I-5 Ship Canal Noise Reduction Options for Consideration – West of I-5

Summary Table

Noise Reduction Strategy	Description	Location	Est. Cost (Total)[1]	Avg. Noise Reduction (dB)[2]		Number of Benefitted Homes (≥3 dB)	Avg. Cost/ Benefitted Residence	Challenges
				Street Level	Upper Floors			
Transparent Barrier	*Mainline*: 6- 8' tall barrier *Express lanes:* 30' tall barrier between express lanes and mainline	Mainline	$390,000 - $480,000	0	1	0	NA	Maintenance (graffiti, etching, vandalism)
		Express Lanes	$1,950,000 - $2,400,000	10	3	100	$19,500 – $24,000	
		Combined	$2,340,000 - $2,880,000	13	6	100	$23,400 – 28,800	
Absorptive Sheet Metal Barrier	*Mainline*: 6- 8' tall barrier *Express lanes*: 30' tall barrier between express lanes and main line.	Mainline	$400,000	0	1	0	NA	Wind loading on structure
		Express Lanes	$3,000,000	10	3	100	$30,000	
		Combined	$3,400,000	13	6	100	$34,000	
Acoustical Louvers and Barrier	*Mainline*: 6-8’ transparent barrier *Express lanes*: 30' tall louvers	Combined	$5,000,000	6	5	100	$50,000	Least noise reduction
Window Upgrades	Acoustically-rated windows for bedrooms facing bridge	Bedrooms facing I-5	$20,000/receiver	10	10	100	$20,000	Equity, historic structures, HVAC, no benefit for exterior noise
Recommended: Transparent and Absorptive Sheet Metal Barriers	*Mainline*: 6-8’ transparent barrier *Express lanes*: 30' tall absorptive sheet metal barrier	Combined[3]	$3,390,000 - $3,480,000	13	6	100	$33,900 - $34,800	Maintenance (graffiti, etching, vandalism) and wind loading on structure

1: All costs are estimated for construction only
2: Uncertainty estimated at +/- 2 dB
3: Average reductions based on modeling of noise wall system where combined reductions exceed reductions on walls evaluated individually.

I-5 Ship Canal Noise Reduction Options for Consideration

Summary

WSDOT hired acoustic consultant Dr. James T. Nelson from Wilson Ihrig Associates to identify options for reducing noise from the I-5 Ship Canal Bridge. Dr. Nelson led the 2008 Expert Review Panel of national acousticians who proposed noise reduction options for the bridge.

The following summarizes the noise reduction options considered and includes estimated costs, benefits, and potential challenges for each. The report focuses on the south approach of the bridge where WSDOT had received the most public feedback about traffic noise. The proposed options should perform similarly on the north end of the bridge.

Noise reductions provided by barriers depend on specific residential locations (vertical and lateral) and their exposure to noise reflections or shielding from mainline and express lane traffic noise.

- Many street level residential "receivers" that are exposed to express lane traffic noise are also shielded from noise coming from the main deck traffic noise by the parapet and/or safety barrier along the main line. A noise wall between the lower and upper decks would control express lane traffic noise at these receivers.

- There is less certainty about suggested noise reductions for residences at, or above, the upper deck, which get noise from the main line and express lanes. A mainline barrier would only benefit higher elevation receivers if combined with a barrier between the mainline and express lanes.

The following noise reduction options were considered. Costs and benefits are for abatement options that stop adjacent Franklin Avenue E, or directly connect the upper and lower decks, to avoid a conflict with an aging water main below the street. The focus of this report is on the west side of I-5 where the most effective noise reduction can be provided.

1. Transparent noise barriers
2. Sheet metal barriers with acoustic absorption
3. Acoustical louvers
4. Residential window upgrades

The following combination would provide substantial noise reductions without disrupting views to neighbors or the traveling public.

- 30-foot tall acoustically absorptive sheet metal barrier along the express lanes
- 6-foot tall transparent barrier along the mainline.

South of the Ship Canal – West Side

1. Site Description

This study focuses on where the express lanes daylight; near where hanging acoustical absorption has already been applied to the underside of the main line deck. A noise wall can be considered here to further reduce noise from the express lanes. The effectiveness of the acoustical absorption was measured by WSDOT and found to be at most 3dB. In the present analysis, the noise reduction was estimated on the basis of reverberant room theory and found to be consistent with previous WSDOT measurements.

The highway geometry, existing sound barriers, and residential topography vary along the alignment. Figure 1 shows the residential structures that make up the first row of receivers along with the estimated number of living units.

West Side

Many multi-family residences exist along the western side of the alignment, some of which are three and four-story apartment or condominium buildings. Almost all receivers are below the mainline deck, though some upper floors may have a grazing view of the main deck pavement. Residential density is much less along the east side of the alignment, consisting of single family and small multi-family residences, almost all of which are at elevations below that of the main line deck.

Figure 1 Aerial Photo

Noise reductions from barriers, transparent or opaque, will depend on the specific residential locations (vertical and lateral) and reflections or shielding. For example, street level or lower floor residential receivers are exposed to express lane traffic noise, but are shielded from the main deck traffic noise by the main deck parapet. A noise wall placed between the lower and upper deck would effectively control express lane traffic noise and thus reduce overall noise exposure at these lower level receivers.

There is less certainty about noise reduction estimates for residences at elevations at, or above, the upper deck, where the noise environment is influenced by both main line and express lane traffic. Adding a light-weight barrier to the upper deck parapet would benefit upper level receivers only if a wall was also installed between the lower and upper deck to control express lane traffic noise. One may conclude that treatment of the lower deck express lane noise is necessary for receivers regardless of elevation.

2. Noise Wall Effectiveness

Noise reductions are described for the following noise wall configurations:

- Main Line barrier
- Express lane barrier
- Combination of express lane barrier and main line barrier
- Combination of acoustical louver for the express lanes and main line barrier

Noise reductions attributed to noise walls would be similar for either transparent barriers or solid (i.e., opaque) sheet metal barriers. The relative contribution of the main line and express lanes to overall noise levels varies as elevation changes. At street-level, noise from the express lane is assumed to be 10 dB higher than noise from the main line. For top-floor residences at similar elevations to the mainline, or higher, the main line and express lanes are assumed to contribute equally to the overall noise levels. Table 1 summarizes the estimated noise reductions, based on the nominal noise levels without treatment.

Mainline Barrier
A 6 to 8 foot tall solid barrier mounted on top of the existing parapet and supported by posts that cant in towards traffic to prevent noise from reflecting back out towards neighbors could reduce noise levels by about 1 decibel for residences at approximately the same elevation as the main line.

Along Boylston Ave E, South of E Shelby St, an existing noise wall currently stops at E Hamlin St. Upper floors of the multi-family residences could get 3 - 5 dB noise reductions by extending the existing at-grade noise wall. At street level between E Hamlin St and the dead end on Franklin Ave E, express lane noise dominates so no noise reductions would be expected from a mainline barrier[i]. Most of the receivers are below the main line elevation so the benefit of a main line noise wall would be limited without also controlling express lane noise.

Express Lane Barrier
A vertical noise wall that extends from the ground, or the express lane parapet, to the underside of the I-5 mainline would effectively eliminate noise from the express lanes at street-level and for upper floors, but would not reduce main line traffic noise. Assuming that noise from express lane traffic is at least 10 dB above the noise from the main line traffic at first floor receivers, the noise reduction at these first floor receivers would be at least 10 dB at homes north of E Shelby St on both sides of the bridge. Noise at elevations comparable to the main line elevation could be reduced by about 3 dB. The amount of noise reduction would increase as receiver elevation decreases. No residences north of E Shelby St are higher than the mainline.

Table 1: Est. Noise Reduction Effectiveness Opposite Express Lane at Concrete Approach

Scenario	1st Floor/Street (dB)				Upper Floors (dB)			
	Main	Express	Total	Noise Reduction	Main	Express	Total	Noise Reduction
Untreated	60	70	70		70	70	73	
Mainline noise wall	3	0		0	3	0		1
Est. Noise Level	57	70	70		67	70	72	
Express Lane wall	0	20		10	0	20		3
Est. Noise Level	60	50	60		70	50	70	
Combined Mainline and Express Lane wall	3	20		13	3	20		6
Est. Noise Level	57	50	58		67	50	67	
Mainline noise wall and Express Lane Louver	3	7		6	3	10		5
Est. Noise Level	57	63	64		67	63	68	

Noise "walls" above refer to both the transparent and sheet metal barriers that are expected to produce the same levels of noise reductions.

Combined: Express Lane and Mainline Barrier
A combination of mainline and express lane barriers would significantly reduce noise for all adjacent residences. The noise reduction achieved by both barriers would be about 13 dB for first floor receivers and about 6 dB for top floor receivers that are at the same elevation as the main line.

Combined: Express Lane Louver and Mainline Barrier
An acoustical louver extending from the express lane parapet to the bottom of the main line deck could attenuate express traffic noise by as much as 10 decibels, but would provide little reduction for low frequency truck noise. For this report, a 7dB noise reduction is assumed. In combination with a main line sound barrier wall, the combined noise reduction would be about 6dB at lower elevations, and about 5dB at the main line elevation.

3. Transparent Barriers

Transparent noise walls are made from acrylic, glass, or polycarbonate combined with steel or aluminum framing,[ii] with acrylic being the most common. Noise reductions are similar for all of these materials. Transparent noise walls have been used throughout the US and Europe, including one Sound Transit application in Montlake Terrace, WA. Compared to other noise barrier materials, transparent barriers have minimal effect on light, views, or aesthetics of the bridge for users and neighbors.

Potential Challenges
Transparent barrier materials have improved to reduce historic concerns about yellowing, cracking, warping, fractures, and repair from vandalism; both from painting and etching.

Increased wind loading could be a challenge for both the main line and express lane locations. Challenges unique to the express lanes barriers are 1) accommodating flexing of the upper and lower decks, which complicates anchoring of the acrylic panel for the express lane barrier, and 2) withstand a uniformly distributed wind pressure load over its surface[iii].

Image Credit: Armtec Paraglas Soundstop https://www.flickr.com/photos/armtec/6141117021/in/photostream/

Estimated Costs
Installed costs from projects in California and Ohio ranged from \$65- \$80/ft^2. Depending on the combination of options, total estimated costs range from \$390,000 to \$5,100,000.

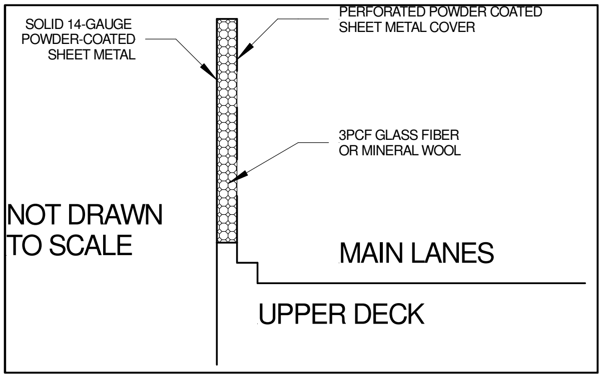
4. Sheet Metal Barriers with Acoustic Absorption

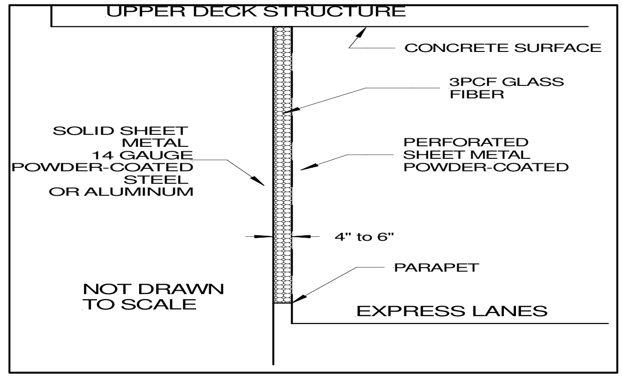
Sheet metal barriers are perforated steel or aluminum sheet metal filled with glass fiber or mineral wool to absorb sound.[iv] Compared to other noise barrier materials, sheet metal barriers are low weight[v] but can still be designed to withstand wind loads up to 110 mph. The lighter weight and smaller foundation requirements of sheet metal compared to concrete could help avoid potential utility conflicts in the area, especially if the sheet metal barrier is supported entirely by the existing structure. Further, acoustical absorption would reduce reverberant noise in the space between the upper and lower deck and reduce driver noise exposure and noise from being transmitted out of the northern end.

Image Credit: Alpha Acoustiki http://alphacoustic.com/en/product/metal-noise-barrier/ and Knauf Insulation http://www.oem.knaufinsulation.com/en/content/road-sound-barriers.

From left to right below, the concept of absorptive barriers placed along the upper deck and lower deck.





Challenges
Wind loading would be the main challenge. Flexure of the upper and lower decks would have to be accommodated with some sort of flexible anchorage or slip-track. The barrier might be supported entirely from the lower deck and tethered at the upper deck. There should be no gaps between the barrier and either the upper or lower deck.

Estimated Costs
A sheet metal barrier may cost as much as \$100 per ft^2.[vi] Barrier costs generally increase with height and with complex installations to account for greater anchoring and/or foundation requirements.

5. Acoustical Louvers

Acoustical louvers may be attractive for controlling express lane traffic noise. Acoustical louvers have a perforated sheet metal casing with glass fiber or mineral wool beneath the "leaves" of the louver[vii] that allow air to pass while reducing noise.

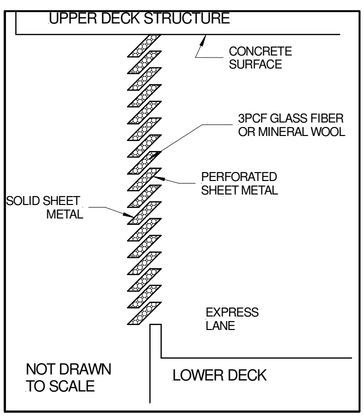


Image Credit: LouverDirect.com [*http://www.louverdirect.com/acoustical-louvers/*](http://www.louverdirect.com/acoustical-louvers/)

Louvers reduce less noise than solid barriers but more ventilation than other noise barrier options.[viii] 30-foot tall acoustical louvers would reduce noise by about 7 dB overall, but only about 5 dB at low frequencies (e.g., truck noise). Overall, acoustical louvers would be more effective than treating the ceiling of the express lanes with acoustical absorption but less effective than solid barrier options, including transparent or sheet metal.

Potential Challenges

Anchoring challenges with acoustical louvers are similar to those of the sheet metal barriers.

Estimated Costs
Acoustical louvers would be the most expensive of the options reviewed at $150/ft^2. Louvers are not recommended for the mainline since there is no benefit for added ventilation at this location.

6. Window Upgrades

Residential window upgrades are most effective for older homes with poorly sealed single pane windows.[ix] Overall reductions inside the home vary by window location relative to traffic and the general condition of the residence. Modern homes and apartments may already have double-paned windows with effective weather stripping that provides substantial noise reduction. However, double-glazed thermally insulating glass may be of limited effectiveness compared to acoustically-rated double glazing with a least one laminated glass element.

Compared to single-pane windows, acoustically-rated windows can reduce noise transmission by 10dB or more.[x] Windows are only effective when closed and permanently closed windows require forced air ventilation. Typical double-glazed thermal insulating windows are not as acoustically effective as laminated ½" thick glass or laminated insulating glass. Windows and glazing should be acoustically-rated with both the sound transmission class (STC) and the inside-outside noise reduction rating that emphasizes low frequency noise reduction. A noise study would be recommended for each residence prior to upgrading windows.

Potential Challenges

1. Permanently closing windows would require additional ventilation that also could require upgrades/modifications to heating, ventilation, or air conditioning systems.
2. Equitable application of upgrades since some property owners may already have upgraded windows.
3. Encountering deteriorated structures that require repair.
4. Complicated or historic structures that are difficult and/or expensive to retrofit.

Estimated Costs
Estimating the cost of window upgrades is complicated and can include the following:

1) Purchase of new windows
2) Removal of existing windows
3) Remedial repairs structural improvements
4) Installation of the windows and finishing
5) Provision of forced air ventilation

Detailed cost estimates are not included. However, replacing existing windows with acoustically-rated windows (steps #1 and #2, above) for an "average" window should be approximately $5,000 per window. In the summary table, four windows are assumed in the cost estimate for each residence.

Conclusions

No significant noise reductions in this area are possible without treating the express lane traffic noise and installing an express lane noise wall of some type appears to be the most cost-effective solution.

Recommendation
A 30-foot tall acoustically absorptive sheet metal barrier along the express lanes combined with a 6 - 8 foot tall noise barrier along the mainline would provide significant noise reductions for residents adjacent to the south approach of the Ship Canal Bridge.

- A sheet metal barrier along the express lanes is recommended because the lighter weight and smaller foundation could avoid potential conflicts with underground utilities. Supporting the barrier entirely by the existing structure would eliminate the need for a foundation and disruption of utilities.

- A transparent barrier along the mainline is recommended because the lightweight construction would limit the additional loading on the bridge from the barrier compared to concrete. The transparent materials would also reduce negative effects on views for neighbors or the traveling public.

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[i] Reductions at night when the express lanes are closed could be higher because the mainline becomes the only noise source.

[ii] Barrier density should be ≥6 lb/ft^2 to control tire road noise and low frequency noise from trucks and exhaust. A 1" thick acrylic/polycarbonate panel of density 1,185 kg/m^3 (74 lb/ft^3) would have the necessary surface density. A 0.5" thick barrier with surface density of 3 lb/ft^2 would effectively control tire road noise, but would be less effective against truck noise.

[iii] The load/ft^2 produced by an 80 mph wind stagnating at the barrier would be 16 lbs/ft^2. Assuming a height of 30 feet, the load per length of barrier would be 480 lbs/ft^2. Additional steel reinforcement would be required at approximately 4-ft to 8-ft intervals to withstand loads of up to 4 * 480=1,920 lbs per rib.

[iv] 14-gauge powder-coated sheet metal or anodized aluminum shell filled with 5 inches of 3 lb/ft^3 glass fiber or mineral faced by a perforated 20-gauge sheet metal protective cover.

The acoustically absorptive barrier provides both sound transmission loss to reduce noise transmitted to the wayside and acoustical absorption to control reflections and thus reverberant noise between the decks. The acoustical properties of the IAC type FS/A aluminum barrier are listed below:

Sheet Metal (absorptive)	Frequency (Hz)						
	125	250	500	1000	2000	4000	8000
Sound Transmission Loss	21	32	37	30	37	28	30
Absorption Coefficient	1.12	1.12	1.1	1.01	0.89	0.76	0.57

Greater attenuation would be obtained with 14 gauge steel, but would be unnecessary in this case.

The acoustical absorption stated for the barrier is in excess of 1. This is the Sabin absorption coefficient, and the high result is due to the ASTM method used for testing. For purposes of design, an acoustical absorption coefficient of 1.0 would be used where coefficients in excess of 1 are indicated. The decrease in absorption coefficient at high frequencies is due to the finite open area of the perforated sheet metal cover. This is of relatively little importance, as the frequency of the peak in the highway noise spectrum is about 1,000 Hz.

In contrast to the transparent barrier, the acoustically absorptive barrier would transmit less noise out of the north end of the enclosed space, thus avoiding any increase of noise at residential receivers opposite the steel truss section, close to the transition. However, unpainted concrete also provides some absorption that may be effective in reducing the reverberant field sound field between the upper and lower deck and reduce sound before it has a chance to propagate to the open end.

[v] Examples include weights of 4.5 lb/ft^2.

[vi] Based on telephone conversation with manufacturer.

[vii] 3 lb/ft^2

[viii] The sound transmission loss of the IAC Model R louver is listed below:

Acoustic Louver	Frequency (Hz)							
	63	125	250	500	1000	2000	4000	8000
IAC Model R	5	7	11	12	13	14	12	9

Acoustic louvers would attenuate noise for at-grade and upper-elevation receivers less than an acoustically absorptive or solid sheet-metal or transparent barrier. The sound transmission loss of the IAC Model R louver is 13 - 14 dB at the 1000 and 2000 Hz, respectively, encompassing the nominal broadband peak frequency in the wayside A-weighted road tire noise spectrum. The louver would provide some modest noise reduction of about 5dB at 63 Hz to reduce truck noise. The acoustical louver would be much more effective than treating the ceiling above the express lane with acoustical absorption, but less effective than a solid transparent barrier or sheet metal barrier, non-absorptive or absorptive.

[ix] Acoustically rated glazing recommendation: ¼" thick laminated glass with a 3/16" thick plate glass separated by a ½" gap filled with an inert gas, permanently sealed. In many situations, the windows would be permanently closed. The sound transmission loss of windows is characterized by its sound transmission class (STC) or outside-inside transmission class (OITC).

[x] Based on assumption that +/- 10 STC is roughly equivalent to +/- 10 dB in apparent loudness.