行有關「防音防護具選用與佩戴」的信心	5.66	7.90	2.24
6. 對於未來執行有關「聽力特殊健康檢查及其管理」的信心	5.69	7.98	2.29
7. 對於未來執行有關「勞工教育訓練」的信心	5.49	7.70	2.21
8. 對於未來執行有關「勞工聽力保護相關資料之建立、保存」的信心	5.71	7.89	2.19
9. 對於未來執行有關「聽力保護計畫績效評估」的信心	5.06	7.63	2.57
10. 對於未來應用「第四版勞工聽力保護計畫指引」的信心	5.04	7.87	2.83
整體信心程度	5.17	7.53	2.36

四、未來展望

4.1 辦理專家學者會議

本次計劃除辦理多場次的研習會外，會後亦針對與會事業單位在問卷上表達的建議與意見，進行完整的整理與分析，分析重點包含事業單位作業場所推行勞工聽力保護計畫之現況、遭遇困難、指引使用狀況與需求、應用指引之滿意度、對未來使用指引之職場需求符合情形及建議，相關資料會做為後續專家學者會議討論之重點，藉由學界及實務界專家的審查與建議，為第四版勞工聽力保護計畫指引作細部修正，使其內容更符合事業單位的需求。

4.2 建立臨廠輔導模式

研習會上多家事業單位表示有高度意願改善工作環境及執行勞工聽力保護計畫，故未來將遴選 2 至 3 家事業單位之噪音作業場所進行介入輔導。遴聘專家輔導員，實際至現場以勞工聽力保護計畫指引為執行參考手冊，進行職場勞工聽力保護計畫相關要項與環境之診斷及評估，依個案現況提出建議並協助改善。輔導內容可能包含作業場所噪音調查與測定、工程控制改善建議、勞工暴露時間管理之可行方法、勞工聽力檢查規劃及記錄管理、防音防護具的選用及勞工聽力保護教育訓練之實施等要項，預計輔導期程為二至三個月，並於輔導前、後進行相關工作的檢核及勞工認知、態度、行為等調查，以作為輔導成果及推動計畫成效評估之參考。而臨場輔導過程及實際推動成效結果亦可作為探討「第四版勞工聽力保護計畫指引」未來適用性及可行性之參考。

五、結論

勞工聽力保護計畫的執行需要團隊，成員的組成多少，與事業單位大小以及噪音暴露勞工數目有關。團隊成員包括下列人員：醫師、護士、聽檢師、工業安全衛生人員、暴露勞工、事業單位的雇主與主管等，但其中最重要的人員應是勞工。雖然計畫執行經費、策略擬定、製程監督均非受雇勞工所能決定，但基層勞工絕對是計畫成功的重要關鍵。當勞工覺得他們是計畫團隊的一份子並有

參與感，認知其為計畫成功的關鍵，他們必定認真執行與監視與其相關各項事物。相反的，如使勞工覺得有被強迫，特別在缺乏參與感情況下，將出現負面的反應，可能規避計畫的執行。

新版勞工聽力保護計畫指引內容的本質與視野，將超越符合目前法令的最低要求，雖然希望事業單位、安全衛生人員與勞工熟悉噪音相關標準與符合法令，但計畫目的並非是要重申法令的要求，而是要傳達一個良好的聽力保護計畫應具有的特質。預計新版勞工聽力保護計畫指引的宣導與推廣後，可以促使事業單位知曉並推行整合性聽力保護計畫之各項工作，落實自主管理，增進勞工的作業環境並且維護勞工聽力的健康。

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廣深港高鐵(香港段)的建築噪音控制
Express Rail Link HK Section - Construction Noise Control

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Abstract: Approximately 26km tunnel is being constructed for Express Rail Link (XRL) Hong Kong Section. Tunnel excavation is always preferred to be carried out in round-the-clock construction programme for both TBM and Drill & Blast methods. Under Noise Control Ordinance (NCO) in Hong Kong, Construction Noise Permits (CNP) must be obtained for operation of Power Mechanical Equipment (PME) in evening (1900-2300 hours) and nighttime (2300-0700 hours). Nighttime construction noise impact (groundborne and airborne) on the residential premises close to tunnel alignment becomes a critical item affecting the overall XRL construction programme. The 26km tunnel construction is divided into 8 civil contracts (820, 821, 822, 823A, 823B, 824, 825 and 826). In order to allow round-the-clock tunnel excavation in all the 8 civil contracts, extensive noise mitigation measures were employed. Since construction commencement, over 15,000m^2 acoustic panels had been installed in the form of noise barrier, enclosures, acoustic doors and shaft covers in the XRL HK Section. With sophisticated noise mitigation measures and effort from various parties, over 200 critical CNPs had been obtained from Environmental Protection Department (EPD) today for evening and nighttime PME operations. From the view of the acoustic consultant working on all the 8 contracts, this paper presents an overview on how MTR and their contractors working closely in noise mitigation design and implementation for construction noise control.

Key words: noise mitigation; construction noise control; acoustic enclosure; Express Rail Link, TBM

摘要: 興建中的廣深港高鐵香港段的隧道全長約二十六公里，由多個承辦商分段建造。為配合工程進度，鑽挖隧道(隧道鑽挖機及爆破)須全日運作。在香港進行夜間建築工程受<<噪音管制條例>>嚴格規管，在晚上(1900 時至 2300 時)和深夜(2300 時至翌晨 0700 時)使用機動設備須要獲得「建築噪音許可證」。減少夜間施工噪音對接近鐵路路線的住宅單位的影響，成為廣深港高鐵香港段的工程進度的其中之一個關鍵。隧道全長二十六公里，分為八個土木工程合同(820, 821, 822, 823A, 823B, 824, 825 和 826)。為了令八個土木工程都能全日進行隧道的鑽挖工作，各承辦商依照聲學顧問的建議採用了廣泛的噪音緩減措施。工程開展至今，用作建造隔音屏障、隔音罩、隧道隔音門及豎井隔音蓋的隔音板面積已超過一萬五千平方米。承辦商目前已取得超過二百個關鍵的「建築噪音許可證」，讓機動設備在晚上和深夜使用。本文以聲學顧問的角度概述八個土木工程的噪音控制經驗，分享如何與香港鐵路有限公司和其承辦商緊密合作，規劃設計和實施度身訂做的噪音緩減措施。

关键词：噪音緩減；建築噪音；隔音罩；廣深港高鐵；隧道鑽挖機

1 INTRODUCTION

1.1 The Guangzhou-Shenzhen-Hong Kong Express Rail Link (XRL)

The Guangzhou-Shenzhen-Hong Kong Express Rail Link (XRL) will provide the strategic linkage from Hong Kong to the comprehensive high-speed rail network in Mainland China. This will significantly increase integration of cities, and promote business and tourism towards a greener economy. In order to minimize the impact on the neighbouring communities, the XRL Hong Kong section is a 26 km long underground railway running from West Kowloon to boundary at Shenzhen, Mainland China. The terminus will be located in West Kowloon next to the planned Cultural District in the waterfront. The tunnel construction of XRL Hong Kong section was commenced in Year 2010 and targeted for operation in Year 2015.

1.2 Potential noise impact from tunnel excavation

The 26km tunnel construction is divided into 8 civil contracts (820, 821, 822, 823A, 823B, 824, 825 and 826) and being executed by 6 different contractors. Potential noise impacts during tunnel/shaft excavation may arise from operation of Power Mechanical Equipment (PME) such as rock drills, rock breakers, Tunnel Boring Machine (TBM), etc., especially for restricted hours (1900-0700 hours)[1,2,3]. Nevertheless, tunnel excavation is always preferred to carry out in round-the-clock construction programme. Under Noise Control Ordinance (NCO) in Hong Kong, Construction Noise Permits (CNP) must be obtained for PME operation in evening (1900-2300 hours) and nighttime (2300-0700 hours) [4].

1.3 Noise control measures for round-the-clock tunnel excavation

In order to allow round-the-clock tunnel excavation in all the 8 contracts, extensive noise mitigation measures had been designed and adopted at individual work sites. Since the construction commencement, over 15,000m^2 acoustic panels had been installed in the form of noise enclosures, tunnel acoustic doors and shaft covers. Many enclosures are capable to provide more than 40dB(A) noise reduction. In addition to supply and installation of quality acoustic panels, gap sealing method and workmanship play important roles to ensure noise insulation performance achieving the design intent and to the satisfaction of Environmental Protection Department (EPD). Enclosure doors for PME and spoil removal are always the most critical item degrading the sound insulation performance. With the implementation of these customized noise mitigation measures, over 200 critical CNPs had been obtained from EPD to-date for carrying out the tunnelling works during the restricted hours. This paper presents an overview on how MTR and their contractors in working closely with the acoustic consultant in the planning design and implementation of these customized noise mitigation measures.

2 Major NOISE SOURCE

2.1 Drill and blast method

Drill and Blast Method is commonly used in tunneling industry on hard rock excavation. Among all activities in a blasting cycle, noise from rock drilling and blasting are the most critical. Drilling noise is normally continuous for hours and being the crucial item for noise control where blasting noise is only lasting for a few seconds and no specific noise control measures are required other than blast cover in general. Hydraulic rock drill, also known as jumbo drill, is used to drill holes at rock for installation of explosive at the tunnel faces. In all cases in XRL HK section, jumbo drills are the most severe noise sources for drill & blast tunnel excavation, among all types of PMEs. According to the “Technical Memorandum on Noise from Construction Work other than Percussive Work” (TM) published by EPD, the Sound Power Level (SWL) of a rock drill is 123 dB(A). Wilson Acoustics Limited (WAL) has conducted SWL measurement of rock drills in various site conditions. The results indicate that the TM value of 123dB(A) SWL is a reasonable value for a normal 2-boom rock drill, but slightly over-estimated for 1-boom rock drill. Noise enclosures and tunnel portal acoustic doors were installed for control of rock drilling noise. CNPs for tunnel excavation during restricted hours were obtained for Contract 821, 822 and 824. With the CNPs, the contractors are able to operate 2 blasts per day, where the tunnel construction rate is double, comparing to 1 blast per day operation in normal situation without CNP.

2.2 TBM method

Tunnel Boring Machine (TBM) is one of the most popular tunnel excavation method in dense urban areas in order to minimize environmental impacts from surface construction activities. TBM method is used in Contract 820, 821, 823, 825 and 826. According to WAL noise data obtained from 10 TBMs (including TBMs in other projects), SWL of TBM is ranging from 105 to 130dB(A), subject to TBM type and noise control measures employed for individual PMEs. Open-type TBM is very noisy; Double-shield gripper TBM is quieter than single-shield gripper TBM; Slurry and earth pressure balance TBMs are the quietest among the other types. TBMs used in XRL are relatively quiet with SWL of 105 to 110dB(A). Comparing to a rock drill, TBM is a quiet machine in the order of 13 to 18dB(A) quieter than a 2-boom rock drill. For TBM method, the critical noise control items would be those supporting PMEs operating at surfaces, such as slurry treatment plant, air compressors, chillers, ventilation fans, etc. Some of the PMEs (e.g. water cooling towers, chillers and gantry cranes) are difficult to be fully enclosed, which increase the challenge of noise control. TBM groundborne noise are discussed in other papers [5,6,7].

2.3 TBM Sound Power Level (SWL) measurement at factory

In order to shorten the time lag between TBM on-site installation and TBM nighttime operation with CNP, TBM SWL may be measured during TBM commissioning at factory. Such SWL measurements were only conducted for close-type TBM (i.e. Slurry and earth pressure balance TBMs) by WAL. Factory noise measurement for open-type TBM may significantly under-estimate the real operation SWL. With SWL measurements in the TBM factory, nighttime CNPs for TBMs in Contract 820 were obtained within 7 days after the TBM operation. It should be noted that TBM operation starts well before the completion of entire TBM installation on-site, which would normally take 1 to 2 months or longer. EPD would be difficult to accept SWL measurement of partial completed TBM during the TBM installation period.

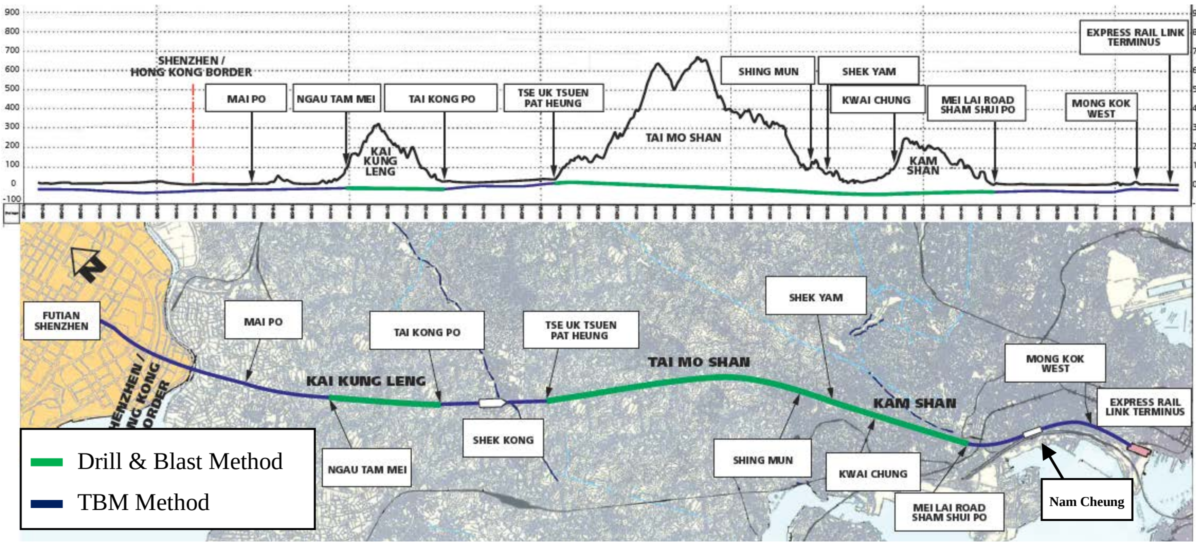

Figure 1. Tunnel Section constructed by Drill & Blast or TBM

3 NOISE CONTROL ORDINANCES FOR CONSTRUCTION NOISE

3.1 Noise Control Ordinance (NCO) and Construction Noise Permit (CNP)

In Hong Kong, construction noise is controlled under NCO. CNP must be obtained for PME operation during restricted hours (1900 to 0700 hours). The noise criteria for issuing CNPs are stipulated in "*Technical Memorandum on Noise from Construction Work other than Percussive Work*" and "*Technical Memorandum on Noise from Construction Site in Designated Areas*" under NCO [1].

3.2 Noise criteria for operation of Power Mechanical Equipment (PME)

The acceptable construction noise levels are defined based on area sensitivity rating of noise sensitive receivers (NSRs), time period for PME operation and multiple permit correction (noise quota used up by other construction sites). If the NSRs are located near major road and the traffic noise is affecting the NSRs, the noise criteria will be relaxed by 5 or 10dB(A) to account for background traffic noise. In general, for nighttime (2300 to 0700 hours) PME operation, the acceptable construction noise levels at 1m from NSR façade is 50 to 55dB(A) in urban area and 45 to 50 dB(A) in rural area, depending on noise levels from major road. If the site is located in an area where other CNPs have been issued, the criteria shall be downward adjusted for accumulated noise emitting from multiple sites. According to EPD practice, multiple site correction up to -7dB(A) may be applied. Then the noise criteria becomes 43 to 48dB(A) in urban area and 38 to 42dB(A) in rural area. Noise levels of this range are generally 5 to 20dB(A) lower the background noise levels in terms of $L_{Aeq,5min}$ (5 minute averaged A-weighted noise levels), however, it may still be audible (or marginally audible) at NSRs during the quietest moment of the ambient noise. As a good practice to the satisfaction of EPD, nighttime construction noise control should be designed to achieve NCO noise criteria with a few dB(A) safety margin such that construction noise impact is unlikely to be audible at NSRs even during the quietest moment of the ambient noise.

3.3 Noise criteria for operation of Specified Power Mechanical Equipment (SPME)

In addition to the above criteria for PME noise control, some PMEs are identified as Specified Powered Mechanical Equipment (SPME) by EPD including hand-held breakers, bulldozer, concrete lorry mixer, dump truck and hand-held vibratory poker. SPMEs are considered creating extra annoyance to the NSRs. It is aiming to eliminate use of SPME in restricted hours, therefore SPME noise criteria is stipulated to be 15dB(A) lower than the PME noise criteria, disregard whether it is audible or inaudible.

4 NOISE CONTROL METHOD

4.1 Noise enclosure

Noise enclosure is commonly used to cover TBM launching shaft, drill and blast shaft and other noisy PMEs. It is a cost-effective method and generally achievable to 40dB(A) noise reduction with proper selection of noise panel and good workmanship for various site conditions. It is possible to achieve 50dB(A) noise reduction in some specific cases. The noise reduction performance of the enclosure is limited by openings and gaps at the enclosure, such as doors, ventilation openings, cable openings, drainage channels, etc. Special acoustic treatment shall be made to prevent noise franking around the enclosure. Table 1 lists the scale of enclosure constructed at different construction sites. Enclosures built in Sheung Mun and Tai Ko Po are shown in Photo 1 and 2.

Table 1 Enclosure at different XRL construction site

Enclosure Location	Enclosure Surface Area, (m^2)	Distance to nearest NSR, (m)
Nam Cheung	~3500	~90
Sheung Mun	~5000	~40
Tai Ko Po	~3800	~30
Mai Po	~1800	~90

Photo 1: Noise enclosure in Sheung Mun

Photo 2: Noise enclosure at Tai Ko Po

4.2 Tunnel acoustic door

Tunnel portal acoustic door is another form of noise enclosure, which is constructed at Kwai Chung, Shek Yam and Pat Heung work sites. This mitigation normally applied to drill and blast tunnels only. In general, tunnel portal acoustic door comprises of a large vehicle access door, a man access door and ventilation openings. Sometimes, louvers would be installed on the door for releasing air pressure during blasting. Doors and ventilation openings usually are the weakest noise insulation points and potentially degrading the overall noise insulation performance. Proper acoustic treatment on the potential flanking path should be applied to ensure a desirable noise reduction performance. Table 2 lists the size of tunnel portal acoustic doors at different sites. Tunnel acoustic doors built in Shek Yam and Pat Heung are shown is Photo 3 and 4.

Table 2 Acoustic door at different XRL construction site

Tunnel Acoustic Door Location	Door Surface Area, (m^2)	Distance to nearest NSR, (m)
Kwai Chung	~200	200
Shek Yam	~200	80
Pat Heung	~200	94

Photo 3: Tunnel acoustic at Shek Yam

Photo 4: Tunnel acoustic at Pat Heung

5 NOISE REDUCTION VERIFICATION TEST

To fulfill CNP requirement, the Insertion Loss (IL) noise of enclosures were measured individually. The test follows 10847- In-situ determination of insertion loss of outdoor noise barriers of all types [1,8]. Normally, the loudest construction activity was pre-recorded and played back through loudspeakers to simulate the worst-case scenario inside the enclosure. The loudspeaker system was able to provide steady continuous noise sources around 128 to 133dB(A) SWL for accurate repeatable noise measurements.

Apart from the IL measurement, additional noise leakage measurements were also conducted around the enclosure in order to prove noise would not leak through particular ventilation openings, gaps and holes. Microphone would be set up 1m to 3m from the enclosure at various locations, normally 100 to 300 measurement points depending on the size of the enclosure. Such measurement would normally require multiple (3 to 6) sound level meters and takes 2 to 5 hours. In some cases, noise monitoring at NSR provide good indication whether noise from the construction activities are within the statutory criteria, however, it is not a strict requirement from EPD.

6 SUMMARY

The XRL tunnels are one of the largest construction projects in Hong Kong. Massive resource had been spent on the noise control to minimize noise nuisance to public. With best effort made from MTR, Contractors and Consultant, noise problems are well managed and achieve 24-hour tunneling operation. Valuable noise control experience is learned and anticipated to be applicable to future tunneling projects.

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輪胎特徵對路面噪音的影響
Impacts of tyre properties on tyre/road noise

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Abstract: This paper reports our study on the tyre properties and their impacts on the tyre/road noise using our twin-wheeled Close-proximity (CPX) vehicle equipped with an acoustic enclosure covering the test tyres. Four Yokohama tyres with various rubber hardness and tread depth were fitted to our CPX vehicle. The vehicle was then run on a porous asphalt (PA) and a dense asphalt (DA) surfaces. It is found that the tyre/road noise level increases with tread rubber hardness on both surface types, and decreases with tread depth on dense asphalt.

Key words: tyre/road noise; tyre rubber hardness; tyre tread depth.

摘要：本文報告一項就輪胎特徵對路面噪音的影響研究結果。我們利用自行研發的路面噪音測量車，配以測試的輪胎，在密鋪與有孔路面進行噪音測試。測量車可以同時裝配一對輪胎作測試，而今次測試的車胎膠軟硬度和胎紋深度不同。結果顯示輪胎的軟硬度越高，在兩種路面上的噪音亦越高；而胎紋越淺，在密鋪路面上的噪音越低。

關鍵詞：路面噪音; 輪胎膠硬度; 胎紋深度

1 INTRODUCTION

As a vehicle travels on a road, tyre/road noise is emitted by the physical interaction between the rolling tyres and the road surface. It is one of the dominant traffic noise sources at speed above 40 km/h. Researchers[1] has categorized the tyre/road noise generation mechanisms into two – air-borne and structural-borne noises, which respectively refer to the aerodynamic and vibration-related noise sources. Upon prolonged usage, vehicle tyres deteriorate and undergo changes in various properties, namely rubber hardness and tread depth. Such changes may affect the generation of tyre/road noise. The impacts by tread rubber hardness and tread depth are investigated in this paper.

2 METHODOLOGY

2.1 Measurement method

A Close-Proximity (CPX) tyre/road noise measurement system as shown in Figure 1 was fabricated and certified[2] at the Hong Kong Polytechnic University (HKPolyU) according to ISO 11819-2[3] in 2009. A twin-wheeled trailer equipped with an acoustic enclosure is towed to travel at specific reference speed on real roads. The noises emitted by the two test tyres are directly measured by two microphones mounted inside for each one. The system is also equipped with microwave speed sensor, accelerometers, GPS receiver, tyre pressure sensor and air and road surface temperature sensors. Theses sensory units are integrated into a single high speed (100 kHz sampling rate) data acquisition device. Collected data can be processed on site and results can be generated right upon finish of measurement.