



Alan G. Davenport Wind Engineering Group

A STUDY OF WIND EFFECTS FOR
**Anna Maria Bridge
Design Alternatives
Anna Maria Island, Florida**

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General Information, Bridge Deck Profile Measurements and Wind Speeds
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SUMMARY AND MAIN FINDINGS

The objective of this report is to provide expected wind speeds on a variety of proposed deck configurations for the Anna Maria Bridge. The scope of the report includes the following information:

1. A description of the wind climate that is expected for the site of the Anna Maria Bridge.
2. Comparisons of the relative wind speeds expected to occur over each of the proposed deck configuration referenced to a gust wind speed at traditional 33' reference height in an open exposure. The comparisons include variations on the cross-section, traffic barrier type and deck elevation.
3. Smoke flow visualization provided in DVD format in order to show in a qualitative manner the effect that the different section types and deck configurations have on the flow above the bridge deck.
4. Wind speeds over the deck that can be expected to affect vehicles of different sizes. Four vehicle sizes, ranging in height from passenger cars to tractor-trailers are considered.
5. A summary of traffic regulations used by other bridge authorities in the area, as well as internationally.

Figure 1 provides some elevation views along with some typical dimensions of the bridge deck sections. The site location is shown in Figure 2.

Wind Climate

- Winds in Anna Maria Island are associated with two basic types of weather systems: hurricane and non-hurricane winds. For non-hurricane winds, a design probability distribution of upper-level (500 m) wind speed and direction were developed for the area on the basis of full scale meteorological records from Tampa, Florida. This climate is considered to exhibit wind characteristics similar to those of Anna Maria Island. For hurricane winds, a simulation technique is used, involving thousands of simulated hurricanes matching the characteristics of actual recorded hurricanes in the area around Anna Maria Island.
- Predictions of mean-hourly wind speeds at the 33' reference height in an open country type of exposure for various return periods are shown in Figure 7. The 50-year return period mean-hourly wind speed at the 33' height is approximately 58 mph. This corresponds to a 3-second gust wind speed of 88 mph. It is the gust wind speed that is commonly reported in the media.
- The directional characteristics of winds associated with various return periods are indicated by the relative importance factors shown in Figure 9. The wind climate model indicates that for 1 year return winds, the southerly direction is the most important. However, for winds with return periods greater than 10 years, easterly directions are more important. This means that for vehicles crossing the Anna Maria Bridge, while commonly occurring winds are at 90° to the direction of travel, extreme winds are more likely to be longitudinal to the bridge, which is a better condition for drivability in high winds.

Bridge Deck Wind Profiles

- Measurements of the vertical profile of velocity and turbulence intensity were performed at two locations on the 1:60 scale models for each of the proposed deck configurations. Each location corresponds to the center of each clear deck width, referred to as upwind and downwind, and is a good representation of the wind velocities experienced by the traffic.



Predicted Bridge Deck Wind Speeds

- Estimates of peak bridge deck wind speeds are provided for the comparison of different deck configurations. The wind speed predictions relate a range of gust wind speeds at a reference height of 33' (30 mph to 90 mph) to wind speeds that can be expected on the bridge deck.
- The wind speed at the mid-level elevation was found to be approximately 11% greater than that at 33' reference height, and the wind speed at the high-level elevation was found to be approximately 19% greater than the 33' reference height. As the ambient wind speed increases with elevation, the bridge deck wind speeds are typically greater at higher elevations.
- For **low profile passenger cars**, such as the types that would be allowed on the bridge under worsening wind conditions, the gust wind speeds are expected to be:

Section Type A

1. Based on a 60mph wind speed at 33' reference height, the winds are expected to be 72 mph on the mid-level deck with a 32" traffic barrier, 74 mph on the high-level deck with a 32" traffic barrier, and 56 mph on the high-level deck with a 42" traffic barrier.
2. The following 33' reference wind speeds are expected to cause 60 mph wind speeds over the bridge deck: 50 mph for mid-level deck with a 32" traffic barrier, 49 mph for a high-level deck with a 32" traffic barrier, and 64 mph for a high-level deck with a 42" traffic barrier.

Section Type A	33' Reference Wind (mph)	Deck Wind Speed (mph)
Mid-level 32" Barrier	60	72
High-level 32" Barrier	60	74
High-level 42" Barrier	60	56
Mid-level 32" Barrier	50	60
High-level 32" Barrier	49	60
High-level 42" Barrier	64	60

Section Type B

1. Based on a 60mph wind speed at 33' reference height, the winds are expected to be 67 mph on the mid-level deck with a 32" traffic barrier, 76 mph on the high-level deck with a 32" traffic barrier, and 74 mph on the high-level deck with a 42" traffic barrier.
2. The following 33' reference wind speeds are expected to cause 60 mph wind speeds over the bridge deck: 54 mph for mid-level deck with a 32" traffic barrier, 47 mph for a high-level deck with a 32" traffic barrier, and 49 mph for a high-level deck with a 42" traffic barrier.

Section Type B	33' Reference Wind (mph)	Deck Wind Speed (mph)
Mid-level 32" Barrier	60	67
High-level 32" Barrier	60	76
High-level 42" Barrier	60	74
Mid-level 32" Barrier	54	60
High-level 32" Barrier	47	60
High-level 42" Barrier	49	60

Note: These tables only represent winds on passenger cars or other low profile vehicles.



Summary of Existing Operational Procedures

- Existing operational procedures currently in place for 4 bridges (2 in the United States, 1 in Canada, and 1 in Scotland) are summarized with regards to wind speed and traffic regulation.

Notes

- Predictions for an R-year return period (mean recurrence interval of R years) represent levels which are expected to occur *on average* once in R years. For reference, the risk of exceeding an R-year return period wind speed in a design life of L years is $1 - (1 - 1/R)^L$. Thus, for example, the risk of exceeding a 50 year wind speed in a design lifetime of 50 years is about 64%, whereas the risk of exceeding a 1000 year wind speed in a 50 year design life is about 5%.
- The predictions in this report are best estimates and **have not been factored** in any way.



DETAILS OF THE STUDY

- Project Name:** Anna Maria Island Bridge Design Alternatives
- Project Location:** The site of an existing bascule bridge connecting Anna Maria Island to the mainland, near Bradenton Florida. Anna Maria Island and the bridge location can be seen in Figure 2.
- Project Description:** A series of wind profile measurements were recorded in the upwind and downwind traffic lanes. The measurements were taken using a hotwire anemometer, which allows measurement of mean wind speed and turbulence intensity, and spanned heights from 15” above the bridge deck to 600” above the bridge deck. The resulting wind profiles were used to assess bridge deck wind speeds, and the impact of the elevation of the bridge deck and the height of the upstream traffic barrier. Drawings of each bridge deck section type can be seen in Figure 1, while photos of the models with varying barrier types can be seen in Figures 3 through 6.
- Smoke flow visualization was carried out in order to observe the interaction of the wind with the leading edge of the bridge deck, as well as flow differences due to the geometry of each deck alternative.
- Test Dates:** Bridge Deck Profile Measurements – September 2008
Flow Visualization – September 2008
- Report Scope and Format:** The results presented in this report include the following components:
1. The full-scale wind climate in order to determine the strength of the wind;
 2. experimental wind tunnel measurements to determine the aerodynamic data relevant to each bridge deck geometry;
 3. the calculation of wind speeds for each deck configuration at each proposed deck elevation.
- Section 1 – The wind climate for Anna Maria Island
Section 2 – The modeling of the bridge deck and the wind
Section 3 – The determination of wind profiles on the bridge deck
Section 4 – The prediction of bridge deck wind speeds
Section 5 – Summary of operational procedures in high-wind conditions
- General Reference:** Discussion and details of the general methodology used by the Alan G. Davenport Wind Engineering Group can be found in “Wind Tunnel Testing – A General Outline” (Reference 1).



1 THE WIND CLIMATE FOR ANNA MARIA ISLAND

1.1 Meteorological Data

- The wind climate for Anna Maria Island consists of two distinct components: extra-tropical (non-hurricane) and hurricane winds.

1.1.1 Extratropical Wind Climate

- The extratropical wind climate for Anna Maria Island was developed based on records of wind speed and direction from Tampa Airport (station number 722110) for the period between 1973 and 2004. The meteorological data include hourly wind records and annual extremes. The analysis of the hourly wind records provides information to develop the statistical climate model of wind speed and direction. From this model, predicted wind speeds regardless of wind direction for various return periods can be derived. The record of annual extremes was also used to predict wind speeds at various return periods.
- Statistical predictions of extreme values of wind speeds were made for various return periods taking into consideration the effects of both hurricane and non-hurricane winds. For non-hurricane winds, an “upcrossing” method is used (Reference 1). For hurricane winds, a “storm passage” method is used, whereby the impact of each of the thousands of hurricanes is tracked at every step during its passage and the resulting wind speeds are determined (Reference 3). Similarly, predictions were made for wind speeds that would occur at a height of 500m, and then adjusted to a height of 33ft, which is the standard reference height for wind speed reporting.
- Based on the analysis of the hourly records, the predicted hourly-mean wind speed at 33’, corrected for a standard open exposure definition, is 58 mph for a return period of 50 years.

1.1.2 Hurricane Wind Climate

- The hurricane climate was obtained from a hurricane simulation study which employs an updated version of ARA’s HURSIM hurricane simulation code (References 2-4), which is the same model used to define the design wind speeds given in ASCE 7-05. The wind field model used in the computer code has been extensively validated for surface level winds at both coastal and inland stations.
- Predictions of wind speed vs. return period are given for surface level winds and are based upon a simulation of 100,000 years of storms passing within 200km of Anna Maria Island. For storms within the 125 mile limit, wind speeds and directions are computed every 10 minutes.
- Predicted wind speeds at the site have been derived using the conditional wind speed exceedence probabilities obtained by rank ordering the simulated maximum wind speeds resulting from the simulation of the 100, 000 years of storms. An interpolation technique is then used to obtain wind speed exceedence probabilities.
- The storm passages approach is used to make statistical predictions of wind speeds during hurricane wind events.

1.2 Predicted Wind Speeds

- Predicted mean hourly wind speeds resulting from the combined extratropical and hurricane wind climates are shown for proposed high-level and mid-level decks, and for the 33’ reference height in Figure 7.
- The design probability distribution of mean-hourly wind speed and wind direction for strong winds at a reference height of 33’ is shown in Figure 8. Annual distributions are shown.



- The directional characteristics of winds associated with various return periods are indicated by the relative importance factors shown in Figure 9. The wind climate model indicates that for monthly and 1 year return winds, the southerly direction is the most important. In other words, commonly occurring winds are likely at 90° to the direction of travel. However, for winds with return periods greater than 10 years, easterly directions are more important. This is due to the influence of the hurricane wind climate. Extreme events associated with hurricanes are likely to involve winds along the span of the bridge, which is beneficial for drivability.



2 THE MODELING OF THE BRIDGE DECK AND THE WIND

2.1 Overall Approach

- The basic tool used is the Laboratory's boundary layer wind tunnel. The wind tunnel is designed with a very long test section, which allows extended models of upwind terrain to be placed in front of the model being tested. The wind flow then develops characteristics which are similar to the wind over the terrain approaching the actual site. This methodology has been highly developed (References 5, 6) and is detailed below.
- The bridge deck sections are placed in boundary layer flow in order to assess the velocity and turbulence characteristics of the wind above the bridge deck.

2.2 Model Design

- Experimental components:
 1. The 1:60 scale bridge deck models; the superstructure was constructed from wood and the railings constructed using rapid prototype technology. Each of the proposed bridge decks were modeled, and are referred to as section type A and section type B.
 2. Generic models of upstream terrain, see below.
- The bridge section models were tested for winds perpendicular to the bridge deck
- The dimensions of the bridge decks were supplied by PBS&J Tampa Structures in the form of 2006 FDOT Standard drawings. Cross-section drawings of each model are shown in Figure 1.
- Close-up views of the 1:60 scale bridge section models are shown in Figures 3 through 6.
- Close-up views of each deck model at the mid-level and high-level elevations can be seen for section type A and section type B in Figures 10 and 11, respectively. The elevations for each elevation are tabulated below.

Deck Description	Vertical Clearance
High-level	65 ft
Mid-level	45 ft
Low-level (existing)	21 ft

- The upstream terrain was modeled using generic roughness blocks, a barrier and turbulence-generating spires to produce wind characteristics representative of those at the project site. A single terrain model was used, which is a good representation of winds over open water during strong wind events, such as those during pre-hurricane conditions. The experimental set-up and the upstream conditions are shown in Figure 12.

2.3 Characteristics of the Modelled Wind

- Figure 13 presents the vertical profile of the mean speed and of the intensity of the longitudinal component of turbulence, measured just upstream of the center of the test section, for the upstream terrain exposure.
- The model profile is a good representation of the expected variation of full-scale wind speed and turbulence at each proposed bridge deck elevation. The reference wind speed measured in the wind tunnel has been scaled such that the expected full-scale wind speeds at the deck elevation are achieved.



3 THE DETERMINATION OF WIND PROFILES ON THE BRIDGE DECK

3.1 General

- The primary aim of the wind tunnel investigation was to identify the effect that deck elevation and traffic barrier configuration have on the wind velocity profile in the upwind and downwind traffic lanes. The experimental component of the investigation included the measurement of the velocity flow field across the bridge deck. The instrumentation was able to capture the mean wind velocity, as well as the turbulence intensity for each deck elevation and traffic barrier size.
- Wind tunnel tests were performed using the 1:60 scale section models (as described in Section 1) as a test bed for the velocity measurements.
- Statistics of the mean wind velocity and turbulence intensity for each location of measurement were determined from recorded time histories.
- Views of the models are shown in Figures 3 through 6.

3.2 Aerodynamic Data

- A hotwire anemometer which was sensitive to both the vertical and longitudinal wind components was used with an automatic traversing apparatus to determine the variation with height of the velocity field in each traffic lane on the bridge deck. The locations of the measurements can be seen marked on the model (as crosshairs) in Figure 14. The locations are measured as +/- 11' from the centerline crown of the bridge deck and are representative of the wind velocity profiles experienced by vehicles. The heights at which the measurements were taken ranged from 15" to 600" (full scale), and are shown in Figure 15 (deck Type B and 32" Barrier case is shown). Identical heights were used for each configuration. At a height of about 300" (full scale), the impact of the bridge on the flow was no longer seen, and the wind exhibited characteristics similar to those in the free-stream.
- The tests were performed in boundary layer winds which simulate those which would exist during pre-hurricane conditions under which vehicles would be expected to use the bridge during evacuation. Values of the mean and root-mean-square (RMS) wind speed were recorded for various heights above the bridge deck for i) different deck elevations and ii) different barrier types.
- The experimental configurations are described below:

Configuration	Section Type	Barrier Height	Deck Elevation	Lane
1	A	32"	Mid-level	Upwind
2	A	32"	Mid-level	Downwind
3	A	32"	High-level	Upwind
4	A	32"	High-level	Downwind
5	A	42"	High-level	Upwind
6	A	42"	High-level	Downwind
7	B	32"	Mid-level	Upwind
8	B	32"	Mid-level	Downwind
9	B	32"	High-level	Upwind
10	B	32"	High-level	Downwind
11	B	42"	High-level	Upwind
12	B	42"	High-level	Downwind



3.3 Velocity Field Over the Bridge Deck

- The vertical profiles of the velocity field for each configuration are plotted in Figures 16 through 21. The wind profiles in the upwind and downwind traffic lanes are plotted on the same chart for each configuration. The mean longitudinal velocity as seen by the hotwire probe is normalized to a value of 1.0 at its maximum height, which is in the free stream mean velocity above the bridge deck. The horizontal component of turbulence is also considered, and is expressed as a gust velocity. The peak velocity, or gust velocity, is formed from the sum of the mean plus 1.5 times the RMS quantity. It is this peak velocity which is indicative of the strength of the wind important for vehicle stability. The velocity is also normalized to the maximum mean speed in order to properly show the increase due to turbulence.
- The shear layer (ie. the layer between the highly turbulent separated flow region immediately above the bridge deck and the undisturbed outer layer), is clearly defined through the measurements. The presence of the shear layer is evident from the bulge in the gust velocities and is generated by the separation of the flow from the top of the barrier at the leading edge of the deck. For section type B, the formation of the shear layer is not as well defined, as it is prevented by the presence of the railing upwind of the barrier.
- For section type A, the upwind lane experiences considerably greater peak wind velocities than the downwind lane. The greatest peak velocity was found to occur at a height of approximately 100" (full scale) from the bridge deck. This can be attributed to an increase in mean velocity due to speed up over the barrier, as well as vortices that create areas of high turbulence intensities over this height range. The mean and peak wind velocity profiles for the section type A tests are plotted in Figures 16 through 18.
- For section type B, the upwind lane again experiences greater peak wind velocities than the downwind lane. The greatest peak velocities were found to occur over a range of approximately 90" to 135" (full scale) from the bridge deck. This is also attributed to speed up over the leading edge of the bridge, as well as turbulence induced by the wall and railing. The traffic barriers appear to have negligible effect for section type B. The mean and peak wind velocity profiles for the section type B tests are plotted in Figures 19 through 21.
- Although providing some shielding to vehicles from the strong mean flow, the presence of the traffic barrier on the leading edge (which is important for bridge section type A), also results in a region of high turbulence intensities and likely flow reversal. This phenomenon of flow reversal was confirmed through the smoke flow visualization, where the vortices created by the traffic barriers can be observed, as seen in Figure 22. The hotwire technique used in the velocity measurements is equally sensitive to positive and negative velocity fluctuations (ie. up or down, upwind or downwind). This insensitivity to flow direction in effect "rectifies" the signal, and therefore will over-estimate the RMS of the fluctuating wind if there is significant flow reversal. The presence of vortices within the separated flow region will cause flow reversal and therefore an apparent increase in the RMS, and hence the turbulence intensity.

3.4 Smoke Flow Visualization

- Smoke flow visualization was performed for section type A with 45' clearance with each traffic barrier, and for section type B with 65' clearance with each traffic barrier. The flow visualization study included proposed section types A and B, as well as the two traffic barrier designs. For each section, the 32" and 42" F-shape barriers were placed on the leading edge of the bridge deck. The flow visualizations were conducted for winds perpendicular to the bridge span and used an upstream profile representative of pre-hurricane water surface conditions.
- From the flow visualization, it was noted for section type A that:
 1. Eddies of turbulent flow result from interaction of the leading edge of the bridge deck with the upstream flow. These turbulent eddies can be seen throughout the flow visualization video and in Figure 22. More turbulence is present in the upstream lane, which is due to its proximity to the traffic barrier initiating the vortices. It can also be seen that the 42" traffic barrier provides more shielding to low-level vehicles than its 32" counterpart.



2. Speed up of the wind flow results as it passes over the leading edge traffic barrier. This leads to slightly higher wind velocities at heights just above the barrier height than are present in the wind flow upstream of the bridge. Wind speeds below the height of the barrier are significantly less than those upstream of the bridge.
- From the flow visualization, it was noted for section type B that:
 1. Lower turbulence levels for small vehicles due to shielding is provided by the wall and railing on the leading edge of the bridge deck. This should result in less 'gusty' wind in the traffic lanes for section type B than with section type A. This can be seen throughout the flow visualization video and in Figure 22.
 2. The flow is diffused as it passes through the railing elements, which results in a greater zone of lower wind speeds in the traffic lanes than with section type A. The presence of the wall and railing also reduces the importance of the traffic barrier height, as the wind flow is primarily affected by the leading edge.
 - The conclusions drawn from the smoke flow visualization corroborate the measurements taken by the hotwire anemometers.

3.5 Comparison of Bridge Deck Configurations

- As mentioned in the above paragraphs, the mean wind speed and turbulence intensities were compared for different bridge deck configurations. Differences in the elevation of the bridge deck are discussed first. Secondly, the differences in mean wind speed on the deck are compared for different traffic barrier heights and section types.
- Effect of Bridge Deck Elevation
 1. For a wind velocity profile with a characteristic roughness length used for rough seas, such as those in pre-hurricane conditions, wind velocities will increase as the elevation above water becomes greater. The mean wind speed at the lower of the proposed heights is expected to be approximately 12% greater than the reference wind speed at 33'. The mean wind speed at the higher of the proposed heights is expected to be approximately 20% greater than the reference wind speed at 33'. It should be noted that winds which occur as hurricanes or accompanying thunderstorms possess different meteorological mechanisms than traditional synoptic winds (such as those resulting from large system pressure gradients). While boundary layer methodology is a good description of strong winds as they approach the bridge, the wind fields that exist in hurricanes will differ significantly in structure. This being noted, it is not expected that any traffic, pedestrian or vehicular, will be present on the bridge during the hurricane event.
 2. For both section types A and B, the elevation of the bridge deck was found to have no influence on the structure of the turbulence. This is most likely due to the similarity in free stream turbulence structure and intensity between each proposed deck elevation (within approximately 1% in magnitude between the heights). This is true for both the upwind and downwind traffic lanes. Each bridge deck elevation will therefore exhibit very similar gust behavior provided the leading edge is the same.
- Effect of Traffic Barrier Height
 1. For section type A, the height of the traffic barrier does have an effect on the structure of the turbulence intensity. A comparison of the RMS values measured for each traffic barrier show that for the 42" traffic barrier, the heights over which the largest turbulence intensities occur are shifted slightly upwards. When comparing the lanes, each lane exhibits similar turbulence intensities to approximately 90", at which point the measurements in the downstream lane become approximately 10% more turbulent until a height of 250" is reached. At this point, each lane exhibits similar profiles once again. These cases are compared for the upwind and downwind lanes in Figures 23 and 24, respectively.



2. For section type B, the height of the traffic barrier does not have an effect on the structure of the turbulence intensity. This is most likely due to the presence of the wall and railing on the leading edge of the bridge, which blocks a great deal of wind from interacting with the traffic barriers. These cases are compared for the upwind and downwind lanes in Figures 25 and 26, respectively.
- Effect of Section Type
 1. While the section type A leading edge results in lower mean and peak wind velocities for low-profile vehicles (<90" in height), the peak wind velocity becomes significantly greater for heights ranging from 100" to 180" (full scale). Heights in this range are significantly important for high-profile vehicles, such as tractor-trailers, which are more sensitive to overturning moments due to their exposed area and height. However, if high-profile vehicles are not considered in evacuation procedures, it can be noted that section type A with a 42" traffic barrier realizes a ~20% reduction in peak wind speed compared to section type B. This reduction is also realized in the downwind lane, but to a lesser extent. The reduction in peak wind velocity could possibly increase with a further increase in traffic barrier height. These wind profile cases are compared for upwind and downwind lanes in Figures 27 and 28, respectively.



4 THE PREDICTION OF BRIDGE DECK WIND SPEEDS

4.1 Overall Approach

- In order to provide estimates of the wind speeds likely to occur on the bridge deck, three components were considered:
 1. Firstly, the aerodynamic data measured during the test was used to provide an expression of the peak wind velocity. This method allows the inclusion of the turbulence intensity, or gustiness, of the wind. These results were presented in Section 3.
 2. Secondly, the wind speeds at each of the proposed elevations (mid-level and high-level) were related to a 33' reference wind speed in open country conditions, which is the standard anemometer placement height for wind records. The profile used for modeling the increase in wind speed over the heights was based on a surface roughness representative of rough water. Consequently, the wind speed at the mid-level elevation was found to be approximately 11% greater than that at 33' reference height, and the wind speed at the high-level elevation was found to be approximately 19% greater than the 33' reference height. As the ambient wind speed increases with elevation, the bridge deck wind speeds are typically greater at higher elevations.
 3. Thirdly, sizes of different vehicles were considered. The sizes used were agreed upon through consultation with the client, and are shown in the table below. The heights are a good representation of the different types of vehicles that use the existing bridge. For each of the heights, the largest peak wind speed measured in the experiment was used to calculate a maximum gust over the height of the vehicle. For each vehicle size, the largest peak wind velocity over the height of the vehicle for each configuration was tabulated. This information is provided in Table 1. These values can also be found in Figures 16 through 21. The peak wind velocity is the increase in wind speed due to the speed up over the leading feature of the bridge.

Vehicle	Height above Deck
Passenger Car	58"
Passenger Van	74"
Industrial van	84"
Tractor trailer	168"

- The wind speed that results from the combination of these factors is useful in providing comparison between the different deck configurations. The peak bridge deck wind speeds as a function of peak wind speed at a reference height of 33' are shown in Tables 2 through 5. These results are shown plotted in Figures 29 through 36.
- An approximate comparison to what can be expected to occur in the existing bridge is also provided, as the existing configuration was not tested. The results provided for the existing configuration used aerodynamic data from configurations 1 and 2 for the upwind and downwind lanes, respectively, as those configurations were deemed closest to the existing conditions. The elevation of the existing deck was also accounted for, which results in winds slightly less than those measured at the 33' reference height. The inferred plots of existing configurations should be used for the purpose of an approximate comparison only.



5 SUMMARY OF OPERATIONAL PROCEDURES IN HIGH WIND CONDITIONS

5.1 Review of Existing Operational Procedures in High Wind Conditions

- The following examples of traffic regulations are operational procedures used by other jurisdictions to maintain safe crossing during high wind conditions and are included for the consideration of the client. The weather patterns and climatic conditions may be significantly different than those experienced by the Anna Maria Island Bridge. The selection of bridges includes the Chesapeake Bay and Mackinac Bridges in the United States, the Confederation Bridge in Canada and the Forth Road Bridge in Scotland. It is important to note that in each of the following cases, site wind conditions are monitored by the bridge operator and used to regulate traffic.

5.1.1 Chesapeake Bay Bridge, Virginia Beach, VA

- The Chesapeake Bay Bridge is a multi-tower suspension bridge with a total span of 4.3 miles and a vertical clearance of 186'. The traffic regulations provided for the Chesapeake Bay Bridge are used for high winds resulting from weather patterns excluding hurricanes and tornadoes. The wind speeds are based bridge-stationed anemometer readings. Operation of the bridge under hurricane and tornado high winds is typically halted.
 1. At a wind speed of 45 mph, empty tractor trailers and small trucks (ie. moving vans, school buses) are restricted.
 2. At a wind speed of 51 mph, motorcycles are restricted.
 3. At a wind speed of 56 mph, the bridge is only open to cars, pickup trucks, commercial buses and heavily laden tractor trailers.
 4. At a wind speed of 68 mph, the bridge is closed until further instruction is received from the Office of the Chief of Police.

5.1.2 Mackinac Bridge, Mackinaw City, MI

- The Mackinac Bridge is a multi-tower suspension bridge with a total span of 5 miles and a vertical clearance of 154'. The traffic regulations provided for the Mackinac Bridge are based on wind speeds recorded by anemometers on the bridge.
 1. At a 5-minute sustained wind speed of 20 mph, traffic speed is limited to 20 mph and drivers are required to travel with 4-way flashers.
 2. At a 5-minute sustained wind speed of 50 mph, partial closure of the bridge occurs and traffic is reduced to a single lane. Passage is limited to passenger cars, passenger vans and empty pickup trucks (without caps or toppers). Traffic speed is limited to 20 mph and drivers are required to travel with 4-way flashers.
 3. At a 5-minute sustained wind speed of 65 mph, complete closure of the bridge occurs. The bridge closure remains in effect until the average wind speed falls below 65 mph for at least 10 minutes.

5.1.3 Confederation Bridge, Northumberland Straits, Canada

- The Confederation Bridge is a multi-span concrete box girder bridge with a total span of 8 miles and a vertical clearance of 197'. The Confederation Bridge has three anemometers over the length of the bridge which provides speed and direction information and are used for traffic regulation.
 1. At a mean wind speed of 44-50 mph with gusts less than 56 mph, traffic speed is limited to 37 mph.



2. At a mean wind speed of 44-50 mph with gusts greater than 56 mph, the bridge is closed to trucks.
3. At a mean wind speed of 68 mph, traffic speed is limited to 25 mph. The bridge is closed to high profile vehicles.
4. At a mean wind speed greater than 68 mph, the bridge is closed to all traffic.

5.1.4 Forth Road Bridge, Edinburgh, Scotland

- The Forth Road Bridge is a suspension bridge with a span of 1.56 miles and a vertical clearance of 145'. The traffic regulations provided for the Forth Road Bridge are based on wind speeds recorded by anemometers on the bridge.
 1. At wind speeds with gusts exceeding 35 mph, traffic speed is limited to 40 mph.
 2. A wind speeds with gusts exceeding 45 mph, the bridge is closed to double-decked buses.
 3. A wind speeds with gusts exceeding 50 mph, the bridge is closed to high-profile vehicles (ie. moving vans, large trailers), motorcycles, bicycles and pedestrians.
 4. At wind speeds with gusts exceeding 65 mph, the bridge is closed to all vehicles except cars. Traffic speed is limited to 30 mph.
 5. At wind speeds with gusts exceeding 80 mph, the bridge is closed to all traffic.

5.2 Commentary on Vehicular Traffic Regulations

- Through the wind tunnel investigation of the proposed Anna Maria Bridge design alternatives, predictions of gust wind speeds for each of the bridge deck types at mid-level and high-level elevations were offered. However, it should be noted that while high winds are a major contributor to vehicle instability, there are many additional factors. Some of these factors include wind direction with respect to travelling direction, type of roadway surface and presence of precipitation (Reference 7). Other factors, which are much more difficult to quantify, include vehicle condition, driver experience/ability and driver fatigue. Important to the situation of evacuation is driver patience and behavior in heavy traffic conditions.

A SUMMARY OF THIS REPORT IS PRESENTED AT THE BEGINNING



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- 2) Vickery, P.J. and Twisdale, L.A. (1995), "Prediction of Hurricane Wind Speeds in the United States" *Journal of Structural Engineering*, Vol. 121 No. 11, pp. 1691-1699.
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- 4) Vickery, P.J., Skerlj, P.F., Steckley, A.C. and L.A. Twisdale (2000b) "A Hurricane Wind Field Model for Use in Hurricane Wind Speed Simulations", *Journal of the Structural Division*, ASCE, October.
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- 6) Surry, D. and Isyumov, N., "Model Studies of Wind Effects - A Perspective on the Problems of Experimental Technique and Instrumentation", Int. Congress on Instrumentation in Aerospace Simulation Facilities, 1975 Record, pp. 76-90.
- 7) Young, R.K., Liesman, J., "Estimating the relationship between measured wind speed and overturning truck crashes using a binary logit model", *Accident Analysis & Prevention*, Vol. 39, 574-580, 2007.



TABLES



**TABLE 1 MAXIMUM GUST WIND SPEED FACTORS FOR
DIFFERENT VEHICLE TYPES**

	Passenger Car	Passenger Van	Industrial Van	Tractor Trailer
Configuration	Max	Max	Max	Max
1	1.201	1.467	1.668	1.722
2	1.086	1.217	1.307	1.490
3	1.237	1.535	1.674	1.786
4	1.179	1.301	1.387	1.591
5	0.941	1.300	1.522	1.857
6	1.103	1.220	1.244	1.630
7	1.124	1.300	1.402	1.541
8	1.116	1.212	1.241	1.429
9	1.275	1.466	1.562	1.643
10	1.195	1.316	1.365	1.581
11	1.222	1.468	1.567	1.679
12	1.189	1.309	1.404	1.588
Existing Upwind	1.053	1.286	1.462	1.510
Existing Downwind	0.952	1.067	1.145	1.306

Notes:

- Existing values are inferred using experimental data measured for Configurations 1 and 2 and are provided as approximate comparative values.



TABLE 2 BRIDGE DECK GUST WIND SPEEDS FOR PASSENGER CARS

Upwind Configurations	Maximum Gust Bridge Deck Wind Speed (mph)						
Gust Wind Speed at 33'	1	3	5	7	9	11	*Existing
35	42.0	43.3	32.9	39.3	44.6	42.8	36.9
40	48.0	49.5	37.6	45.0	51.0	48.9	42.1
45	54.1	55.7	42.3	50.6	57.4	55.0	47.4
50	60.1	61.9	47.0	56.2	63.7	61.1	52.6
55	66.1	68.0	51.7	61.8	70.1	67.2	57.9
60	72.1	74.2	56.4	67.4	76.5	73.3	63.2
65	78.1	80.4	61.2	73.1	82.9	79.4	68.4
70	84.1	86.6	65.9	78.7	89.2	85.5	73.7
75	90.1	92.8	70.6	84.3	95.6	91.6	79.0
80	96.1	99.0	75.3	89.9	102.0	97.7	84.2
85	102.1	105.2	80.0	95.5	108.4	103.9	89.5
90	108.1	111.3	84.7	101.2	114.7	110.0	94.8
95	114.1	117.5	89.4	106.8	121.1	116.1	100.0
100	120.1	123.7	94.1	112.4	127.5	122.2	105.3

Downwind Configurations	Maximum Gust Bridge Deck Wind Speed (mph)						
Gust Wind Speed at 33'	2	4	6	8	10	12	*Existing
35	38.0	41.3	38.6	39.0	41.8	41.6	33.3
40	43.4	47.1	44.1	44.6	47.8	47.6	38.1
45	48.9	53.0	49.6	50.2	53.8	53.5	42.8
50	54.3	58.9	55.1	55.8	59.8	59.5	47.6
55	59.7	64.8	60.7	61.4	65.7	65.4	52.4
60	65.2	70.7	66.2	66.9	71.7	71.3	57.1
65	70.6	76.6	71.7	72.5	77.7	77.3	61.9
70	76.0	82.5	77.2	78.1	83.7	83.2	66.6
75	81.5	88.4	82.7	83.7	89.6	89.2	71.4
80	86.9	94.3	88.2	89.3	95.6	95.1	76.2
85	92.3	100.2	93.7	94.8	101.6	101.1	80.9
90	97.8	106.1	99.2	100.4	107.6	107.0	85.7
95	103.2	112.0	104.8	106.0	113.5	113.0	90.4
100	108.6	117.9	110.3	111.6	119.5	118.9	95.2

Notes:

1. The values presented in these tables are plotted for upwind configurations and downwind configurations in Figures 29 and 30, respectively.



TABLE 3 BRIDGE DECK GUST WIND SPEEDS FOR PASSENGER VANS

Upwind Configurations Gust Wind Speed at 33'	Maximum Gust Bridge Deck Wind Speed (mph)						
	1	3	5	7	9	11	*Existing
35	51.4	53.7	45.5	45.5	51.3	51.4	45.0
40	58.7	61.4	52.0	52.0	58.6	58.7	51.4
45	66.0	69.1	58.5	58.5	66.0	66.1	57.9
50	73.4	76.8	65.0	65.0	73.3	73.4	64.3
55	80.7	84.4	71.5	71.5	80.6	80.7	70.7
60	88.0	92.1	78.0	78.0	88.0	88.1	77.2
65	95.4	99.8	84.5	84.5	95.3	95.4	83.6
70	102.7	107.5	91.0	91.0	102.6	102.7	90.0
75	110.0	115.1	97.5	97.5	110.0	110.1	96.5
80	117.4	122.8	104.0	104.0	117.3	117.4	102.9
85	124.7	130.5	110.5	110.5	124.6	124.8	109.3
90	132.1	138.2	117.0	117.0	132.0	132.1	115.8
95	139.4	145.8	123.5	123.5	139.3	139.4	122.2
100	146.7	153.5	130.0	130.0	146.6	146.8	128.6

Downwind Configurations Gust Wind Speed at 33'	Maximum Gust Bridge Deck Wind Speed (mph)						
	2	4	6	8	10	12	*Existing
35	42.6	45.5	42.7	42.4	46.0	45.8	37.4
40	48.7	52.1	48.8	48.5	52.6	52.4	42.7
45	54.8	58.6	54.9	54.5	59.2	58.9	48.0
50	60.9	65.1	61.0	60.6	65.8	65.5	53.4
55	67.0	71.6	67.1	66.6	72.4	72.0	58.7
60	73.0	78.1	73.2	72.7	78.9	78.5	64.0
65	79.1	84.6	79.3	78.8	85.5	85.1	69.4
70	85.2	91.1	85.4	84.8	92.1	91.6	74.7
75	91.3	97.6	91.5	90.9	98.7	98.2	80.0
80	97.4	104.1	97.6	96.9	105.3	104.7	85.4
85	103.5	110.6	103.7	103.0	111.8	111.3	90.7
90	109.6	117.1	109.8	109.0	118.4	117.8	96.0
95	115.7	123.6	115.9	115.1	125.0	124.4	101.4
100	121.7	130.1	122.0	121.2	131.6	130.9	106.7

Notes:

1. The values presented in these tables are plotted for upwind configurations and downwind configurations in Figures 31 and 32, respectively.



TABLE 4 BRIDGE DECK GUST WIND SPEEDS FOR INDUSTRIAL VANS

Upwind Configurations Gust Wind Speed at 33'	Maximum Gust Bridge Deck Wind Speed (mph)						
	1	3	5	7	9	11	*Existing
35	58.4	58.6	53.3	49.1	54.7	54.8	51.2
40	66.7	67.0	60.9	56.1	62.5	62.7	58.5
45	75.1	75.3	68.5	63.1	70.3	70.5	65.8
50	83.4	83.7	76.1	70.1	78.1	78.3	73.1
55	91.7	92.1	83.7	77.1	85.9	86.2	80.4
60	100.1	100.4	91.3	84.1	93.7	94.0	87.7
65	108.4	108.8	99.0	91.1	101.5	101.8	95.0
70	116.7	117.2	106.6	98.1	109.3	109.7	102.3
75	125.1	125.6	114.2	105.1	117.2	117.5	109.6
80	133.4	133.9	121.8	112.1	125.0	125.3	117.0
85	141.8	142.3	129.4	119.1	132.8	133.2	124.3
90	150.1	150.7	137.0	126.2	140.6	141.0	131.6
95	158.4	159.0	144.6	133.2	148.4	148.8	138.9
100	166.8	167.4	152.2	140.2	156.2	156.7	146.2

Downwind Configurations Gust Wind Speed at 33'	Maximum Gust Bridge Deck Wind Speed (mph)						
	2	4	6	8	10	12	*Existing
35	45.7	48.6	43.6	43.4	47.8	49.1	40.1
40	52.3	55.5	49.8	49.6	54.6	56.2	45.8
45	58.8	62.4	56.0	55.8	61.4	63.2	51.5
50	65.3	69.4	62.2	62.1	68.3	70.2	57.3
55	71.9	76.3	68.4	68.3	75.1	77.2	63.0
60	78.4	83.2	74.7	74.5	81.9	84.2	68.7
65	84.9	90.2	80.9	80.7	88.7	91.3	74.5
70	91.5	97.1	87.1	86.9	95.6	98.3	80.2
75	98.0	104.0	93.3	93.1	102.4	105.3	85.9
80	104.5	111.0	99.6	99.3	109.2	112.3	91.6
85	111.1	117.9	105.8	105.5	116.0	119.3	97.4
90	117.6	124.9	112.0	111.7	122.9	126.4	103.1
95	124.1	131.8	118.2	117.9	129.7	133.4	108.8
100	130.7	138.7	124.4	124.1	136.5	140.4	114.5

Notes:

1. The values presented in these tables are plotted for upwind configurations and downwind configurations in Figures 33 and 34, respectively.



TABLE 5 BRIDGE DECK GUST WIND SPEEDS FOR TRACTOR TRAILERS

Upwind Configurations	Maximum Gust Bridge Deck Wind Speed (mph)						
Gust Wind Speed at 33'	1	3	5	7	9	11	*Existing
35	60.3	62.5	65.0	53.9	57.5	58.8	52.8
40	68.9	71.4	74.3	61.6	65.7	67.2	60.4
45	77.5	80.4	83.6	69.3	73.9	75.6	67.9
50	86.1	89.3	92.9	77.0	82.2	84.0	75.5
55	94.7	98.2	102.1	84.7	90.4	92.4	83.0
60	103.3	107.1	111.4	92.5	98.6	100.8	90.6
65	111.9	116.1	120.7	100.2	106.8	109.2	98.1
70	120.6	125.0	130.0	107.9	115.0	117.6	105.7
75	129.2	133.9	139.3	115.6	123.2	125.9	113.2
80	137.8	142.9	148.6	123.3	131.4	134.3	120.8
85	146.4	151.8	157.9	131.0	139.7	142.7	128.3
90	155.0	160.7	167.2	138.7	147.9	151.1	135.9
95	163.6	169.6	176.4	146.4	156.1	159.5	143.4
100	172.2	178.6	185.7	154.1	164.3	167.9	151.0

Downwind Configurations	Maximum Gust Bridge Deck Wind Speed (mph)						
Gust Wind Speed at 33'	2	4	6	8	10	12	*Existing
35	52.2	55.7	57.0	50.0	55.3	55.6	45.7
40	59.6	63.6	65.2	57.1	63.3	63.5	52.3
45	67.1	71.6	73.3	64.3	71.2	71.4	58.8
50	74.5	79.5	81.5	71.4	79.1	79.4	65.3
55	82.0	87.5	89.6	78.6	87.0	87.3	71.9
60	89.4	95.4	97.8	85.7	94.9	95.3	78.4
65	96.9	103.4	105.9	92.9	102.8	103.2	84.9
70	104.3	111.3	114.1	100.0	110.7	111.1	91.5
75	111.8	119.3	122.2	107.1	118.6	119.1	98.0
80	119.2	127.3	130.4	114.3	126.5	127.0	104.5
85	126.7	135.2	138.5	121.4	134.4	135.0	111.0
90	134.1	143.2	146.7	128.6	142.3	142.9	117.6
95	141.6	151.1	154.8	135.7	150.2	150.8	124.1
100	149.0	159.1	163.0	142.9	158.1	158.8	130.6

Note:

1. The values presented in these tables are plotted for upwind configurations and downwind configurations in Figures 35 and 36, respectively.



FIGURES



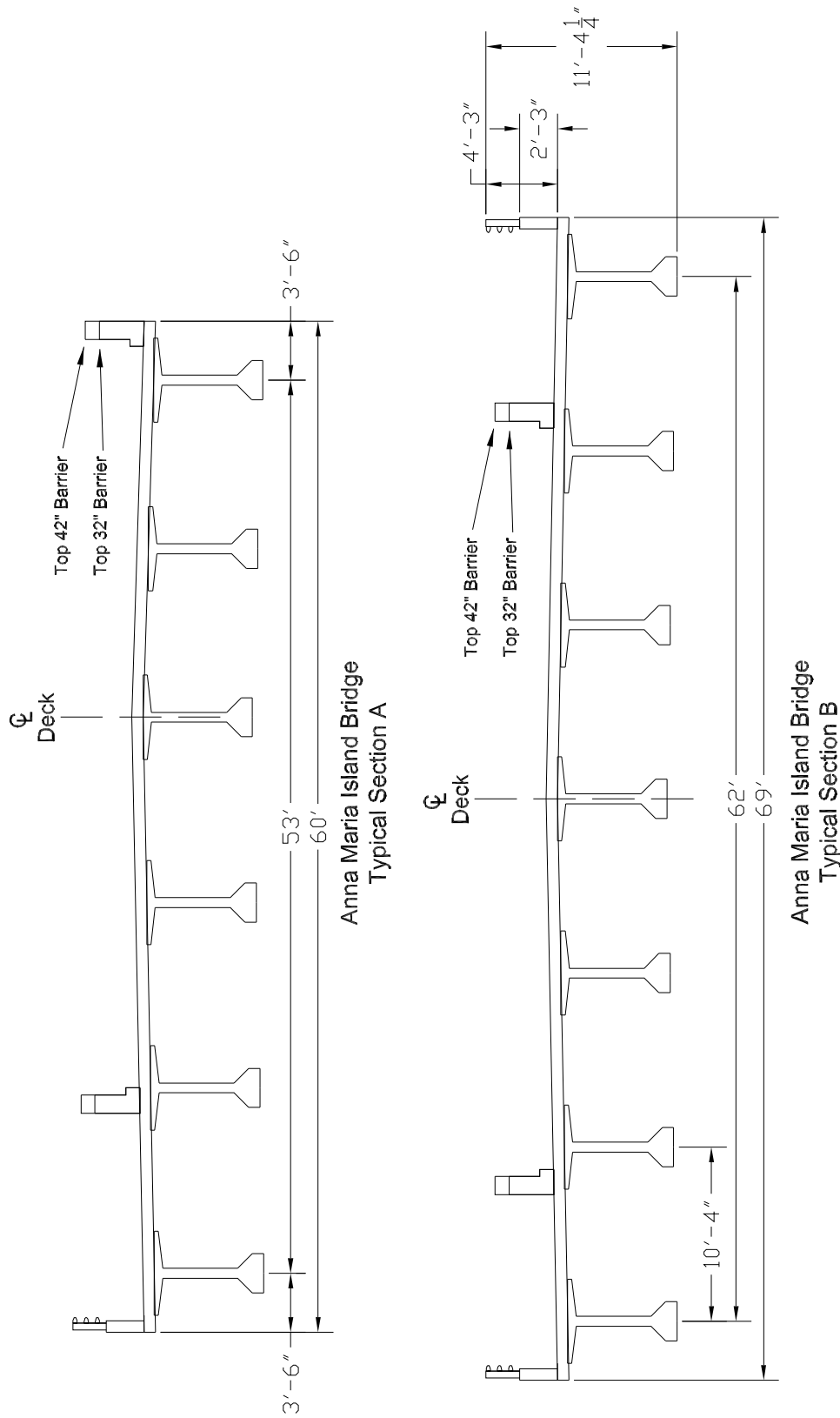


FIGURE 1 SECTION VIEWS OF THE BRIDGE DECK ALTERNATIVES

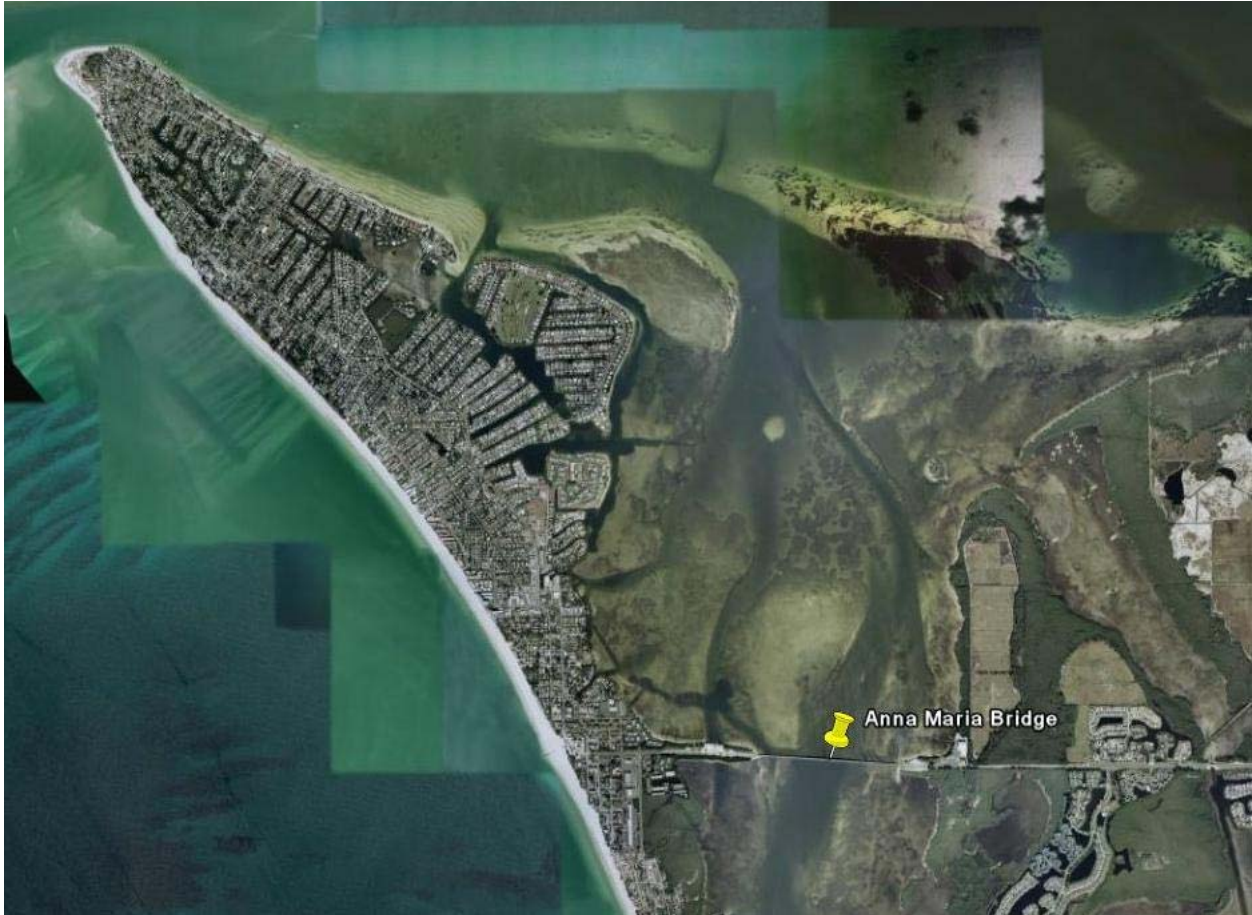


FIGURE 2 VIEW OF ANNA MARIA ISLAND AND BRIDGE SITE





FIGURE 3 **CLOSE UP VIEWS OF THE BRIDGE DECK MODEL TYPE A WITH 32" TRAFFIC BARRIER**





FIGURE 4 **CLOSE UP VIEWS OF THE BRIDGE DECK MODEL TYPE A WITH 42" TRAFFIC BARRIER**





FIGURE 5 CLOSE UP VIEWS OF THE BRIDGE DECK MODEL TYPE B WITH 32" TRAFFIC BARRIER





FIGURE 6 **CLOSE UP VIEWS OF THE BRIDGE DECK MODEL TYPE B WITH 42" TRAFFIC BARRIER**



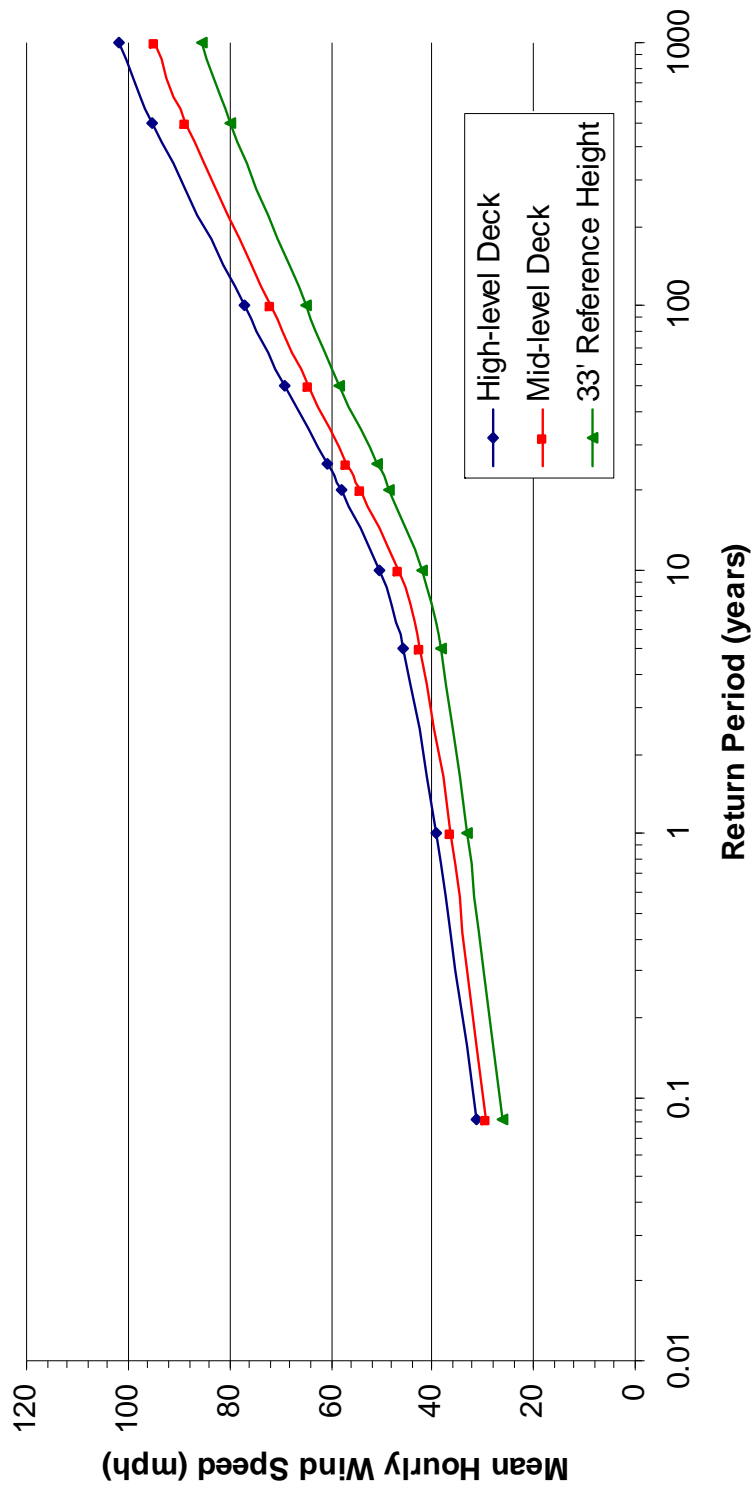
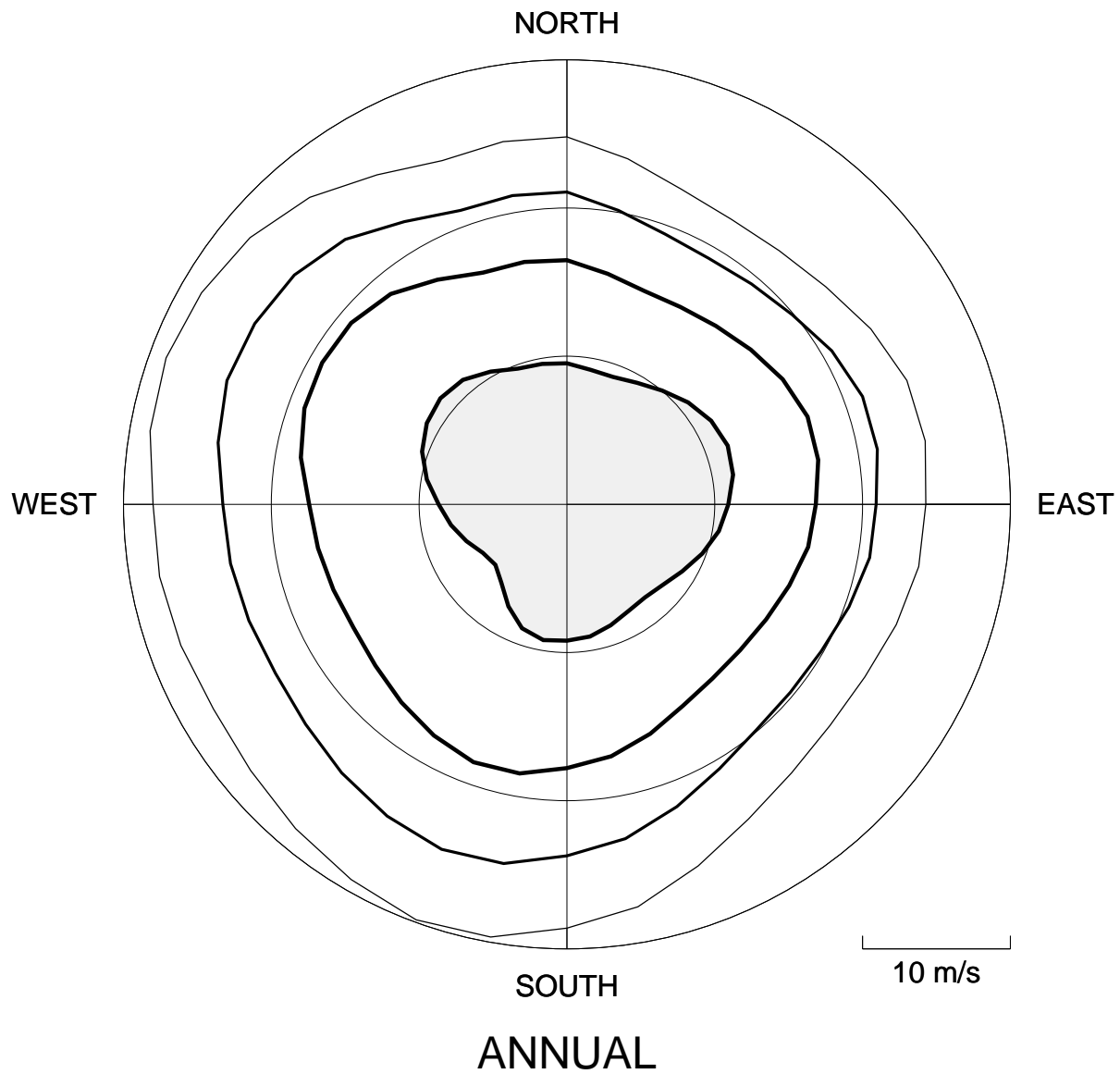


FIGURE 7 PREDICTED ANNUAL EXTREME WIND SPEEDS FOR VARIOUS RETURN PERIODS AT DIFFERENT DECK ELEVATIONS





A point on the innermost contour represents the wind speed exceeded 1% of the time within a 10 degree sector centred on that direction.
 Other contours represent probability levels of:
 0.1%, 0.01% and 0.001% respectively.

FIGURE 8 PROBABILITY DISTRIBUTION OF MEAN-HOURLY WIND SPEED



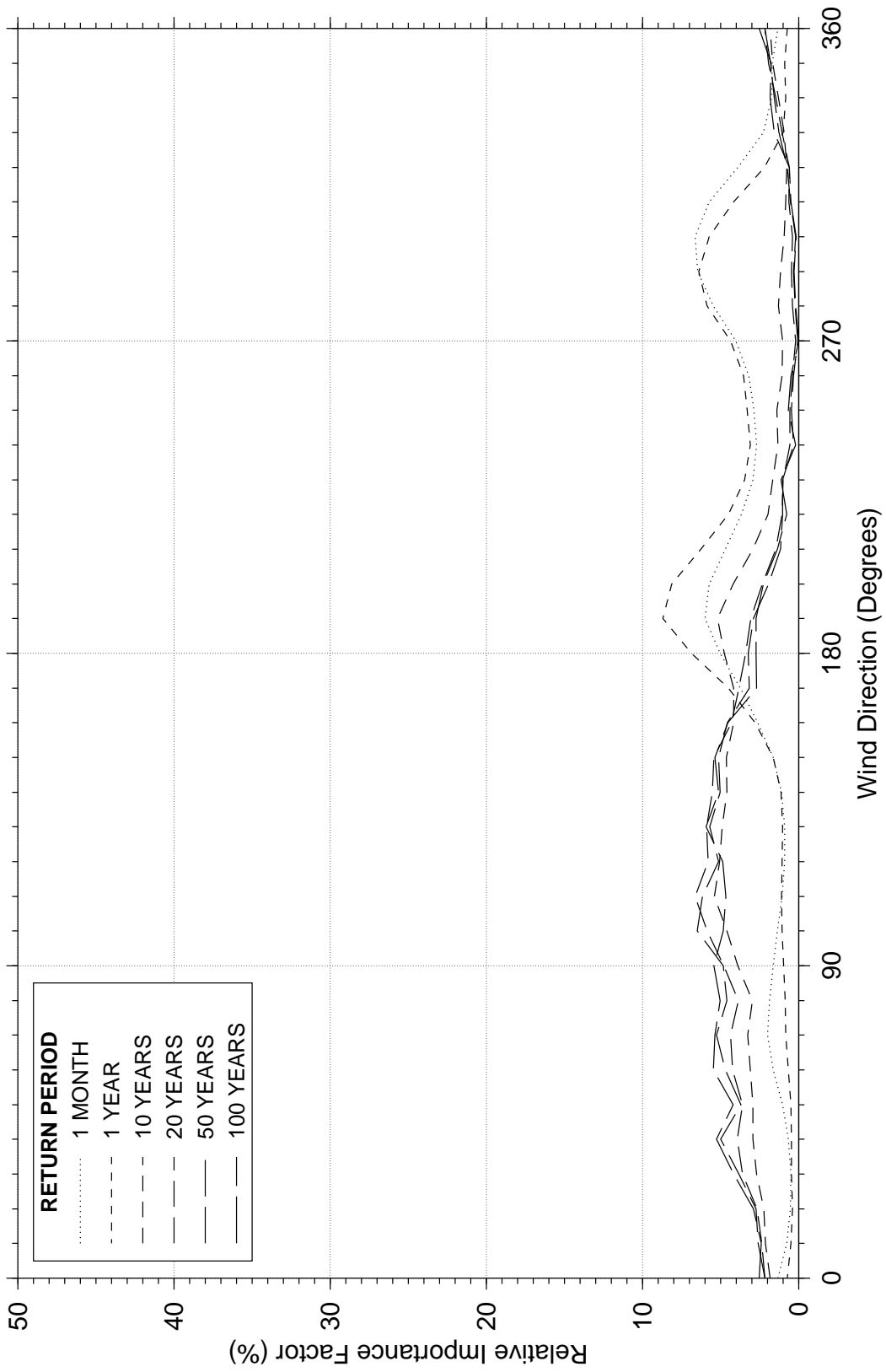


FIGURE 9 RELATIVE IMPORTANCE OF AZIMUTHAL SECTOR TO THE PROBABILITY OF EXCEEDING VARIOUS RETURN-PERIOD WIND SPEEDS



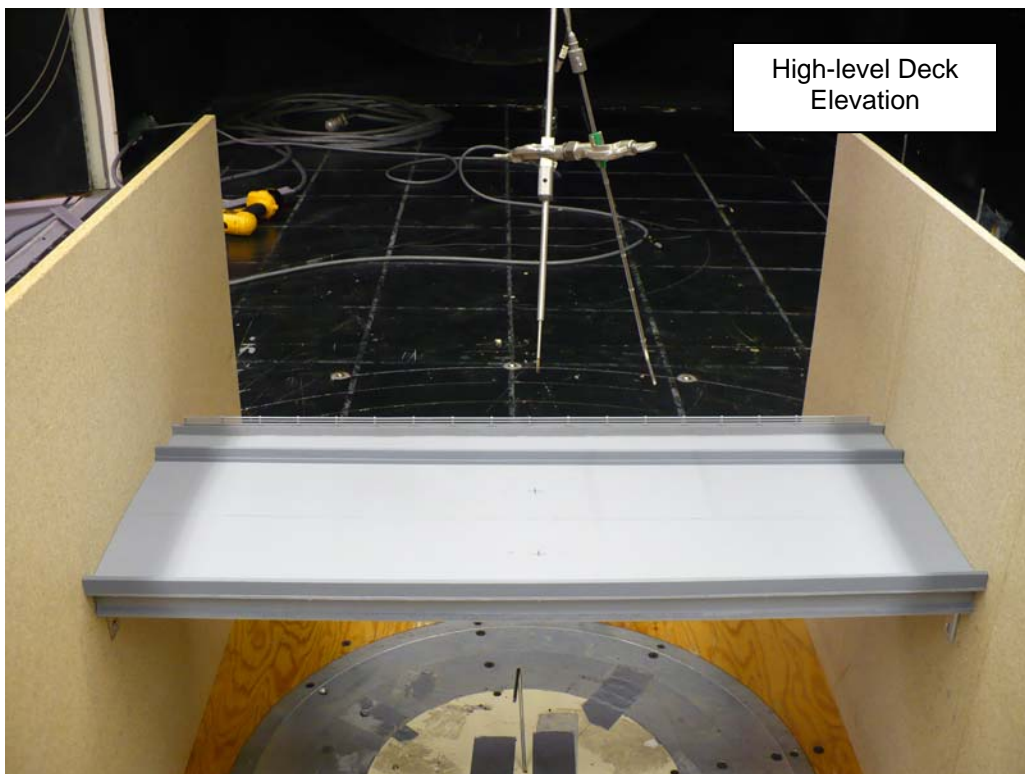
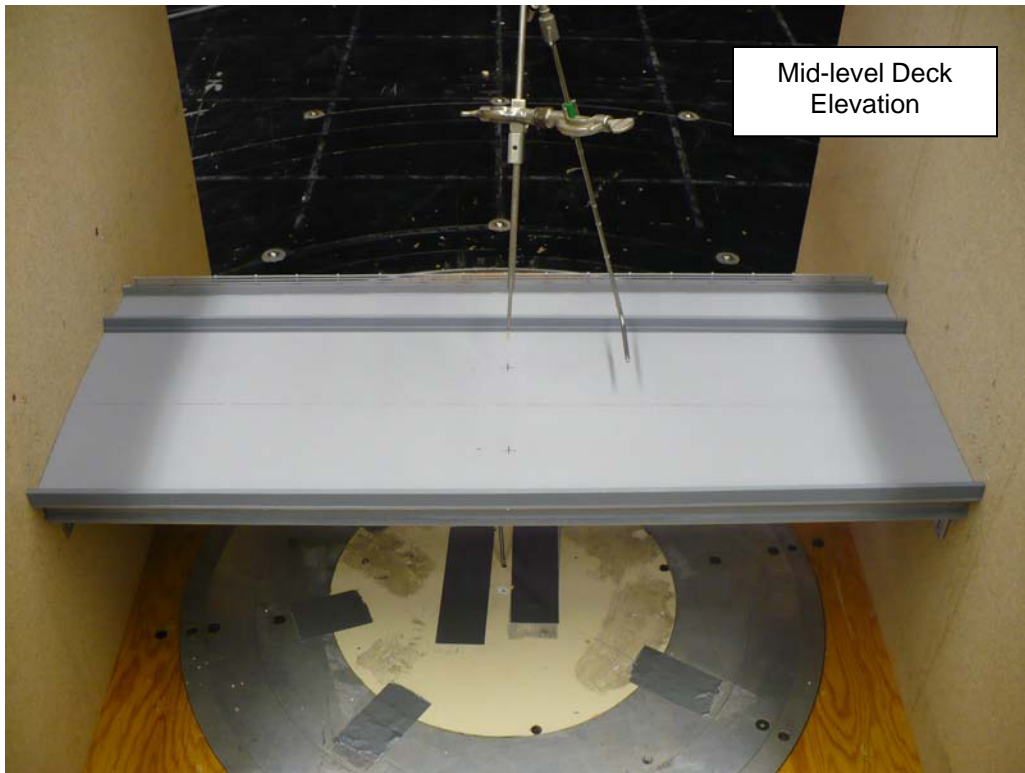


FIGURE 10 CLOSE UP VIEWS OF THE BRIDGE DECK SECTION TYPE A AT EACH OF THE PROPOSED ELEVATIONS



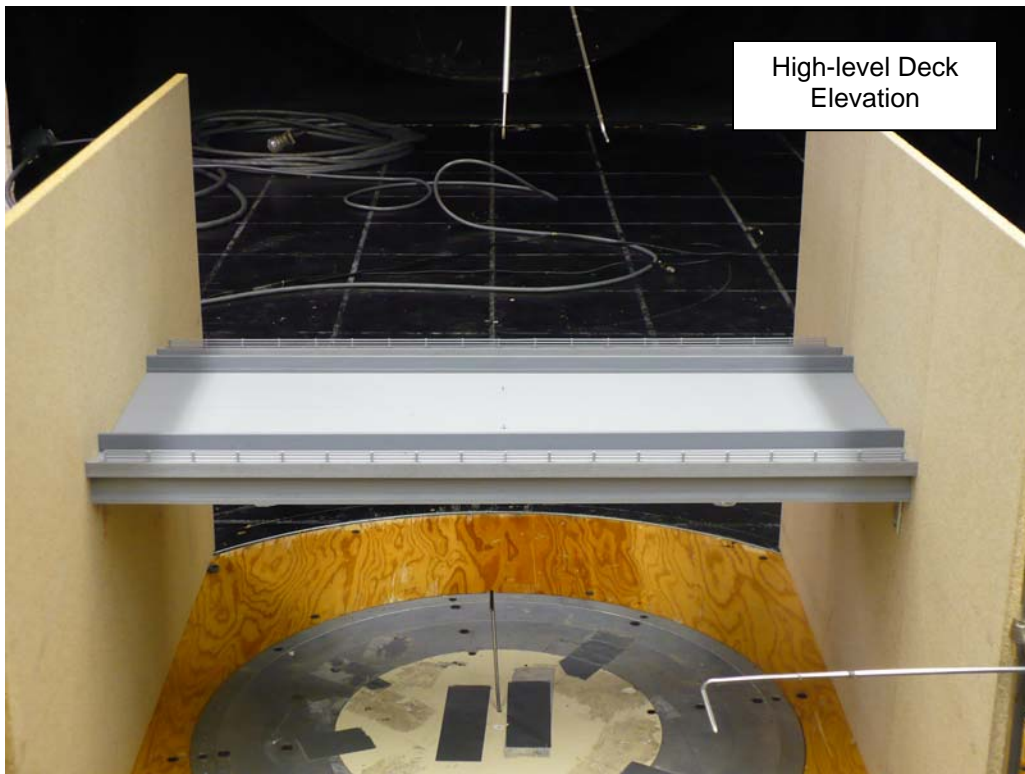
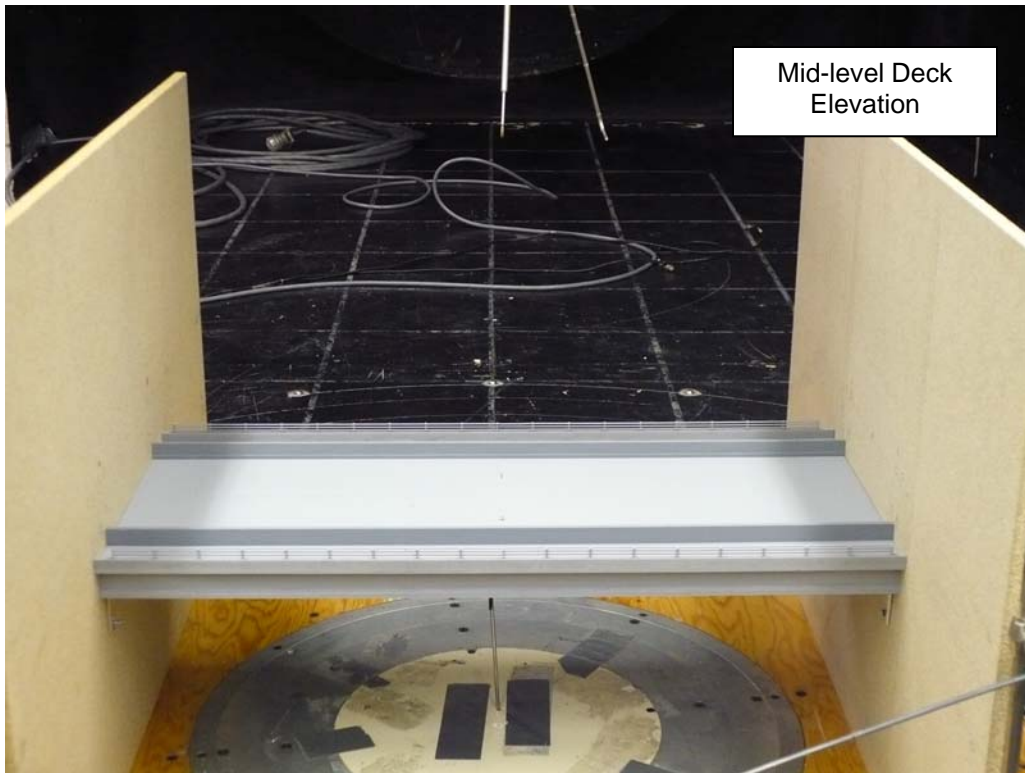


FIGURE 11 CLOSE UP VIEWS OF THE BRIDGE DECK SECTION TYPE B AT EACH OF THE PROPOSED ELEVATIONS





FIGURE 12 VIEW OF EXPERIMENTAL SET-UP SHOWING UPSTREAM MODELING ELEMENTS



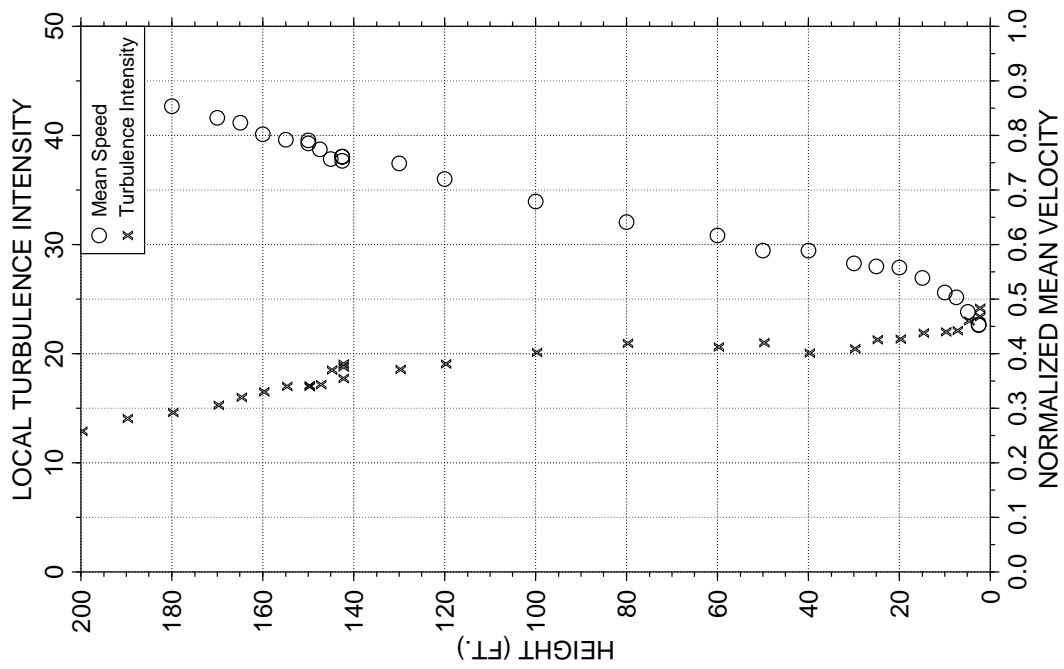


FIGURE 13 VERTICAL PROFILES OF MEAN WIND SPEED AND LONGITUDINAL TURBULENCE INTENSITY MEASURED JUST UPSTREAM OF THE TEST SECTION



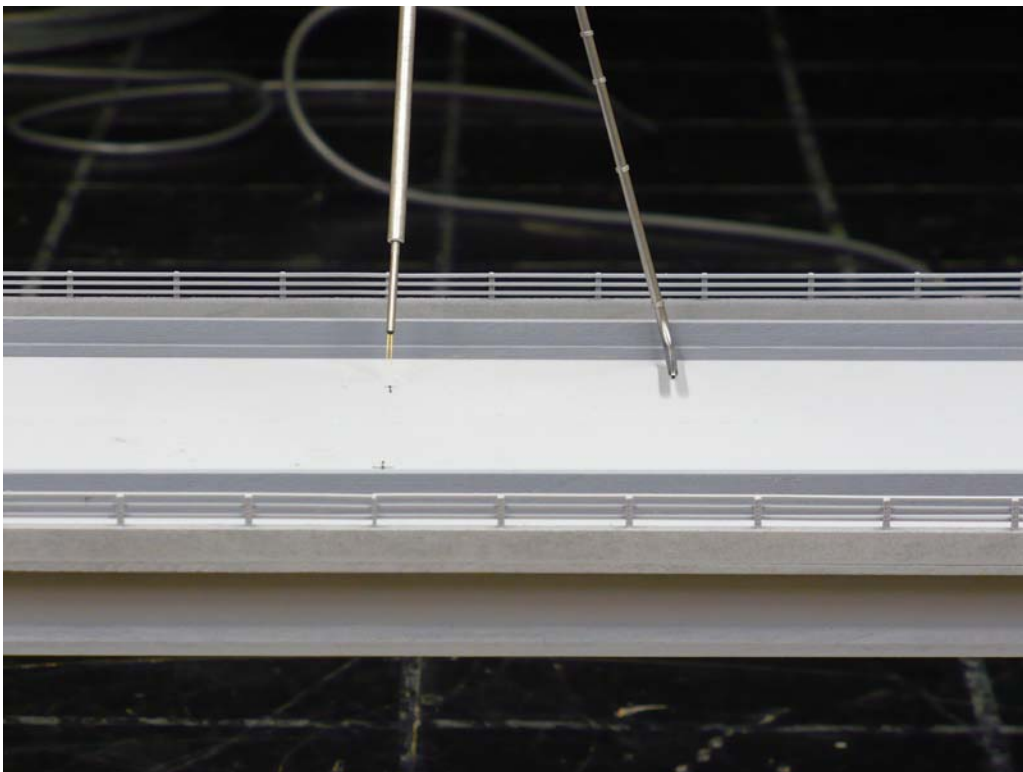


FIGURE 14 CLOSE UP VIEWS OF THE BRIDGE DECK MODELS WITH 32" TRAFFIC BARRIER SHOWING UPWIND AND DOWNWIND MEASUREMENT LOCATIONS



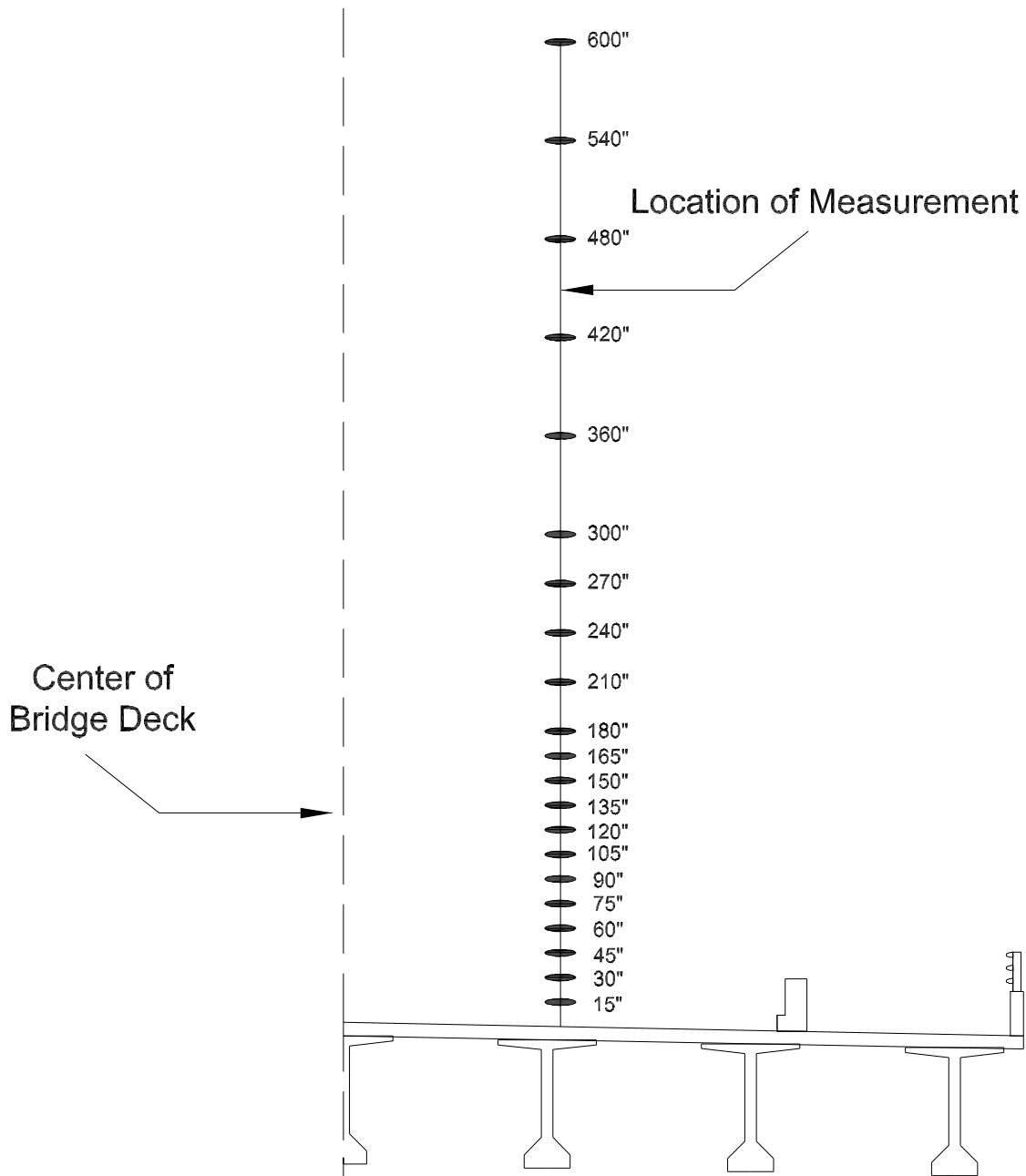


FIGURE 15 LOCATION OF HOTWIRE ANEMOMETER MEASUREMENTS WITH RESPECT TO HEIGHT FROM BRIDGE DECK



Section Type A - Bridge Deck Wind Velocity Profiles - 32" Barrier at Mid-level Deck Elevation

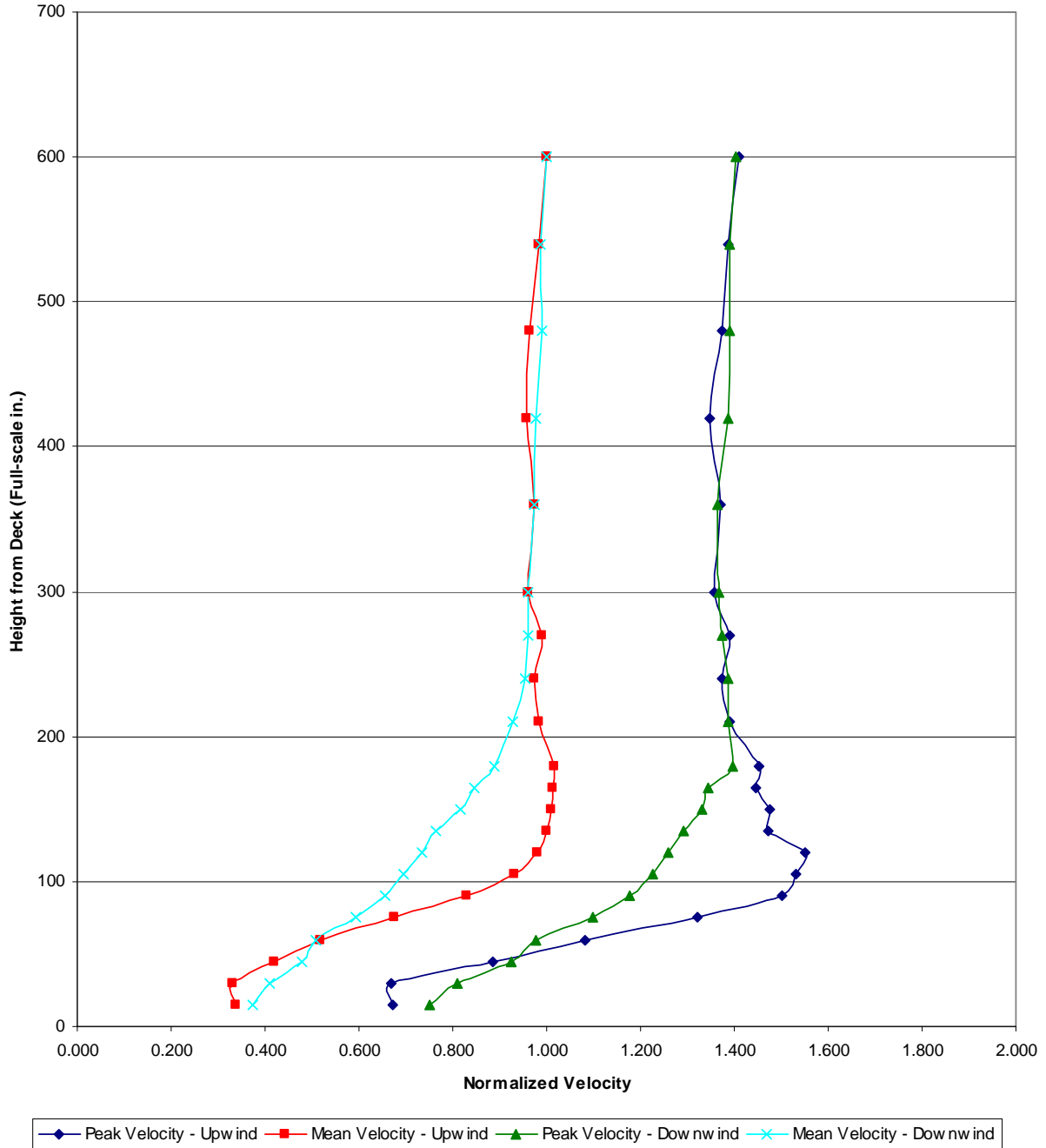


FIGURE 16 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 1 AND 2



Section Type A - Bridge Deck Wind Velocity Profiles - 32" Barrier at High-level Deck Elevation

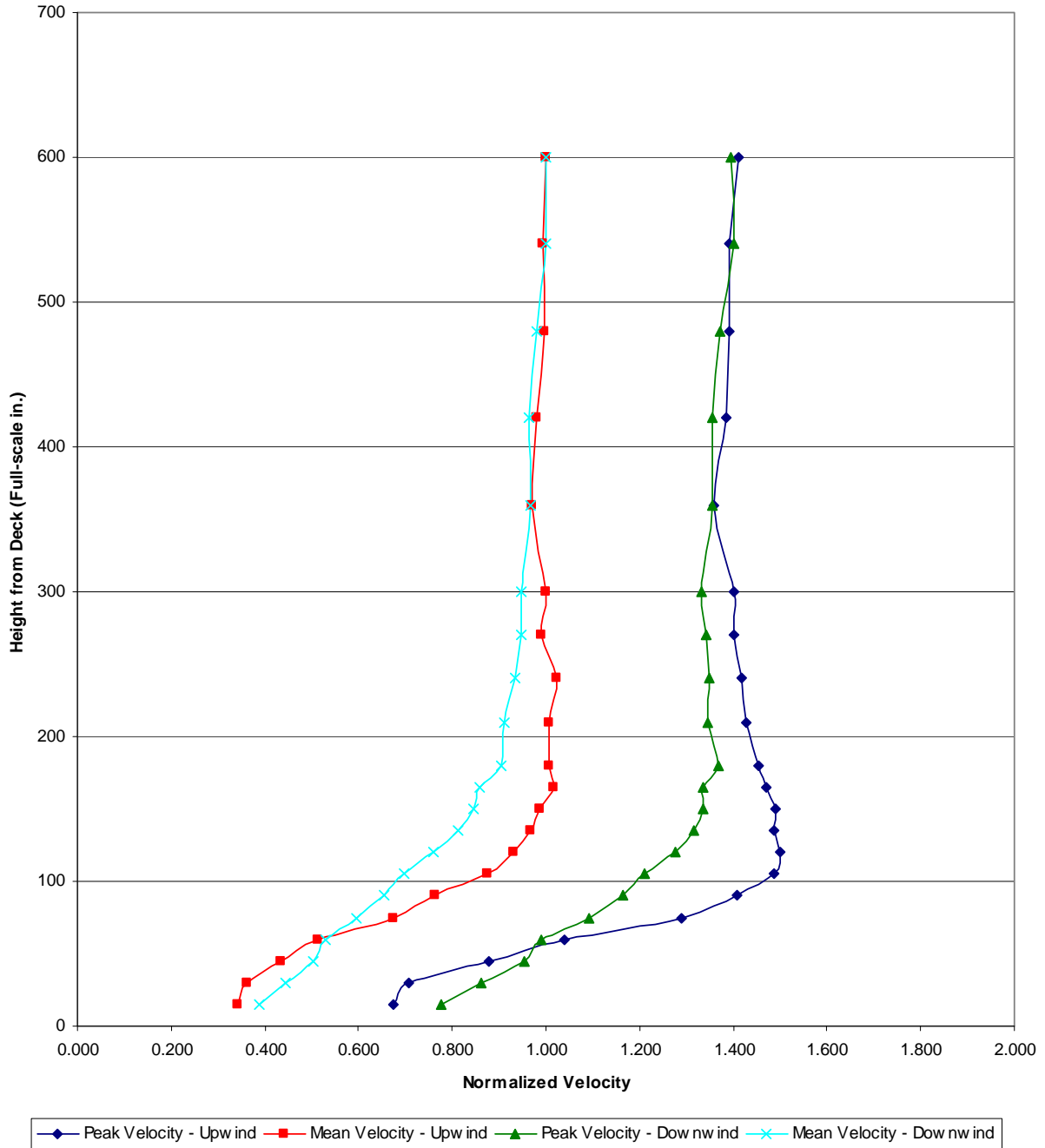


FIGURE 17 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 3 AND 4



Section Type A - Bridge Deck Wind Velocity Profiles - 42" Barrier at High-level Deck Elevation

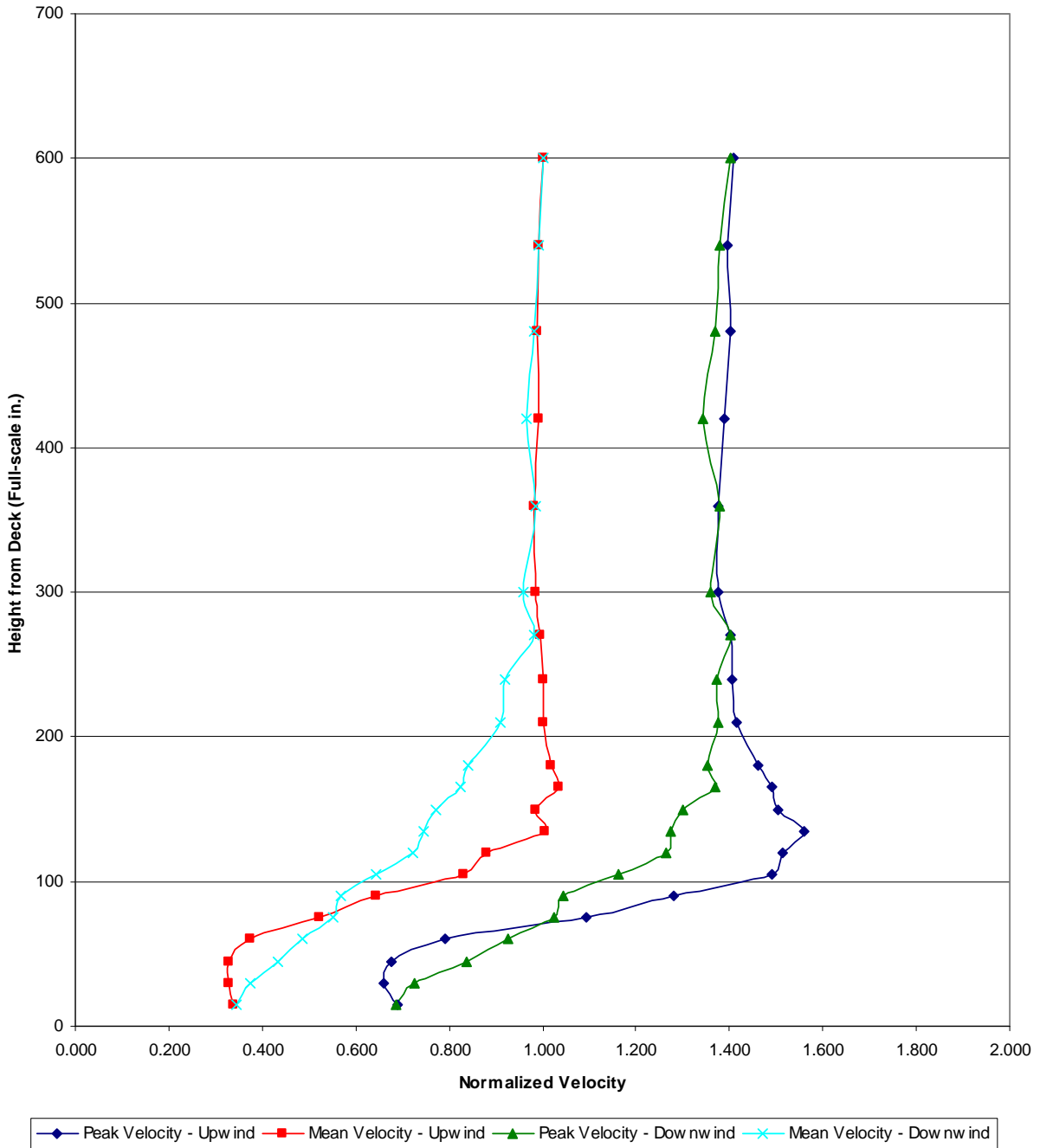


FIGURE 18 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 5 AND 6



Section Type B - Bridge Deck Wind Velocity Profiles - 32" Barrier at Mid-level Deck Elevation

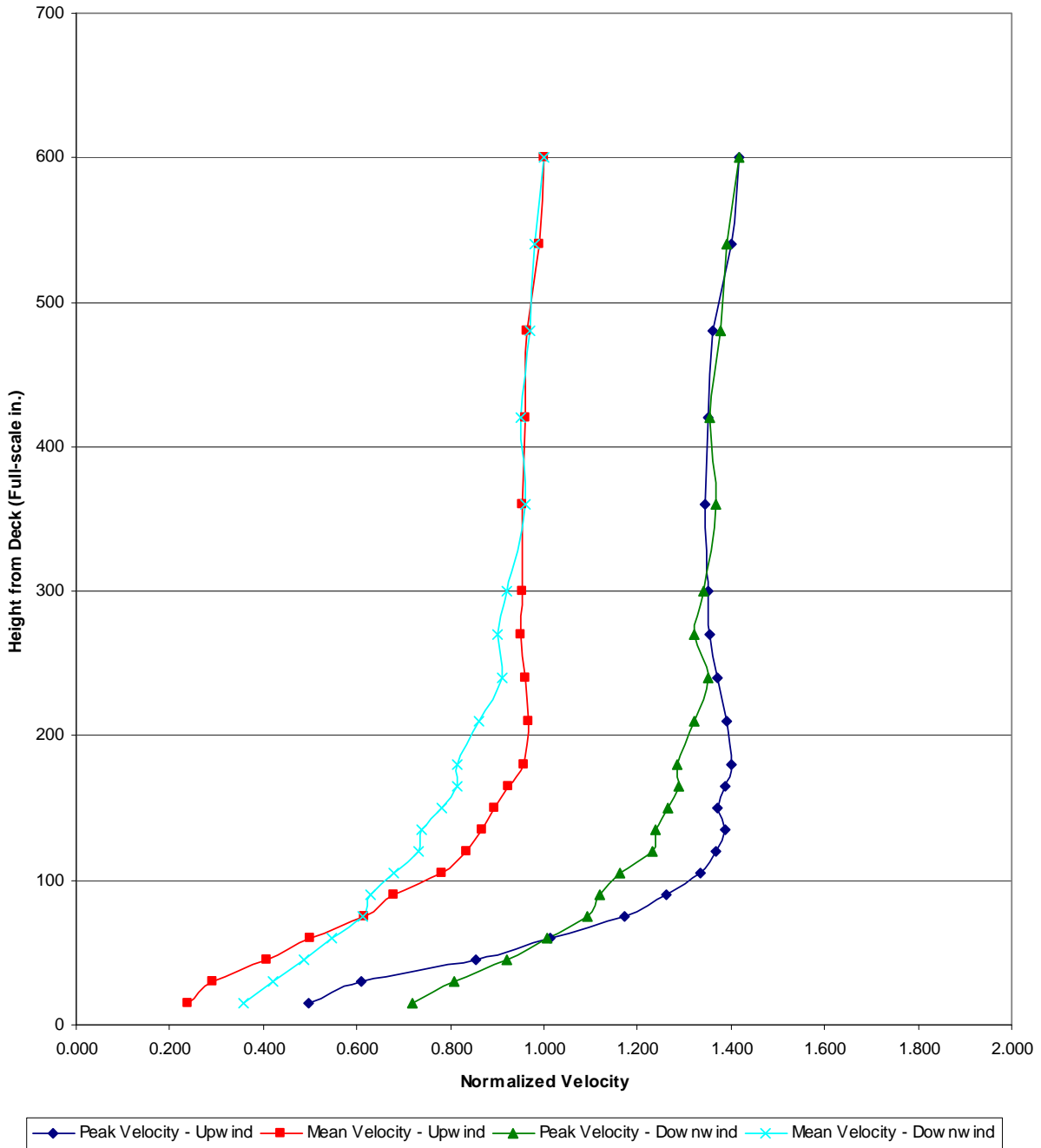


FIGURE 19 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 7 AND 8



Section Type B - Bridge Deck Wind Velocity Profiles - 32" Barrier at High-level Deck Elevation

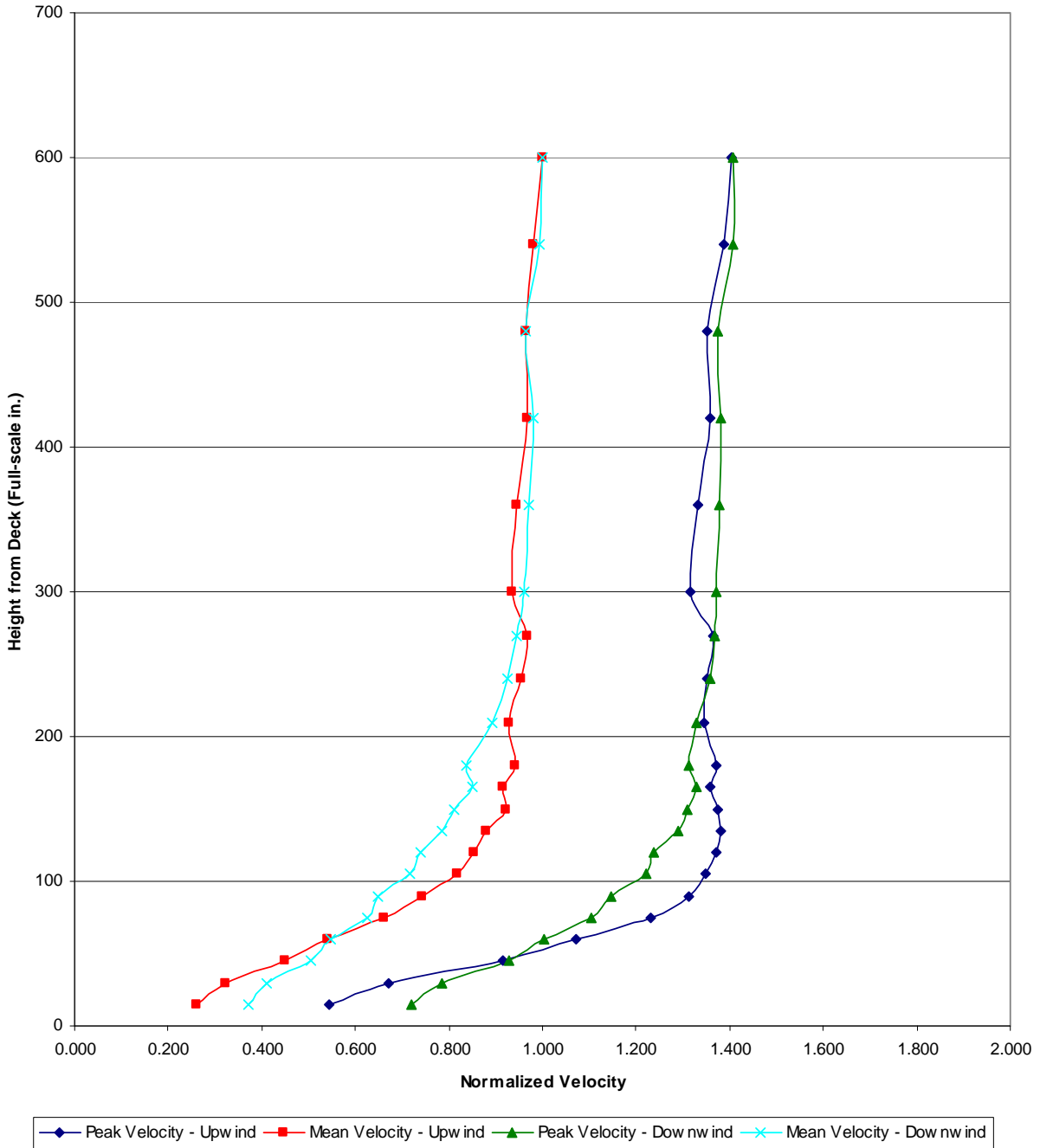


FIGURE 20 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 9 AND 10



Section Type B - Bridge Deck Wind Velocity Profiles - 42" Barrier at High-level Deck Elevation

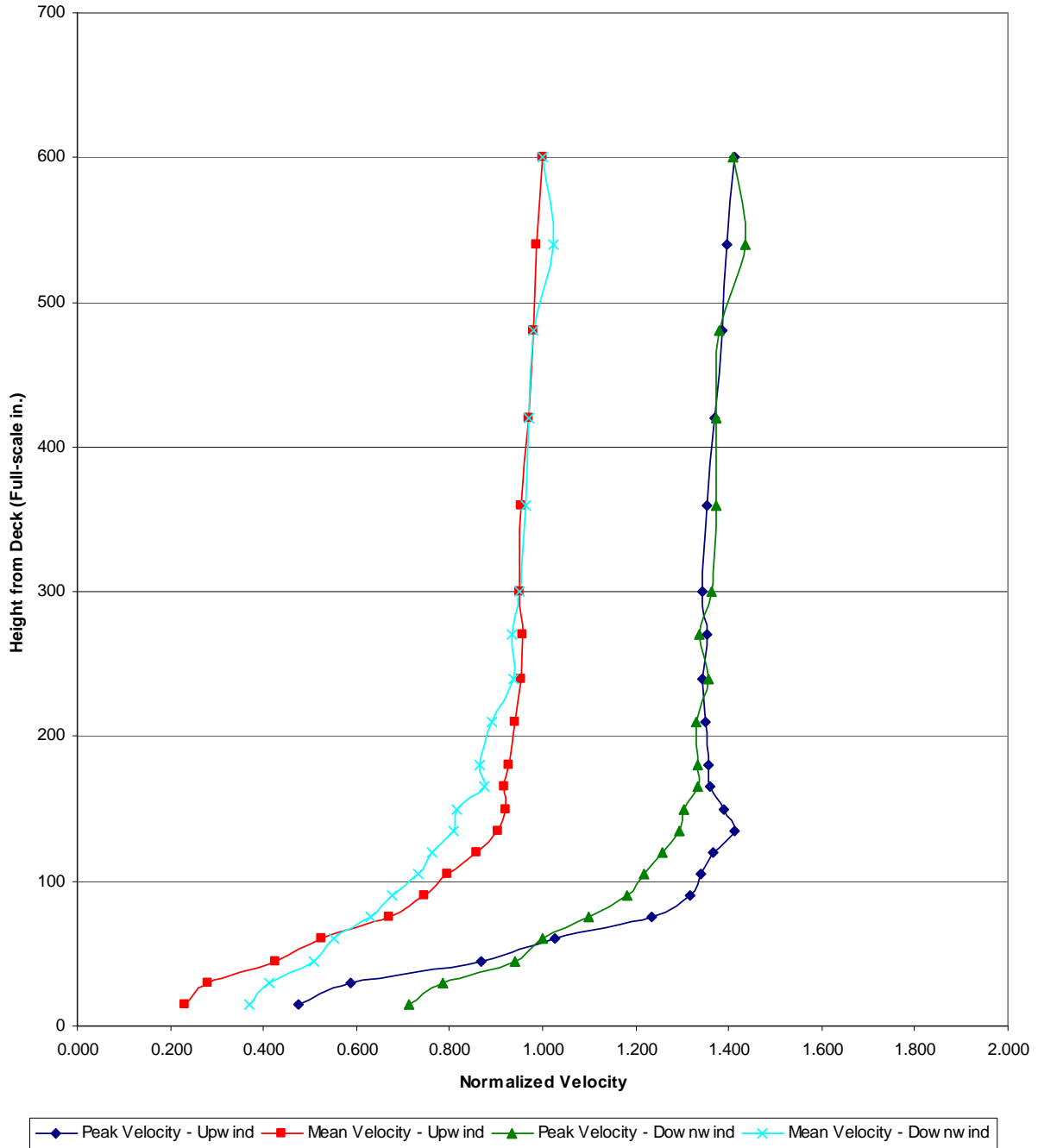


FIGURE 21 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 11 AND 12



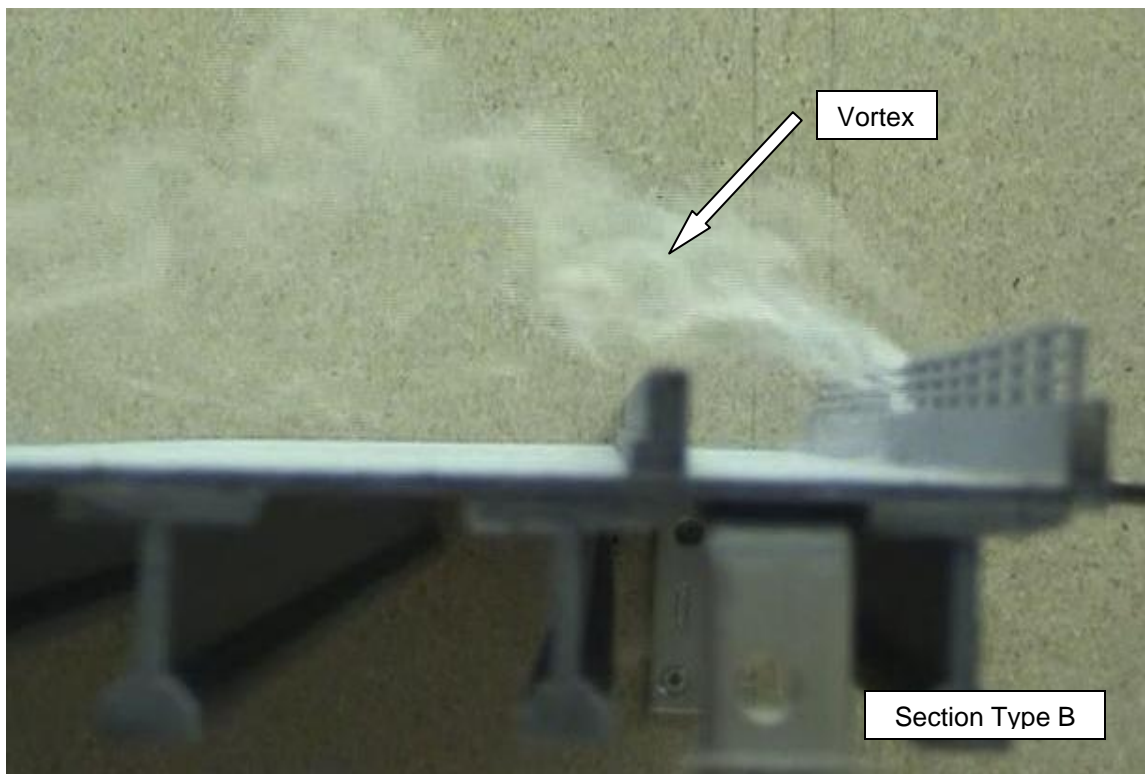
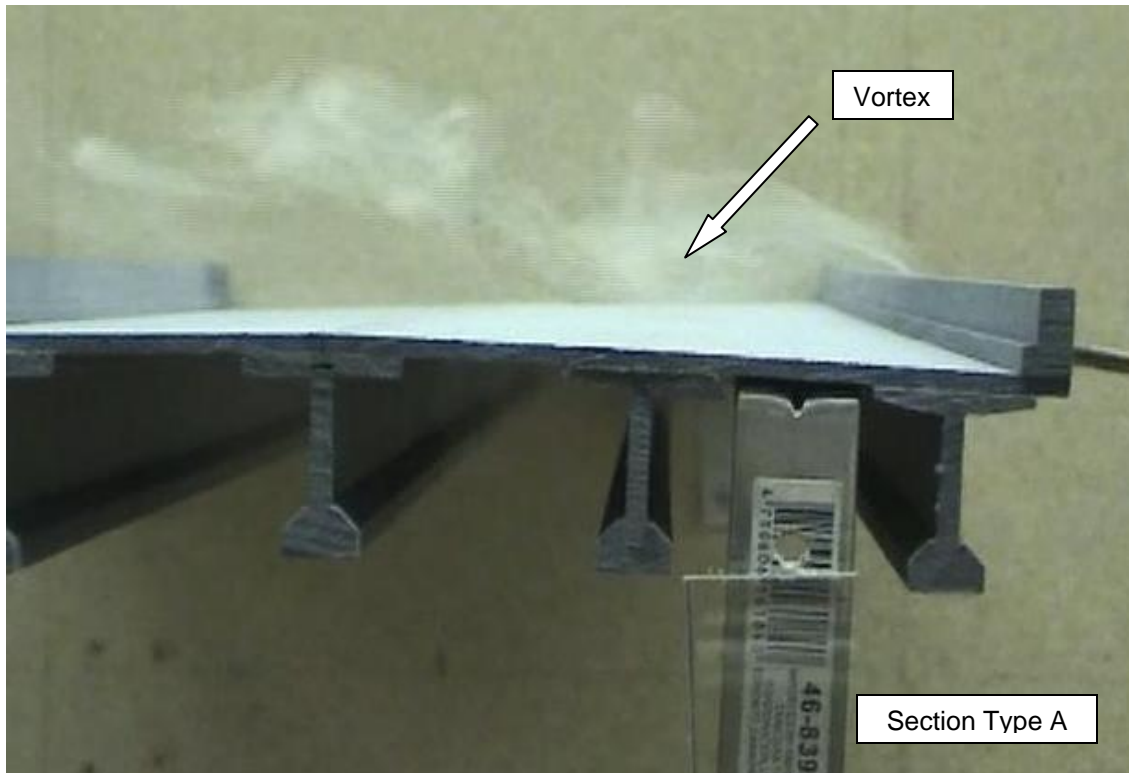


FIGURE 22 PHOTOS FROM THE SMOKE FLOW VISUALIZATION



**Section Type A - Bridge Deck Wind Velocity Profiles - High-level Deck Elevation -
Upwind Lane**

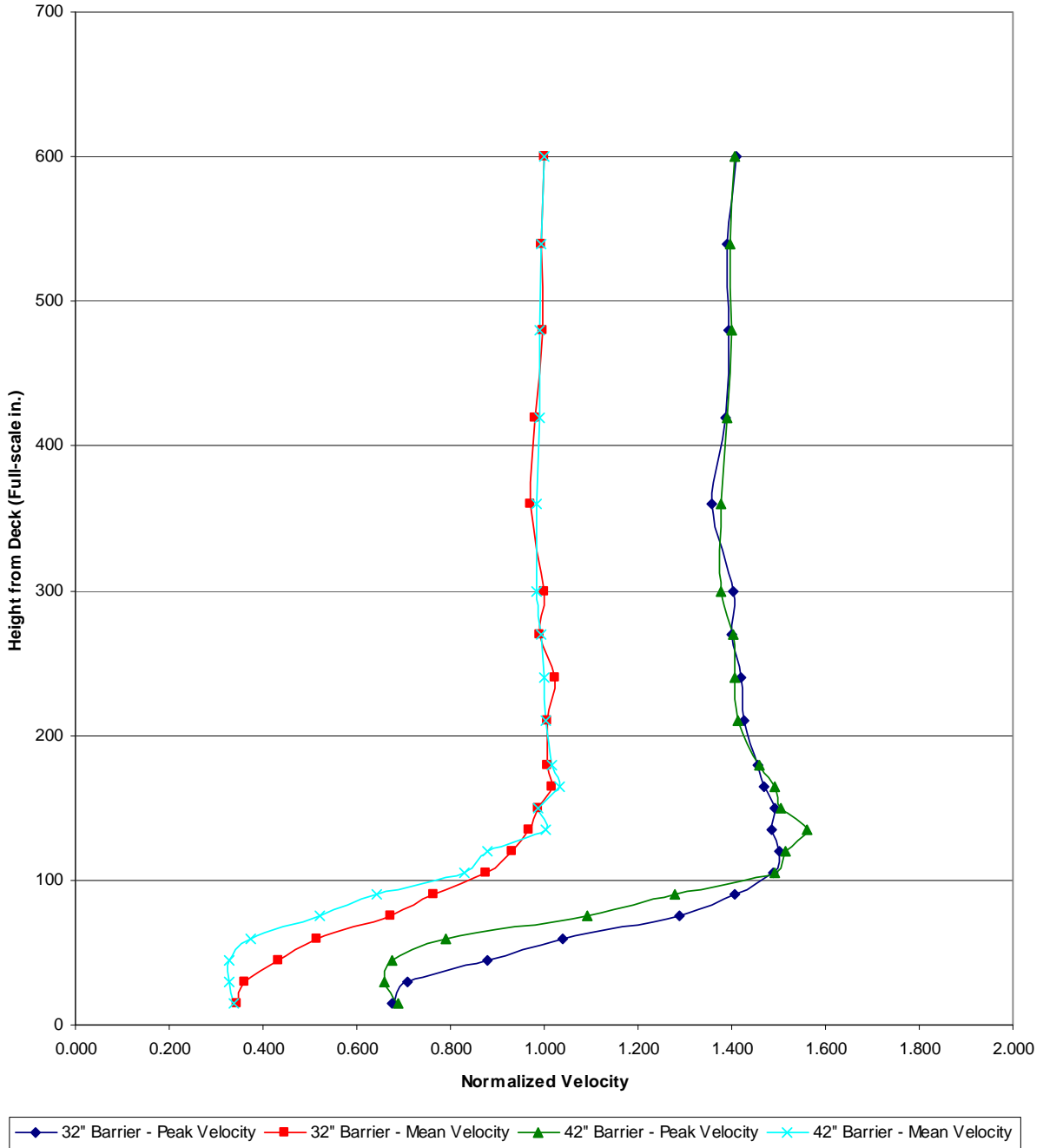


FIGURE 23 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 3 AND 5



**Section Type A - Bridge Deck Wind Velocity Profiles - High-level Deck Elevation -
Downwind Lane**

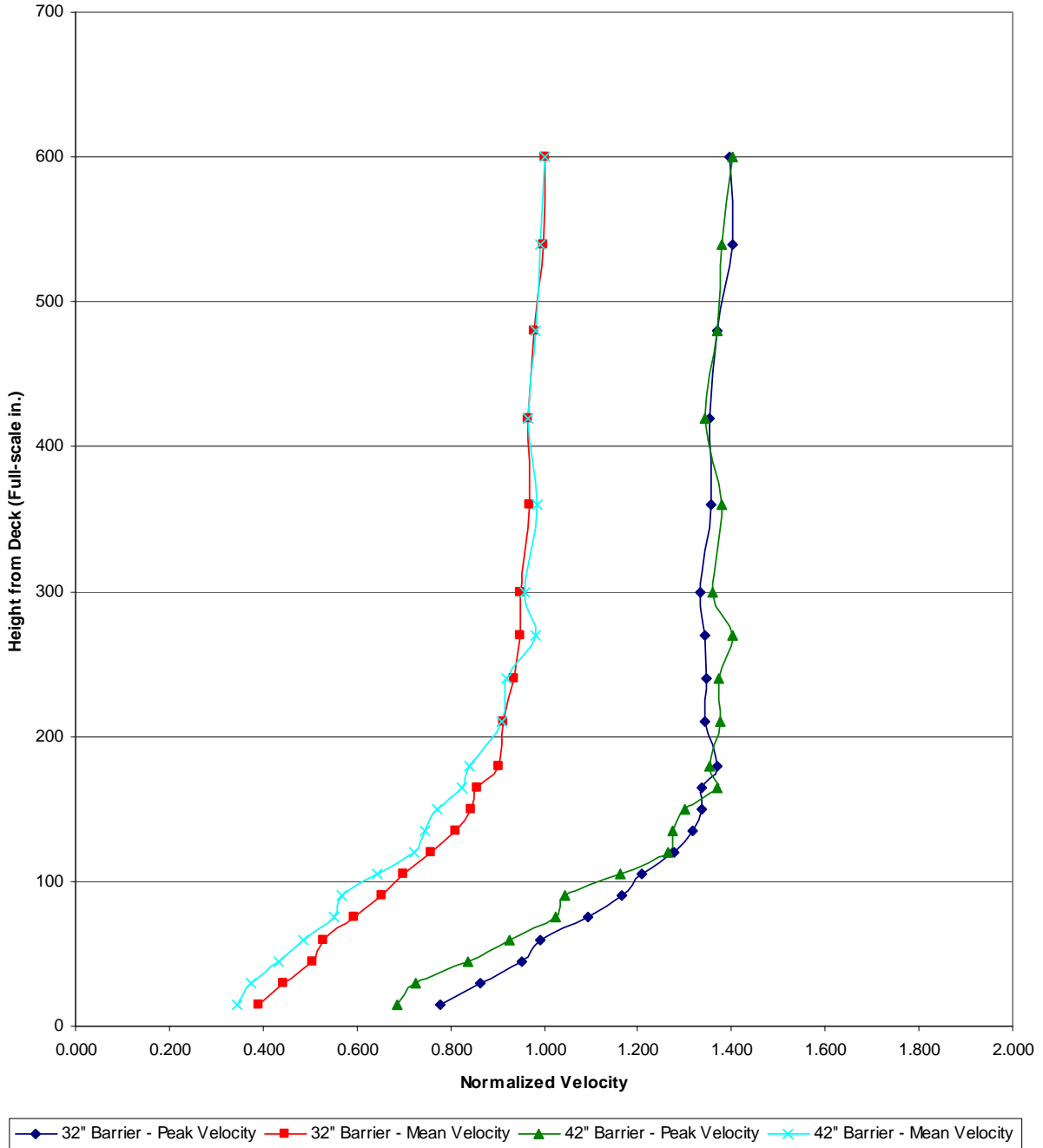


FIGURE 24 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 4 AND 6



**Section Type B - Bridge Deck Wind Velocity Profiles - High-level Deck Elevation -
Upwind Lane**

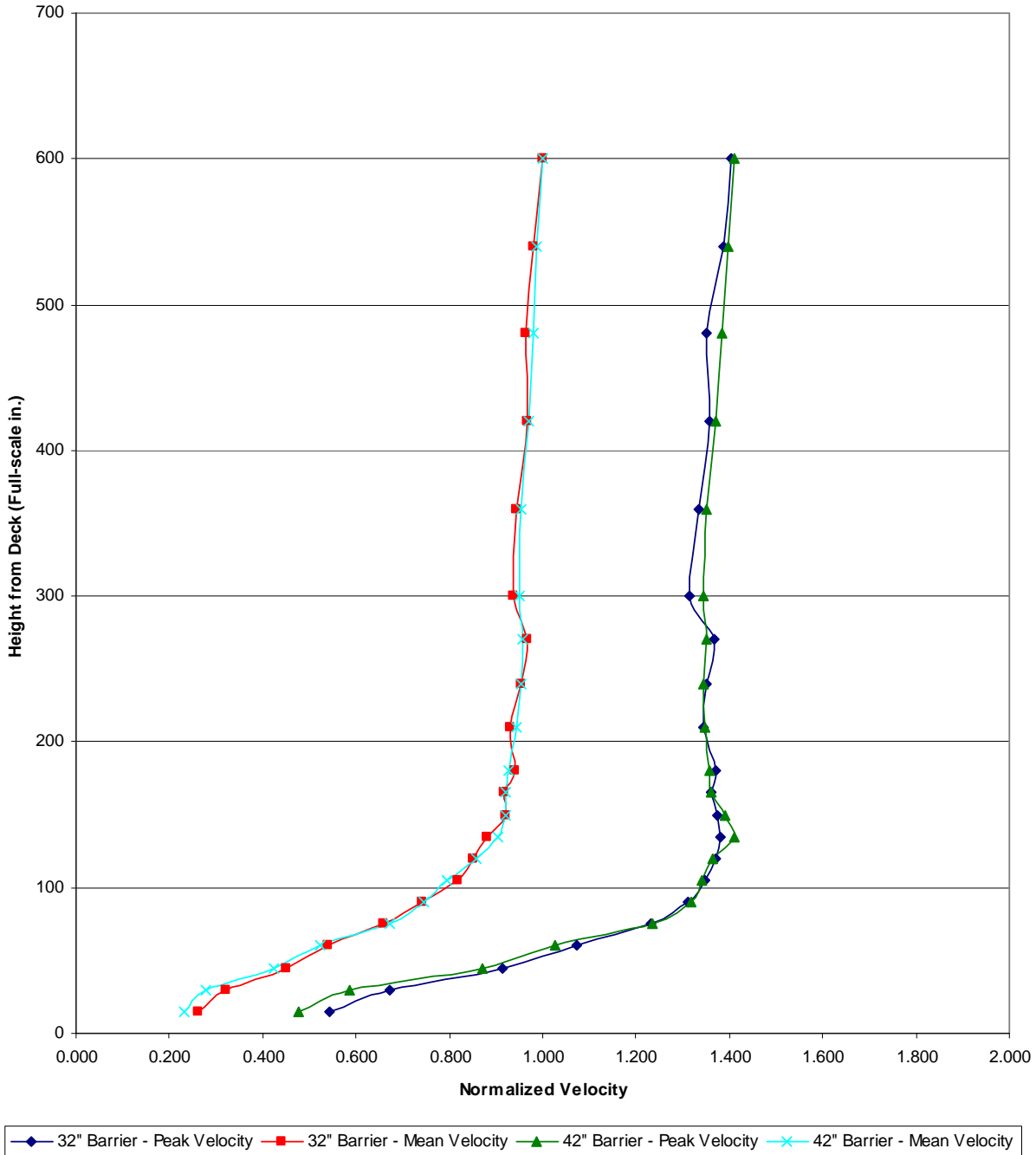


FIGURE 25 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 9 AND 11



**Section Type B - Bridge Deck Wind Velocity Profiles - High-level Deck Elevation -
Downwind Lane**

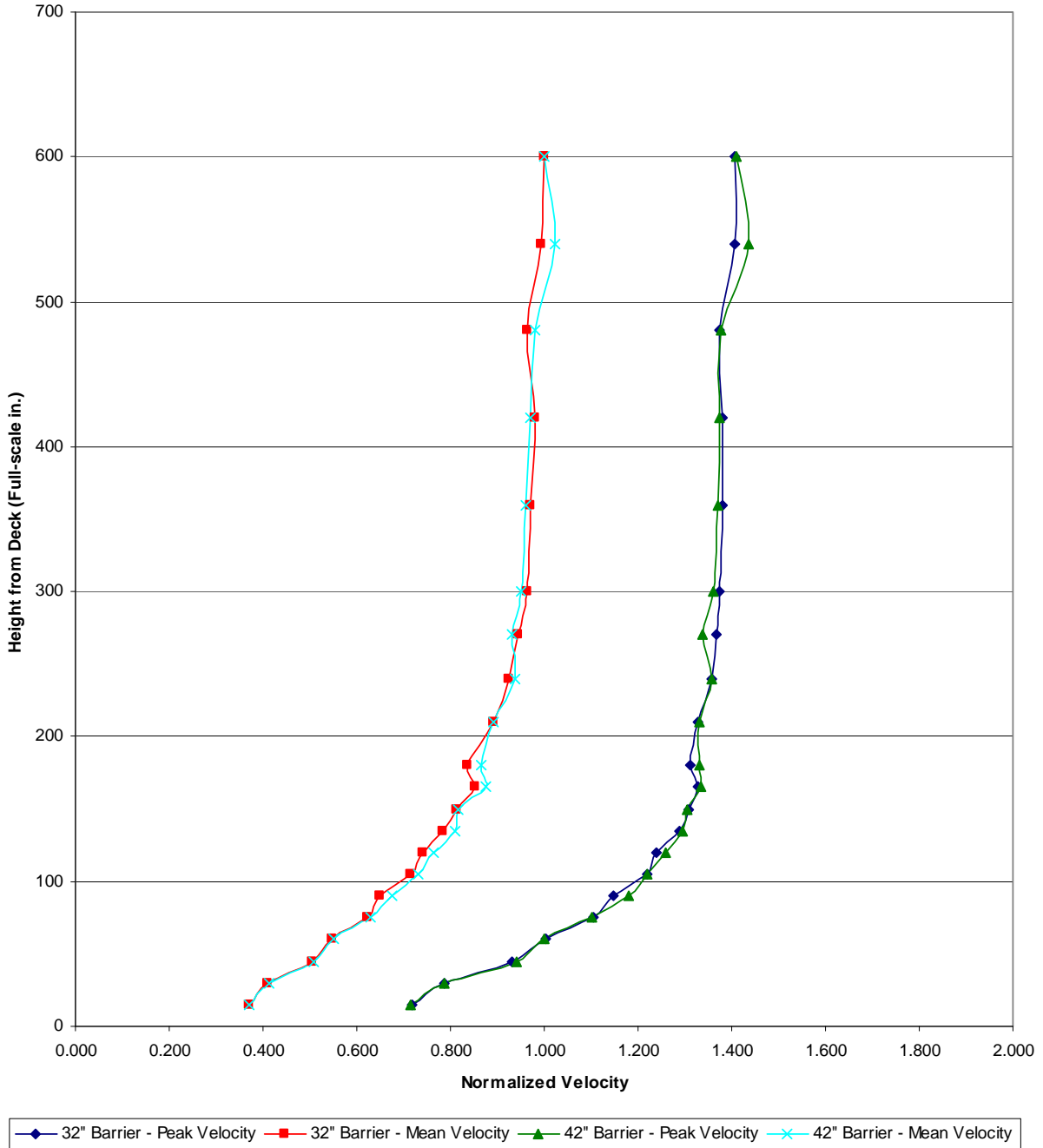


FIGURE 26 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 10 AND 12



Section Type A vs. Section Type B - Bridge Deck Wind Velocity Profiles - High-level Deck Elevation - Upwind Lane

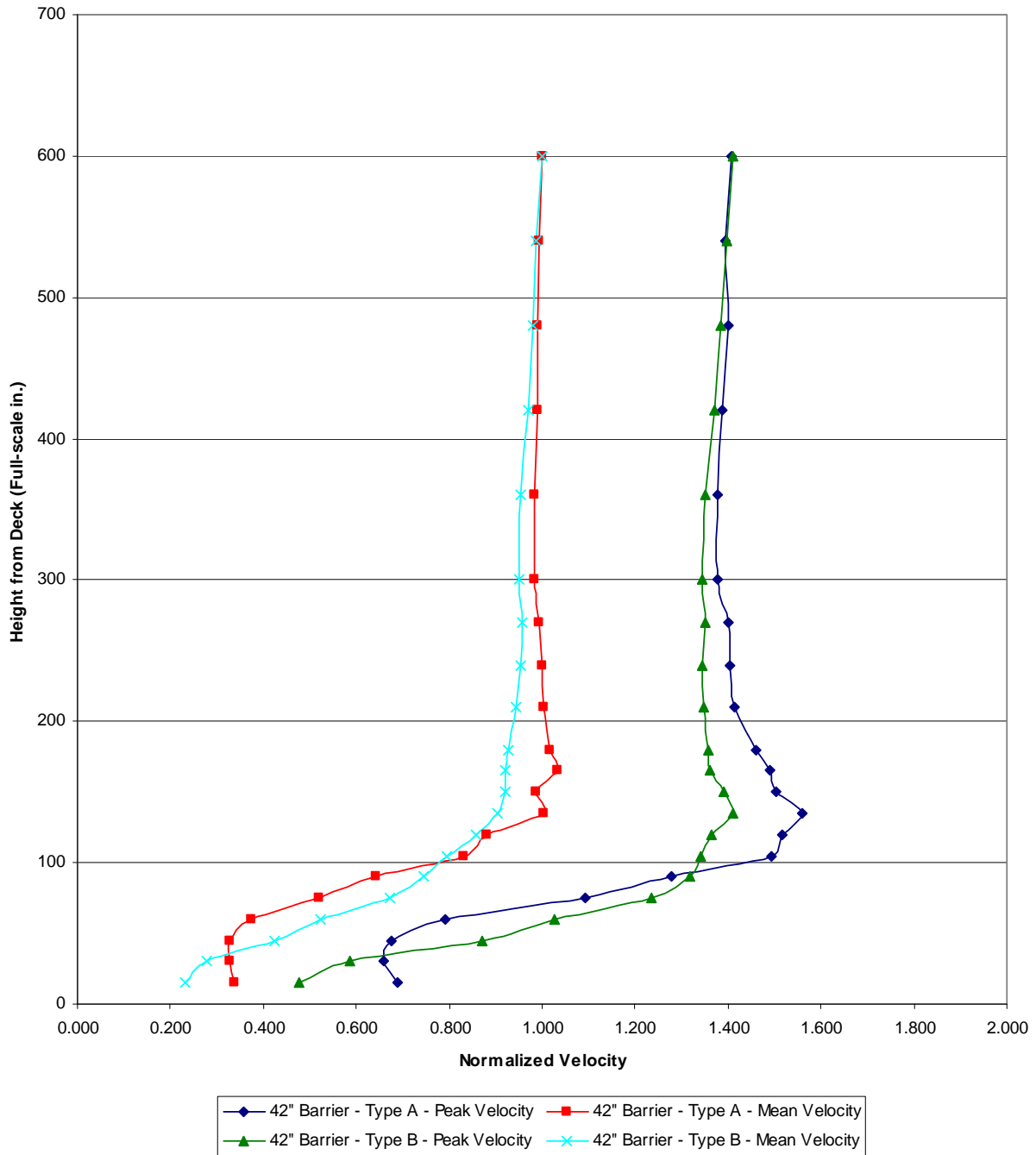


FIGURE 27 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 5 AND 11



**Section Type A vs. Section Type B - Bridge Deck Wind Velocity Profiles - High-level
Deck Elevation - Downwind Lane**

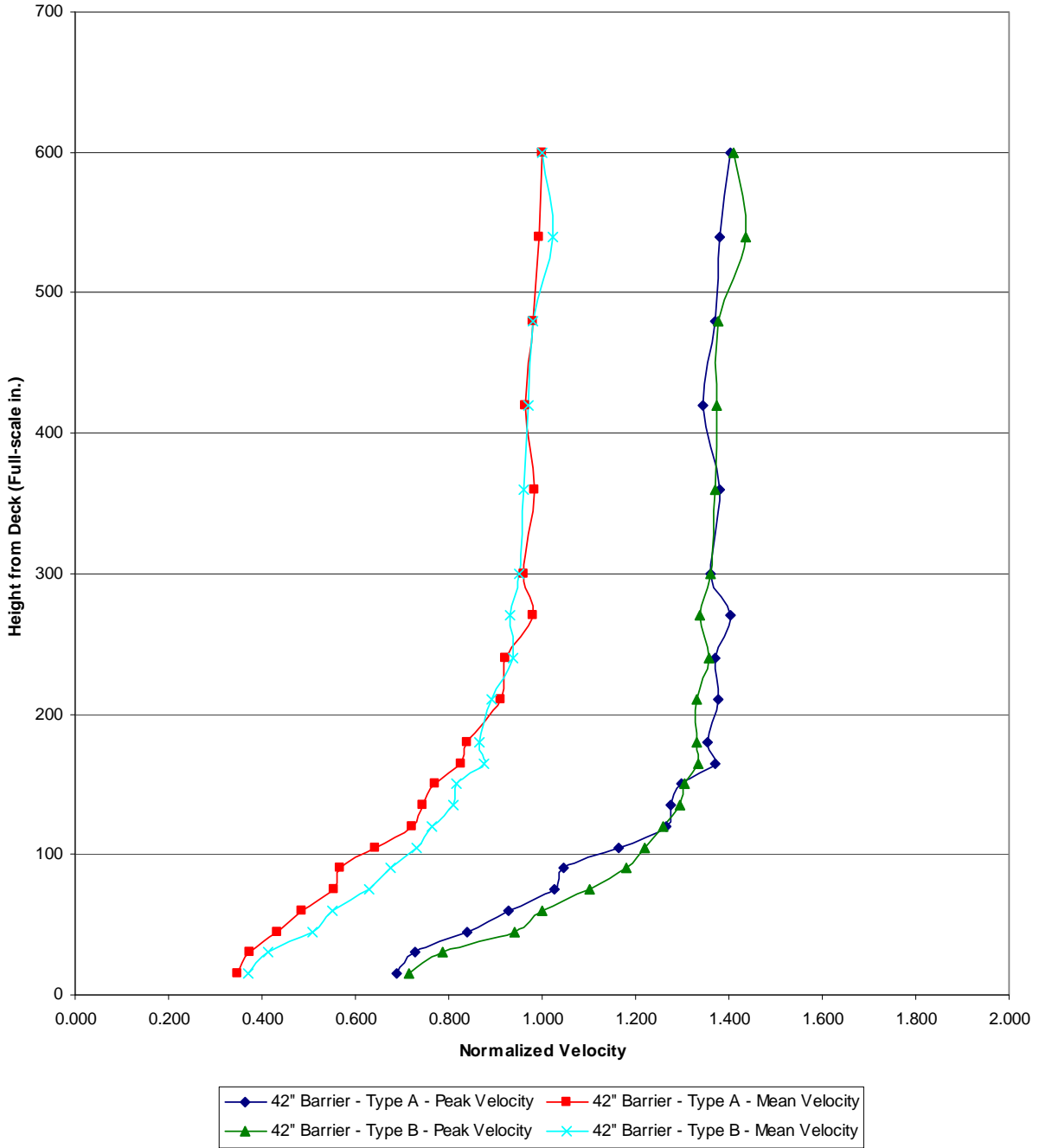


FIGURE 28 MEAN AND PEAK WIND VELOCITY PROFILES – CONFIGURATIONS 6 AND 12



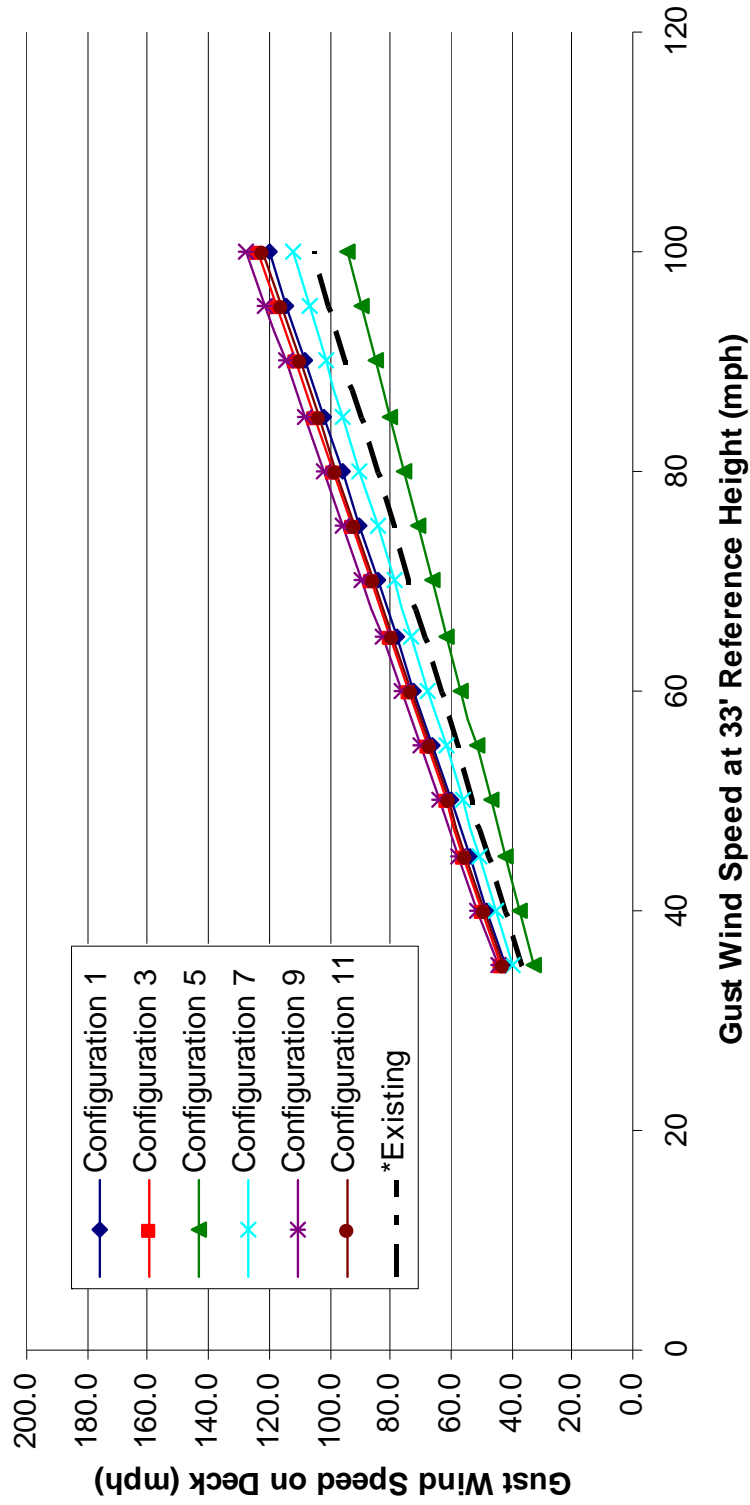


FIGURE 29 BRIDGE DECK GUST WIND SPEEDS VS 33' REFERENCE GUST WIND SPEEDS FOR EVALUATION OF PASSENGER CARS – UPWIND CONFIGURATIONS



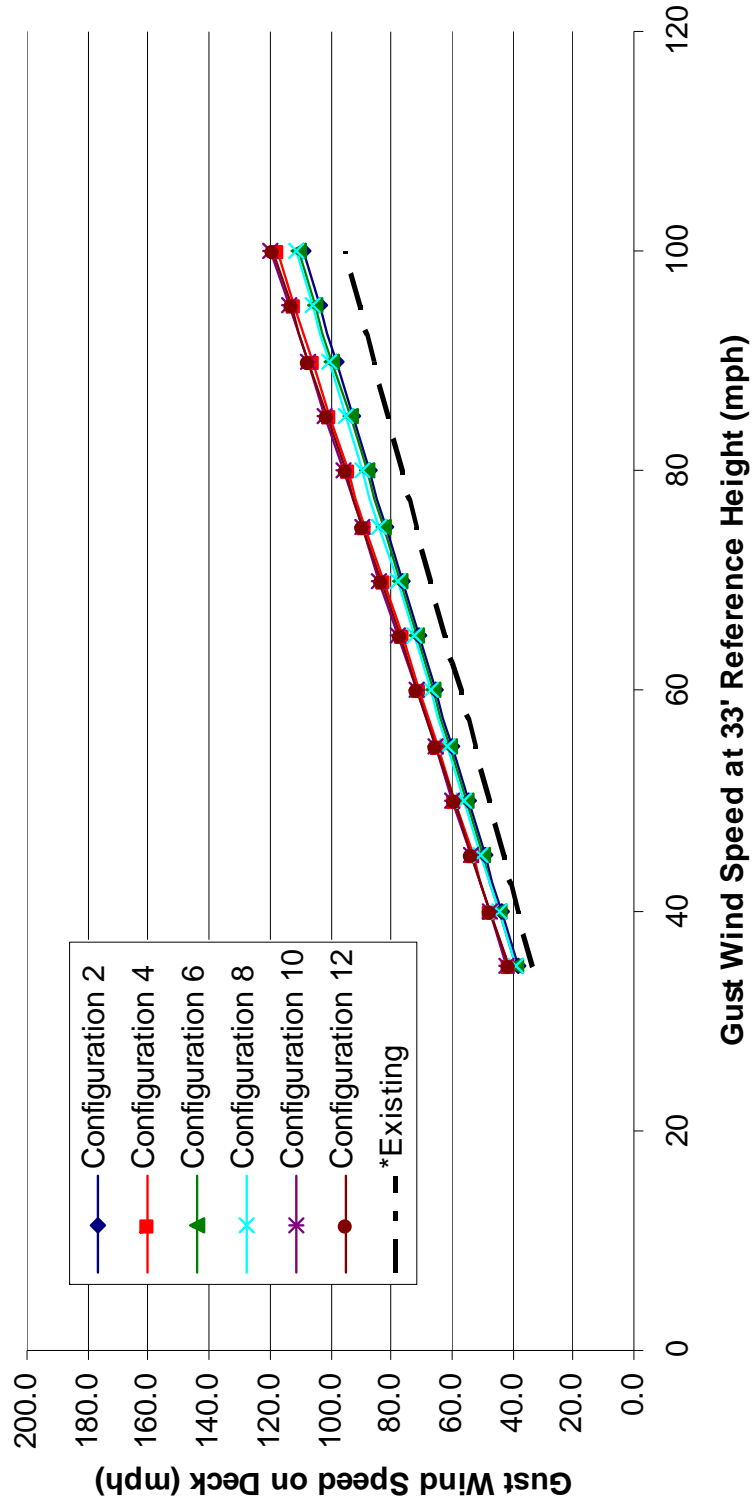


FIGURE 30 BRIDGE DECK GUST WIND SPEEDS VS 33' REFERENCE GUST WIND SPEEDS FOR EVALUATION OF PASSENGER CARS – DOWNWIND CONFIGURATIONS



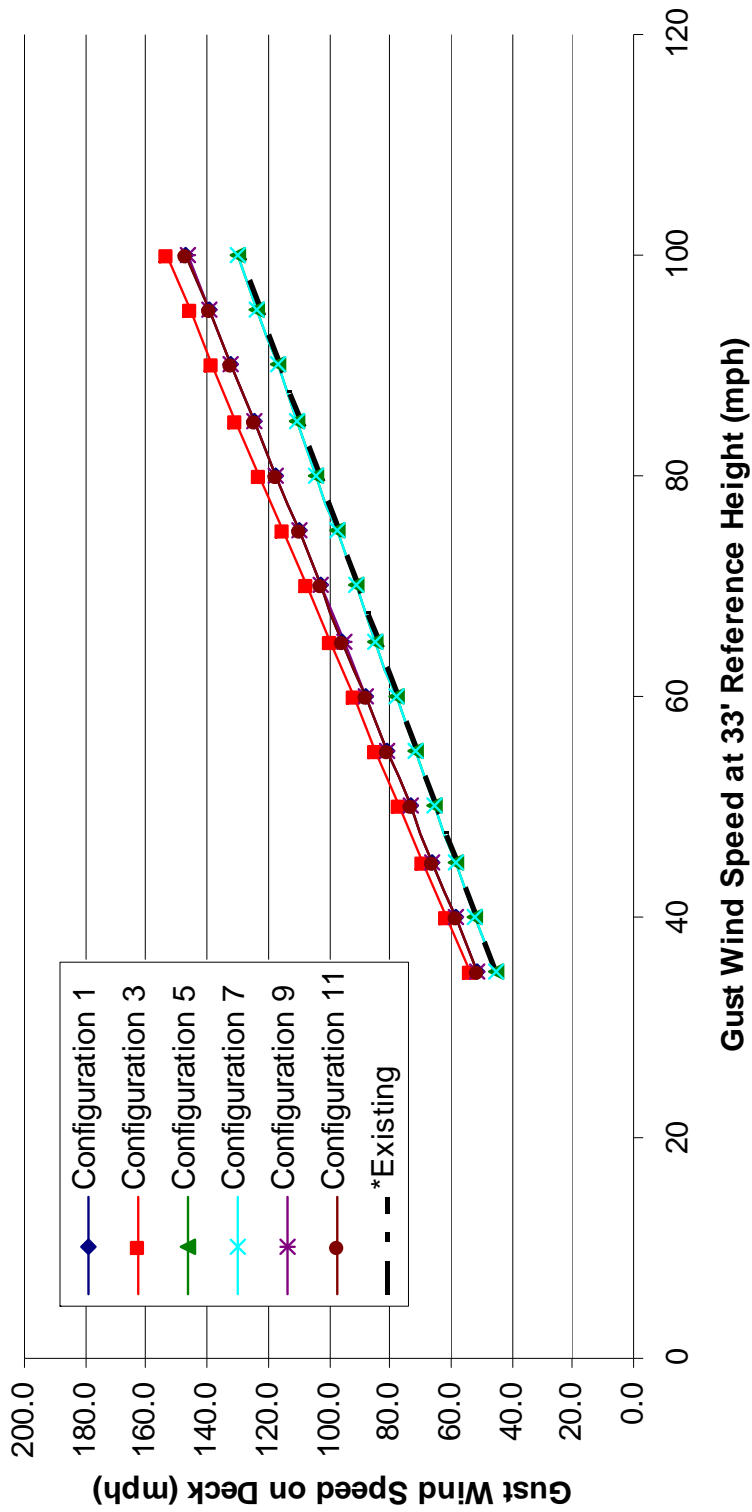


FIGURE 31 BRIDGE DECK GUST WIND SPEEDS VS 33' REFERENCE GUST WIND SPEEDS FOR EVALUATION OF PASSENGER VANS – UPWIND CONFIGURATIONS

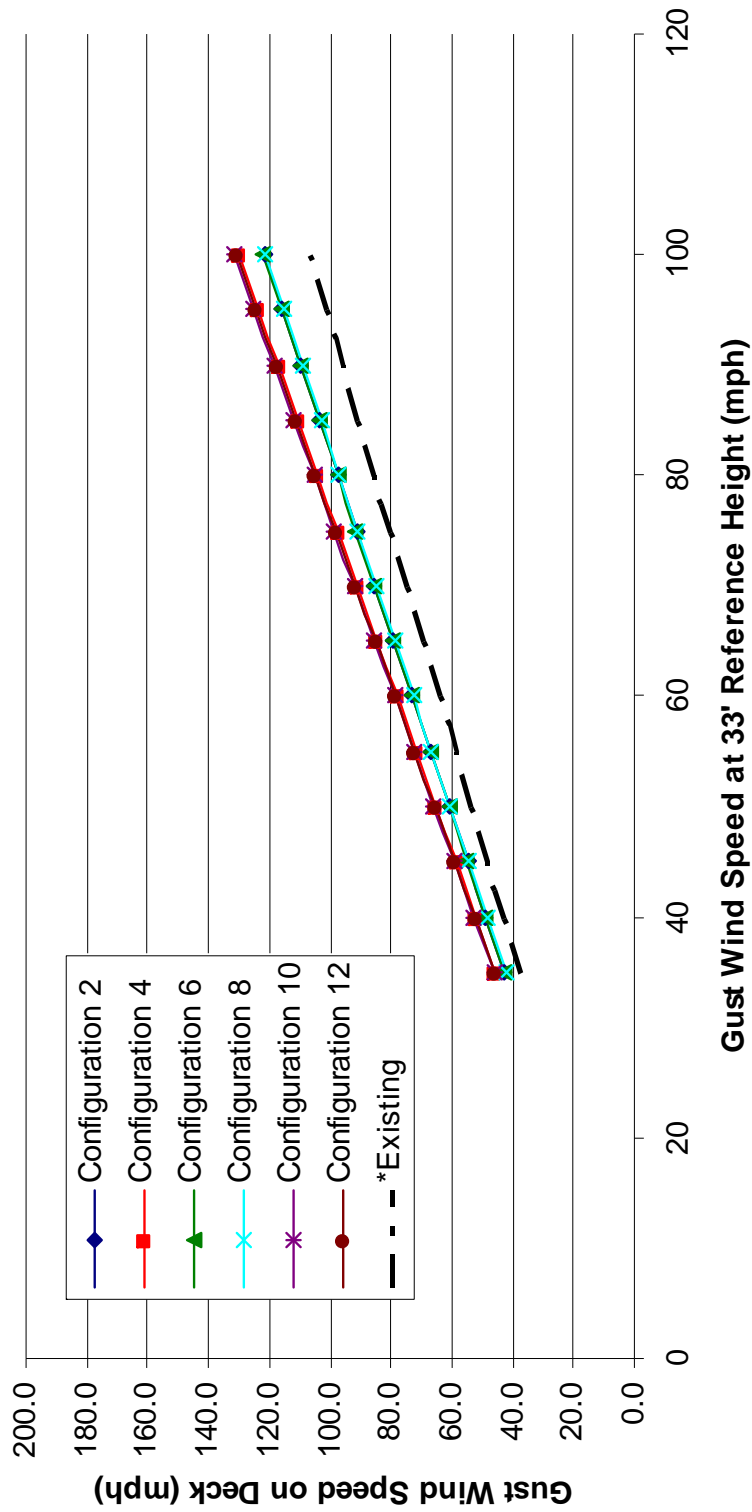


FIGURE 32 BRIDGE DECK GUST WIND SPEEDS VS 33' REFERENCE GUST WIND SPEEDS FOR EVALUATION OF PASSENGER VANS – DOWNWIND CONFIGURATIONS



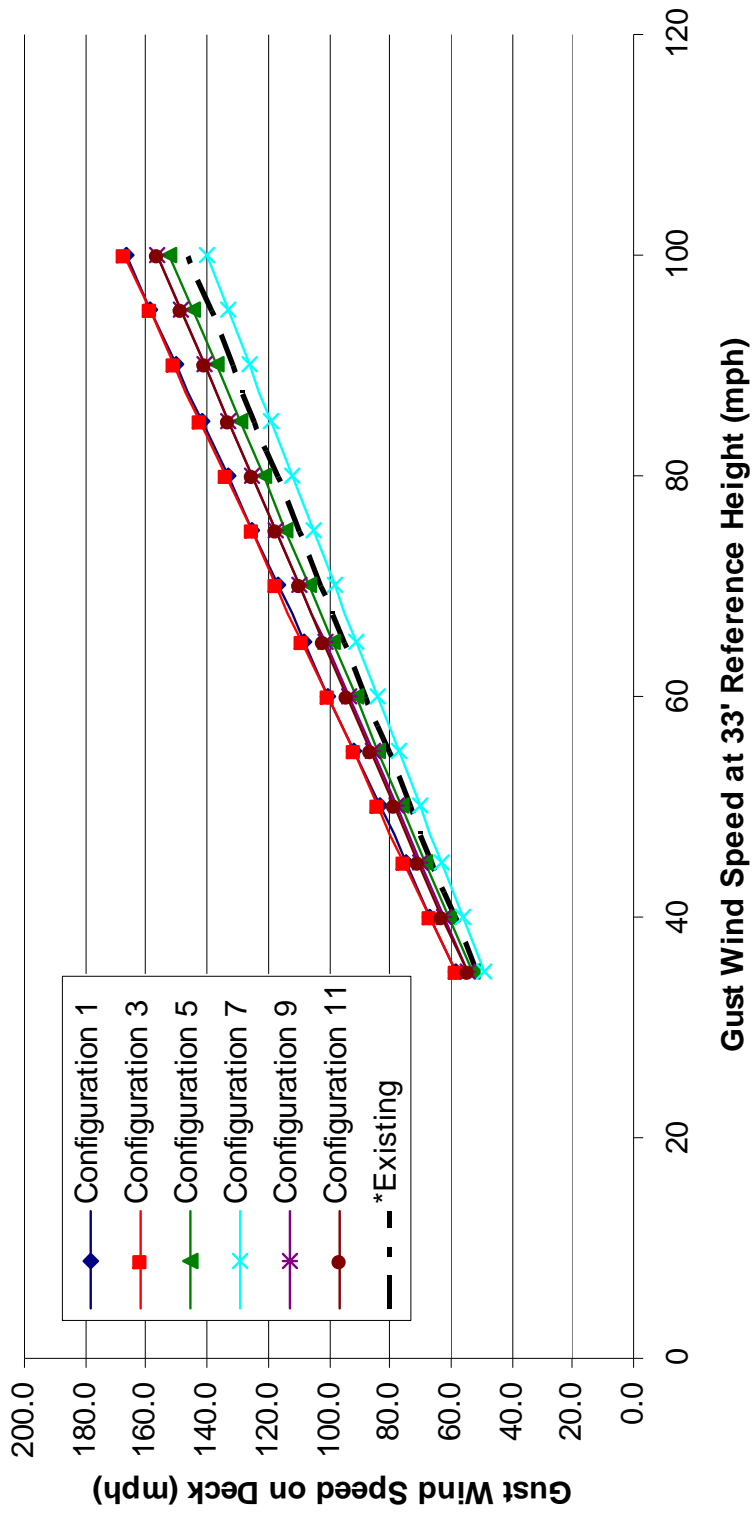


FIGURE 33 BRIDGE DECK GUST WIND SPEEDS VS 33' REFERENCE GUST WIND SPEEDS FOR EVALUATION OF INDUSTRIAL VANS – UPWIND CONFIGURATIONS

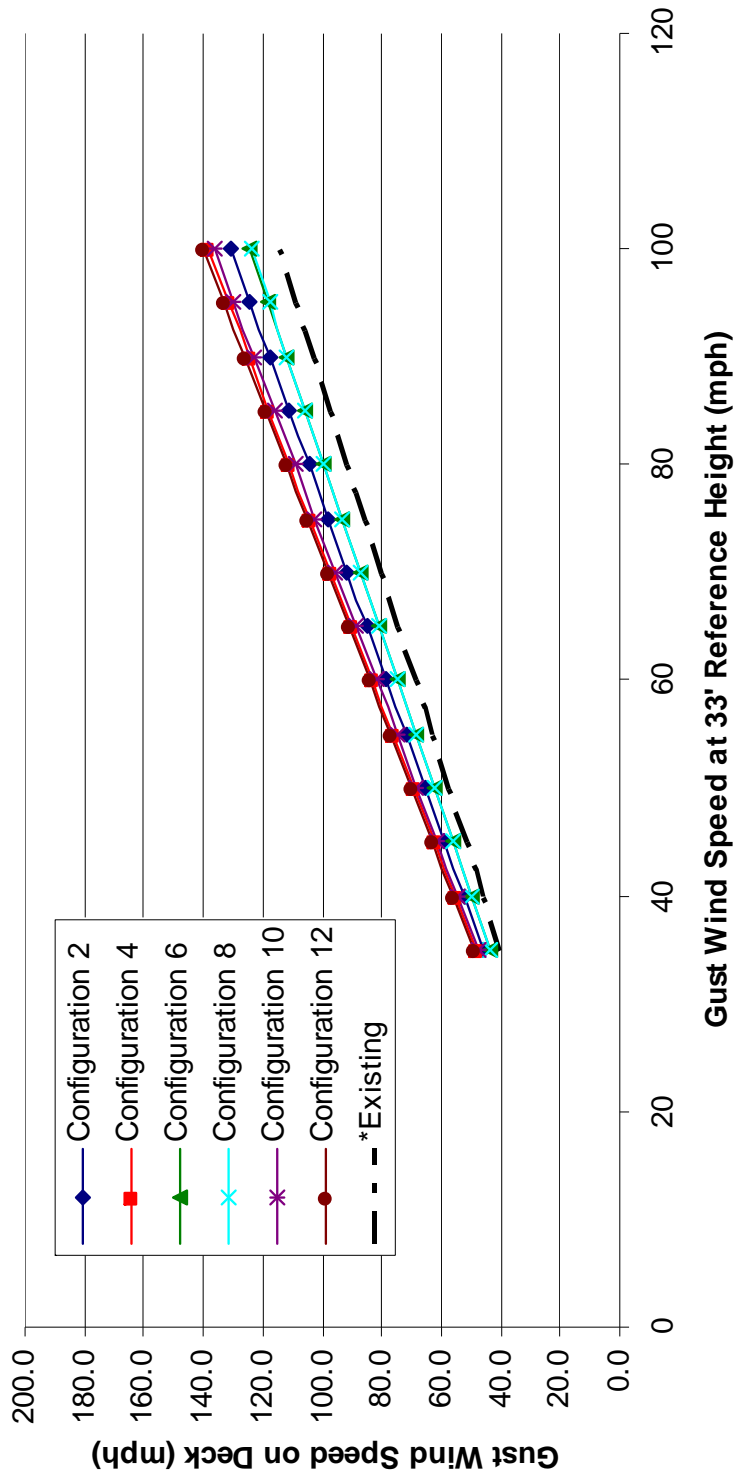


FIGURE 34 BRIDGE DECK GUST WIND SPEEDS VS 33' REFERENCE GUST WIND SPEEDS FOR EVALUATION OF INDUSTRIAL VANS – DOWNWIND CONFIGURATIONS



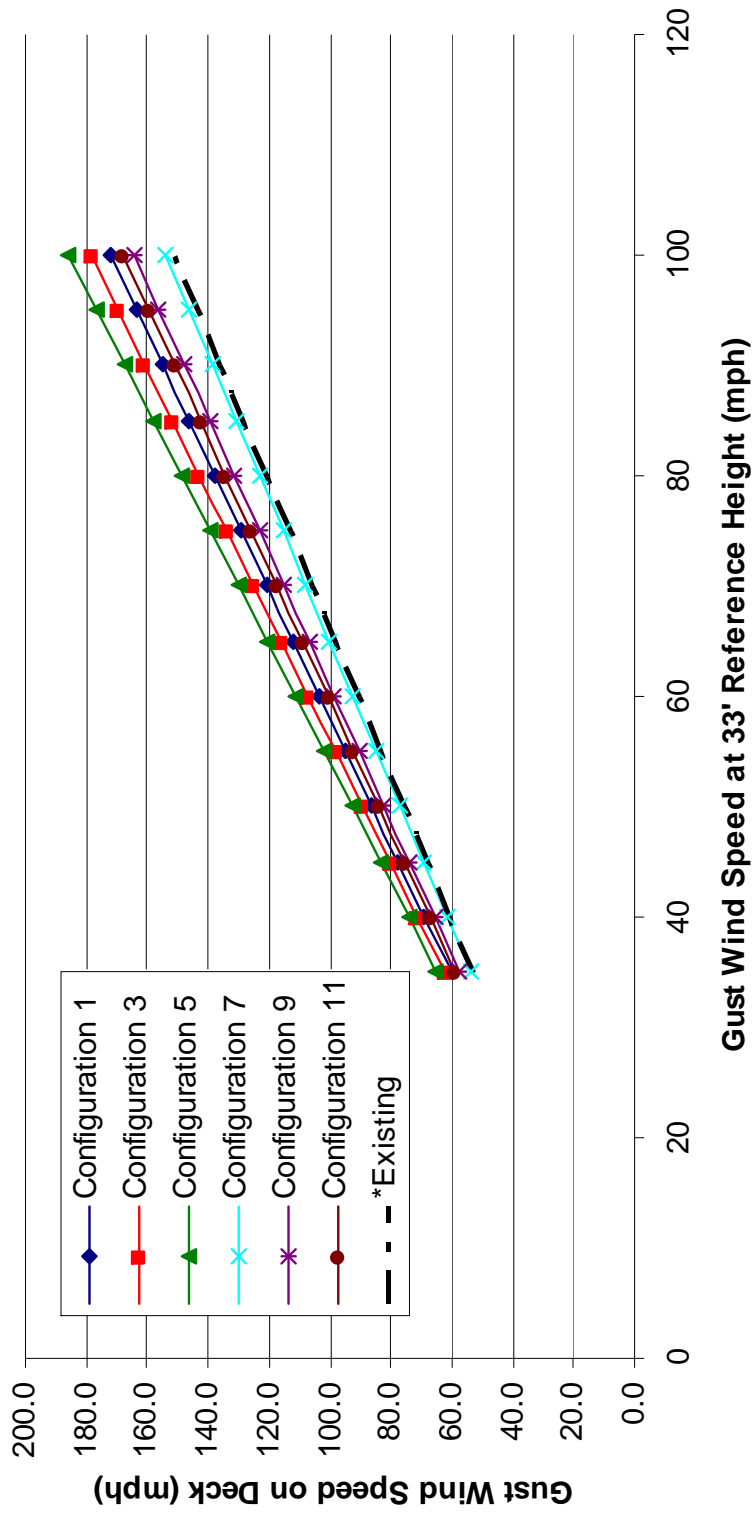


FIGURE 35 BRIDGE DECK GUST WIND SPEEDS VS 33' REFERENCE GUST WIND SPEEDS FOR EVALUATION OF TRACTOR TRAILERS – UPWIND CONFIGURATIONS

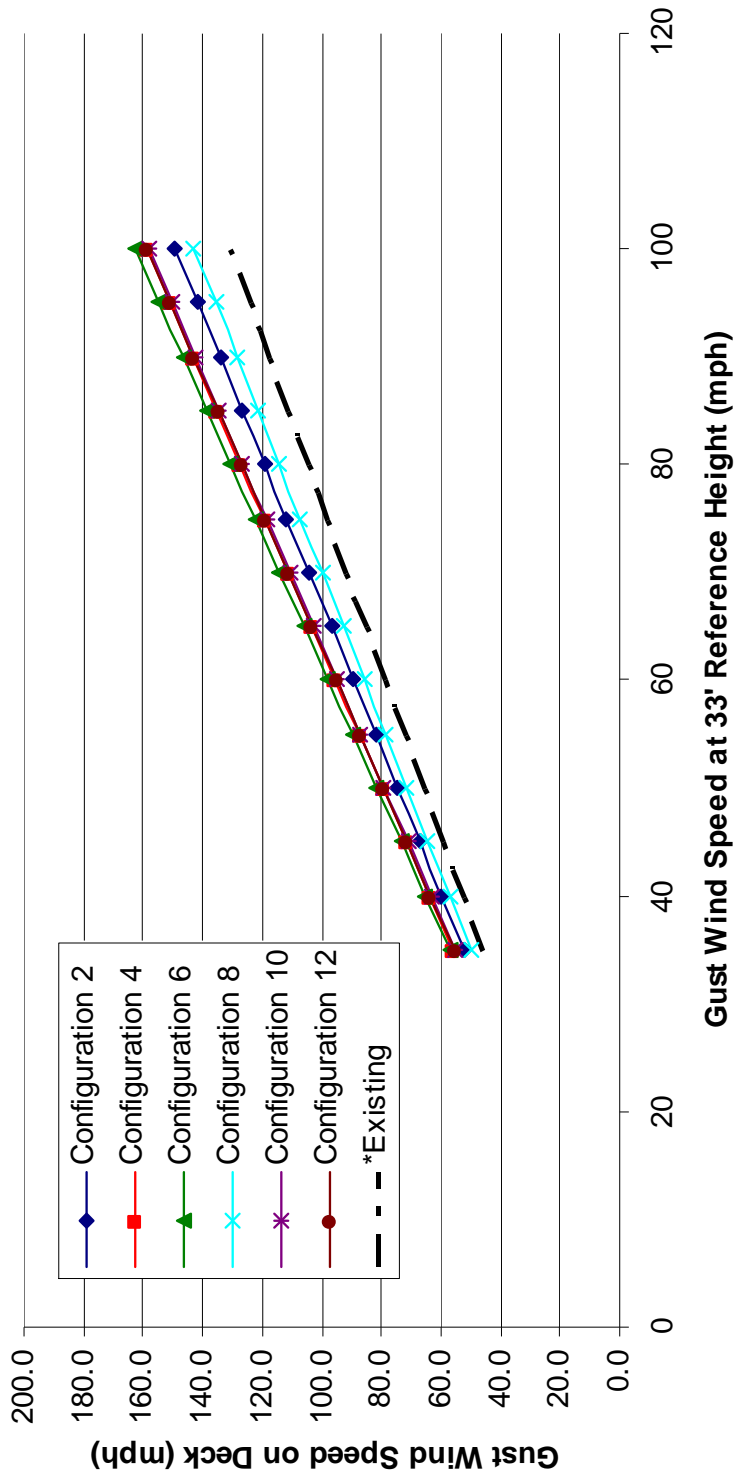


FIGURE 36 BRIDGE DECK GUST WIND SPEEDS VS 33' REFERENCE GUST WIND SPEEDS FOR EVALUATION OF TRACTOR TRAILERS – DOWNWIND CONFIGURATIONS

