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NOISE DEGRADATION IMPACTS FROM DRAINAGE HOLES IN SOUNDWALLS— THE TEXAS EXPERIENCE

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INTRODUCTION

The Texas Department of Transportation has encountered several situations where soundwall construction created or compounded drainage problems. The use of noise barriers for above-ground drainage is sometimes necessary to move flood waters from rights-of-way or from residential property abutting noise barriers. Numerous walls with above-surface drainage have been built in the Houston area using different sizes and shapes of drains. A field evaluation of barrier degradation from these drainage holes has recently been completed and some interesting and hopefully useful information has been found.

TEXAS DEPARTMENT OF TRANSPORTATION'S NOISE POLICY

The Texas Department of Transportation's Type I noise abatement program has constructed nearly 20 miles of noise barriers within the past 10 years. Commitments have been made to construct an additional 38 miles of barriers in the near future if the Transportation Improvement Plans meet conformity requirements under the 1990 Clean Air Act Amendments. All the projects involving proposed noise walls are located in ozone nonattainment areas.

Commitment to noise abatement is usually made during the environmental assessment phase of highway planning. Texas has taken a proactive stance towards noise abatement whenever abatement is reasonable and feasible. Reasonable and feasible equate with lowering noise levels at least 5 decibels (dB) for less than $25,000 per front row receiver. Commitments are reevaluated during the Plans, Specifications, and Estimates (PS&E) design stage, and land-use changes are checked again just prior to construction letting. Major land-use changes initiate a reevaluation of noise impacts and may lead to abatement.

Public involvement begins during the environmental assessment phase, and citizens are alerted to noise abatement plans early in the design process. Public meetings are held with affected property owners at the PS&E stage, at which time they are asked if they want a noise wall and, if so, their preference regarding surface treatment and color. First-row landowners are sent questionnaires asking if they are in favor of the proposed noise walls. Construction of the barrier requires a simple majority approval.

The Texas Department of Transportation firmly believes that the public should be informed of construction plans early in the environmental process and that environmental commitments should be made prior to completing the NEPA review. Noise impact is one of the factors to be considered during the environmental process, and sincere efforts are made to address noise issues early in the design process.

Although the Texas Department of Transportation has built several wooden soundwalls, concrete post and panel soundwalls atop a concrete footing are preferred. This design prevents erosion and facilitates maintenance operations. Although wooden walls are initially less expensive, high maintenance and replacement costs raise their overall costs to that of concrete walls. Because of concern about corrosion, only one steel panel wall has been built.

The preferred soundwall configuration consists of 20 foot long concrete panels placed between steel I beams. If above-ground drainage is deemed necessary, the drainage holes are cast along the bottom of all ground-level panels (a design that reduces casting costs). Panels are stacked to achieve the appropriate height indicated by Stamina 2.0, the Federal Highway Administration Noise Prediction Model. Joints are sealed and caulked to minimize the loss of noise transmission through the barrier. Noise barriers are built along departmental rights-of-way and are normally constructed about 18 inches inside property lines. This layout allows working space behind the barriers and minimizes the area to be maintained behind the soundwalls. Periodic weed-eating conducted behind the barriers can control weeds. Property owners' fences are left standing whenever possible.

Drainage facilities in and under the soundwalls are not a major problem in most areas of the state. Natural slopes, borrow ditches, or subsurface drains can be used to move excess rainfall into natural drainage patterns. Thus, drainage holes in noise barriers are normally not needed.

Drainage is a problem in Houston and in other flat, flood-prone Gulf Coast areas. These areas have little natural relief and lack natural drainage. Soils are mainly dense clays having a very slow water absorption rate. These "Hurricane Alley" areas also have high annual rainfall. Minor flooding occurs annually, with major floods expected about once every 10 years (when hurricanes come ashore). Because noise barriers increase the risk of flooding in these areas, drainage is a major consideration. Drainage through the soundwall is usually required, since there are few relief features to utilize. Below-ground pipes are not usually effective because they lack the natural slope necessary to carry excess water. Trenching along soundwalls has proven similarly ineffective because of the distances to natural drainages and because of their potential for creating standing pools that turn into mosquito breeding sites.

PREVIOUS RESEARCH

During the late 1980s the Texas Department of Transportation grew concerned that the soundwalls planned for the Houston area might cause flooding. Equally concerned, the Harris County Flood Control District banned all construction that risked raising Houston's base flood elevation. The department, committed to building soundwalls in the area, was certain that above-ground drains were needed in the noise barriers to reduce flood risk. Before making a final commitment to build barriers with above-ground drains, the department contacted other state DOTs having active noise programs and conducted a literature search on degradation related to holes in barriers.

Noise personnel in other state agencies indicated that their active noise mitigation programs avoided constructing holes in soundwalls whenever possible. Holes, when required, were baffled or covered with flaps to reduce noise degradation. None of the DOT contacts had experimented with above-ground drainage facilities in soundwalls.

The literature review identified National Cooperative Highway Research Program Report 174, "Highway Noise: A Design Guide for Prediction and Control" (1976), as the only document that discusses degradation of noise barriers. This NCHRP report emphasized that holes in soundwalls can greatly reduce the effectiveness of the barrier.

NCHRP Report 174 assumed an 80-dB noise level at the source side of the barrier and a barrier transmission loss of 30 dB. This would create a 50-dB noise level on the receiver side of the barrier if no noise comes through holes or over the top of the barrier. The report also assumed that 10 percent of the surface area consisted of holes. Six dB were then added to noise levels passing through the open areas. (This increase is due to more energy passing through the hole than is straight-incident to it.) The noise level was calculated to be 76 dB. The 10 percent holes reduced the barrier effectiveness from 30 to 4 dB.

The NCHRP report is a major and worthwhile effort at calculating the amount of noise passing through soundwall holes. In most highway situations, considerable noise comes over the top of barriers. Because of this it was necessary to measure a highway barrier situation. In most studies, noise levels are modeled or measured near a receiver, rather than directly behind the soundwall. Distance doubling effects on noise transmitted through the holes should reduce the noise level before it reaches the receiver.

The Texas DOT used aspects of Stamina 2.0 and the NCHRP report to estimate a typical Texas barrier scenario. Stamina was used to model a barrier configuration with a receiver 50 feet behind a 10 foot high barrier. Stamina predicted 72 dB Leq at the barrier, and 67 dB fifty feet behind the barrier. The NCHRP report degradation tables were then used to calculate noise levels from 1 percent, 2.5 percent, and 4.0 percent openings for drainage in the barrier. Stamina algorithms for distance effects were used to calculate the expected drop in noise levels from the wall to the receiver. Alpha factors were predicted to reduce sound levels at least 4.5 dB between the soundwall and receiver.

Table 1 contains projections on actual sound levels at a receiver 50 feet behind the barrier. Noise coming through the barrier has been adjusted by subtracting 4.5 dB for distance effects. (If noise coming through drainage holes is considered as a point source, 6.0 dB should be subtracted for distance doubling effects.) Decibel addition was used to calculate the combined effect of noise coming through the wall and over the barrier (*Fundamentals and Abatement of Highway Traffic Noise Textbook and Training Course*). Calculations suggested that noise levels would not be compromised by drainage holes representing less than 2.5 percent of the surface area of a soundwall.

Table 1: Predicted Noise Levels from Soundwall Drainage Holes

Percent Openings	Calculated Noise Level Through Wall	Noise Level at Receiver from Holes	Modeled Level at Receiver Over Wall	Calculated Combined Level
0.0	0	0.0	67	67.0
1.0	58	53.5	67	67.0
2.5	62	57.5	67	67.0
4.0	64	59.5	67	67.7

TEXAS SOUNDWALLS

The seriousness of the degradation of effectiveness in noise walls was questioned partially because the walls were at ground level and partially because they represent a very small percentage of the total surface area. The earliest designs called for 5 by 6 inch rectangular drainage holes drilled into concrete soundwall panels. Three openings were evenly spaced in each 20 foot long panel. The bases of drainage holes were placed at ground level in an effort to keep noise levels down and to provide adequate drainage.

No complaints of noise coming through these holes were received from residents behind the barriers. However, maintenance personnel were spending a disproportionate amount of time unclogging these small drainage holes. The drains required frequent cleaning because of their tendency to clog with aluminum cans and other litter.

Drainage hole dimensions were gradually increased to provide relatively maintenance-free openings that still kept noise abatement degradation in check. Hole sizes for each barrier location were based on projected drainage areas, potential flooding problems, and overall barrier dimensions. Different configurations were utilized until reaching the maximum size of 13 inches by 9 inches. Property owners often covered the holes to prevent their small pets from entering them and/or to block excess noise coming through the openings. By this time, several soundwalls were built with drainage holes, giving an adequate sample to field check.

FIELD RESEARCH

Field research was directed towards determining the real-world impact of drainage holes on the soundwalls. Research goals were to determine (l) if noise levels increased as sound passed through drainage holes, (2) if drainage hole shape or surface area affected the noise levels passing through the drainage holes, (3) if drainage holes caused any degradation in noise levels, and (4) if degradation could be related to drainage hole size, shape, or percentage of total surface area.

Data collection required that we measure, simultaneously, noise directly in front of and behind drainage holes for each wall studied. These data were used to compare the amount of noise coming through drainage holes with the amount of noise hitting the soundwall. Measurements from several walls with different heights and drainage hole sizes were then compared to determine the amount of noise passing through the hole. Drainage hole surface area and shapes were compared to examine the relationship between noise passing through a hole and the dimension of the hole.

Degradation impacts were measured by simultaneously measuring noise levels behind two barrier segments. The drainage holes were blocked in one segment and left open in the other. Equal distances from the barrier and the roadway were maintained for both sound level meters. Degradation at a measured distance was calculated by subtracting the covered noise levels from the open noise levels. Measurements from several walls having different heights and drainage hole sizes were compared to determine if drainage hole area or shape affected degradation.

Length and height measurements of barrier panels and drainage holes were taken and used to calculate the surface area of the panel and drainage holes. Length/height ratios were calculated for the drainage holes to evaluate the shape of drainage holes. The percentage of the wall represented by drainage holes was calculated by dividing the surface area of the drainage hole into the surface area of the soundwall panel.

A number of barriers with ground-level drainage holes have been constructed in the Houston area. These were classified by wall height and drainage hole size to determine the number of different combinations for study. These were field checked to locate areas which (1) were easily accessible, (2) were relatively free of extraneous noise sources, (3) lacked privacy fences along the barrier, and (4) had minimal noise levels coming around the end of the barrier.

Six representative barriers were chosen for study. These represented three different wall heights and contained five variously sized drainage holes. Dimensional data are presented in Table 2. Five walls have straight rectangular holes, while the sixth has the hole offset at a 45° angle. The offset holes in Barrier 1 were constructed to minimize the surface area through which noise could pass directly. Although the openings were 6 inches long, only 3 inches of this length allowed unreflected noise to pass through the wall.

All noise measurements were taken with freshly calibrated Metrosonics 308 sound level meters. These type 1 meters were programmed to take simultaneous noise measurements (to eliminate noise differences over time). Five-minute noise readings were taken to reduce impacts of extraneous noise sources. Whenever extraneous noises were noted, the samples were discarded. These sources included lawnmowers, traffic on roadways behind the barrier, barking dogs, and airplane flyovers. Sampling continued until three valid samples were obtained. These were averaged to eliminate variations between individual runs. All measurements were taken on calm winter days when wind speeds were less than 3 mph to reduce leaf rustling sounds. All measurements were recorded as Leq.

Table 2: Dimensions of Soundwalls Used in this Study

Barrier	One	Two	Three	Four	Five	Six
Panel Size (ft)	12x20	12x20	12x20	16x14	16x14	22x22
Hole Size (in.)	5x6	11x7	12x7	13x9	13x9	7x4
# Holes	3	3	3	3	3	2
Hole Angle	45	90	90	90	90	90
Panel Feet(2)	240	240	240	224	224	484
Holes Feet(2)	0.70	1.62	1.74	2.43	2.43	0.38
Percent Holes	0.02	0.67	0.72	1.08	1.08	0.07

RESEARCH QUESTIONS

A. How much noise comes through the drainage holes?

Before beginning the research, it was expected that noise transmitted through a drainage opening would be somewhat louder than that transmitted through portions of the wall unaffected by these openings. Measurements were made of the degradation at the receiver side of the soundwall by locating the microphone of one Metrosonics 308 sound meter directly in the opening. A second sound meter was placed midway between the drainage holes to measure the noise levels at the receiver side of the wall.

Noise levels are higher behind the drain openings than behind more sheltered portions of the soundwall. These differences ranged from a low of 5.3 dB for Barrier 4 to a high of 23.1 dB for Barrier 6. Table 3 lists the measured noise levels at the wall, the noise coming through holes, and shielded noise levels. It also lists the size of drainage holes in square feet, the length/height ratio of the holes, and the percentage of surface area of drainage holes.

Shielded noise levels refer to noise levels directly behind the wall and are unaffected by the drainage holes. Shielded levels are influenced by ambient noise levels and by reflections from the top of the wall. The shielded noise levels for Barriers 1-5 are quite similar. The much lower shielded levels of Barrier 6 are a result of its 22 foot tall soundwall.

Table 3 ranks soundwalls by the noise levels measured at the source side of the wall. Degradation through drainage holes increases as sound levels at the source side of the wall increase. This can be expected since the shielded levels are similar, and higher noise levels at the wall allow more noise to come through the drainage holes. Degradation was calculated by subtracting the shielded noise level from the noise passing through the drainage holes.

Noise levels coming through the holes are higher than those behind portions of the wall without drainage holes. Measurements failed to show any increase in noise levels as soundwaves traveled through the wall. Conversely, measurements on the 6 inch thick concrete walls consistently showed the roadway side of the barrier to be 1 dB louder than the receiver side of the holes. Noise levels passing through the drain holes are slightly lower than noise levels striking the barrier.

Table 3: Measured Noise Levels through Drainage Holes in Soundwalls. Barriers Are Ordered by Sound Levels Striking the Soundwall

	Four	Two	Three	Five	One	Six
Noise at wall	71.1	72.0	72.3	76.2	80.6	82.3
Noise through wall	70.1	71.0	71.3	75.2	79.6	81.3
Shielded noise	64.8	65.1	65.4	67.8	68.9	58.2
Degradation at wall	5.3	5.9	5.9	7.4	10.7	23.1
Size openings (sq ft)	2.43	1.62	1.74	2.43	0.70	0.38
Opening (Length/Height)	1.4	1.5	1.7	1.4	0.8	1.7
% Wall as Holes	1.08	0.67	0.72	1.08	0.02	0.07

B. Does degradation from drainage holes affect barrier effectiveness?

Before beginning this phase of field research, it was suspected that distance doubling effects would rapidly reduce the noise levels coming through the drainage holes. Minimal degradation was expected for locations close to the barrier and degradation was not expected more than 10 feet from the soundwall. Distance doubling effects and noise coming over the barrier were expected to rapidly reduce any degradation effects from drainage holes.

Degradation effects were measured by blocking the drains in a section of barrier. One sound meter was placed 1 foot behind this panel, and a second meter was placed 1 foot behind a barrier section where the drainage holes were left open. Both meters were mounted 18 inches above ground level to maximize the effects of sound coming through drainage holes and to minimize sound levels coming over the wall. Identical procedures were conducted 6 feet behind the barrier sections. Data from Barrier 1 and 2 were discarded because they were affected by extraneous noise coming from behind the barriers. (Barrier 1 readings were influenced by a lawnmower being operated behind the wall, while a persistently barking dog ruined the readings behind Barrier 2.)

Noise levels from the open barrier segment were 2-3 dB higher than those in the closed section at a distance of 1 foot from the barrier. Barrier 6 showed 0.9-dB increase. Measurements taken 6 feet behind the wall showed a definite drop in degradation. The open segment measured only slightly higher than the closed segment. Table 4 lists the average sound levels and degradation.

The size, shape, and percentage of the surface area dedicated to drainage holes correlate strongly with degradation. Barriers 4 and 5 are identical in panel dimensions and drainage hole configuration. As expected, they show identical degradation patterns. Larger openings show more degradation at both 1 and 6 feet. Barrier 6 had the smallest holes and showed much less degradation than Barriers 4 and 5 with the largest holes. Barrier 3 falls between 1 and 4-5 in both degradation and size of drainage holes.

There is a distinguishable pattern showing that degradation increases as drainage holes increase in total surface area. Barriers 4 and 5 have holes representing 1 percent of the surface area and show a degradation of 1 dB six feet behind the wall. Barrier 3 is composed of 0.7 percent holes and shows a degradation of 0.1 dB at 6 feet. Barrier 6 had no degradation 6 feet from the wall.

The shape of the drainage hole also affects degradation. Barriers 4 and 5 had the tallest openings in relation to width and showed the most degradation. Barriers 3 and 6 had identical length/height ratios but showed considerable difference in degradation. Length/height ratios have a weaker correlation than surface area of the hole and the percentage of the surface area occupied by holes.

Drainage holes do cause a degradation in soundwall effectiveness. Measurable degradation can be expected at least 1 foot behind the wall and may extend beyond 6 feet, depending on the size and number of the holes and the percentage of total surface area represented by drainage holes. Walls having 1 percent of their surface area in holes may experience a 1-dB degradation six feet from the wall. Higher percentages would result in greater degradation, which may affect noise levels at receivers.

The effect of 1 percent drainage holes measured 6 feet from the barrier is roughly the same as would be expected with a 2 foot shorter wall without drainage holes. However, the taller walls create a greater noise shadow effect and provide more attenuation at distances beyond 10 feet.

Table 4: Comparison of Open and Blocked Drainage Holes in Soundwalls

	Three	Four	Five	Six
Leq Blocked Section @ 1 ft behind wall	65.4	64.8	67.8	58.2
Leq Open Section @ 1 ft behind wall	67.4	67.8	70.8	59.1
Leq Open Section @ 6 ft behind wall	65.5	65.8	68.8	58.2
Degradation from holes @ 1 ft	2.0	3.0	3.0	0.9
Degradation from holes @ 6 ft	0.1	1.0	1.0	0.0
Size Openings (sq ft)	1.74	2.43	2.43	0.38
Openings (Length/Height)	1.7	1.4	1.4	1.7
% Wall as Holes	0.72	1.08	1.08	0.07

CONCLUSIONS

The Texas Department of Transportation has constructed a number of soundwalls with above-ground drainage holes. A field evaluation of representative barriers has recently been completed and has provided some useful data for evaluating barrier degradation caused by holes in soundwalls. This evaluation and further observations will be useful in other research and field work.

Sound waves passing through the barriers showed no indications of increasing in volume, which was contrary to what had previously been believed. Conversely, data indicated that noise levels drop 1 dB when passing through drainage holes in 6 inch thick concrete noise walls. Noise levels on the receiver side of drainage holes were always less than those on the roadway side of the hole. Data also failed to show the 6-dB increase in noise coming through openings, as reported in National Cooperative Highway Research Program Report 174.

Actions of property owners may speak louder than phone calls and letters. Although there were few complaints about drainage holes, a visual examination of barriers indicates that many property owners will block drainage holes that are longer than 1 foot. These actions may represent attempts to block perceived noise level increases or to keep pets contained in their yards.

Drainage holes do cause some degradation of barrier effectiveness near the barrier. The size of the openings and the percentage of total surface area represented by drainage holes correlate with the amount of degradation. Larger holes and higher percentages of holes lead to greater degradation. Drain holes representing 1 percent of the total surface area produced a 3-dB degradation one foot from the wall and 1 dB six feet from the wall. The 3-dB increase in noise levels represents the minimal difference most humans can hear.

Stamina 2.0, the Federal Highway Administration's Noise Prediction Model, frequently overpredicts noise levels. Barriers designed with this model are more effective than the model predicts. Noise degradation from drainage holes in 1 percent of the total surface area is more than compensated for by the overpredictions of Stamina 2.0.

Drainage holes comprising less than 1 percent of a barrier's surface area do not greatly compromise the effectiveness of the barrier. If privacy fences are left in place behind the barrier, degradation losses are expected to be minimal. Additional mitigation may be necessary when holes exceed 1 percent of the total surface area.

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