Feasibility of Transparent Noise Barriers

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The preliminary investigations by the Ministry of Transportation of Ontario into the possibility of using transparent sheet glazing products made of glass or plastic in noise barriers are documented. The political issues and principles of using these types of barriers are not addressed. The concerns of the Design Development and Application Section with regard to the ability of various substances to meet current standards for noise barrier materials are discussed, providing a substantial foundation for establishing standards with regard to properties unique to glass or plastic such as transparency, flammability, safety under impact, and design considerations.

The Ministry of Transportation of Ontario (MTO, originally the Ministry of Transportation and Communications) has been actively involved in decreasing the impact of highway noise since 1971 when the first barrier was constructed. The Ministry's concern and involvement have grown with the increase in traffic volume, development along freeways, and public awareness and expressed concern about highway noise. Although freeway noise generation is not completely under MTO control, the Ministry nevertheless accepts some responsibility for it. In 1977 a retrofit program was established that identified existing residential sites in need of barriers and ranked them in order of priority. Under this program, funding was allocated to construct a number of these sites every year until all sites had been addressed. Transparent noise barriers, in general, have been considered for aesthetic reasons for many years. However, the MTO had not conducted any feasibility studies until a proposal was made to construct such a barrier along a portion of the Queen Elizabeth Way, west of Toronto. Representatives of a shopping mall and service station at that location expressed concern that the construction of a concrete or steel noise barrier at the site would obstruct the view of their operations from the roadway, cutting off a free source of advertising for them. Because a transparent barrier at this site might solve this problem, this site was suggested as a test area for this system. Although it would have entailed only a short stretch of barrier, the MTO did not want to test transparent products on such a scale without having done some background work on a smaller scale. It was feared that the proposed test area might also set a precedent that would result in more demands by other enterprises for visual access from major roadways (*1–4*).

CONSULTATION WITH INDUSTRY AND PUBLIC ORGANIZATIONS

As part of the investigation into the use of transparent barriers for noise control, the initial task was to consult others with experience in related areas. Organizations consulted included

- The French Ministries of the Environment and Quality of Life and of Transportation,
- Glass and plastics manufacturers,
- Two state highway departments (Maryland and Massachusetts) in the United States that had previous experience with transparent noise barriers, and
- The City of Toronto.

This section contains background information on the organizations consulted and the projects they pursued. The information on various aspects of transparent noise barriers that was received is summarized in a later section.

A report (*5*) obtained from the French Ministries of the Environment and Quality of Life and of Transportation contains guidelines for the construction of glass noise barriers based on experiences of the ministries. This report covered such topics as

- Safety—strength and shatter tests,
- Implications of the sizing of glass plates,
- Technical arrangements to avoid glare from opposing traffic,
- Vandalism,
- Vibrations,
- Installation,
- Maintenance, and
- Repair.

Representatives of the Plastics Divisions of Canadian General Electric (J. N. Coutu, private communication) and of Dupont Canada (G. W. Haywood, private communication), were contacted. Although Dupont does not manufacture sheet glazing products, it does manufacture ethylene copolymer laminates such as Butacite, a polyvinyl butaryl film, and Surlyn ionomer resin. These products are used by the glass fabricating industry as a laminate material between sheets of glass. Companies using them are Advanced Glass Systems (N. P. Bolton, private communication), which uses Surlyn Film, and Lamilite Ltd. (*6*), which uses Butacite.

Laminated glass consists of a layer of a plastic product, such as one of the preceding, bonded between layers of either tempered or annealed glass to improve the strength, safety, sound control, and penetration resistance characteristics of the glass. Tempered glass requires high impact energy to break; however, it shatters completely upon impact. Annealed glass is more easily fractured and produces long, sharp-edged splinters, but is less expensive.

After extensive discussions with various glass companies, it was found that the Monsanto product Butacite is similar to Surlyn and is used interchangeably with Surlyn.

Canadian General Electric manufactures Lexan, which is a sheet glazing product made of high-strength polycarbonate

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(*7*). It is more resistant to impact than glass, but less resistant to abrasion, heat, and ultraviolet rays.

Promotional material from the plastics and glass manufacturers describes various installation, strength, sound attenuation, and safety properties of their products. Samples of all types are available from the companies contacted that could be used to test their claims.

American Experience with Lexan Noise Barriers

Canadian General Electric was able to provide information regarding Fanwall Corporation (E. W. Angove, private communication), a noise barrier fabricating company, that had already constructed noise barriers of Lexan for two American State Highway Departments, the Massachusetts Department of Public Works (B. Reynolds, private communication) and the Maryland State Highway Administration (R. Douglas, private communication).

In 1980 the Maryland State Highway Administration had chosen a limited length of roadway along I-95 as the site for experimental transparent noise walls. A report published in 1981 (*8*) detailed the selection process that led to the choice of Lexan and evaluated the project at that time in terms of construction details, aesthetics, and acoustics, drawing positive conclusions with respect to all aspects. The administration, contacted in February 1987, described a favorable public response to the Lexan walls when they were first constructed but reported that after 6 years' experience, some of their conclusions were not as favorable.

The Massachusetts Department of Public Works, under extenuating circumstances, offered transparent material as an option at a public meeting for a project. The report on its use dealt mainly with the acoustic properties of the project (*9*).

Glass Applications in the Toronto Area

The City of Toronto is involved in two projects in which large pieces of glass are used along the roadway. The first is a glass-enclosed walkway along Bay Street; the second is the system of bus shelters throughout the city. A city representative (K. Greenberg, private communication) was able to provide detailed information about the walkway. Mediacom, a company contracted with to be responsible for the construction and maintenance of these bus shelters, uses them to display advertising for their clients.

The walkway along Bay Street consists of sheets of glass mounted on concrete traffic barriers. Located immediately adjacent to the roadway in an area of high traffic volume, it was constructed in 1984 of tempered laminated glass to reduce the effects of vehicle exhaust fumes and roadway runoff that was being splashed on pedestrians walking under a viaduct. The City of Toronto is very pleased with the results of this project.

EXAMINING THE CONCERNS OF THE MTO

MTO-preapproved manufacturers' noise barrier designs must meet the standards set by the Ministry (*10,11*). Glass and plastic products would have to meet these standards for the materials currently used in noise barriers—namely, concrete, steel, and wood—in order to be considered at all. The standards include requirements for sound transmission loss and structural design. Also, because of the nature of these materials, new standards would have to be developed for properties such as transparency and shatterability. The different types of laminated glass and Lexan should be evaluated on these counts to see whether any are usable, and if so, which are best suited for this type of application.

Aesthetics

The major advantage of transparent materials over traditional materials in noise barriers is aesthetics. Residents living next to visually imposing walls of concrete or steel liken it to living next to the Berlin Wall. With the use of transparent materials, the motorists' view of the roadside and the sunlight penetration to the highway would not be blocked. With these advantages, the highway and barrier appear less imposing. Maryland and Massachusetts both report a positive public response to the appearance of their transparent noise walls (*8, 9*).

The MTO's aesthetic requirements are limited to visual and physical relief at uniform intervals, which is required on both the residential and freeway sides of the barrier. The current guidelines recommend that false posts be used to break up an otherwise repetitive pattern, that alignments and heights be varied, and that barrier texture and surface treatments such as painting be used to a limited extent. Such devices would not be necessary with transparent barriers. Restrictions of manufacturing of both plastic and glass limit the size of the actual panels, so there will be enough real posts that false posts would be superfluous. Also, the variation of the landscape beyond the barriers would provide sufficient relief from monotony.

Safety

Flammability

Currently, neither the MTO nor any other government agency has set any restriction on the flammability of structures along the highways. However, the plastic in Lexan and laminated glass is much more flammable than the materials most often used in conventional noise walls. The MTO is therefore concerned with developing standards to protect itself from liability in the event that a barrier should be exposed to open flame. The American Society for Testing and Materials (ASTM) has a number of tests to gauge the fire properties of clear stiff plastics. It does not, however, set any minimum standard, and takes pains to inform readers that none of the tests can stand alone as a fire standard. It was agreed that the MTO might be held liable if it were possible for the wall to exacerbate damage in the event of a fire. For example, if the wall caught fire because of brush, grass, or vehicle fires, the smoke might be so thick as to cause loss of visibility along the highway. If there were a fire near the barrier, the barrier might cause the fire to spread more than if there had been a wood barrier or no barrier in place. It was decided that the factors

most likely to cause damage could be determined through a burn rate test (ASTM D-635) and a smoke density test (ASTM D-643). As a minimum standard, the transparent materials must be compared with wood (pine), the material with the highest burn rate and smoke density of all approved barrier materials.

Laminated glass offers an advantage over Lexan in this respect. The glass must be broken and the laminate material almost entirely exposed before the flame can spread. Breakage is not, however, an improbable scenario and therefore should be investigated further.

Behavior on Impact

Because of the peculiar nature of glazing products and possible risk of injury to third parties, it is necessary to verify that the glass or plastic splinters produced during fragmentation are not harmful and that the glazing has a high resistance to perforation. The various organizations contacted used different impact acceptance testing method.

Maryland (*8*) subjected polycarbon sheets to pellet guns, 0.22 longs, and 0.38 police missiles, and found that there was no shattering in any of the tests; only the 0.22 longs penetrated, leaving tiny holes of inconsequential acoustic concern.

The City of Toronto also required bulletproof glass for its glass-enclosed walkway, and as a result, laminated tempered glass was used. The bus shelters used throughout Metropolitan Toronto are required to be shatterproof as well. To be able to withstand the force of a thrown rock, they are made of ½-in. tempered glass.

The French have a ball test to evaluate the resistance of the glass to perforation and a hammer test to verify that the glass splinters produced during fragmentation are small enough not to cause serious or fatal injuries. Both of these tests are explained in their report (*5*). The Canadian Standards Association standard for automobile glass (CSA D263) could also be used. The MTO could choose any one of these standards for its own use. It is likely that annealed (nonlaminated) glass would not meet any of these standards because of the large slender shards it produces on impact.

Reflection of Light

The French report (*5*) probed the dangers of temporary blindness from the glare caused by reflection of vehicle light by the glass or the confusion produced by seeing the reflection of a phantom vehicle's image. These problems arise, in particular, in the case of curved roadways because of the low angle of incidence of the light. When the sun is low on the horizon, it may dazzle a driver on the highway or a service road. At night the main source of reflection is vehicle headlights, whose rays generally strike the baffles at a low angle of incidence. Several solutions are proposed.

- Inclination of the barriers up to 12 degrees toward the roadways makes it possible to deflect the reflected rays down to a preferred area of the road surface. This also solves the problem of reflection of the sun.
- If glass plates are mounted behind posts, the posts act as obstacles to the propagation of light beams with a low angle of incidence.
- The use of transparent glass specially designed to be nonreflecting is not recommended, because the costs involved are largely prohibitive. Nonreflecting, or even opaque, materials like concrete or painted, corrugated steel can be used for the lower part of the baffle, to a height of at least 4 ft above the surface of the roadway. This may be quite acceptable because most noise barriers are mounted on or behind traffic barriers.
- Glare caused by the headlights of opposing traffic may be diminished by installing an antiglare screen on the median barrier. Care must be taken that this screen does not alter the acoustic characteristics of the roadway, that is, does not reflect sound.

When determining a standard for transparent noise barriers, these suggestions must be taken into consideration and perhaps they should be reevaluated after barriers have been in place for a while.

Neither Maryland nor Massachusetts state departments of transportation using Lexan reported complaints about reflection of light. However, their test sites were of limited length and on tangent sections of roadway.

Structural Design Requirements

MTO's noise barrier design requirements (*10*) state that, except where otherwise noted, the noise barrier should be designed in accordance with the *Ontario Highway Bridge Design Code* (*12*) as a slender structure, not unusually sensitive to wind action. Design loads and ice accretion loads should be prescribed as for sign panels. The reference wind pressure for a 25-year return period should be used for each specific site as described in the Bridge Code. The Maryland State Highway Administration had the Lexan panels tested at an independent testing laboratory and found that they could withstand a loading of 8,142 Pa with no failure or pullout from the posts. Although this more than meets the Ministry requirements, it is, of course, peculiar to their mounting system. The French report (*5*) states that glass products can withstand these pressures, but it depends on the mounting system, the thickness of the glass, and the dimensions of the glass plate. Therefore, it is the duty of the noise barrier manufacturer to ensure that the proposed barrier designs meet the MTO standard.

Acoustic Qualities

The MTO requires that the random incidence sound transmission losses of the noise barrier system, when tested in accordance with ASTM E 90–87, should have an effective sound transmission loss of T greater than or equal to 20 dB. Glazing materials have no difficulty in meeting the MTO's minimum requirements (see Table 1).

Glass and plastic are considered to be totally sound-reflective materials. These materials could not be used for a close parallel barrier situation or for a barrier located between a highway and service road. In these situations, it has been shown that the use of barriers made of sound-reflective materials actually increases the noise levels on adjacent property

TABLE 1 COMPARISON OF SOUND TRANSMISSION CLASS OF VARIOUS MATERIALS

Material	Thickness (mm)	Sound Transmission Class (dB)
Concrete	132	32
Steel	0.91	20
Lexan	6.35	31
Lexan	12.7	34
Laminated glass	7.24	35
Laminated glass	12.25	39

(*13*). Either the service road noise is reflected back toward the community or, in the case of parallel barriers, the reflection and diffraction of sound reduce the effectiveness of the barrier. This, however, would limit the general use of glass and plastic as a noise barrier material. It is believed that some of this reflection can be relieved by tilting the panels slightly so that the noise is reflected upward. More research is required into this theory for both transparent and opaque barriers.

Costs

Costs of transparent materials could prohibit their use as usable noise barrier materials, especially when the added lifetime costs of maintenance are taken into account. Table 2 presents the approximate costs of transparent and opaque materials.

All of the glazing products are comparable when it comes to acoustic and aesthetic qualities; however, in general, as the strength of the product increases, the price increases. Except for annealed laminated glass, which is suspected of not meeting MTO safety standards, all of the glazing products are substantially more expensive than the traditional materials of concrete and steel. Because no mounting system has been discussed yet, it is not known how the price of installed transparent barriers will compare to the cost of installed opaque barriers.

TABLE 2 COMPARISON OF COSTS OF VARIOUS MATERIALS

Material	Thickness of Laminate (mm)	Total Thickness (mm)	Cost per Square Meter ($ Can)
Mar-resistant Lexan	—	12.25	205.00
Mar-resistant Lexan	—	6.63	118.00
Standard Lexan	—	12.25	160.00
Standard Lexan	—	6.63	71.00
Laminated tempered glass	0.06	12.31	113.00
Laminated tempered glass	0.03	12.28	97.00
Laminated tempered glass	0.03	6.66	75.00
Laminated annealed glass	0.03	12.28	43.00
Laminated annealed glass	0.03	6.66	37.60
Concrete (reflective and absorptive)	—	132.00	60.00
Steel (reflective)	—	0.91	36.00

NOTE: All costs are for panel material only. They do not include posts, mounting hardware, or installation.

Maintenance

One of the MTO's requirements for noise barriers is that all materials be durable, with a predicted maintenance-free life expectancy of 20 years. Taking into account some of the special qualities of glass and plastic, it can be seen that this life expectancy will not be possible for these materials. They are also more susceptible to breakage than steel or concrete.

Washing

One of the major concerns when evaluating transparent materials for use in noise barriers is the ability of the material to maintain transparency. Unfortunately, the transparency of glass may be reduced, or even eliminated, as a result of heavy traffic on the roadways. One solution may be to design the panels with an inward inclination, making it possible for the glass to be washed somewhat by rain. The residential side, away from the traffic, is less likely to become dirty. Therefore, it does not have to be cleaned as frequently, if at all.

In 1987 the MTO initiated a field testing program to monitor the buildup of dust and its effect on visibility. From this, the MTO hopes to determine how frequently transparent barriers will need to be cleaned when they are located on Ontario highways and whether there is any difference in the rate of buildup of dirt on the various samples. This project will be discussed later in this paper.

Permanent Degradation of Transparency

It is hoped that the field test mentioned above would also detect any degradation of visibility due to abrasion or exposure to ultraviolet rays. This field test for abrasion would be in addition to comparing the performance of glass and plastic in ASTM D-1044.

As mentioned, the Maryland State Highway Administration attributes the degradation of the transparency of their Lexan barriers to exposure to ultraviolet rays. Of the four materials that were tested (three being plastic and one tempered glass), under accelerated and natural weathering conditions, the tempered glass was favored because of its ability to better withstand abrasion and discoloring (*14*). Under the same conditions, it was found that polycarbonate materials were more susceptible to abrasion and loss of transparency than were acrylics. The manufacturers of Lexan now market products treated with more ultraviolet ray and abrasion-resistant coatings, Lexan XL and Margard. However, there are three disadvantages to these products:

- They are significantly more expensive than the regular Lexan product,
- The performance of the coating in maintaining clarity is only guaranteed for 3 years, and
- Because they cannot be cleaned with petroleum-based products, their suitability for roadside use is questionable.

Breakage

Apart from the concerns regarding safety under impact already noted, the MTO would like to use a high-strength sheet glaz-

ing product in order to minimize this aspect of maintenance. The ability for some of the panels to remain integral would be an asset. This feature would allow the noise barrier to continue to function at least to some extent until the maintenance crews are prepared to make repairs. A standard for minimum strength under impact will have to be set.

Comparing the breakage histories of the other organizations reveals the performance of the various products. Neither of the two state highway departments using Lexan reported any breakage in the collective 8 years that their barriers were in place. The French—who use a variety of glass products, laminated and nonlaminated, tempered, and annealed—recommend putting aside 10 percent of the glass that is needed to construct the original barrier, because that much breakage can be expected. They also suggest that easy remounting of broken panes be taken into consideration in design. In the 4 years that the Toronto walkway has been in place, however, there has been no breakage.

Design and Installation

The use of new materials such as laminated glass and Lexan brings new concerns in design and installation. Advice from the organizations consulted permits avoidance of the problems that they encountered.

Maryland reported that Lexan had a very good anchoring system. Because of the low melting point of the Lexan panels (275°F), the hot asphalt could not be allowed to contact the panels directly. This condition resulted in a 13- to 51-mm gap between the panel and the asphalt, which had to be filled with highway joint sealers. The Massachusetts Department of Public Works reported many problems with the construction of their Lexan barrier. Some panels broke during construction. Also, the panels were left in the sun, and the protective paper backing melted onto the plastic and was hard to peel off. The contractor used linseed oil in an attempt to remove the paper, which had a harmful effect on the panels.

From the laminated glass manufacturers and the French report (*5*), some insight was gained into the design and installation of laminated glass as well. For example, a sealant should be used between the laminated glass and the mounting bracket; this protects the laminate core from water vapor. Any materials that come into contact, such as polycarbonate and metal and the laminate core and the sealant, should be chemically compatible to avoid deterioration. Care should be taken not to break the edges, which helps avoid breakage due to thermal differences.

Some of the design considerations apply to both laminated glass and Lexan. To enhance visibility, it is better to have large pieces of glazing and to limit the number of brackets. The size of the panel is limited by the manufacturers. In the case of Lexan, the maximum size of the sheet is 12 by 10 ft (3.66 by 3.05 m). The dimensions of the laminated glass panels are limited to 12 by 6 ft (3.66 by 1.82 m). The French report (*5*) recommended that wind pressures be taken into consideration. The thickness should be determined by sound attenuation, mechanical study, and shock resistance.

Some concern was raised about vibrations. The Lexan material is strong but flexible. The Maryland State Highway Administration reports that their panels tend to vibrate when heavy trucks drive by. This has caused no problems structurally; however, it does produce an unsettling rattle. The French report (*5*) stated that glass baffles are subject to vibrations from wind as well as highway traffic, especially the backwash of trucks. Studies have shown that these effects produce stresses that are not dangerous and are not likely to lead to breakage of the panels.

Summary of Concerns

Transparent materials thicker than 6.35 mm meet many of the standards for the materials currently used in noise barriers. They are far superior to opaque materials when noise barrier aesthetics are considered. If properly designed, they can meet the necessary structural design requirements. However, there is still work to be done in setting the standards for properties such as transparency and shatterability. The glass and polycarbonate products should be tested to see whether they meet these standards, and their flammability should be compared with that of wood for burn rate and smoke density. The Ministry should choose which of the many shatter standards to use. Glare should be considered in design.

It might be necessary to test these designs on a larger scale once specific sheet glazing products have been approved for use. The cost becomes higher when the lifetime cost of cleaning and replacing broken panes is taken into consideration. Because these materials are sound reflective, their range of use will be limited unless investigation shows that tilt-mounting is a workable way of reducing the negative effect of noise reflections.

MONITORING VISIBILITY DEGRADATION OF SAMPLES AT A ROADSIDE TEST SITE

The MTO has initiated a program to field test samples of tempered glass, annealed glass, and various Lexan products. The buildup of dust and its effect on visibility will be monitored. From this information, it will be determined how frequently transparent barriers should be cleaned. Any difference in the rate of buildup of dirt on the various samples will be noted. A test site that met the following criteria was chosen:

- Ability to mount samples low to the ground and near the driving edge of the road to maximize effects of airborne dirt and grime,
- Sufficient exposure to the sun,
- Protection of the samples from traffic and the traffic from the mounting system, and
- Location near the technical resources of the MTO Head Office.

Description of Project Location

The location chosen for the installation of the test samples generally meets all of these requirements. The mounting system is attached to the steel posts of an existing noise barrier on the east side of Highway 427, approximately 0.2 mi north of the Rathburn Road interchange. Highway 427 at this loca-

tion is 16 lanes wide with a 1987 annual average daily traffic of 223,350 (20 percent trucks). The posted speed in this area is 100 km/hr. The samples face WSW, permitting the sun's rays to strike them at approximately 10:00 a.m., and are unobstructed until sunset. The samples are mounted 1.75 m above the roadway and 4 m back from the driving edge of the pavement. The site is protected by a steel beam and a channel traffic barrier.

Mounting of Samples

The samples were mounted at an angle of 10 degrees to get the full washing benefit of rain. The cut edges of the samples were covered with waterproof tape to protect them from the environment.

Method of Testing

The prime criterion for any interim testing of the samples must be that it be done in the field to avoid disturbing any buildup of dirt. Other criteria were that the testing be reasonably accurate and easy to perform, and that it conform to financial constraints without recourse to an independent laboratory. After investigating most of the methods used by various experts in the field, the MTO settled on one that used a simple photometer and a single light source.

Apparatus

After trial and error, a reasonably accurate and easy-to-use testing device was developed on the principle that the amount of light emitted from a constant light source can be measured accurately if all ambient light is eliminated. If an object is introduced between the light source and the receiver, the amount of light reaching the receiver is reduced in varying degrees. As a light source, a standard automotive brake light bulb was used. The receiver consists of an array of five cadmium selenide photoconductive cells wired in series. The power source for the light bulb was obtained from the vehicle used by the testing crew. The voltage was regulated to 10.5 Vdc. To measure the resistance of the photoconductive cells, a standard multimeter was used with a range of 0 to 2 MΩ. To prevent ambient light from interfering with the measurements, the source and sensors were mounted in separate cases designed to create a light seal around the entire 1-ft-square samples. The equipment was mounted in two separate casings to permit easy movement of the testing apparatus behind and in front of the mounted samples without disturbing the surface of the samples.

After initially adjusting the values of various components, it was possible to measure any degradation as slight as 0.5 percent. This sensitivity was considered to be acceptable for any field testing, considering the accuracy of the voltage regulator (±5 percent).

Preliminary Results

After 3 years of installation, three tests were conducted, one initial and two followups, with 1 year in between. The results of these tests are presented in Table 3.

Analysis

Although the field testing of the samples indicated that there was some loss of transparency, it is still too premature to draw any definite conclusions as to the individual and comparative performance of these products.

CONCLUSIONS

Valuable information regarding the feasibility of using transparent materials such as laminated glass and plastic sheets in noise barriers was obtained by consulting public and private organizations with expertise in this field.

Transparent materials could be used in the construction of barriers that meet MTO's standards for acoustics and structural strength.

The aesthetics of barriers made of transparent materials are superior to those made of opaque materials.

TABLE 3 PERCENTAGE OF SAMPLE DEGRADATION FOR THREE ANNUAL TESTS

Sample	Initial Reading (8/12/87)	Difference	Second Reading (9/7/88)	Difference	Third Reading (7/5/89)	Accumulated Difference
Lexan						
Clear[a]	10.0	0.5	10.5	1.5	12.0	2.0
Clear[a]	5.5	1.0	6.5	3.5	10.0	4.5
Grey	21.0	1.0	22.0	0.5	22.5	1.5
MRS[a]	7.0	1.0	8.0	1.5	9.5	2.5
XL	7.5	0.5	8.0	2.5	10.5	3.0
Glass	9.5	0.0	9.5	1.5	11.0	1.5
Laminated tempered	10.5	0.0	10.5	4.0	14.5	4.0
Laminated tempered	10.0	0.5	10.5	4.0	14.5	4.5
Laminated tempered	10.5	0.5	11.0	3.5	14.5	4.0
Laminated annealed	9.5	0.5	10.0	3.5	13.5	4.0
Laminated annealed	9.5	0.5	10.0	4.5	14.5	5.0
Laminated tempered[a]	9.5	1.0	10.5	5.0	15.5	6.0

[a]Original samples were discovered missing in December 1987 and were replaced on April 20, 1988.

Materials that could be used in transparent noise barriers have several unique properties such as transparency and high strength under impact. These products do not meet the MTO's requirement that all materials be durable and have a predicted maintenance-free life expectancy of 20 years. The properties mentioned and others such as reflection of light, flammability, and resistance to abrasion are not alike in all transparent materials.

The locations at which transparent materials may be used will be limited by their sound-reflective properties.

The actual design of the noise barrier system is hampered by the various size limitations of each product.

In general, transparent materials cost more than conventional noise barrier materials.

RECOMMENDATIONS

It is recommended that the MTO set material specifications for the unique properties of transparent materials, such as flammability, safety under impact, transparency, and reflection of light. Transparent materials should be compared with wood (pine) with regard to burn rate and smoke density in order to set a standard for flammability. Wood is the material with the highest burn rate of all approved barrier materials. The MTO must devise a standard for safety under impact and for resistance to permanent degradation in transparency due to abrasion and exposure to ultraviolet rays. Precautions to reduce the reflection of light must be taken into consideration in design. The different types of sheet glazing products could then be evaluated on how they met the above standards.

The samples of the different sheet glazing materials must continue to be tested at a roadside location to monitor the degradation of transparency. Any cost analysis of a barrier design must take into consideration the projected lifetime costs of cleaning and replacement of broken panes. Because of the size limitations of the transparent sheets, the design of the noise barrier system must be able to accommodate any transparent product available.

MTO policy regarding future implementation of transparent noise barriers must be developed. Such policy would have to deal with the following topics:

- Establishing criteria for identification and priority ranking of transparent noise barrier locations, and
- Assessing the responsibility for the supplemental costs incurred by erecting a transparent noise barrier instead of an opaque one.

More investigation should be carried out to test the theory that the tilting of sound-reflective barriers will reduce the noise impact on the surrounding community.

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