PHASE 1 WIND STUDIES REPORT

ENVIRONMENTAL STUDIES AND PRELIMINARY DESIGN
FOR A SUICIDE DETERRENT SYSTEM

Contract 2006-B-17

24 MAY 2007

Golden Gate Bridge
Highway and Transportation District

GOLDEN GATE BRIDGE
HIGHWAY & TRANSPORTATION DISTRICT

ENVIRONMENTAL STUDIES AND PRELIMINARY DESIGN FOR A SUICIDE DETERRENT SYSTEM ON THE GOLDEN GATE BRIDGE

PHASE 1 WIND STUDIES REPORT
EXECUTIVE SUMMARY

Introduction

On September 22, 2006, the Golden Gate Bridge, Highway and Transportation District (District) Board of Directors (Board) authorized the commencement of environmental studies and preliminary design work for a Suicide Deterrent System on the Golden Gate Bridge (Bridge). This is a two-phased effort.

Phase 1 of this effort is wind tunnel testing and analysis of generic suicide deterrent concepts. Phase 1 is now complete and the results are contained herein.

Phase 2 will take the Phase 1 generic concepts that passed the wind test and develop potential alternatives for further evaluation. Phase 2 will include both the required federal and state environmental review processes of each potential alternative and will include preliminary engineering of the potential alternatives. The potential alternatives will also be evaluated against each of the Suicide Deterrent Study Criteria that was adopted by the Board, and for the anticipated environmental affects. The required evaluation of potential alternatives will consider both a "no-build" alternative as well as several "build" alternatives.

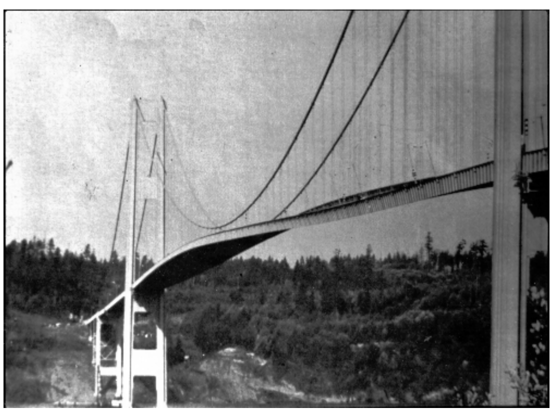
Wind and Long-Span Bridges

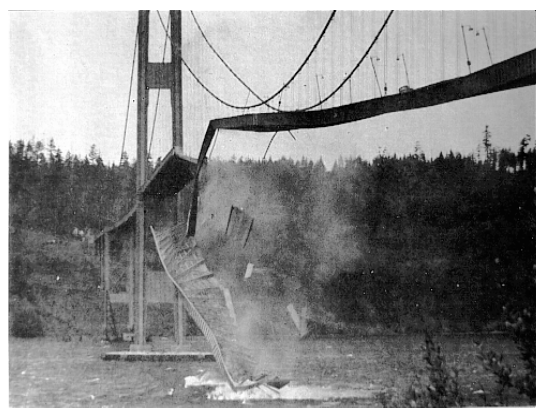
Long span suspension bridges are flexible structures that respond dynamically and potentially dramatically to wind. The original design of the Golden Gate Bridge provides

for the roadway deck of the Bridge to move a considerable amount. At the mid-point between the towers the deck was designed to move approximately six feet down, ten feet up and sideways about twenty-seven feet. This flexibility allows the Bridge to move during wind and earthquake events.

The cross section of the Bridge at the roadway consists of a stiffening truss, roadway deck and railing as depicted in the photographs above. The shape of the Bridge cross section has a significant impact on the Bridge's aerodynamic stability during high winds. Minor alterations to the shape of the Bridge including changes to the stiffening truss, roadway deck or railing will affect the aerodynamic form of the Bridge which changes how it moves during strong wind.

The movement of long span suspension bridges due to wind was most memorably demonstrated by the Tacoma-Narrows Bridge failure. On the day of its collapse in 1940, a 40 mph sustained wind applied at just the right angle caused the bridge to vibrate, resulting in wave motions and twisting of the deck that far exceeded the normal movement of the bridge. This motion grew continuously over a period of a few hours, ultimately leading to the collapse of the bridge.





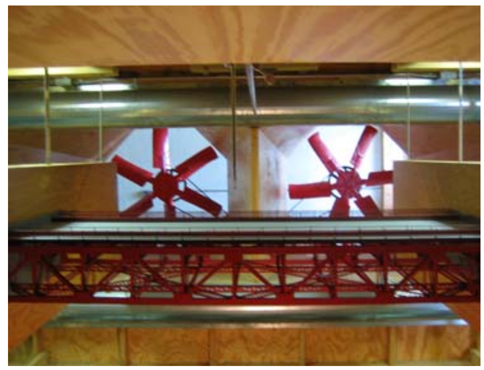
Tacoma-Narrows Bridge Failure

The sensitivity of a suspension bridge to wind is most pronounced between the two main towers, where the bridge is most flexible, as evidenced in the above two photographs of the Tacoma-Narrows Bridge. The flexibility of the Tacoma-Narrows Bridge and the shape of its roadway cross section combined to make it highly unstable to relatively low wind speeds.

As a result of the ensuing studies after the Tacoma-Narrows collapse, engineers have a greater understanding of how wind affects long span bridges like the Golden Gate Bridge, and what factors will determine whether or not a particular bridge will remain stable when subjected to high winds. Wind tunnel testing is now performed on models of all new long span suspension bridges to determine how sensitive the proposed bridge cross section is to wind and ensure that an event such as the Tacoma-Narrows Bridge failure does not occur.

Golden Gate Bridge Wind Testing – Overview

Any modifications to the existing railings or any additional netting added on the Golden Gate Bridge will affect how the Bridge responds to strong wind. Wind tunnel testing and complex computer analyses were performed on potential modifications to the Golden Gate Bridge to determine which modifications do not result in problems during strong winds. Wind tunnel testing was performed using a geometrically accurate 1:50 scale model of a portion of the Bridge deck.



Golden Gate Bridge Test Model - West Wind Laboratory

The District has established the wind design criteria for the Golden Gate Bridge consistent with that used in the design of new long span bridges. That is the Bridge, with any contemplated suicide deterrent system installed, should remain stable for wind speeds that are expected to occur once every 10,000 years. Previous meteorological studies of high winds in the San Francisco area and the bridge site in particular determined the wind speeds associated with this probability as 100 mph for winds blowing from the west, and 66 mph for winds from the east. These wind speeds are an average wind speed over a ten minute interval. The prevailing wind direction at the Bridge is from the west, so this is why the speed is higher from the west for the 10,000 year wind.

The wind tunnel testing considered a range of variables for three different generic concepts. The generic concepts consisted of the following:

1. Add on to the existing railing
2. Replace the existing railing
3. Add a netting system that extends out horizontally from the Bridge

The variables included:

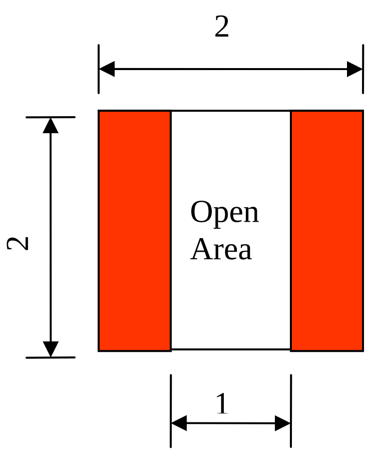
1. Different heights (8 feet to 14 feet)
2. Different "solids ratios"
3. Different types of "wind devices" to achieve the wind design criteria

In total, over 70 different variations of these generic concepts were tested. In accordance with the Board criteria, each of these generic concepts that met the design criteria was also tested with a moveable median barrier in all possible lane configurations (7 lane configurations per concept). This resulted in the performance of approximately 200 individual wind tunnel tests.

The heights tested varied from 8 ft to 14 ft for generic concepts in the first two categories (tall railing systems); extensions of 10 ft were considered for horizontal netting concepts. These dimensions were selected after reviewing barriers that have been implemented at other facilities.

Wind Tunnel Testing indicated that each generic concept has a different maximum solid ratio that satisfies the wind criteria.

Solid ratio is defined as the total area of all solid components of the railing, divided by the total area of the railing (length x height); an example depicting this calculation is shown below.



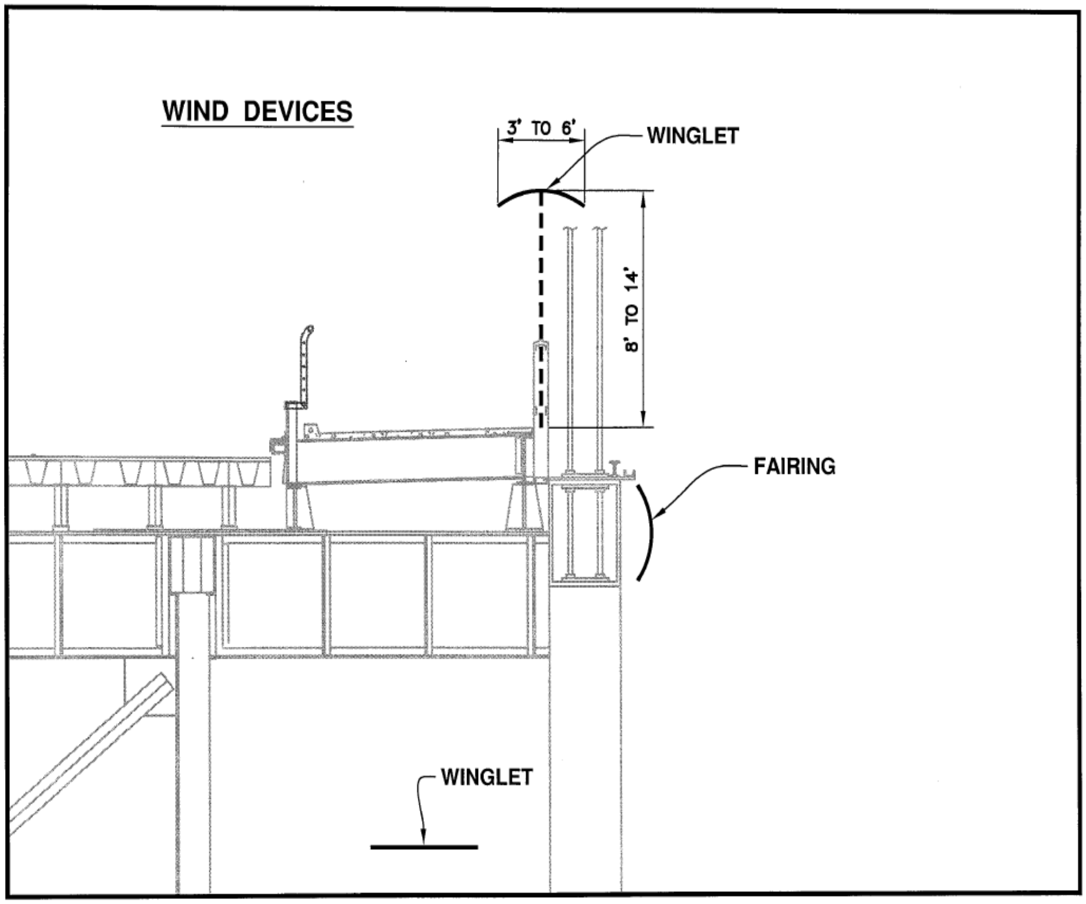
Solid Ratio % = (Solid Area) / (Total Area) x 100

Solid Area = 2 x 1 = 2
Total Area = 2 x 2 = 4

Solid Ratio = 2/4 x 100 = **50%**

The wind tunnel testing confirmed that additions to the Bridge were very susceptible to wind since the solid ratio of acceptable generic concepts varied from between 12 and 23 percent.

Initial testing of generic concepts revealed that all concepts require the installation of a wind device in order to meet the stated wind criteria. Wind devices are components that are added to the Bridge so the various concepts can achieve the wind design criteria. From the perspective of bridge users there are two types of wind devices: visible and hidden from view; while technically, there are two different types of wind devices which work in fundamentally different ways: "fairings" and "winglets".



Cross Section Depicting Wind Devices

Fairings are wind devices that are added to the side of the Bridge and work in concert with a replacement railing that is less solid and more aerodynamically efficient. The fairings act to bring the airflow around and over the top of the stiffening truss more efficiently and in a streamlined fashion which reduces the energy input into the Bridge due to wind and lessens the resulting movement of the Bridge.

Winglets are in essence airfoils or small wings. They are non-adjustable surfaces that generate lift. As the wind speed increases, the generated lift increases. The force of the lift resists the tendency of the bridge to twist in strong wind. This is referred to as aerodynamic damping. When winglets are used they must minimally be positioned between the towers where there is the greatest twisting in strong wind.

Results & Conclusions

Wind tunnel testing and analysis has determined the combinations of height, solid ratio and wind devices for all three generic concepts that will comply with the established wind stability criteria for the Golden Gate Bridge. Testing has further confirmed that these concepts will not prevent the future installation of a moveable median barrier system, meaning that wind stability will still be achieved if and when a moveable median barrier is implemented.

The parameters defining each generic concept are summarized below. Sketches and examples illustrating these concepts are immediately following this Executive Summary.

Generic Concept Type 1 – Add on to the Existing Railing

The existing railing is comprised of pickets between a top and bottom rail. Though it appears that the existing railing is open and will allow wind to pass through, in actuality the railing is 60 percent solid. This presents a challenge for concepts that add on to the existing railing.

In order to satisfy the wind criteria while keeping the existing railing it is necessary to have a winglet on top of the railing as depicted in Figure 1.1. Hidden wind devices do not work.

The width of the winglet decreases as the height of the railing increases. This arises because the air at a higher level above the deck is less disturbed and is more streamlined which results in the winglet being more efficient.

A range of heights between 10 and 14 feet tall was satisfactorily tested.

The testing indicated that any addition to the existing railing must be very open so that the wind can easily pass through. The testing determined that the addition must have no more than 12 percent solids.

Figures 1.2a through 1.4b provide illustrative examples of how this concept might look, using various components.

Generic Concept Type 2 – Existing Railing replaced with New Railing

The removal of the existing railing provides much greater latitude in the design for this concept as compared to the first concept. The replacement concept can have a solid ratio of up to 23 percent. A sensitivity analysis was performed which indicates that the "vertical" replacement railing can be tilted 20 degrees inboard or outboard from the vertical upright position with no appreciable change in the wind response of the Bridge.

The removal of the existing railing provides more options for acceptable wind devices. Testing has confirmed that this concept can be implemented in combination with any one of the wind devices developed:

- Two below deck winglets, positioned underneath the east sidewalk and a winglet that functions as a "catwalk" (or maintenance walkway) positioned under the west sidewalk. This is depicted in Figure 2.1; Figures 2.2a through 2.4b provide illustrative examples of how this concept might look with this wind device.
- Wind fairings placed on the outer vertical face of the west stiffening truss and on the outside face of the west sidewalk as depicted in Figure 2.5; Figures 2.6a and 2.6b show an example that incorporates vertical glass blades.
- Above deck "winglets" (the width of the winglet varies with the height above deck) as depicted in Figure 2.7; Figures 2.8a through 2.9b show examples depicting this concept and wind device.

A range of heights between 8 and 14 feet tall was tested with satisfactory results with the above mentioned wind devices and maximum solid ratio.

Generic Concept Type 3 – Add a Netting System that extends out Horizontally from the Bridge

It was surprisingly difficult to arrive at acceptable net options. Netting systems that extend out horizontally disturb the airflow as it approaches the top of the stiffening truss and railing. To satisfy the wind criteria with horizontal netting it is necessary to replace the existing railing between the main towers with a less solid and more aerodynamically efficient railing and it is necessary to add winglets. The addition of fairings to this concept did not satisfy the wind design criteria.

Previously, the District performed studies in order to incorporate modifications to enhance the wind stability of the Bridge in the seismic retrofit program. As part of this effort the District developed a design for a "replicated" railing. The replicated railing uses the same structural elements as the existing railing for the support posts and top rail cap, but with new ¼ inch plate verticals spaced 6 inches on center replacing the existing pickets. The Phase 3 Seismic Retrofit design incorporates the replacement of the railing on the west sidewalk between the two main towers with the replicated railing and adds fairings on the west side between the two main towers.

This replicated railing, which has a maximum solid ratio of 23 percent, was successfully tested with a net system that had a maximum solid ratio of 16 percent coupled with winglets. Both above deck and below deck winglets worked with this combination. Both the replicated railing and the winglets are only necessary between the two main towers, not along the entire length of the Bridge. Figure 3.1 depicts the acceptable net parameters with the below deck winglets.

Figure 3.2a through Figure 3.3b illustrate net concepts with hidden wind devices. Sketches of net options that incorporate an above deck winglet were not prepared, because any visual advantage of a net option would be obviated by the above deck winglets.

EXECUTIVE SUMMARY – CONCEPT FIGURES

CONCEPT 1: ADDING TO THE EXISTING RAILING TO INCREASE ITS HEIGHT

CONCEPT 2: AN ALL NEW VERTICAL BARRIER/RAILING SYSTEM

Concepts with no above deck aerodynamic elements

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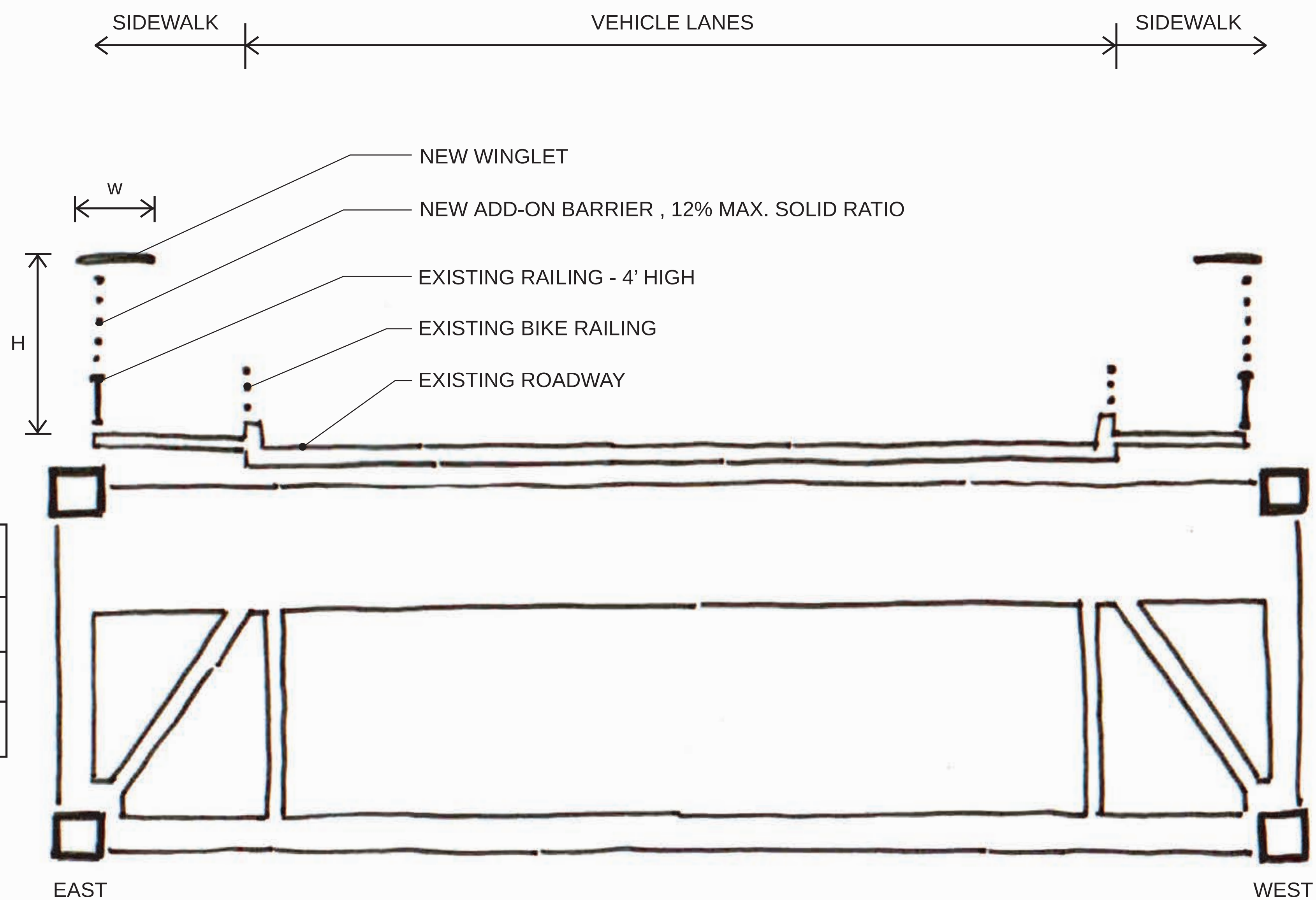


H (FT.)	W (IN.)
10	72
12	64
14	64

FIGURE 1.1 - CONCEPT 1 : ADDING TO THE EXISTING RAILING
SCALE : NOT TO SCALE

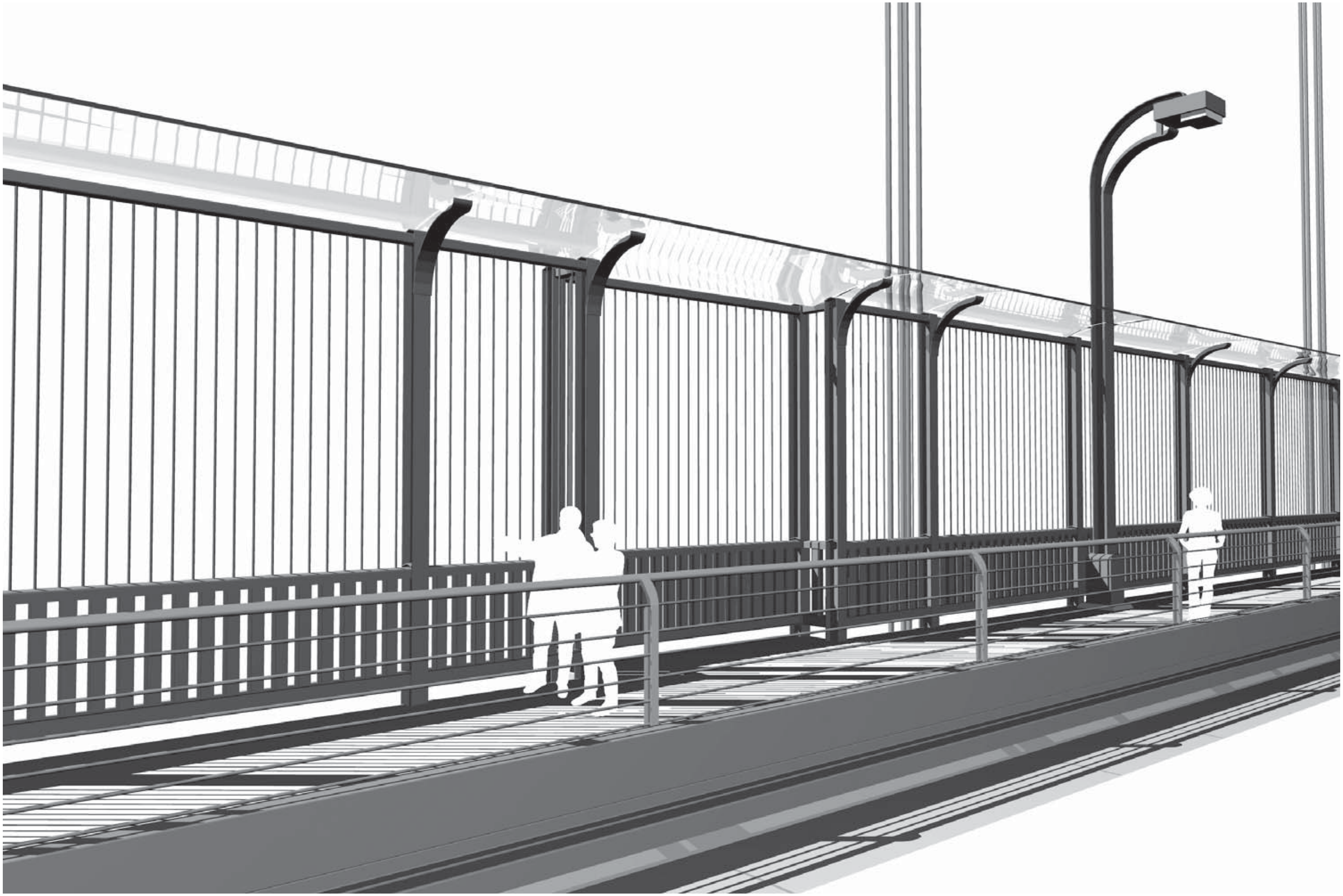


FIGURE 1.2a - EXAMPLE OF CONCEPT 1 (EXAMPLE SHOWN WITH HEIGHT OF 14’-0” TRANSPARENT WINGLET OF 64”, VERTICAL MEMBERS SPACED AT 6”, SOLID RATIO OF 12%) *VIEW FROM ROADWAY*

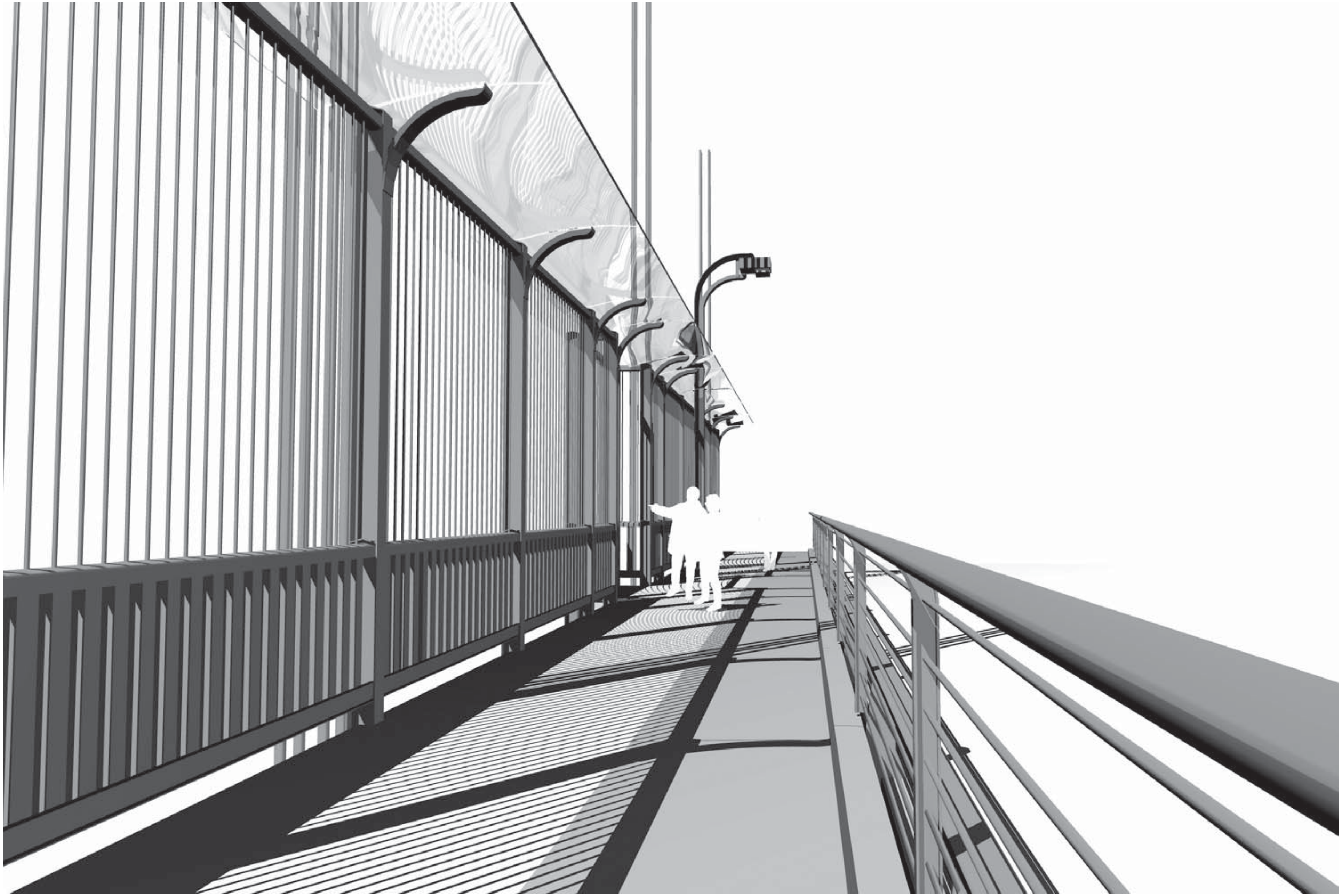


FIGURE 1.2b - EXAMPLE OF CONCEPT 1 (EXAMPLE SHOWN WITH HEIGHT OF 14’-0” TRANSPARENT WINGLET OF 64”, VERTICAL MEMBERS SPACED AT 6”, SOLID RATIO OF 12%) *VIEW FROM SIDEWALK*

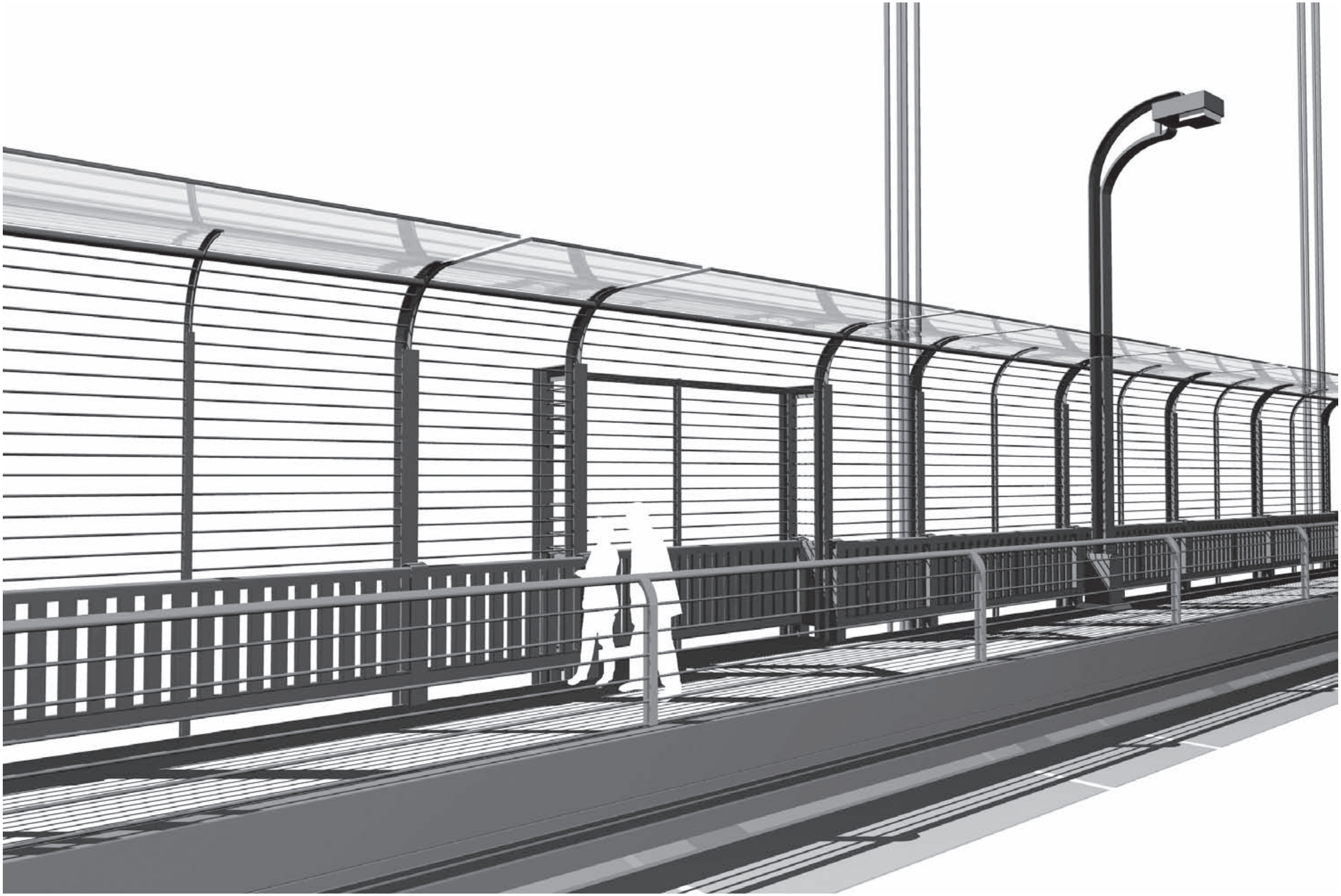


FIGURE 1.3a - EXAMPLE OF CONCEPT 1 (EXAMPLE SHOWN WITH HEIGHT OF 12’-0” TRANSPARENT WINGLET OF 64”, HORIZONTAL MEMBERS SPACED AT 6”, SOLID RATIO OF 9%) *VIEW FROM ROADWAY*

FIGURE 1.3b - EXAMPLE OF CONCEPT 1 (EXAMPLE SHOWN WITH HEIGHT OF 12'-0" TRANSPARENT WINGLET OF 64", HORIZONTAL MEMBERS SPACED AT 6", SOLID RATIO OF 9%) *VIEW FROM SIDEWALK*

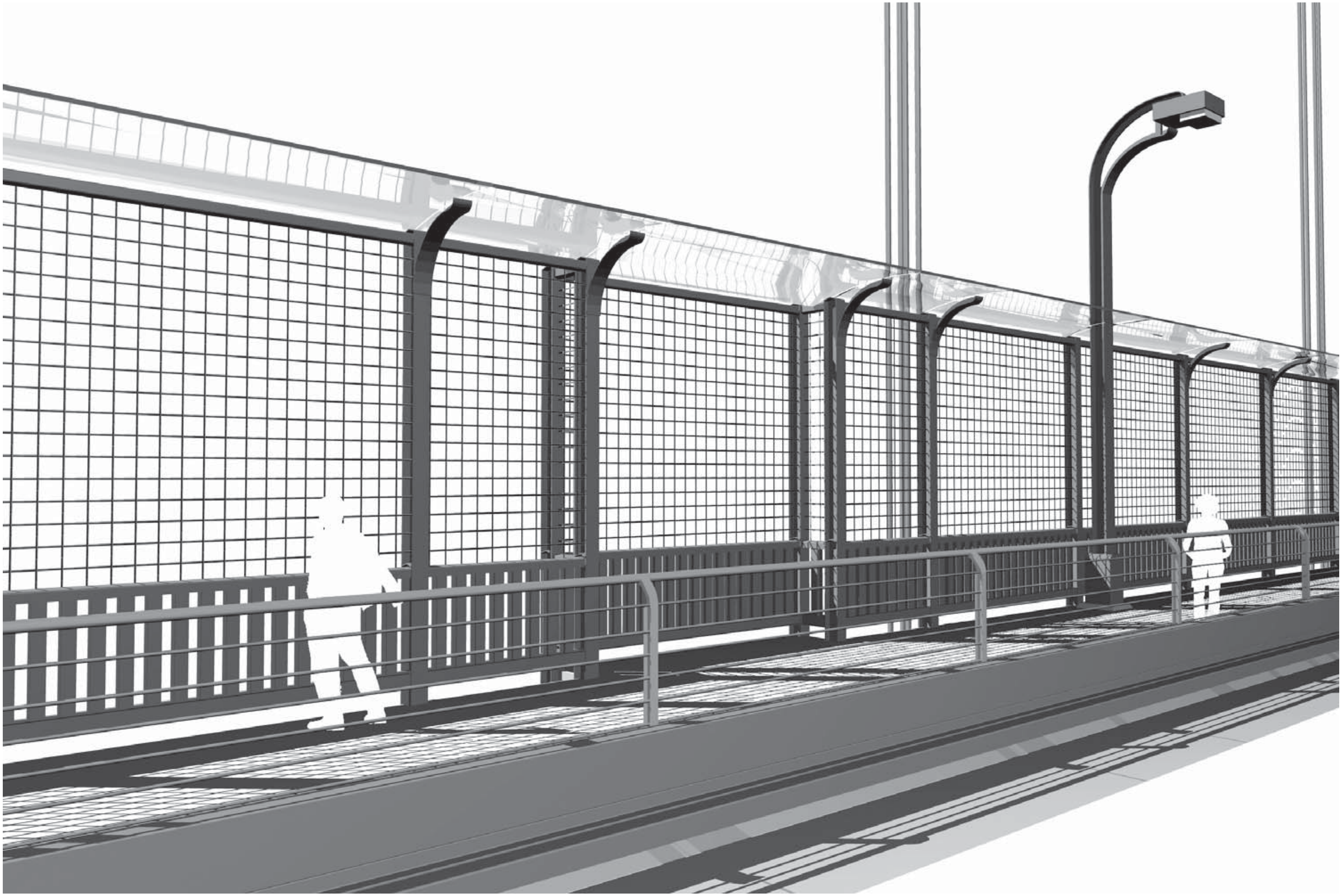


FIGURE 1.4a - EXAMPLE OF CONCEPT 1 (EXAMPLE SHOWN WITH HEIGHT OF 14’-0” TRANSPARENT WINGLET OF 64”, VERTICAL AND HORIZONTAL WIRE MESH OF 6”, SOILD RATIO OF 11%) *VIEW FROM ROADWAY*

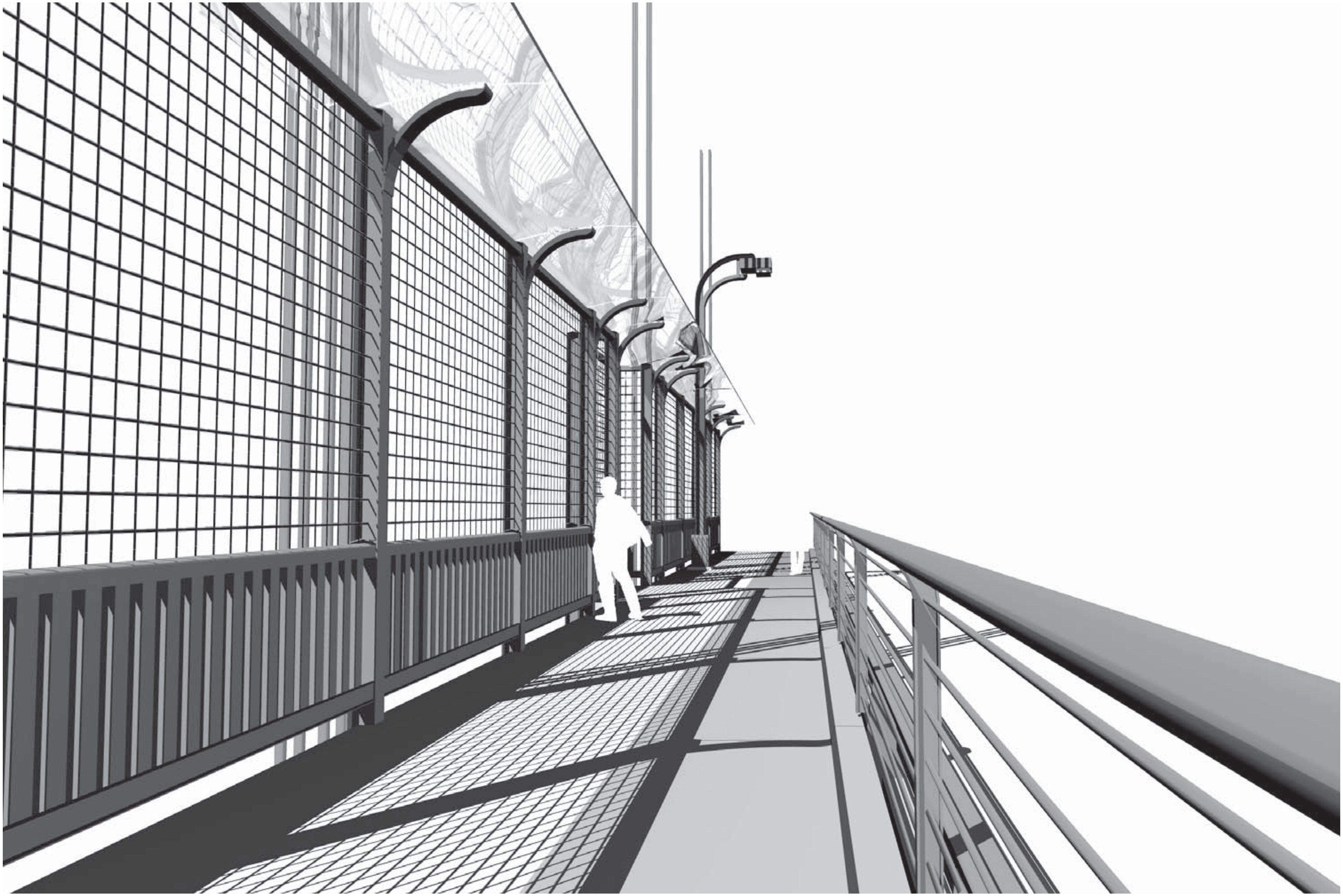


FIGURE 1.4b - EXAMPLE OF CONCEPT 1 (EXAMPLE SHOWN WITH HEIGHT OF 14'-0" TRANSPARENT WINGLET OF 64", VERTICAL AND HORIZONTAL WIRE MESH OF 6", SOILD RATIO OF 11%) *VIEW FROM SIDEWALK*

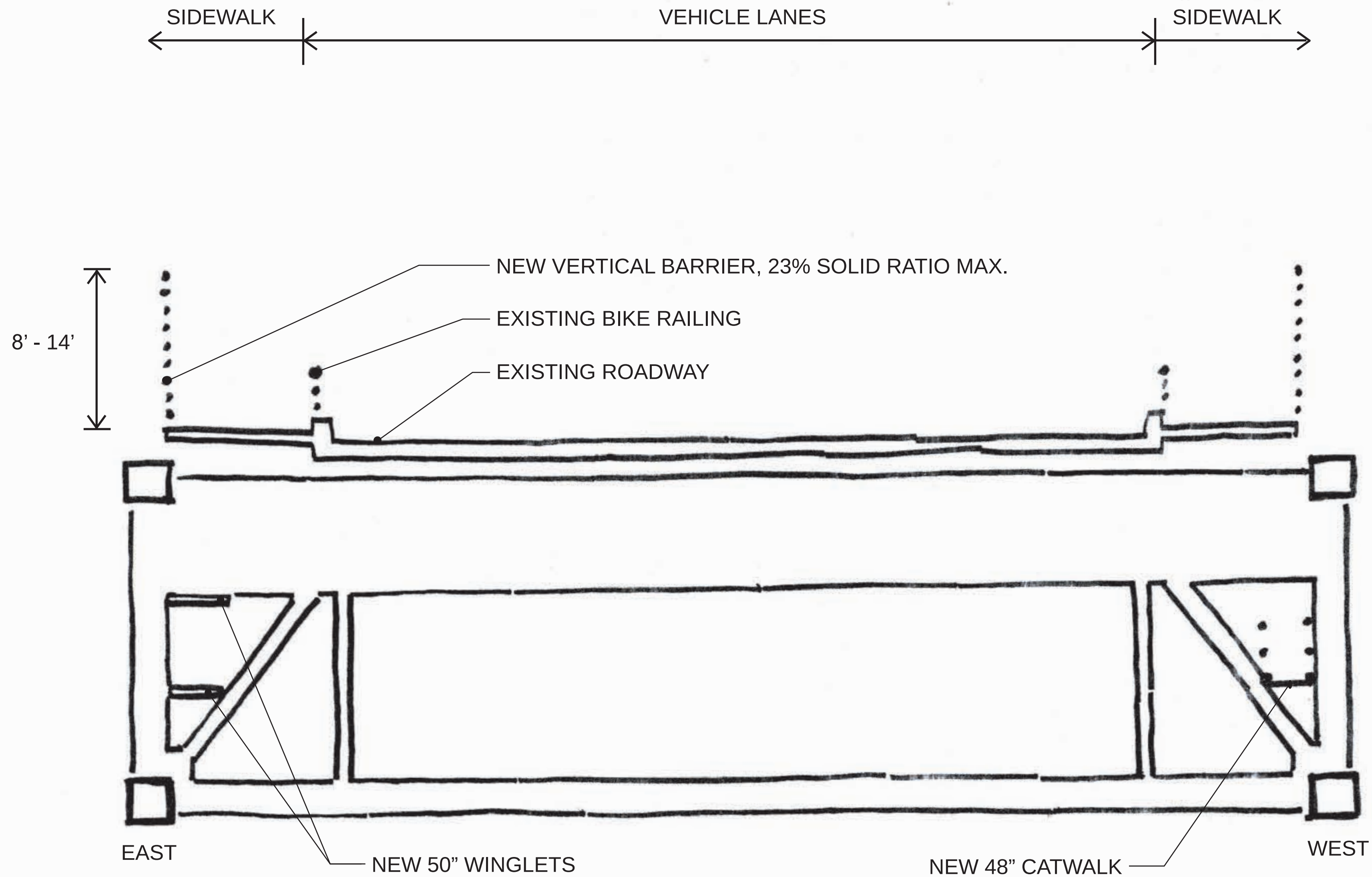


FIGURE 2.1 - CONCEPT 2 : REPLACING THE EXISTING RAILING; WINGLETS UNDER DECK

SCALE : NOT TO SCALE8

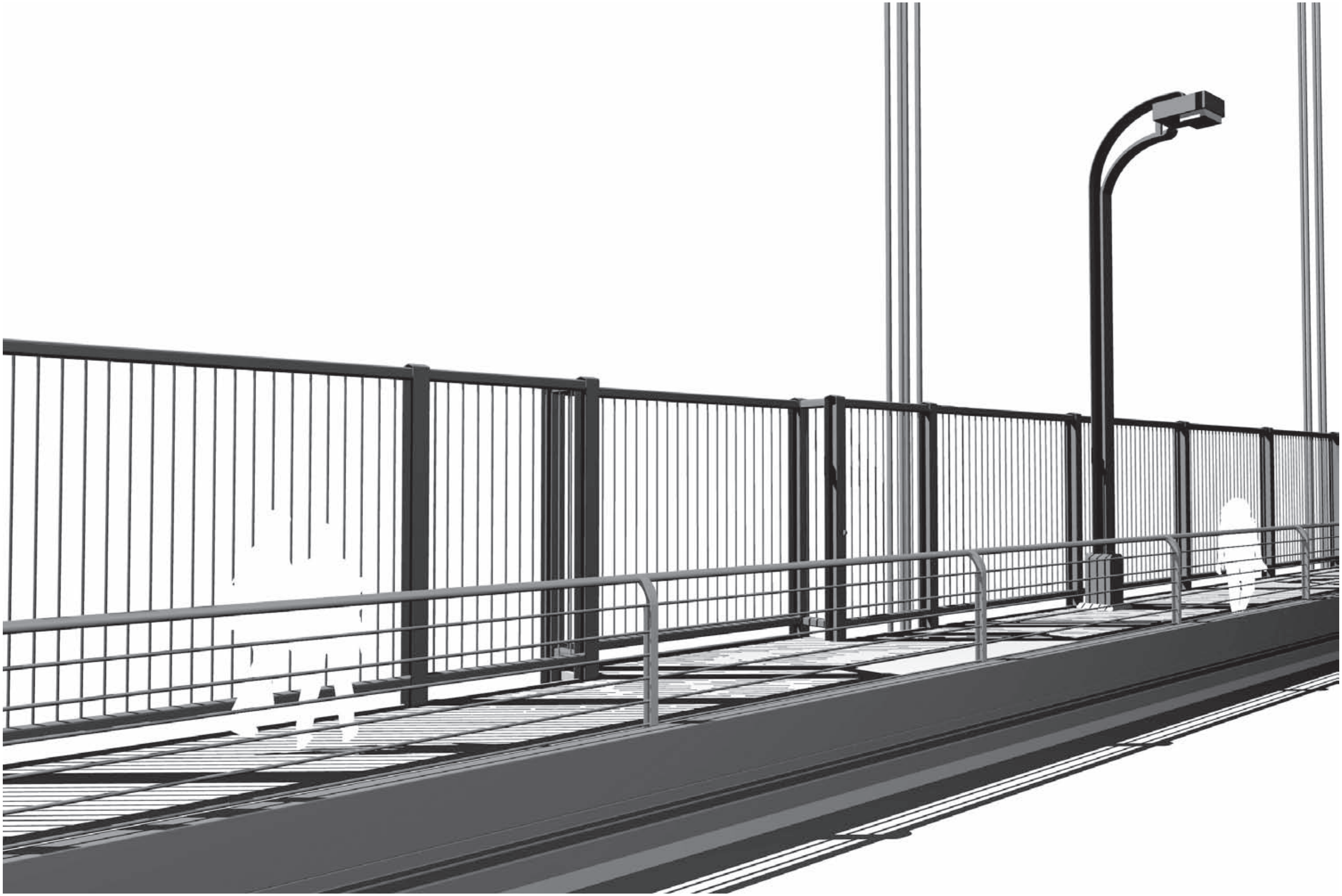


FIGURE 2.2a - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 10’-0”, NO VISIBLE WINGLET ; 50” UNDER DECK WINGLET ON EAST SIDE AND 48” CATWALK ON WEST SIDE, VERTICAL ROD MEMBERS SPACED AT 6”, SOLID RATIO OF 18%)
VIEW FROM ROADWAY

FIGURE 2.2b - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 10'-0", NO VISIBLE WINGLET; 50" UNDER DECK WINGLET ON EAST SIDE AND 48" CATWALK ON WEST SIDE, VERTICAL ROD MEMBERS SPACED AT 6", SOLID RATIO OF 18%)
VIEW FROM SIDEWALK

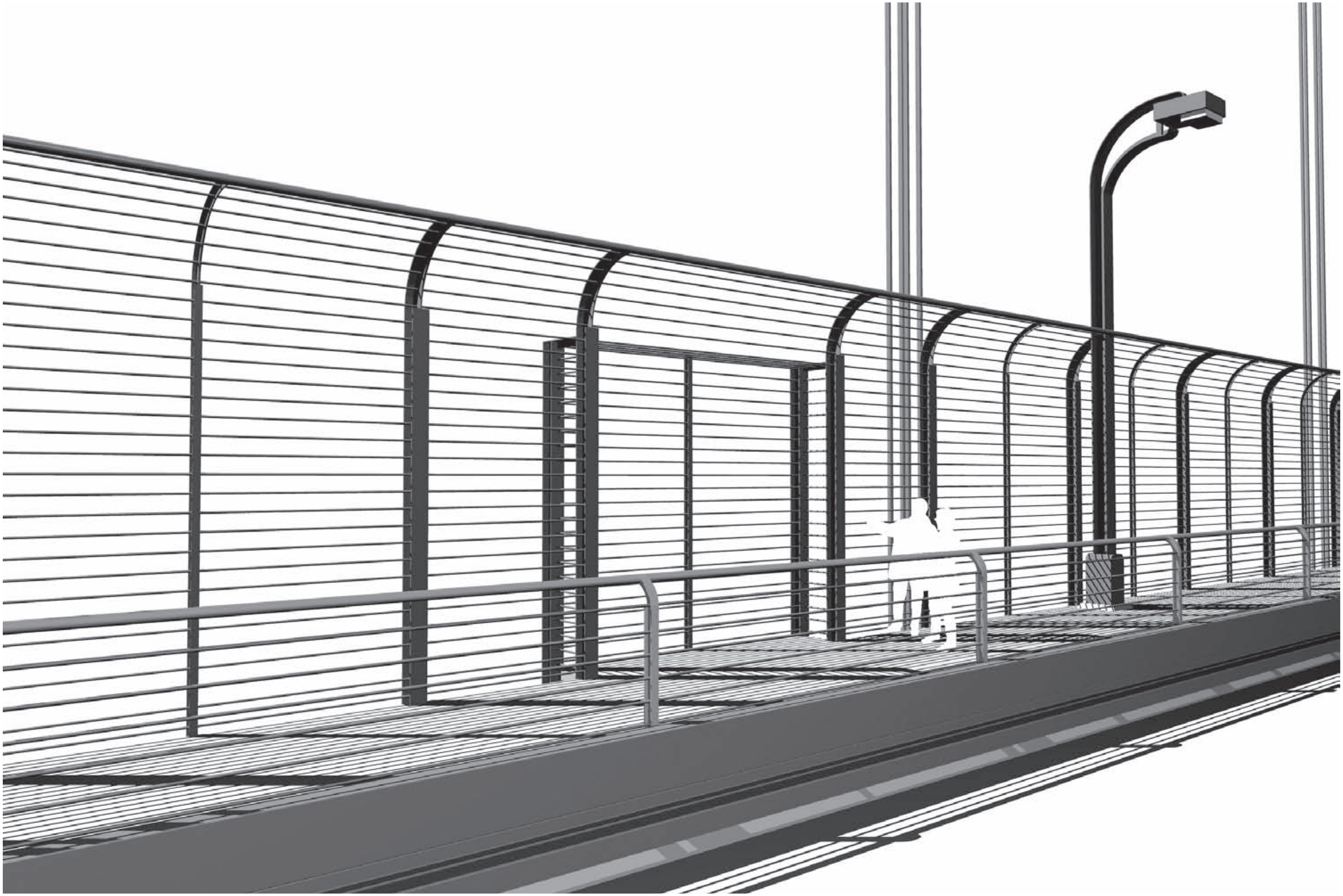


FIGURE 2.3a - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 14'-0", NO VISIBLE WINGLET; 50" UNDER DECK WINGLET ON EAST SIDE AND 48" CATWALK ON WEST SIDE, CURVED TOP, HORIZONTAL CABLE MEMBERS SPACED AT 6", SOLID RATIO OF 16%) *VIEW FROM ROADWAY*

FIGURE 2.3b - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 14’-0”, NO VISIBLE WINGLET; 50” UNDER DECK WINGLET ON EAST SIDE AND 48” CATWALK ON WEST SIDE, CURVED TOP, HORIZONTAL CABLE MEMBERS SPACED AT 6”, SOLID RATIO OF 16%) *VIEW FROM SIDEWALK*

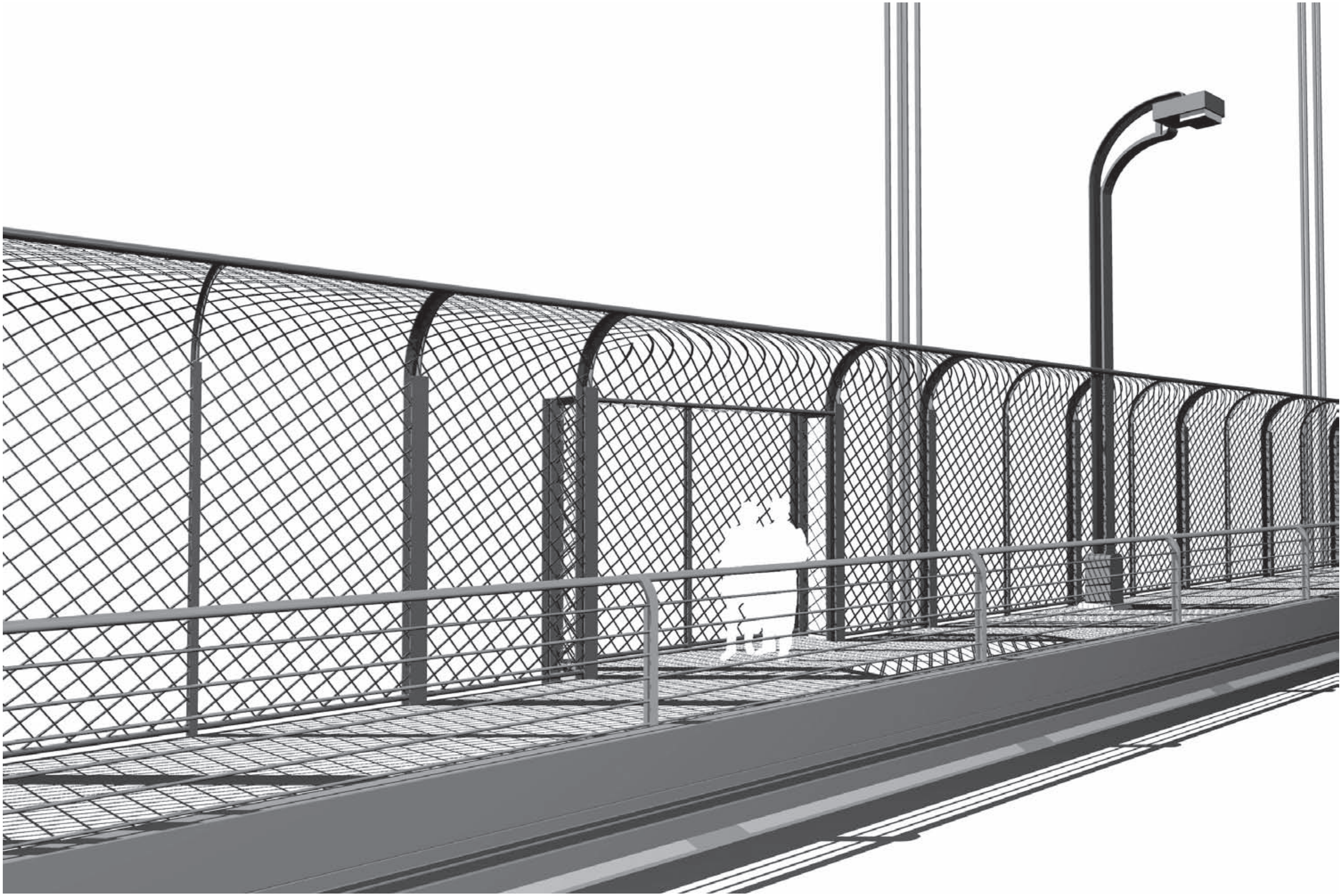


FIGURE 2.4a - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 12’-0”, NO VISIBLE WINGLET; 50” UNDER DECK WINGLET ON EAST SIDE AND 48” CATWALK ON WEST SIDE, DIAGONAL WIRE MESH OF 6”, SOLID RATIO OF 16%)
VIEW FROM ROADWAY

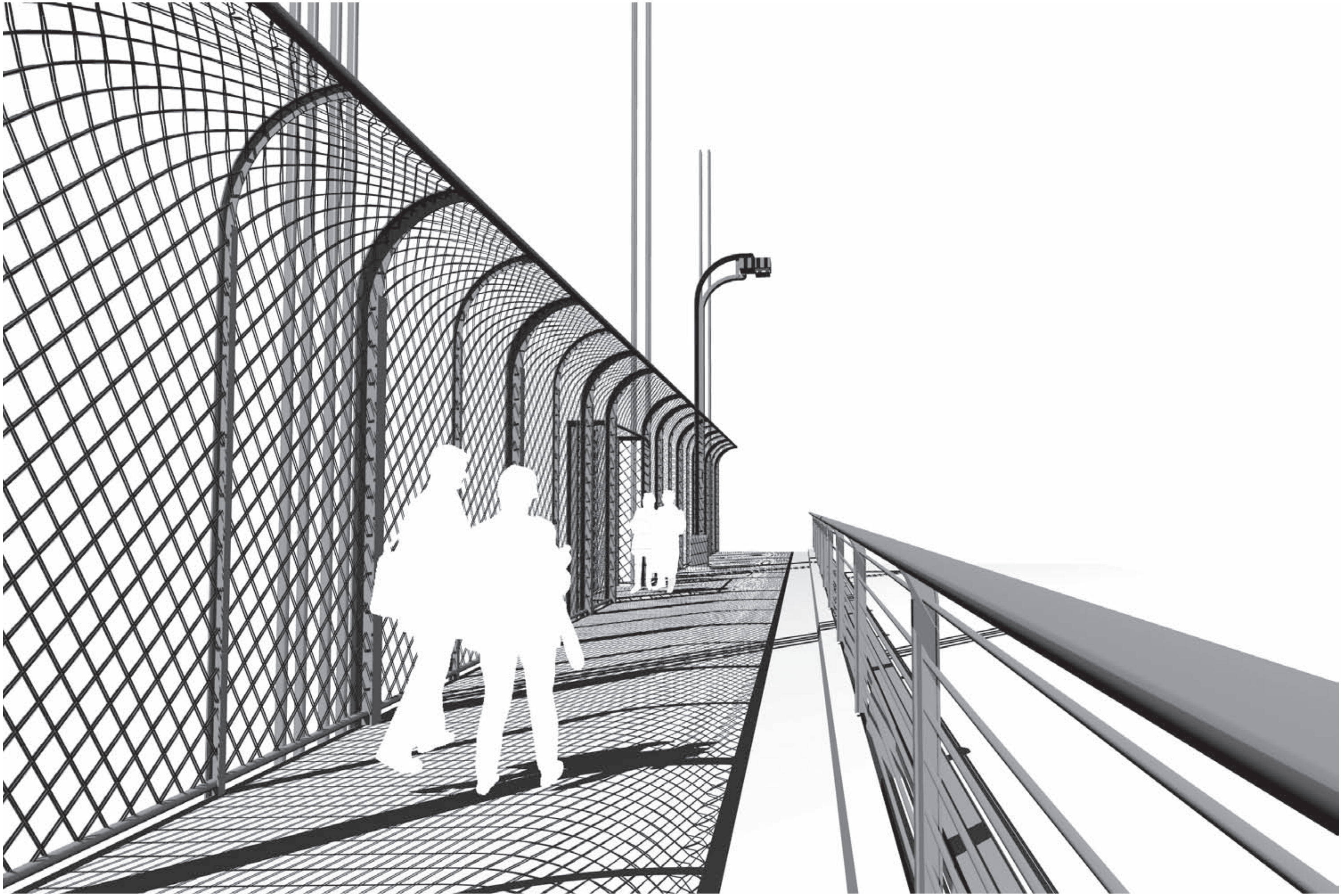


FIGURE 2.4b - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 12'-0", NO VISIBLE WINGLET; 50" UNDER DECK WINGLET ON EAST SIDE AND 48" CATWALK ON WEST SIDE, DIAGONAL WIRE MESH OF 6", SOLID RATIO OF 16%)
VIEW FROM SIDEWALK

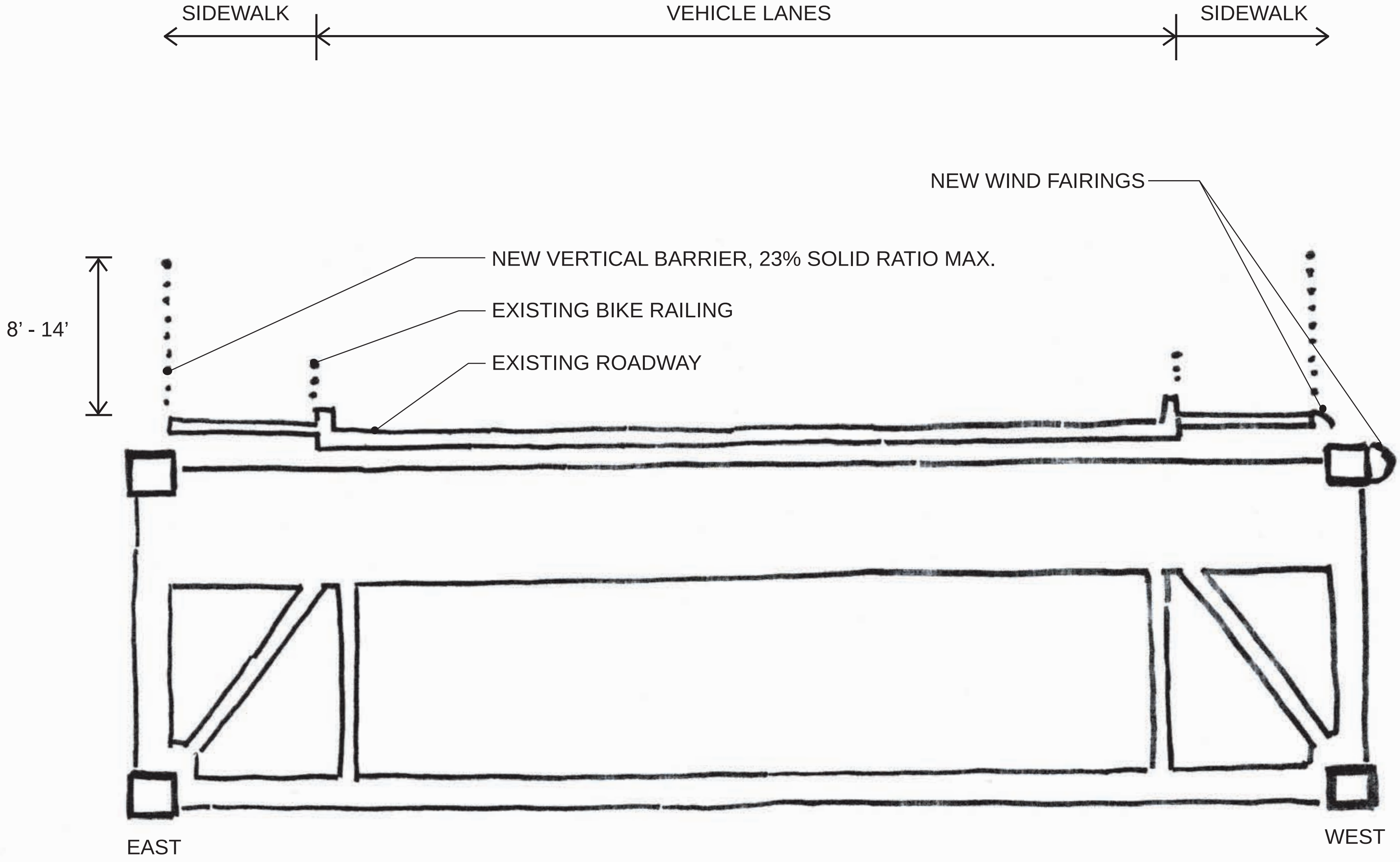


FIGURE 2.5 - CONCEPT 2 : REPLACING THE EXISTING RAILING; WIND FAIRINGS ON TRUSS

SCALE : NOT TO SCALE

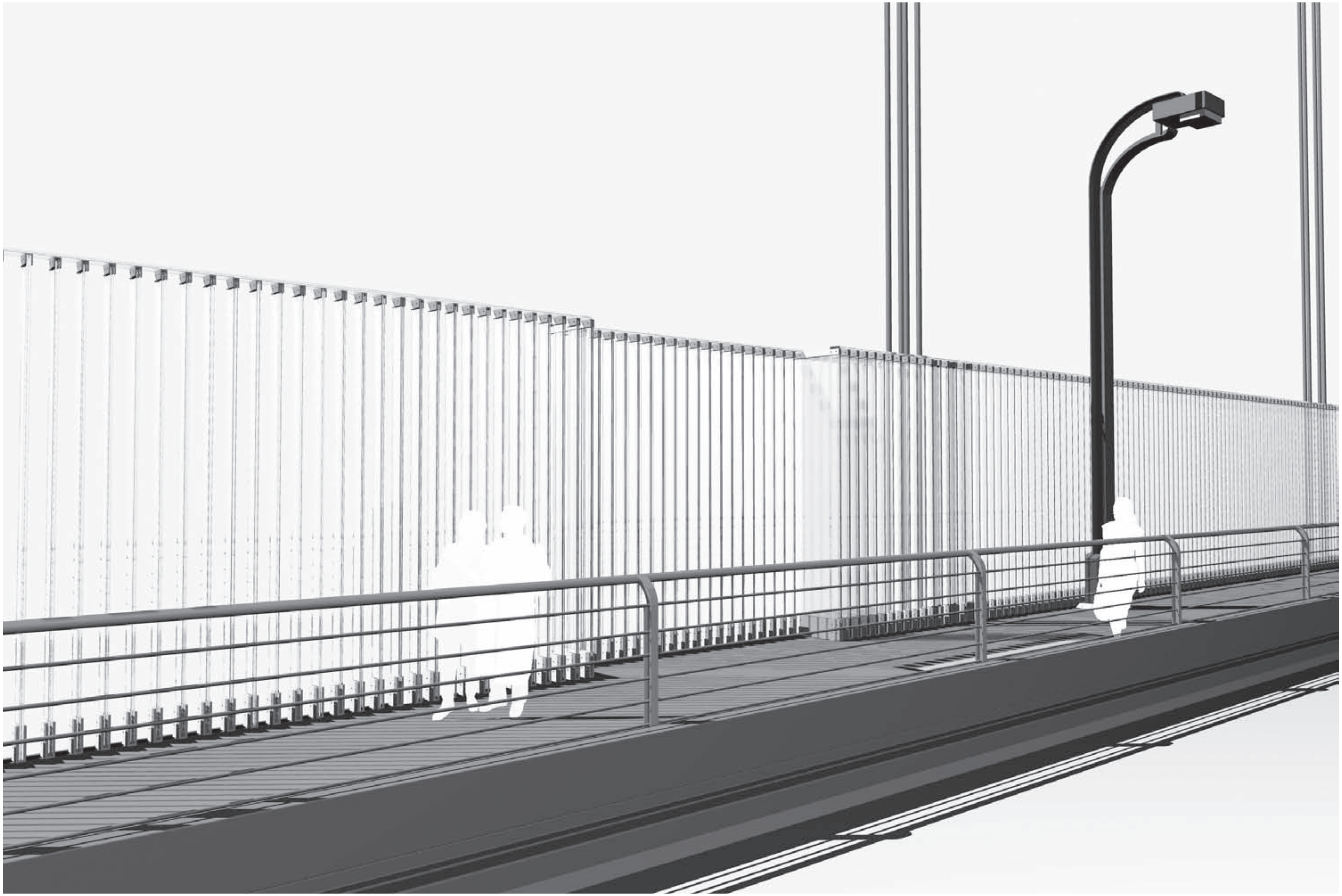
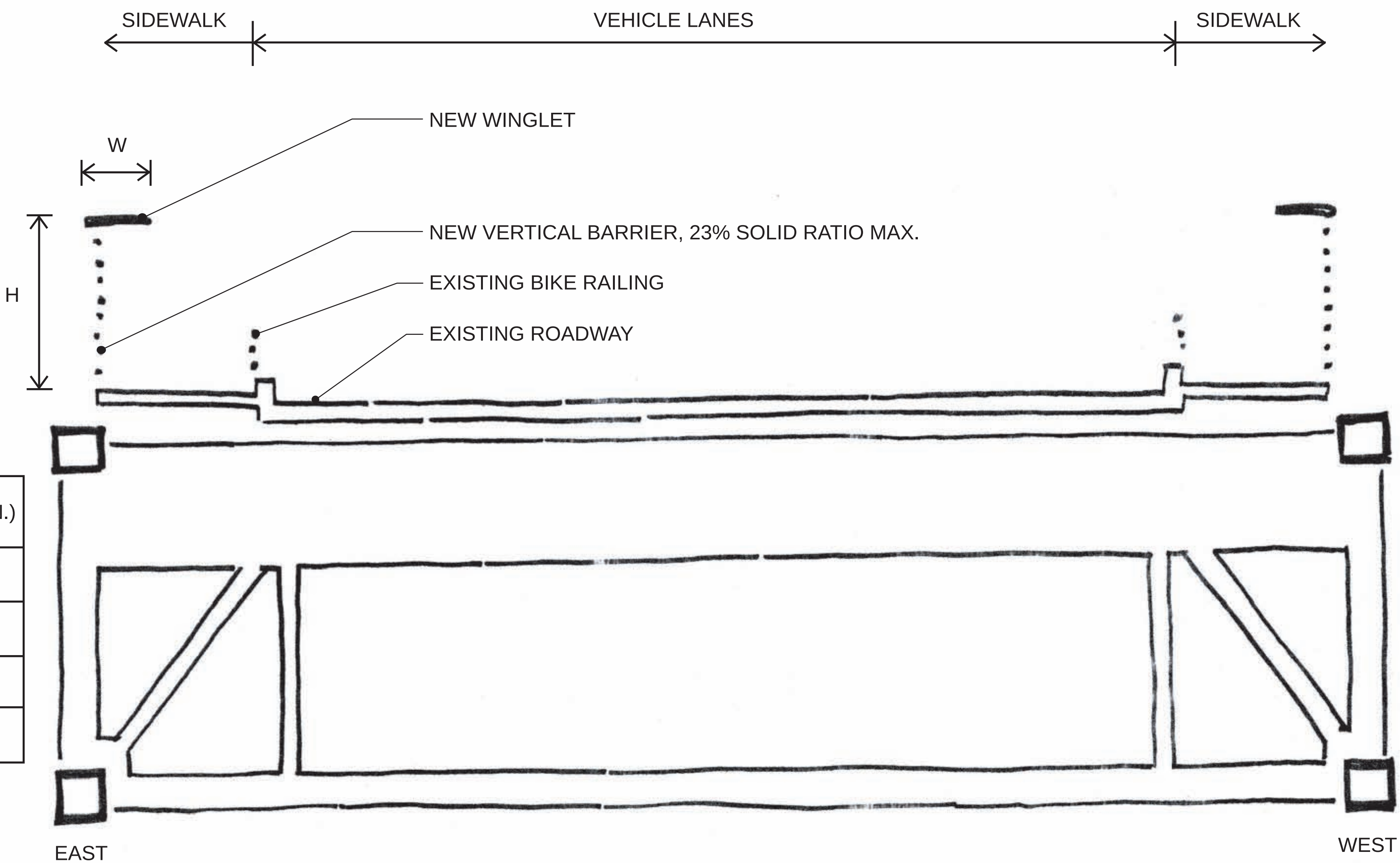


FIGURE 2.6a - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 12'-0", NO WINGLET; WIND FAIRINGS ON TRUSS AND SIDEWALK, VERTICAL GLASS PICKETS SPACED AT 7", SOLID RATIO OF 23%) *VIEW FROM ROADWAY*

FIGURE 2.6b - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 12’-0”, NO WINGLET; WIND FAIRINGS ON TRUSS AND SIDEWALK, VERTICAL GLASS PICKETS SPACED AT 7”, SOLID RATIO OF 23%) *VIEW FROM OUTBOARD*



H (FT.)	W (IN.)
8	54
10	48
12	42
14	36

FIGURE 2.7 - CONCEPT 2 : REPLACING THE EXISTING RAILING ; WINGLETS MOUNTED OVER BARRIER
SCALE : NOT TO SCALE

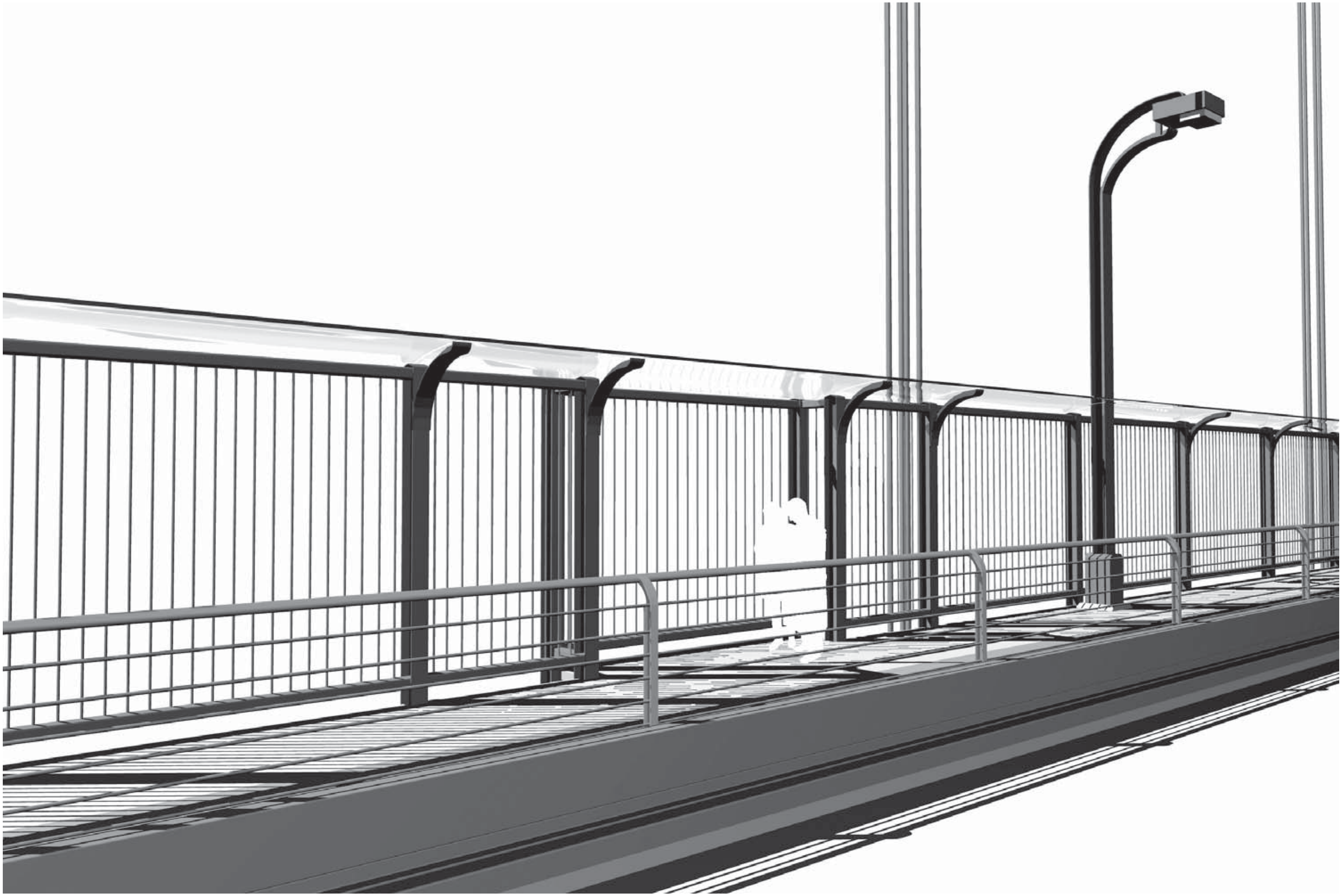


FIGURE 2.8a - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 10'-0", 48" TRANSPARENT WINGLET, VERTICAL MEMBERS SPACED AT 6", SOLID RATIO OF 18%) *VIEW FROM ROADWAY*

FIGURE 2.8b - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 10’-0”, 48” TRANSPARENT WINGLET, VERTICAL MEMBERS SPACED AT 6”, SOLID RATIO OF 18%) *VIEW FROM SIDEWALK*

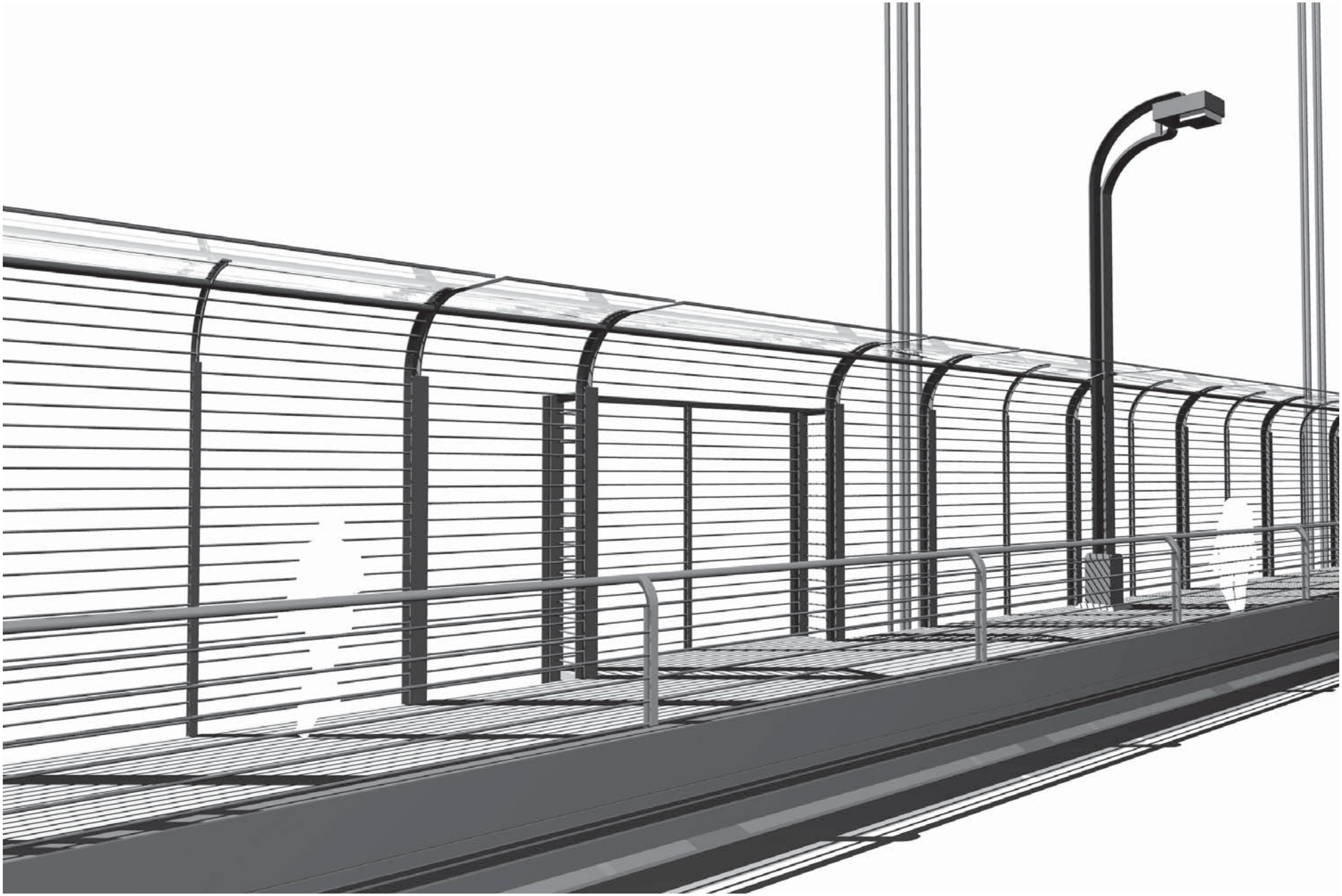


FIGURE 2.9a - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 12’-0”, 42” TRANSPARENT WINGLET, HORIZONTAL MEMBERS SPACED AT 6”, SOLID RATIO OF 17%) *VIEW FROM ROADWAY*

FIGURE 2.9b - EXAMPLE OF CONCEPT 2 (EXAMPLE SHOWN WITH HEIGHT OF 12'-0", 42" TRANSPARENT WINGLET, HORIZONTAL MEMBERS SPACED AT 6", SOLID RATIO OF 17%) *VIEW FROM SIDEWALK*

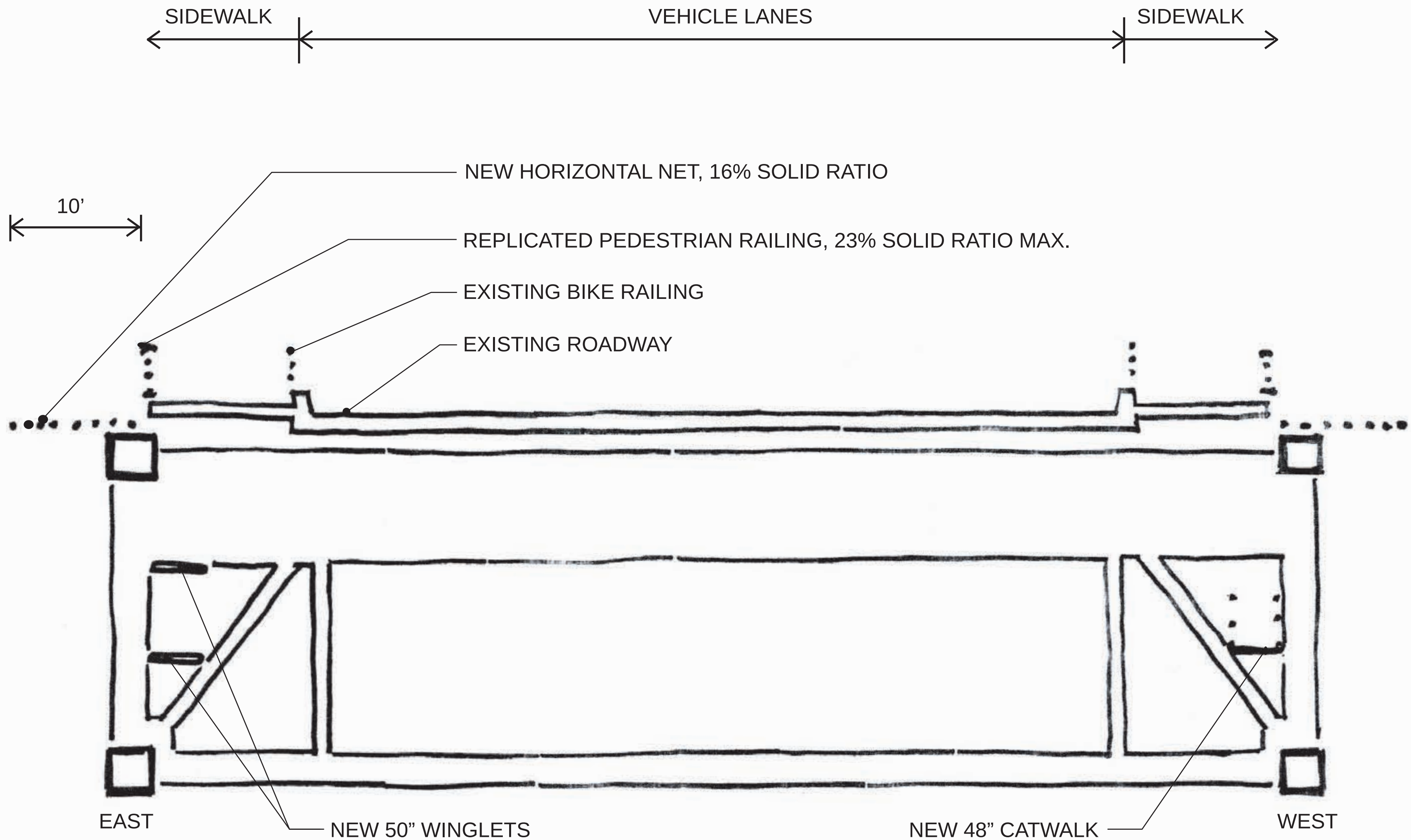


FIGURE 3.1 - CONCEPT 3 : UTILIZING NETS THAT CANTILEVER OUT HORIZONTALLY W/ REPLICATED PEDESTRIAN RAILING
SCALE : NOT TO SCALE

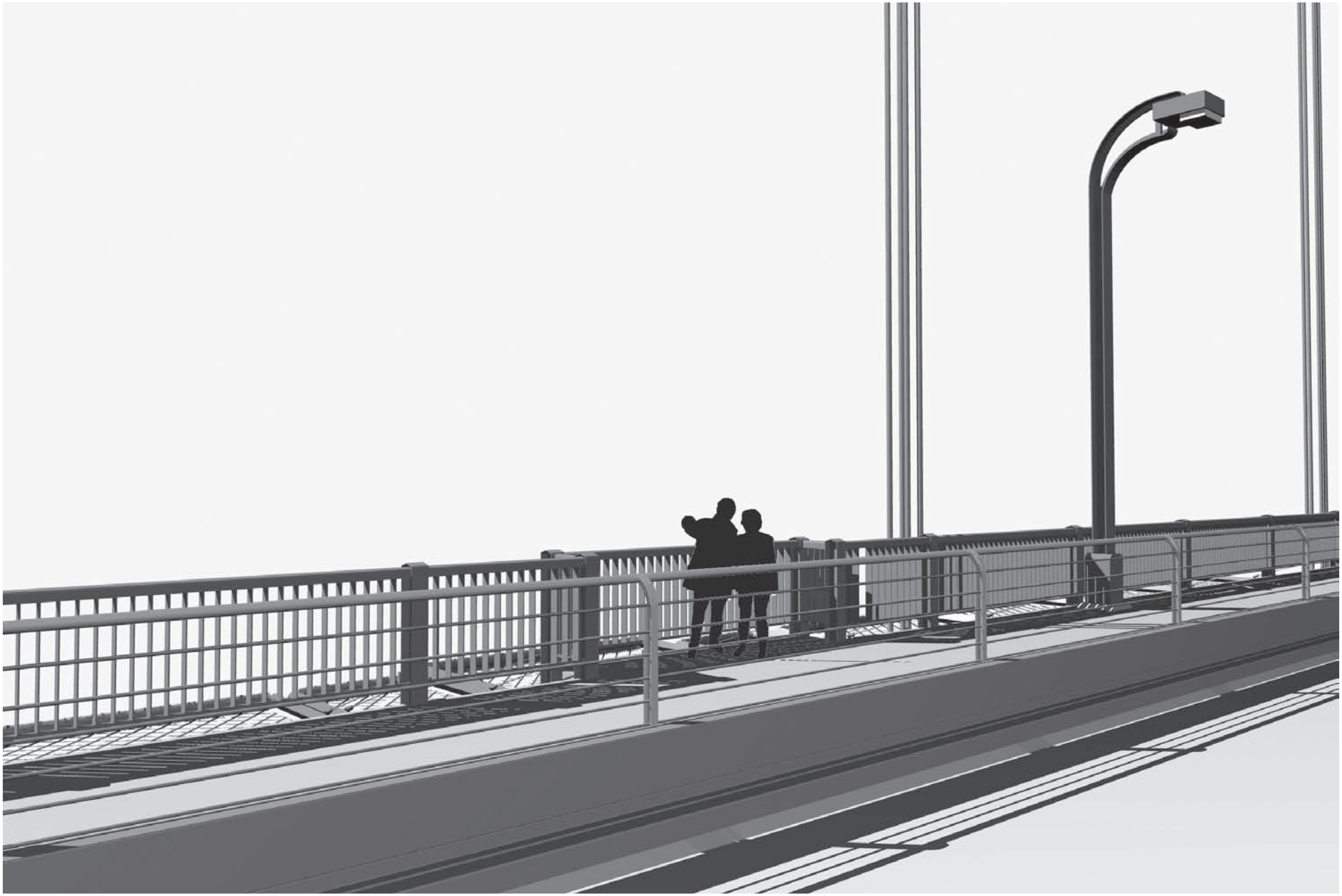


FIGURE 3.2a - EXAMPLE OF CONCEPT 3 (EXAMPLE SHOWN WITH A NET PROJECTING 10’ AT LEVEL OF REPLICATED PEDESTRIAN RAILING, SOLID RATIO OF 23%, NET SOLID RATIO OF 16%) *VIEW FROM ROADWAY*

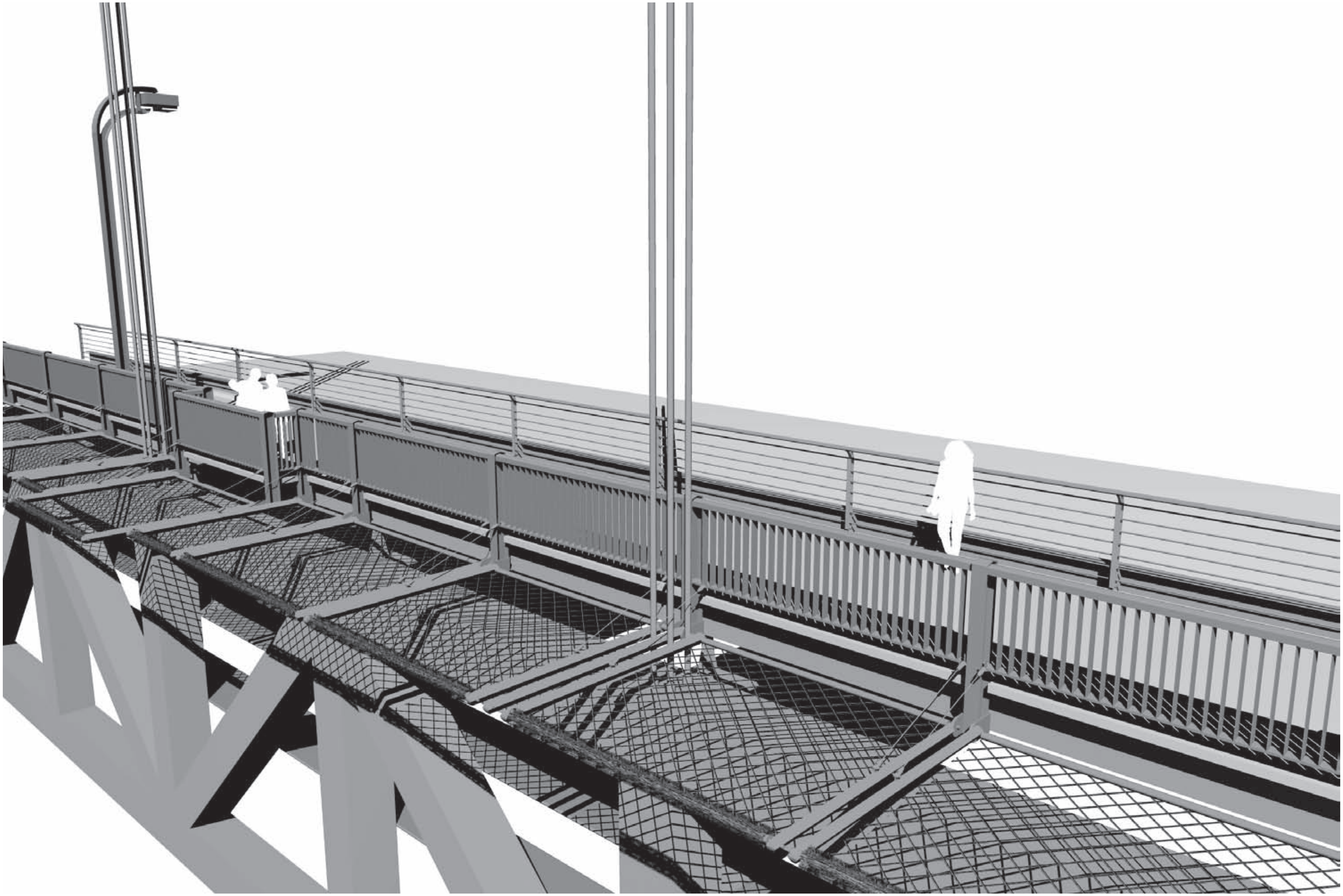


FIGURE 3.2b - EXAMPLE OF CONCEPT 3 (EXAMPLE SHOWN WITH A NET PROJECTING 10’ AT LEVEL OF REPLICATED PEDESTRIAN RAILING, SOLID RATIO OF 23%, NET SOLID RATIO OF 16%) *BIRDS EYE VIEW FROM OUTBOARD*

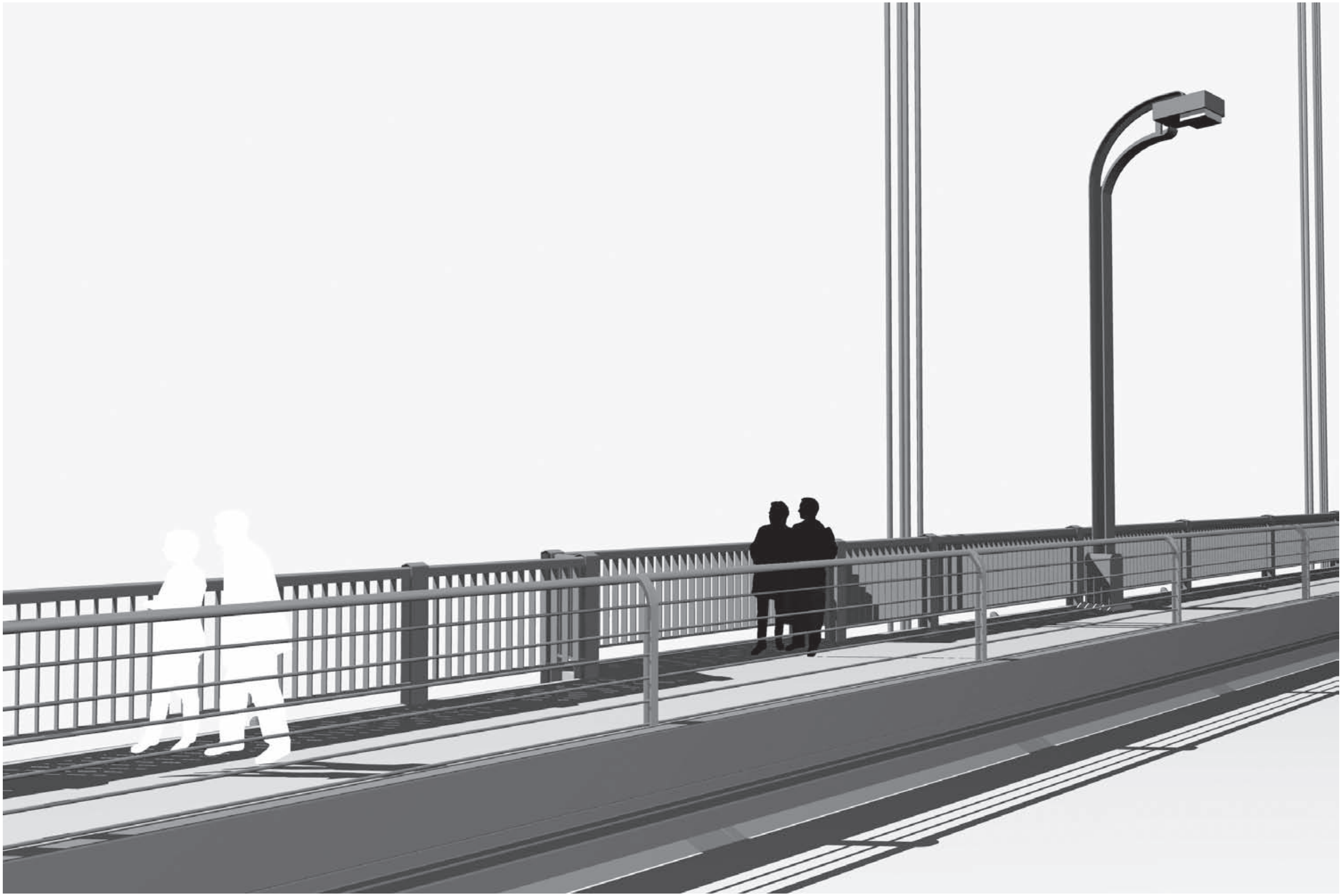


FIGURE 3.3a - EXAMPLE OF CONCEPT 3 (EXAMPLE SHOWN WITH A NET PROJECTING 10' MOUNTED BELOW REPLICATED PEDESTRIAN RAILING, SOLID RATIO OF 23%, NET SOLID RATIO OF 16%) *VIEW FROM ROADWAY*

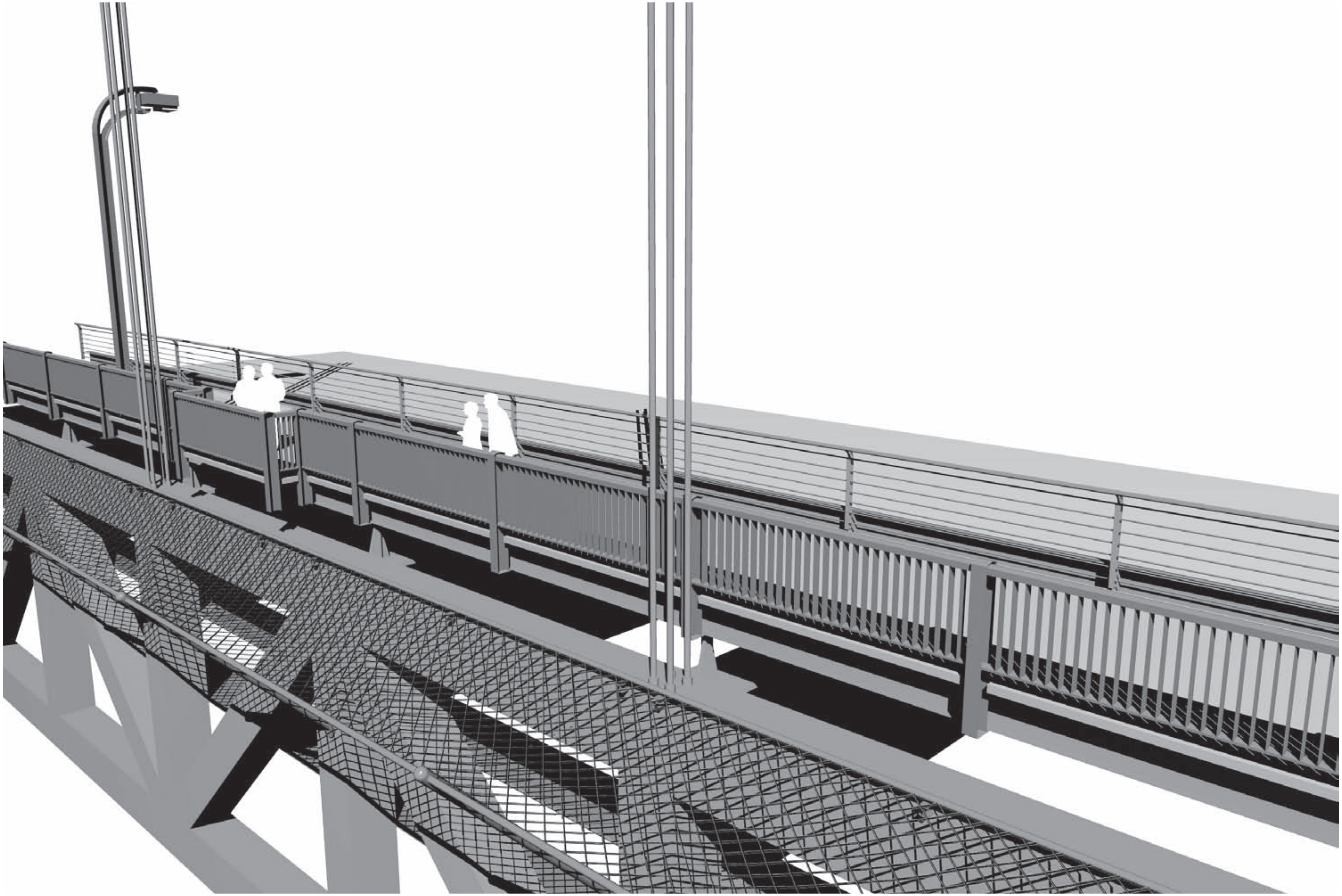


FIGURE 3.3b - EXAMPLE OF CONCEPT 3 (EXAMPLE SHOWN WITH A NET PROJECTING 10’ MOUNTED BELOW REPLICATED PEDESTRIAN RAILING, SOLID RATIO OF 23%, NET SOLID RATIO OF 16%) *BIRDS EYE VIEW FROM OUTBOARD*