EVALUATION ON EFFECTS OF NOISE BARRIER DEFECTS ON THEIR NOISE REDUCTION EFFICIENCIES

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ABSTRACT

In this study, in-situ performance of noise barrier on Taiwan national freeway was measured following procedures specified in ISO 10847. The measured in-situ performance was numerically evaluated by using the Traffic Noise Model (TNM) developed by Federal Highway Administration. By comparing measured data with numerical data, the adequacy of applying TNM to perform numerical evaluation on noise barriers was verified. It was found that TNM will overestimate roadside energy equivalent noise level (L_{Aeq}) measured in Taiwan. Yet, TNM can give satisfactory results in terms of the difference between before- and after-installation comparisons. Numerical experiments were then executed to investigate effect of noise barrier defects on their noise reduction performance. Commonly observed noise barrier defects, viz. single panel missing and inadequate overlapping, were evaluated. It was observed from numerical simulation that these defects do have significant effects on noise barrier performance. Reduction on effective noise can be more than 3.5 dBA while width of broken barrier varied from 0 to 2 meters. On the other hand, inappropriate overlapping is observed to have about 3 dBA difference on effective noise reduction. It is inferred from current results that appropriate and swift remedy actions should definitely be done to reduce the impact of noise barrier defects onto adjacent residents.

KEY WORDS

ISO 10847, FHWA TNM, noise barrier defects, performance evaluation, effective noise reduction

INTRODUCTION

Traffic noise comes along with modern highway developments. As highways being built closer and closer to residential areas, residents will be exposed to higher or even unbearable noise levels. Such a problem is particularly severe in small countries like Taiwan. Due to the fact that highway is one of the most convenient modes of transportation to many people; more highway construction as well as more traffic noise problems can be reasonably

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projected. To overcome traffic noise problem, noise barrier, low noise pavements, low noise vehicles, traffic control schemes, and proper land uses have been proposed. Being considered to have merits of easy installation, better noise reduction performance, and ability to soothe annoyed residents, noise barriers have become the most prevalent countermeasures adopted by most highway agencies. Take United States as an example. Data revealed by the US DOT bureau of transportation statistics (BTS) indicates that length of noise barrier is increased at an average rate of 92.6 miles per year, and total lengths of noise barrier constructed in US have already reached 1,831 linear miles through 2001, which is about twice of that through 1991. The length of noise barrier built during 1991~2001 period in the US is about the same as those built during 1963~1991. One can tell from such fast growth of noise barriers construction that traffic noise problem is indeed getting worse than ever.

Noise barrier is a passive noise reduction measure, which impede noise propagation through reflection, absorption, or diffraction. Hence, any defects in noise barriers may allow unnecessary noise propagation and thus degrade their performance. Consequently, noise barriers should be constructed and maintained with care to uphold their designed noise reduction capability. Nonetheless, it is easy to find noise barrier defects resulted from traffic accidents, poor workmanship, or inappropriate maintenance along highways. Although most residents feel comfortable, as long as there are noise barriers in between their houses and highways. How these barriers perform is also not that important to them. However, as Anday (1979) discussed in his study that warpage of wood panel will render the entire barrier acoustically ineffective. Flodine (1991) also reported that shrinkage cracks may significantly reduce the acoustical effectiveness of wooden noise barriers. On the other hand, noise barriers generally have long life cycles. Kay (1996) investigated service life of highway noise barriers over 40 states in US. She found that average service life can range from 20 to 50 years. Yet, better performance was observed for those barriers installed within 20 years. She also indicated that not all agencies execute periodical check on noise barriers; and less than 1% of all noise barriers have ever been retrofitted or replaced. This implies that performance of great amount of existing noise barriers may be questionable. Overlapping barriers are sometimes needed for maintenance or emergence access. The FHWA *highway noise barrier design handbook* (2000) requires the overlap length equal to at least 4 times of the overlap width. On the other hand, HongKong environmental protection department specifies 3 times plus using absorptive materials for overlap surfaces. Herman et al (2002) also reported the generally specified 2~3 time requirement is useful for controlling line-of-sight propagation. However, one can still find cases of short or even zero overlap length once in a while. The above mentioned phenomena do indicate that there is apparently a need to evaluate the effect of defects on performance of commonly observed damaged or inappropriately constructed noise barriers. Such information can illustrate severity of degradation of acoustical effectiveness, and serve as a reference for decision makers to properly allocate the generally limited budgets of their agencies.

Effectiveness of noise barriers has been evaluated via various approaches. Numerical models (such as boundary element method (Jean, 2000)), in situ measurements (such as insertion loss or transmission loss (Watts, 1997)), and life cycle cost analysis have all been adopted. In terms of noise reduction performance, in situ measurement and numerical models are often adopted. For in situ measurement of insertion loss, procedure described in International Standard Organization (ISO) standard ISO 10847 (1997) is generally followed. As to numerical models, commercial software, such as traffic noise model (TNM), Cadna-A and SoundPlan, can now be used to perform such evaluation. Commercial software is generally generated based on theoretical formulas. Meanwhile, factors such as vehicle categories, average speed, and pavement types, are normally incorporated as input factors in such software. Due to the fact that these factors may vary from country to country, noise prediction based on default values may thus be under or over estimated. Consequently, accuracy on model predicted noise barrier effectiveness may also be affected. Koushki (1993) applied TNM to evaluate traffic noise level in Saudi Arabia and reported under-estimation was observed from TNM output. On the other hand, Wayson (2003) compared prediction results from TNM and STAMINA. He concluded that TNM can give better before and after evaluation on noise barrier installation.

From the above discussion, it is clear that noise barrier defects can degrade effectiveness of noise barriers, and evaluation on degree of such degradation is needed. Meanwhile, TNM was considered appropriate for evaluation on effectiveness of noise barrier. The subjective of this study is thus to confirm TNM is indeed an appropriate tool for noise barrier evaluation. Moreover, effects of various modes of noise barrier defects on noise barrier performance are evaluated.

ANALYTICAL FRAMEWORK

IN-SITU NOISE MEASUREMENT & VERIFICATION OF TNM

To evaluate performance of noise barriers, in situ traffic noise measurement was performed at 133K+500 north bond of national freeway one (three lanes each direction) in Taiwan for 3 consecutive days. Indirect measurement method specified in ISO 10847 was followed since noise barrier was already installed in that section. Two RINO NL-31type I sound level meters were used for sound level measurement at the time period. Receiver positions were both 9 m from road edge and 1.2 m above road surface; yet one with and another without barrier in between. All restrictions regarding to acoustical environment specified were measured and met. Traffic volume, vehicle categories, and vehicle speed were recorded using digital camcorder and RIEGL laser speed measurement system. Meanwhile, geometrical parameters of measurement site were also collected for numerical model analysis.

A-weighted energy equivalent sound levels (L_{Aeq}) were calculated from measured data. Numerical model for the test site and test condition were constructed using TNM at the same time. A comparison between measured and model predicted L_{Aeq} were given in table 1. It can be seen that all three TNM predicted L_{Aeq} were over-estimated. The over-estimation ranges from 4.9 ~ 5.7 dBA, which is quite a difference from energy point of view. Nonetheless, the measured L_{Aeq} reductions were within 0.5 dBA difference, which implied TNM can not give accurate prediction on absolute noise level when used under traffic conditions in Taiwan's highway, yet it shall be capable of giving acceptable estimation on relative differences. Compare data reported by Liu et al (figure 1, 2003) and by Sandberg et al (figure 2, 2002) following ISO 11819-1(1997), one can observe that L_{Amax} calculated for all three vehicle categories in Europe have higher dBA than that in Taiwan at specified reference speeds. This difference may be resulted from differences in vehicle category definitions, vehicle characters, vehicle compositions, pavement characters, pavement maintenance, and nature environment etc. Consequently, the observed over-estimation from TNM is considered understandable. Meanwhile, model calibration for local characters is suggested for better prediction results. While TNM was confirmed to be able to properly evaluate effectiveness of noise barriers, it was further applied to evaluate effects of noise barrier defects on their performance.

Table 1: A comparison between measured and TNM predicted L_{Aeq}

Measure period	Noise barrier existence	Measured L_{Aeq}	TNM predicted L_{Aeq}	differences
Day 1	No	68.7	74.4	+5.7
	Yes	59.1	64.3	+5.2
	Noise reduction	9.6	10.1	+0.5
Day 2	No	71.9	77.1	+5.2
	Yes	62.2	67.3	+5.1
	Noise reduction	9.7	9.8	+0.1
Day 3	No	69.7	74.6	+4.9
	Yes	60.2	95.2	+5.0
	Noise reduction	9.5	9.4	–0.1

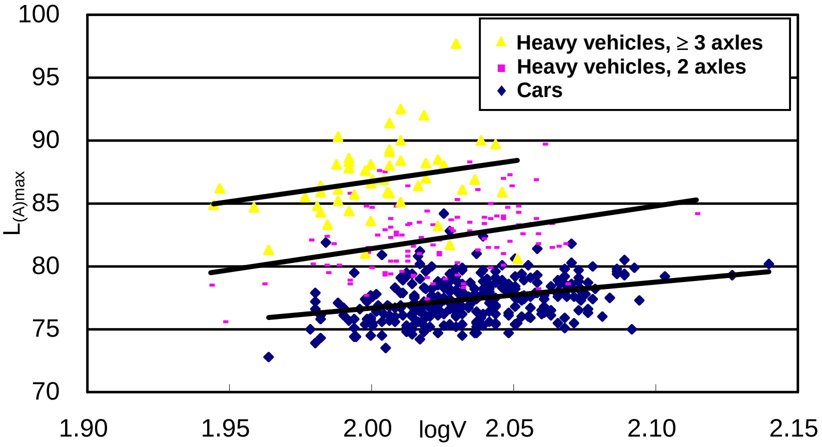


Figure 1: Relationship between $L_{(A)max}$ & log V measured in Taiwan (Liu et al, 2003)

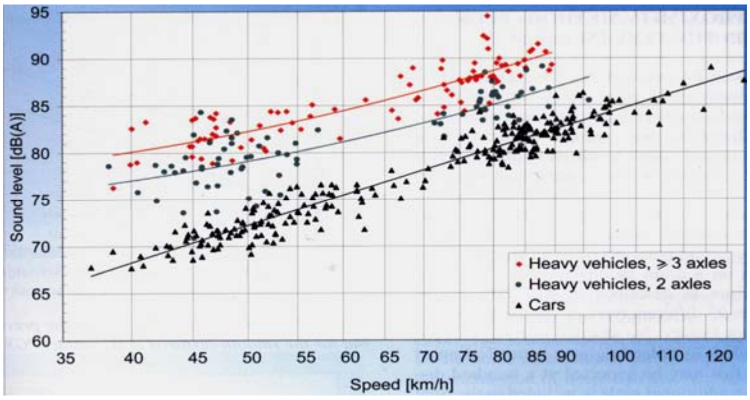


Figure 2: Relationship between $L_{(A)max}$ & V measured in Europe (Sandberg et al, 2003)

EFFECTS OF NOISE BARRIER DEFECTS

Broken panel, missing panels, and inadequate overlapping lengths are three most frequently observed noise barrier defects. Due to the fact that TNM has difficulty in simulating small breakages in panels, only effects of missing panels and inadequate overlap lengths were evaluated. However, it should be noted that vertical linear breakage of barriers can still be simulated by changing width of missing panel.

Missing Single Panel

TNM model constructed for simulation of missing panels can be illustrated in figure 3, in which H and D stands for height of noise barrier and width of missing barrier panel, respectively, and the symbol of small diamond on top of a post represents receivers. A series of receivers were aligned parallel to noise barrier to observe effects of missing panel on various locations behind that missing panel. By varying values of H and D, effects of missing panels on degrading barrier effectiveness can be simulated for various situations.

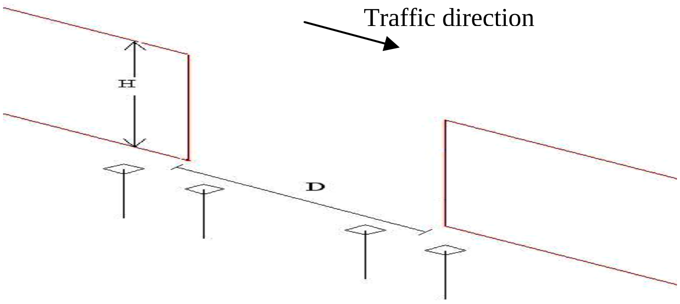


Figure 3: Illustration of TNM model for simulation of missing panels

The simulation result for fixed barrier height and varied missing panel width is depicted in figure 4. The vertical axis represents effective noise reduction in dBA, and the horizontal axis represents receiver distance to center of opening. One can observe from figure 4 that the center of missing panel will be the most severely affected spot by the simulated vertical linear defect. As width of such opening increased, adverse effect may be more significant, and the affected area may expand significantly as well. Typical panel length of post-and-panel type barrier is about 1.8 m. Hence, according to figure 4, there will be about 3 dBA L_{Aeq} increase when one such typical panel is missing. That is, twice amount of sound energy propagates through such defect to receiver even when only one single panel is missing. As to the affected area, only about a 4 m range behind the opening will have 0.4 dBA increases when the opening is 0.2 m wide; whereas at least a 20 m range will have 1.5 dBA increases when the opening is up to 1.8 m wide.

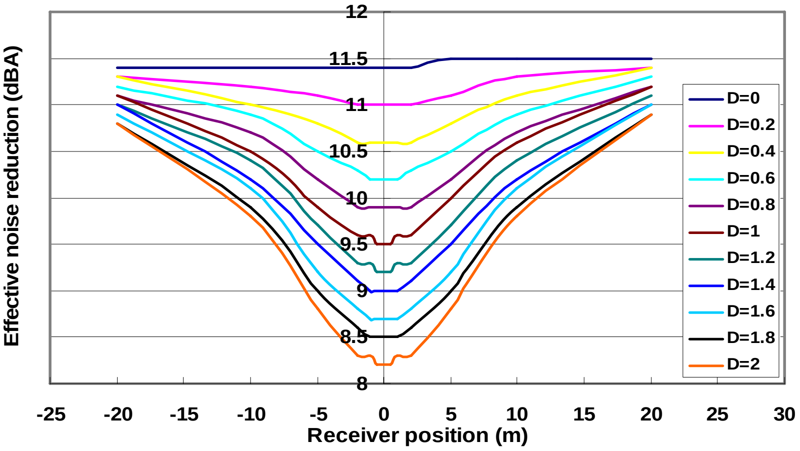
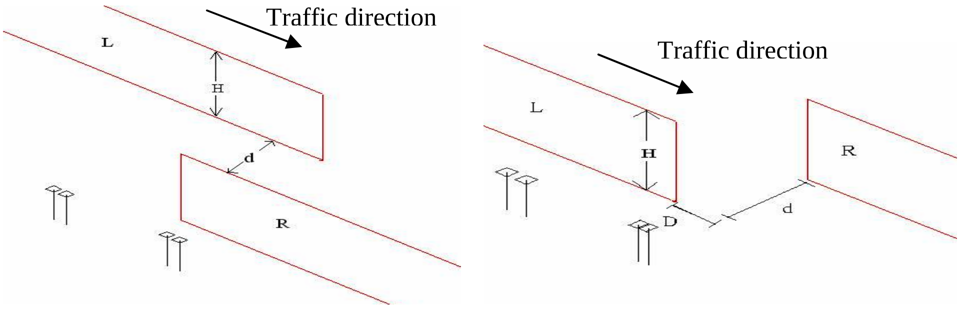


Figure 4: Simulation for fixed barrier height and varied missing panel width

Inadequate Overlap Length

TNM model constructed for simulation of inadequate overlap barrier is illustrated in figure 5, in which H, D, and d stands for height of noise barrier, overlap length of overlap barriers, and gap width of overlap barriers, respectively. Again the symbol of small diamond on top of a post represents receivers, and a series of receivers were also aligned parallel to noise barrier as shown in figure 5. It should be noted that a negative D indicates barrier overlap exists. By changing values of d and D, various situations of overlap barriers can be simulated, and their effects on degrading barrier effectiveness can be also simulated.



(a) downstream overlap (b) upstream overlap

Figure 5: Illustration of TNM models for simulation of inadequate overlap length

As depicted in figure 5a & 5b, overlap barriers can be arranged either way. A direct thinking will normally lead us to downstream type overlap since noise may have to go “backwards” to reach the other side of barriers. However, the simulated result illustrated in figure 6 indicates that these cases are symmetric. That is, similar effect should be observed for either downstream overlap or its corresponding upstream overlap. In figure 6, a fixed D (= 0.4 m) was selected to simulate non-overlap situation. It can be seen that less than 1 dBA increase occurred when small gap (d = 0.6 m) is present. Nonetheless, as gap getting larger, degradation on noise effectiveness is more obvious on the downstream portion for the upstream overlap. This is reasonable since noise wave can propagate directly through the gap to downstream area. On the other hand, the adverse effect is about 1.5 dBA, which is lesser than that observed in missing panel situation.

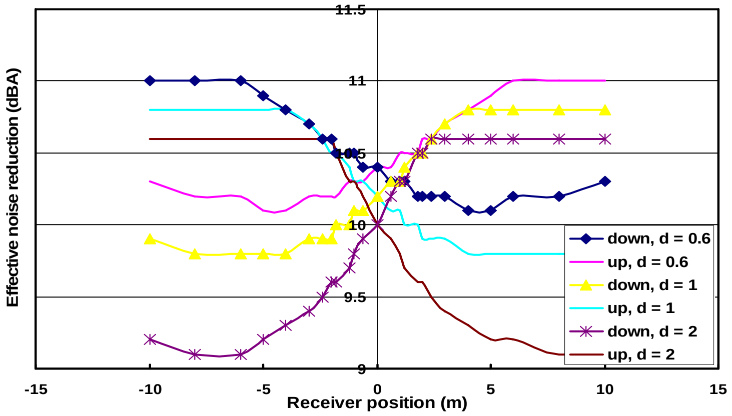


Figure 6: Effect of overlap gap width on degrading barrier effectiveness

Effect of overlap length was evaluated by changing overlap length with respect to three different gap widths. Figure 7 gives the simulation result. It can be seen that effective noise reduction increases as gap width decreases for fixed overlap length. Meanwhile, for fixed gap width, effective noise reduction increases as overlap length increase. Again, reasonable trends are observed.

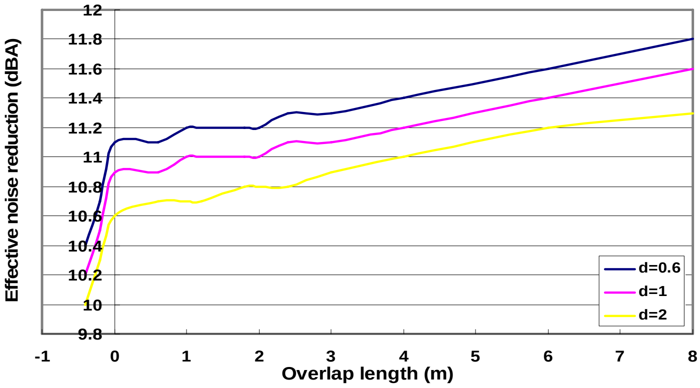


Figure 7: Effect of overlap length on degrading barrier effectiveness

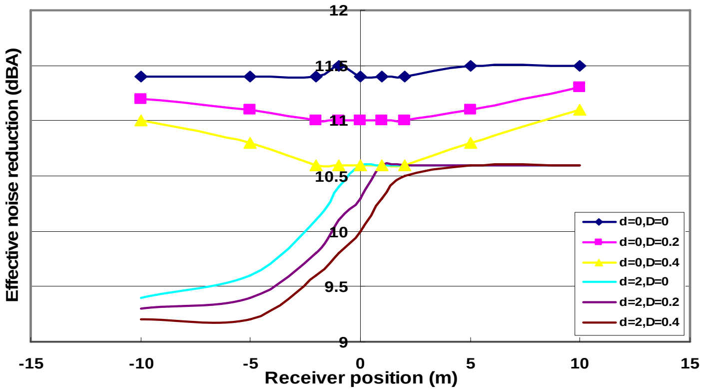


Figure 8: Comparison of effectiveness between single and overlap barriers

Finally, comparison of effectiveness between single and overlap barriers is given in figure 8. Curves with icons illustrate behavior of single barrier, whereas others illustrate that of overlap barriers. One can easily tell that single barrier outperform overlap barriers by as much as 2 dBA in all three cases. Although more cases should be tested, this result implies that overlap barriers should be avoided unless no other alternative can be found.

CONCLUSION

In this study, in situ measurement on noise barrier effectiveness was performed. Numerical estimation using TNM on noise barrier at the same location was also generated. It was found that TNM will over-estimate L_{Aeq} under input conditions in Taiwan by as much as 5.7 dBA. Nevertheless, in terms of estimation on effective noise reduction, TNM gave acceptable results. TNM was thus further applied to analyze effects of barrier defects on barrier performance. It was found that panel missing can lead to as much as 3 dBA degradation on barrier effectiveness. Consequently, appropriate and swift remedy actions should be done to reduce the impact of noise barrier defects onto adjacent residents. In the meantime, adequate overlap length is needed to minimize adverse effect of gap appearance. Moreover, single barrier generally outperform overlap barriers, thus single barrier should always be selected where it is possible.

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