WIND-TUNNEL STUDY OF

INTERNATIONAL PLACE, BOSTON

PART 1: PEDESTRIAN FLOW VISUALIZATION

by

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FLUID MECHANICS AND
WIND ENGINEERING PROGRAM

COLLEGE OF ENGINEERING

COLORADO STATE UNIVERSITY
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

The Development

International Place at Fort Hill Square is a major urban development comprised of approximately 1,800,000 square feet. The project entails development of 1,700,000 square feet of office space, 100,000 square feet of retail space and 800 underground parking spaces on 2.6 acres of land bounded by Oliver Street, Purchase Street and High Street in Boston.

The project's distinctive design is composed of two cylindrical, high-rise towers and three rectangular building elements of varying heights and shapes. The taller of the towers is a 46 story structure augmented by two lower rectangular elements of 19 and 27 stories. The second tower is a 35 story structure with a connected rectangular element of 11 stories. Joining the two towers is a glass-covered, courtyard of approximately 25,000 square feet.

Urban Wind Characteristics

The winds blowing over a city are slowed and mixed by interaction with trees, buildings, and other features which contribute to "surface roughness." The result of this interaction is that the average wind speeds increase with elevation above the local terrain up to a level called the gradient height (usually 275 to 400 m, or 900 to 1,350 ft). Above this level, the wind speed is known to be relatively constant and unaffected by the surface development. This region where the surface roughness affects the wind characteristics is known as the atmospheric boundary layer.

High winds at ground level around tall buildings, such as the high rise towers included as the major portions of International Place design, result from the interaction between the buildings and the higher-speed winds that exist at greater heights. The pressure exerted on the windward face of a building increases with wind velocity. Thus the pressures will be greater near the top than near the bottom of the building. As a result of this vertical pressure gradient, high level winds are deflected down the building face from the high pressure to the low pressure region. Winds flowing down the windward face hit the ground and are accelerated around the windward corners by low pressures existing on the sides of the building. High wind speeds at ground level are most pronounced near tall buildings which are surrounded by structures whose heights are low in comparison to the tall building. Examples of this situation in Boston include the Prudential and John Hancock Towers. At ground level, the highest winds are often found around building corners. This corner flow is usually steady high-speed wind that changes to a lower speed but gusty wind as it moves farther from the building. The presence of other nearby buildings can also redirect winds and cause additional increases in wind speed due to funneling or channeling.

The Wind Studies

The Chiofaro Company has retained the authors, of the Colorado State University Fluid Mechanics and Wind Engineering Program (CSU), to study the potential pedestrian level wind impacts associated with the development of International Place at Fort Hill Square. The wind tunnel studies will be undertaken in two primary parts. This report describes Part 1, Pedestrian Flow Visualization Testing; Part 2 is the Quantitative Wind Tunnel Modeling of Pedestrian Levels Wind. Part 2 will follow at a later time.

The Part 1 studies had several objectives. The authors have attempted to:

1. Provide general conclusions on the nature of the wind environment in the project site area.
2. Describe, qualitatively, the nature and locations of project-related changes in the wind environment.
3. Test the relative difference in wind environment associated with various phases of project development.
4. Compare qualitatively the wind environment at the International Place site to wind conditions adjacent to other tall buildings in Boston.
5. Investigate potential for affecting local dispersion of air pollutants, and
6. Select the ground level locations from which the detailed, quantitative wind tunnel data will be recorded in the subsequent Part 2 wind tunnel modeling effort.

The objectives were accomplished through "smoke test" observations of flow patterns in the wind tunnel under a variety of wind speeds and directions.

2. SUMMARY OF RESULTS

Flow visualization with a smoke tracer was performed for a radial distance of 1,500 feet (full scale) around the proposed site (see Figure 1). The following five construction configurations were examined:

PRE - preconstruction configuration (Figure 2)

PH1 - Phase 1 tower (south tower) and part of the lowrise (Figure 3)

PH2 - complete project including south tower, north tower and lowrise structure (Figure 4)

PH1F - configuration PH1 with replacement of the freeway with three 140 foot buildings (Figure 5)

PH2F - configuration PH2 with replacement of the freeway with three 140 foot buildings (Figure 6)

The results of the flow visualization analysis are summarized in the following points:

1. The pre-construction site (PRE) and adjacent streets were neither especially windy nor calm.
2. Addition of the International Place as Phase 1 (PH1) or Phase 2 (PH2) increased wind speeds on streets and sidewalks bounding the project site.
3. Neither the PH1 nor PH2 development significantly increased wind speeds in areas farther away from the project site than the streets bounding the project.
4. Ground level wind speeds adjacent to the project base appeared similar to those observed for other tall buildings in an exposed site. Tall in this sense refers to buildings of about 10 stories or more.

5. Presence of the PH1 or PH2 projects decreased winds directly downwind for one or two blocks.
6. The addition of buildings over the freeway, configurations PH1F and PH2F, changed somewhat the flow patterns about the project site but did not clearly increase or decrease the overall wind environment.
7. Several high wind areas were observed about the bases of other tall buildings within the study area which appeared to have wind speeds of qualitatively the same intensity (could be slightly higher or lower) as those about the International Place project.
8. Presence of the PH1 or PH2 projects will most likely increase pollution dispersal through vigorous vertical mixing of the atmospheric boundary layer adjacent to the project towers.
9. Recommendations for study locations for quantitative evaluation of pedestrian level winds were made for the next phase of the study(see Figure 12).

3. STUDY APPROACH

Pedestrian level winds were studied in an atmospheric boundary layer wind tunnel utilizing flow visualization techniques with a smoke tracer of TiO_2. A model of the proposed site and surroundings was developed at a scale of 1:384. The model covers the area within a radial distance of 1800 feet from the site. Figure 7 shows the completed model.

Vertical wind speed profiles were developed to simulate actual wind conditions in the project area. In addition the wind tunnel provides the capability of rotating the model so that pedestrian level winds can be simulated and examined at different wind directions.

The flow visualization methodology involved observing wind flow patterns at ground level in the study area with a smoke probe.

By performing the wind analysis at a number of wind directions, some of which may be selected on the basis of observations just made at other wind directions, "hot spots" of high velocities may be identified. An experienced practitioner can quickly cover a wide area, identifying hot spots or recording wind speed levels. A written record of the flow visualization can identify specific locations which should be investigated in more detail in the quantitative study.

Examination of pedestrian winds should not concentrate only on high velocity "hot spots". Areas where low velocities are changed to moderate velocities for a number of wind directions may represent a significant deterioration in pedestrian environment. The reverse is also true. High traffic areas should be addressed even if "hot spots" are not evident, as modest changes in environment may change pedestrian traffic patterns. This is particularly true for pedestrian areas which were designed for long-duration activities.

In addition to defining wind speeds at ground level, smoke visualization provides an understanding of why a particular flow speed exists by examining the flow conditions upwind and above the surface. For example, high wind velocities at the corner of a building may be seen to be the result of wind flow down the windward face of the building causing wind to "converge" toward the surface at the corner.

With this procedure, a qualitative evaluation of local wind speed was obtained by classifying wind speeds into categories of high, moderate, low, and stagnant. A moderate wind speed is best representative of the velocity in an open area away from any significant influence of structures. High wind speed is a velocity significantly faster than "moderate." High wind speeds may be observed at isolated spots rather than in large areas, but any high velocity "hot spot" in an area would result in classifying the entire area as high velocity. Low velocity is lower than moderate wind speed, but not stagnant. Stagnant indicates very little or no air motion in an area. Where an area was classified as high, maps were marked with the location of the high velocity "hot spots" within the area as well.

For the International Place project, tests for high velocity locations were made out to a radius of 1500 feet from the site. The area examined is shown in Figure 8. In addition nineteen specific study areas were identified in advance by representatives of BRA and the Chiofaro Company during a working meeting. These are presented in Figure 8 as well. Each area was examined by smoke flow for each of the eight compass points. For each wind direction the velocity in the different area was rated in one of the four wind speed categories described above. The five construction configurations as presented in Section 2 were examined. The results are presented in Table 1.

4. RESULTS AND DISCUSSION

The flow visualization study examined pedestrian level winds out to 1500 feet from the proposed International Place project site. A number of locations were identified (see Figure 9a-e) which had high wind speeds based on the definition provided in Section 3. No changes in high wind areas were observed beyond one block from the project site with changes in project configuration. It was evident from observation of smoke flow that significant influences from any of the model configurations did not extend beyond about one half block from the project site, except directly downwind where some decreases in wind speed were observed at one to two blocks downwind. It is possible (and probable based on previous experience with other projects) that measurable decreases in wind speed might be found 500 to 1000 ft downwind of the project.

High wind speeds were observed about the base of the International Place project. One of these areas is shown in Figure 10 for an east wind. High wind speeds were also observed at several locations considerably removed from the project site where the project had no influence on the wind flow. Two of these areas are shown in Figure 11 for an east wind. No qualitative differences could be identified between the three high wind areas. Thus, it is possible that these areas experienced higher wind speeds than those at the base of the International Place project.

In addition, data compiled in Table 1 for the nineteen specific areas present the following points:

Area 1. The PRE case was evenly divided between moderate and low winds with no high wind areas. The influence of the various projects was to slightly decrease or leave unmodified the wind speeds with no evidence that the projects might increase wind speeds.

Area 2. The PRE case showed high winds for an easterly wind direction and moderate winds for most other directions. The PH1 project did not change that environment. The other project configurations reduced the one high wind direction to moderate leaving wind speeds at other directions qualitatively unchanged.

Area 3. The PRE case was evenly divided between moderate and low winds with no high wind areas. Both the PH1 and PH2 cases increased the wind speeds with 4 of the 8 wind directions producing high winds (NE, E, SE, S). Tracing the source of the high winds demonstrated that the project towers deflected high velocity winds from upper levels down to street level. Inclusion of PH1F and PH2F halved the number of wind directions with high winds. Their effect was to inhibit full penetration to sidewalk level of winds deflected downward by the tower for wind directions where the freeway projects were upstream. The shielding effect of the freeway projects is expected to increase if their heights are increased.

Area 4. This area was not greatly affected by any adjacent structures in the PRE configuration. Addition of any of the other configurations decreased wind speeds in this area for wind directions where the projects were upwind blocking the approaching wind. Accelerated winds about the base of the International Place towers did not extend a sufficient distance from the tower to significantly increase winds in this area.

Area 5. Two wind directions showed high wind speeds in this area in the PRE configuration. The other wind directions were split between moderate and low. The high winds were caused by winds deflected by an adjacent building to the south. The 4 built configurations reduced the high winds by blocking wind flow into the area. A net benefit to this location appeared to occur as a result of the proposed project.

Area 6. Winds at this location were split between moderate and low. No influence of any of the project configurations were detected.

Area 7. Winds in this area were predominantly moderate with low winds observed for a few wind directions. The presence of the various project configurations had little influence on winds in this area.

Area 8. Winds were primarily moderate in the PRE configuration. Addition of PH1 decreased the wind speeds. Accelerated winds near the base of PH1 did not reach far enough from the structure to adversely affect the winds in this area. The presence of PH2 caused accelerated winds about the base of the project to be directed into this area. The high winds occurred for north and northeast winds where the site is exposed to an open approach and where orientation of the project tends to deflect higher elevation winds down to the surface. The winds in this area tended to be high near the west entrance to the project site near the intersection of Oliver and High Streets and near the base of the north tower.

Area 9. Winds were predominantly moderate in the PRE configuration. No structure in the PRE configuration had a major impact on this area. The presence of the PH1 and PH2 configurations blocked approach winds for some wind directions, thus decreasing somewhat wind speeds in this area. This area fell between two buildings in the PH1F and PH2F configurations and was thus dominated primarily by these structures. These configurations did not cause a major change in velocity categories even though they caused changes in wind flow patterns in this area (all winds were east/west between the buildings).

Area 10. This area had high winds for a number of wind directions due to the presence of two tall adjacent buildings (Harbor Towers). These winds were not affected by the PH1 or PH2 configurations and decreased slightly for the PH1F or PH2F configurations.

Area 11. Winds were predominantly moderate in the PRE configuration. Addition of the PH1 or PH2 configurations decreased wind speeds by blocking approaching winds. Addition of PH1F or PH2F increased wind speeds to match or slightly exceed the PRE level. Wind channeling between the freeway buildings and the building east of area 11 was the cause of the increased wind speeds with PH1F or PH2F.

Areas 12,13. Both areas had similar winds divided between moderate and low for the PRE configuration. Location 12 experienced some changes in wind characteristics with introduction of the various building configurations, but none sufficient to greatly modify wind speed classifications. Location 13 was too far from the construction site to experience significant modification to its wind environment.

Area 14. Wind speeds were predominately moderate in the PRE configuration. PH1 did not significantly change this environment. PH2 brought higher velocity winds to area 8 and, at the same time, brought an increase at one wind direction and decrease at another wind direction to area 14. The high winds generated by PH2 were at the intersection with area 8 across the street from the PH2 addition. Configurations PH1F and PH2F provided slight decreases in wind speed over the corresponding PH1 or PH2 case.

Area 15. Wind classifications were split between moderate and low in the PRE configuration. All built configurations provided decreases in wind speeds, primarily by blocking wind for one or two wind directions.

Area 16. Winds were mostly moderate in the PRE configuration. No structures nearby were sufficiently large to significantly modify the wind field. Addition of PH1 and PH2 increased winds in this area by deflecting high velocity wind from well above the surface down to ground level. This occurred primarily for winds with an easterly component. The addition of PH1F and PH2F did not improve the wind environment. Channeling of winds between the new structures tended to increase wind speeds while the height of the freeway structure tended to keep winds deflected from the towers from penetrating to the ground with strength; the trade-off left the winds high in this region.

Area 17. Winds were predominately moderate with local areas adjacent to a tall tower (west tower of Harbor Towers) having high wind. PH1 and PH2 configurations did not change that environment. The accelerated winds about the towers could not reach this far. PH1F and PH2F provided a small modification to the local wind speeds.

Area 18. Winds were mostly moderate in the PRE configuration. PH1 induced a decrease in winds by blocking southerly winds. PH2 provided both increases and decreases by deflecting wind into this area for one wind direction and blocking winds for some other wind directions. PH1F and PH2F changed wind flow directions locally but did not change the wind speed levels noticeably.

Area 19. Winds in the PRE configuration were split between moderate and low in this portion of the Broad Street historic district. The addition of all other configurations decreased wind speeds by blocking approach winds.

Flow visualization showed clearly that the International Place building site is exposed to winds with essentially unobstructed paths from the north to north-northeast and from the south-southwest along the adjacent freeway corridor. In addition, the building is subject to an open exposure with only a line of low buildings upwind for wind directions from east-northeast to south. The building site is thus more exposed to winds than most of the tall buildings in the downtown area. Smoke flow confirmed these observations. Other tall buildings in the area which have open exposure to wind, for example, the two towers (Harbor Towers) northeast of the site across the freeway, also showed high wind velocities about their bases which appeared to be similar in magnitude to velocities about the International Place project site.

Smoke visualization showed that the concentration of buildings from the southwest to north-northwest of the project site significantly decreased the strength of winds approaching the site. These wind directions contain the most frequent winds.

The results presented in Table 1 and their discussion, along with the other flow visualization results discussed above, demonstrated that significant changes in pedestrian wind speeds as a result of the International Place development only occurred on the three streets directly adjacent to the project site. The changes at these three locations were increases in pedestrian level wind velocities. The velocity increases covered the full width of Oliver Street between Purchase and High Streets. On Purchase Street from Oliver to High Street and on High Street from Oliver to Purchase, the velocities were greatest on the half street width nearest to the project site with lesser increases on the half street width further from the project site.

The flow visualization study was not specifically designed to address air pollution concerns. However, some conclusions can be drawn relative to concern that the project might block natural wind flow into or out of the downtown area thereby increasing pollution levels. The flow visualization techniques demonstrated that the International Place structures will bring air from higher levels down to the surface on the windward side and pull surface winds up to higher levels on the lee side of the building. Thus, the building acted like a large stirring rod mixing polluted surface air into the upper levels of the atmospheric boundary layer where winds could disperse the pollutants. The slight decrease in wind speeds observed at a distance downwind of the project can be expected to decrease slightly the local pollution dispersal action in those areas. It is probable that the strong mixing action of the building increasing dispersion will outweigh the small decrease downwind.

5. SUGGESTED STUDY LOCATIONS FOR THE QUANTITATIVE ANALYSIS

On the basis of data and the analysis presented above, pedestrian level wind locations were recommended for the quantitative evaluation which will examine in more detail the wind environment about the International Place buildings and their impacts on nearby areas. Figure 12 shows the chosen locations. These were selected to define the existing wind environment on streets adjacent to the project site and out to one block away from the site under the PRE project configuration. In addition, a number of recommended high, moderate, and low velocity locations more than one block from the site were chosen. For the PH2 project configuration, the same locations were selected to define changes to the wind environment in the study area as a result of the proposed project.

Only one project configuration (PH2), in addition to the preconstruction (PRE) configuration, are recommended for further study as the qualitative analysis provided relative comparisons between the four built project configurations and since PH2 provided the worst wind environment of the four. Configuration PH2 added high velocity areas to those identified in PH1 and did not decrease windy areas created by PH1. Thus, examination of PH2 should adequately define the wind environment for PH1 as well as PH2. The primary effects of PH1F and PH2F were to decrease winds about the project site, except for minor increases noted in one area.

APPENDIX A

WIND STUDY METHODOLOGY

WIND STUDY METHODOLOGY

Modeling of the aerodynamic loading and wind flow characteristics for a structure requires special consideration of flow conditions in order to obtain similitude between model and prototype. A detailed discussion of the similarity requirements and their wind-tunnel implementation can be found in references (1), (2), and (3). In general, the requirements are that the model and prototype be geometrically similar, that the approach mean velocity at the building site have a vertical profile shape similar to the full-scale flow, that the turbulence characteristics of the flows be similar, and that the Reynolds number for the model and prototype be equal.

These criteria are satisfied by constructing a scale model of the structure and its surroundings and performing the wind tests in a wind tunnel specifically designed to model atmospheric boundary-layer flows. Reynolds number similarity requires that the quantity UD/ν be similar for model and prototype. Since ν, the kinetic viscosity of air, is identical for both, Reynolds numbers cannot be made precisely equal with reasonable wind velocities. To accomplish this the air velocity in the wind tunnel would have to be as large as the model scale factor times the prototype wind velocity, a velocity which would introduce unacceptable compressibility effects. However, for sufficiently high Reynolds numbers ($>2\text{x}10^4$) the pressure coefficient at any location on the structure will be essentially constant for a large range of Reynolds numbers. Typical values encountered are 10^7-10^8 for the full-scale and 10^5-10^6 for the wind-tunnel model. In this range acceptable flow similarity is achieved without precise Reynolds number equality.

A scale model of the surroundings was constructed at a scale of 1:384 (1/32" = 1 ft) to a distance of 1800 ft from the site. The model was constructed from styrofoam and wood and included the elevated freeway. A model of the project site including current massing for the project was supplied by the architect (see Section 3).

Wind-engineering studies are performed in the Fluid Dynamics and Diffusion Laboratory at Colorado State University (Figure A1). Three large wind tunnels are available for wind loading studies depending on the detailed requirements of the study. The environmental wind tunnel used for this investigation is shown in Figure A2. The wind tunnel has a flexible roof adjustable in height to maintain a zero pressure gradient along the test section. The mean velocity in the environmental wind tunnel can be adjusted continuously to a maximum velocity of 35 fps. This speed is more than adequate to satisfy Reynolds number similarity requirements discussed above.

The region in the wind tunnel upstream from the modeled area was covered with a randomized roughness constructed using cubes placed on the floor of the wind tunnel. Different roughness sizes may be used for different wind directions. Spires were installed at the test-section entrance to provide a thicker boundary layer than would otherwise be available. The thicker boundary layer permited a somewhat larger scale model than would otherwise be possible. The spires were approximately triangularly shaped pieces of 1/2 in. thick plywood 6 in. wide at the base and 1 in. wide at the top, extending from the floor to the top of the test section. They were placed so that the broad side intercepts the flow. A barrier approximately 8 in. high was placed on the test-section floor downstream of the spires to aid in development of the boundary-layer flow.

The distribution of the roughness cubes and the spires in the roughened area was designed to provide a boundary-layer thickness of approximately 40 in., a velocity profile power-law exponent similar to that expected to occur in the region approaching the modeled area for each wind direction (a number of wind directions may have the same approach roughness). A photograph of the completed model in the wind tunnel is shown in Figure 7. The wind-tunnel ceiling was adjusted after placement of the model to obtain a zero pressure gradient along the test section.

At the sponsor's request, three different approah profiles were to be used in the study. They were:

Profile	Wind Directions	Power Law Exponent, α
a)	25-125°	0.16
b)	125-215°	0.23
c)	215-360°,0-25°	0.30

For the first phase flow visualization study, experience has shown that with a qualitative analysis using smoke for a tracer, no differentiation can be made in flow characteristics for modest changes in approach profile. Thus, a single approach profile with $\alpha = 0.27$ was selected to represent all three approach characteristics. The approach wind profile used for the qualitative study of pedestrian winds is shown in Figure A3. Quantitative evaluation of pedestrian winds which will be performed later can be affected by approach profile characteristics so that study will use the appropriate boundary layer for each approach wind direction.

The entire city model is mounted on a turntable so that it may be rotated to any desired wind direction.

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2. Cermak, J. E., "Applications of Fluid Mechanics to Wind Engineering," A Freeman Scholar Lecture, ASME Jl. of Fluids Engineering, Vol. 97, No. 1, March 1975.

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Table 1. Results of Flow Visualization Study

Number of Wind Directions with Specified Wind Speed

		Wind Speed						Wind Speed			
Area No.	Config.	High	Mod	Low	Stag	Area No.	Config.	High	Mod	Low	Stag
1	PRE		4	4		6	PRE		5	3	
	PH1		2	5	1		PH1		5	3	
	PH2		3	5			PH2		5	3	
	PH1F		3	5			PH1F		5	3	
	PH2F		4	4			PH2F		5	3	
2	PRE	1	5	2		7	PRE		6	2	
	PH1	1	5	2			PH1		6	2	
	PH2		6	2			PH2		6	2	
	PH1F		6	2			PH1F		5	3	
	PH2F		6	2			PH2F		6	2	
3	PRE		4	4		8	PRE		6	2	
	PH1	4	3	1			PH1		4	4	
	PH2	4	4				PH2	2	4	2	
	PH1F	2	5	1			PH1F		4	4	
	PH2F	2	6				PH2F	1	4	3	
4	PRE		8			9	PRE		7	1	
	PH1		6	2			PH1		4	4	
	PH2		6	2			PH2		5	3	
	PH1F		5	3			PH1F		3	5	
	PH2F		5	3			PH2F		4	4	
5	PRE	2	3	3		10	PRE	5	3		
	PH1		3	5			PH1	5	3		
	PH2		4	4			PH2	5	3		
	PH1F		4	4			PH1F	5	2	1	
	PH2F		4	4			PH2F	5	2	1	

Table 1. continued.

Number of Wind Directions with Specified Wind Speed											
		Wind Speed						Wind Speed			
Area No.	Config.	High	Mod	Low	Stag	Area No.	Config.	High	Mod	Low	Stag
11	PRE	1	6	1		16	PRE		6	2	
	PH1		7	1			PH1	4	2	2	
	PH2		6	2			PH2	2	4	2	
	PH1F	2	6				PH1F	5	3		
	PH2F	1	6	1			PH2F	3	5	1	
12	PRE	1	4	3		17	PRE	1	6	1	
	PH1		5	3			PH1	1	6	1	
	PH2		5	3			PH2	1	6	1	
	PH1F		6	2			PH1F		8		
	PH2F		6	2			PH2F		8		
13	PRE		5	3		18	PRE		7	1	
	PH1		5	3			PH1		6	2	
	PH2		5	3			PH2	1	4	3	
	PH1F		5	3			PH1F	1	5	2	
	PH2F		5	3			PH2F	1	4	3	
14	PRE		7	1		19	PRE		4	4	
	PH1		7	1			PH1		2	6	
	PH2	1	5	2			PH2		1	7	
	PH1F		6	2			PH1F			8	
	PH2F	1	3	4			PH2F			8	
15	PRE		3	4	1						
	PH1		3	5							
	PH2		1	6	1						
	PH1F		2	6							
	PH2F		2	5	1						

FIGURES

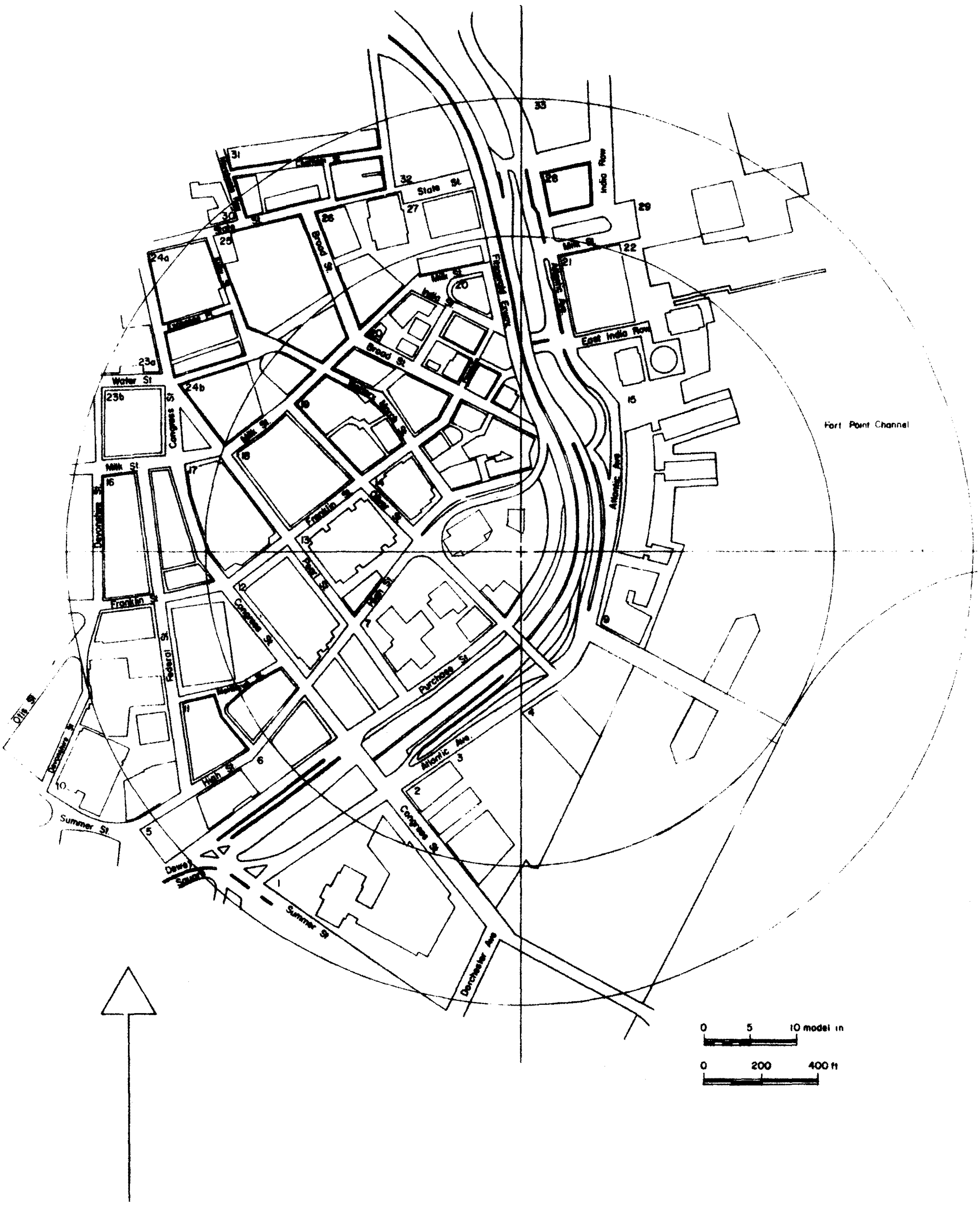

Figure 1. International Place Site and Surroundings

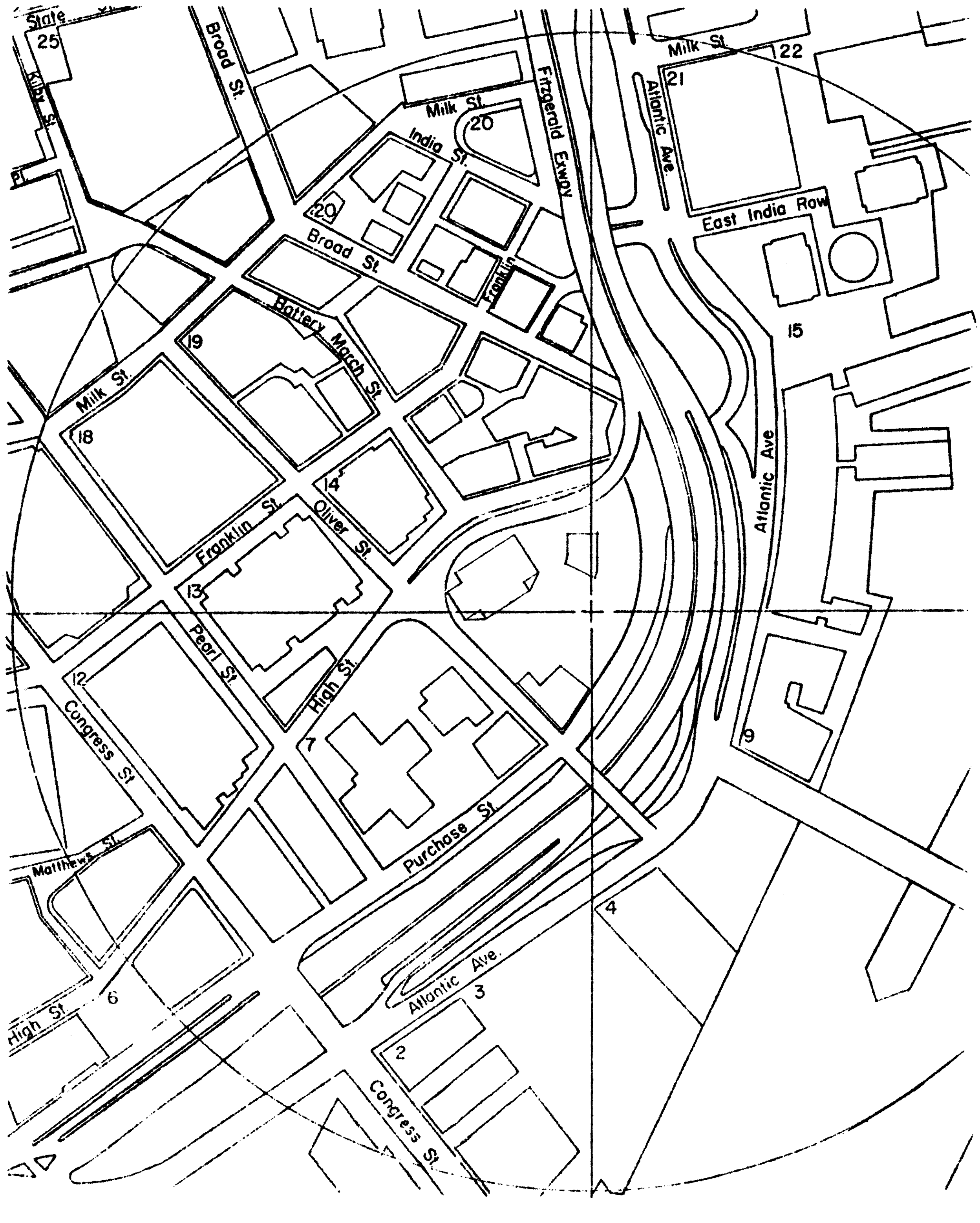

Figure 2. Site Configuration PRE -- Pre-Construction Phase

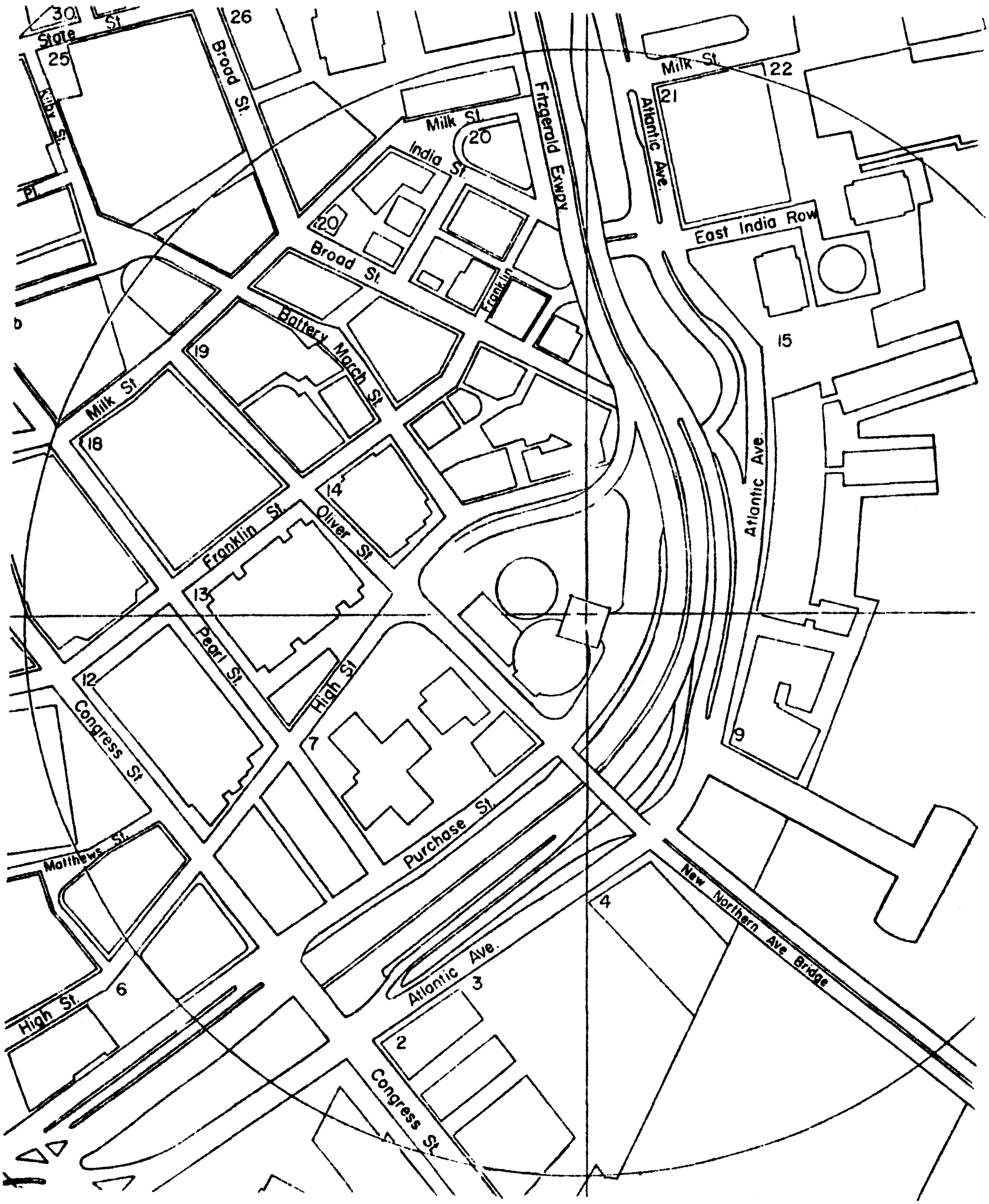

Figure 3. Site Configuration PH1 -- South Tower and Lowrise

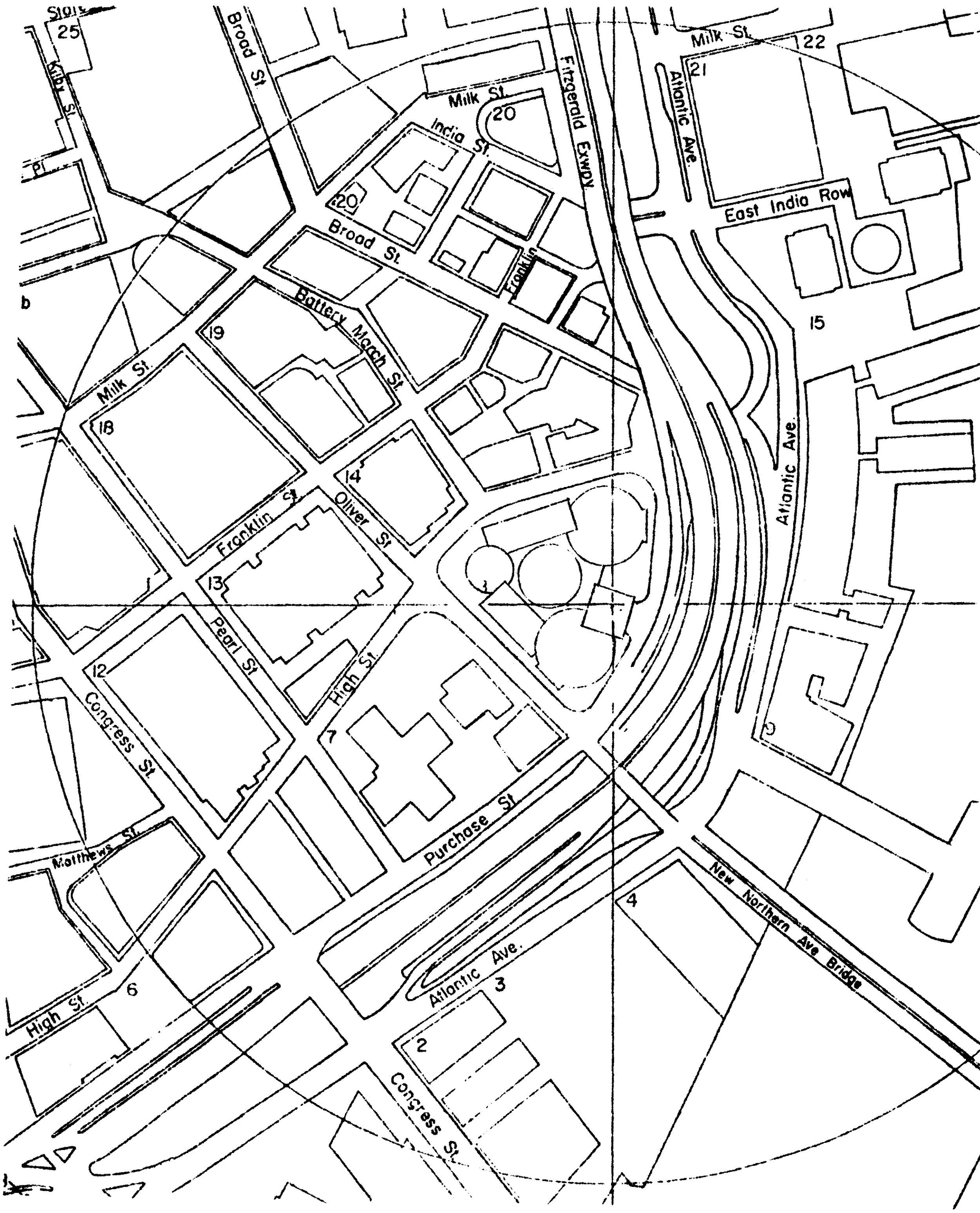

Figure 4. Site Configuration PH2 -- Both Towers in Completed Project

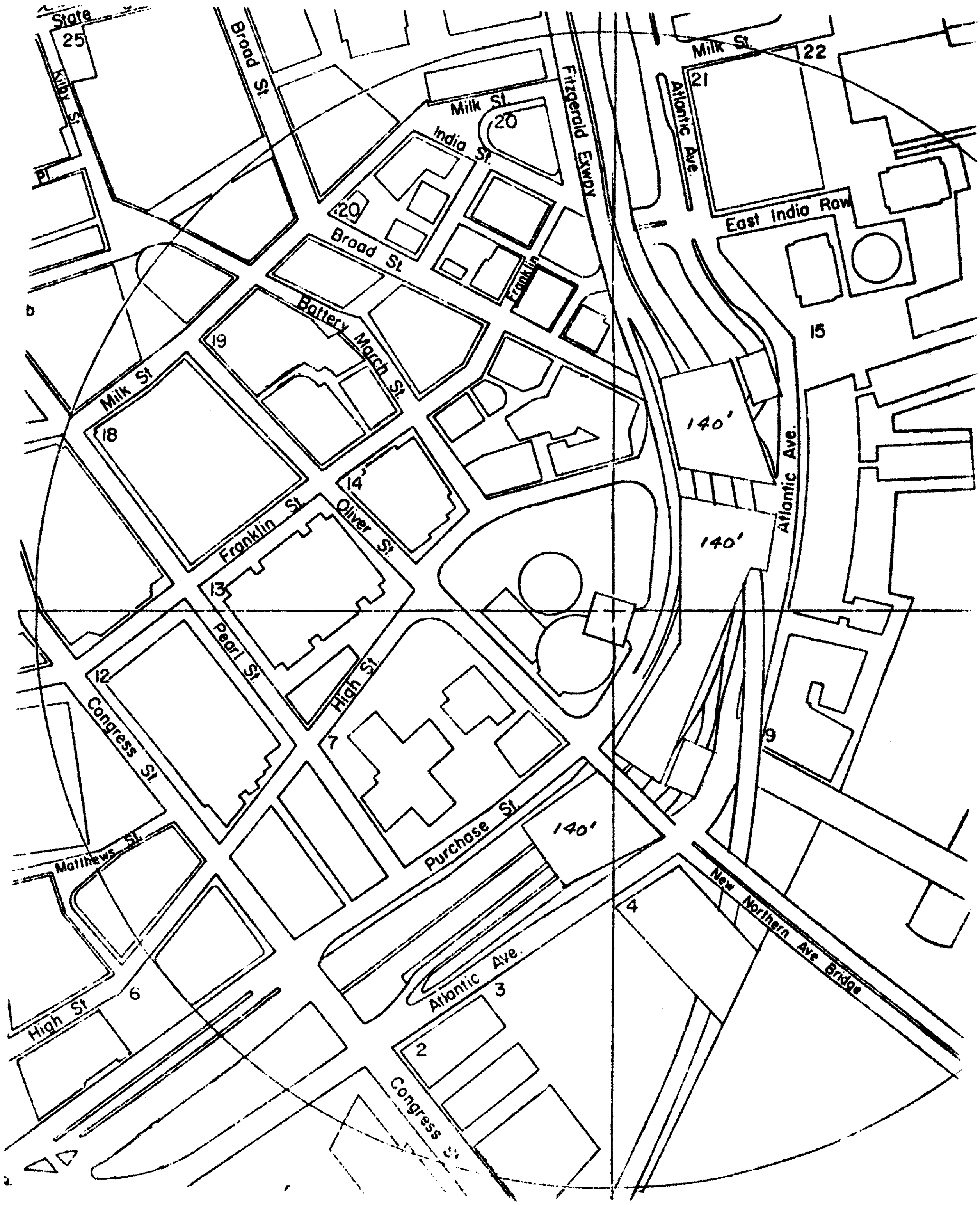

Figure 5. Site Configuration PH1F -- Configuration PH1 with Added Freeway Structures

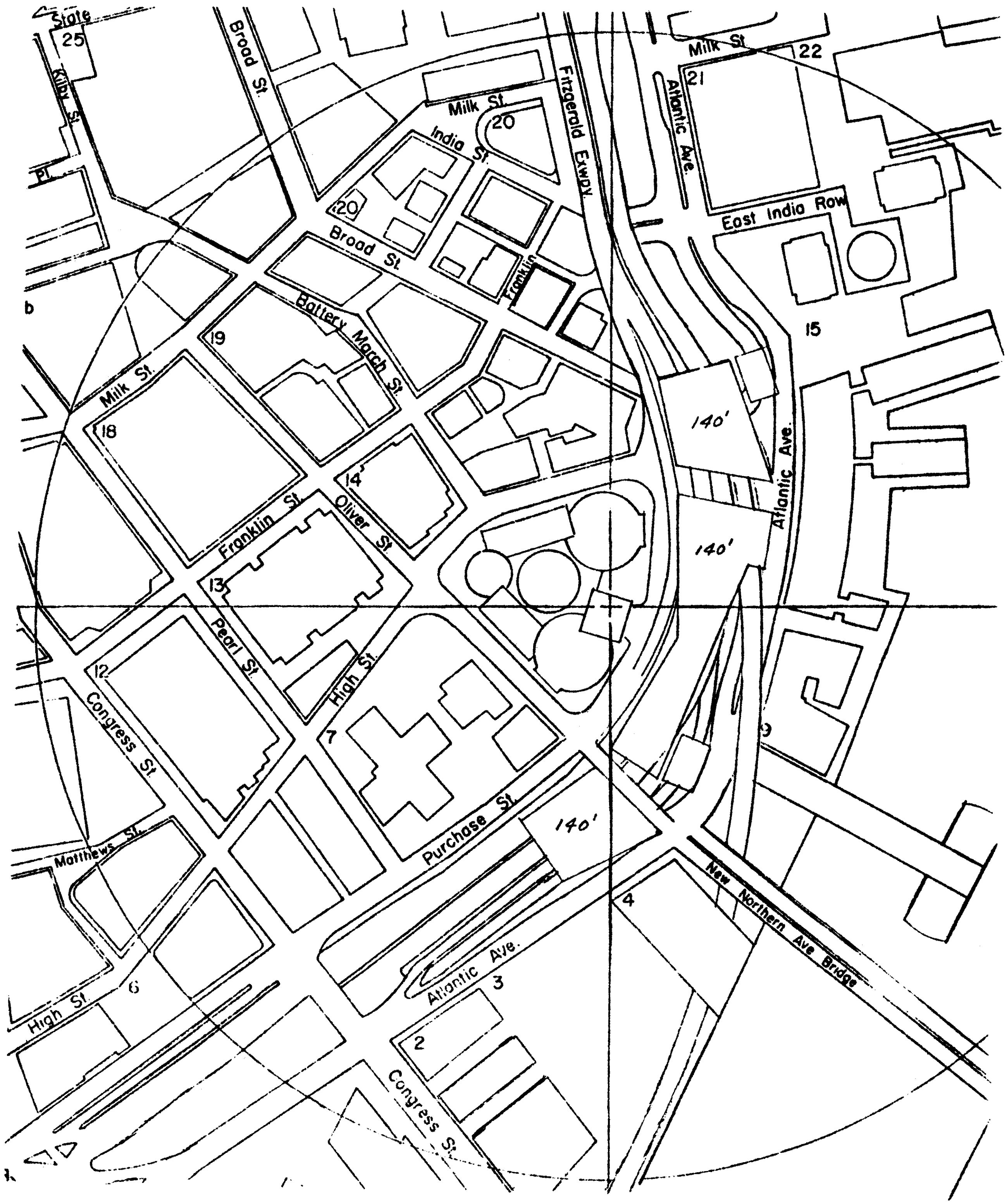

Figure 6. Site Configuration PH2F -- Configuration PH2 with Added Freeway Structures

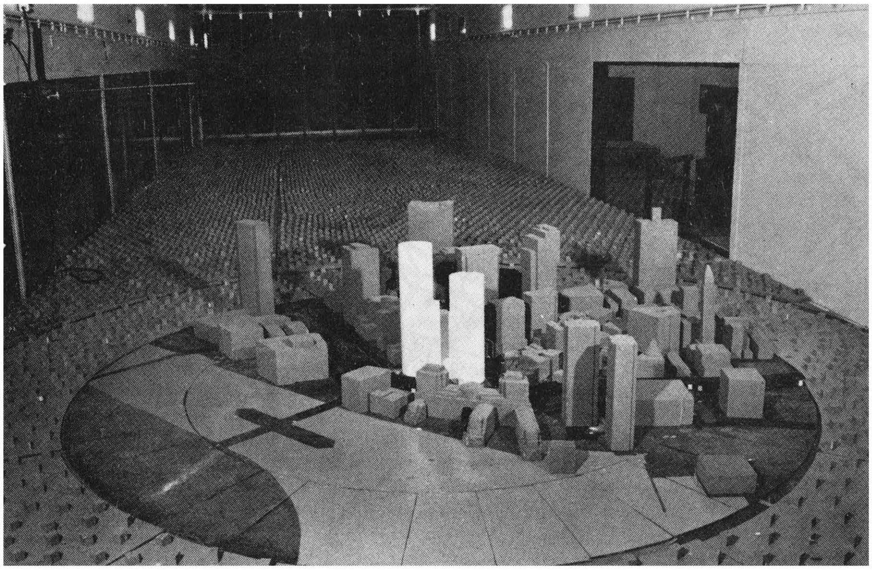

Figure 7. Completed Model in the Wind Tunnel

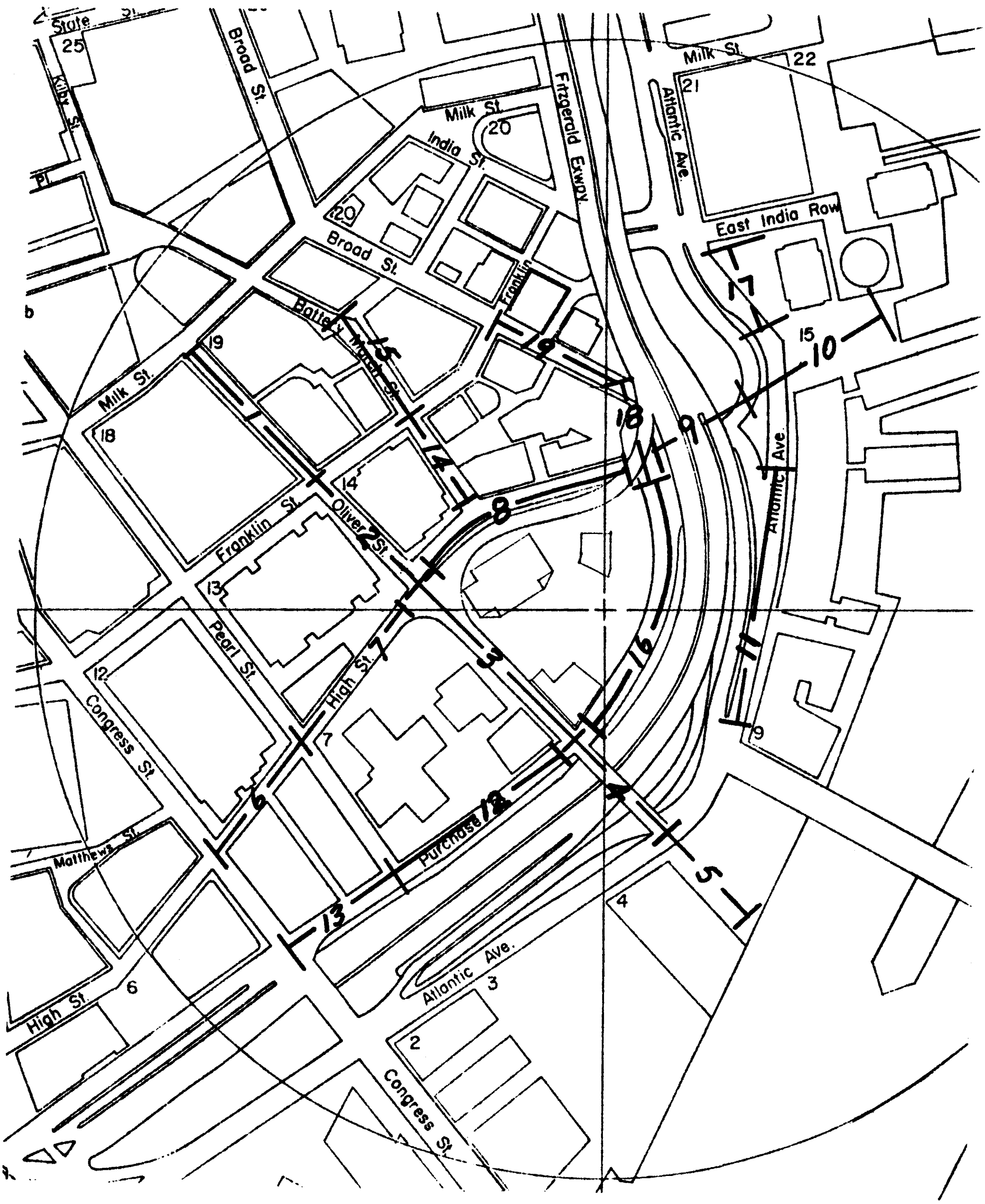

Figure 8. Location of Pedestrian Areas for Qualitative Evaluation

Figure 9a. High Velocity Areas for Configuration PRE

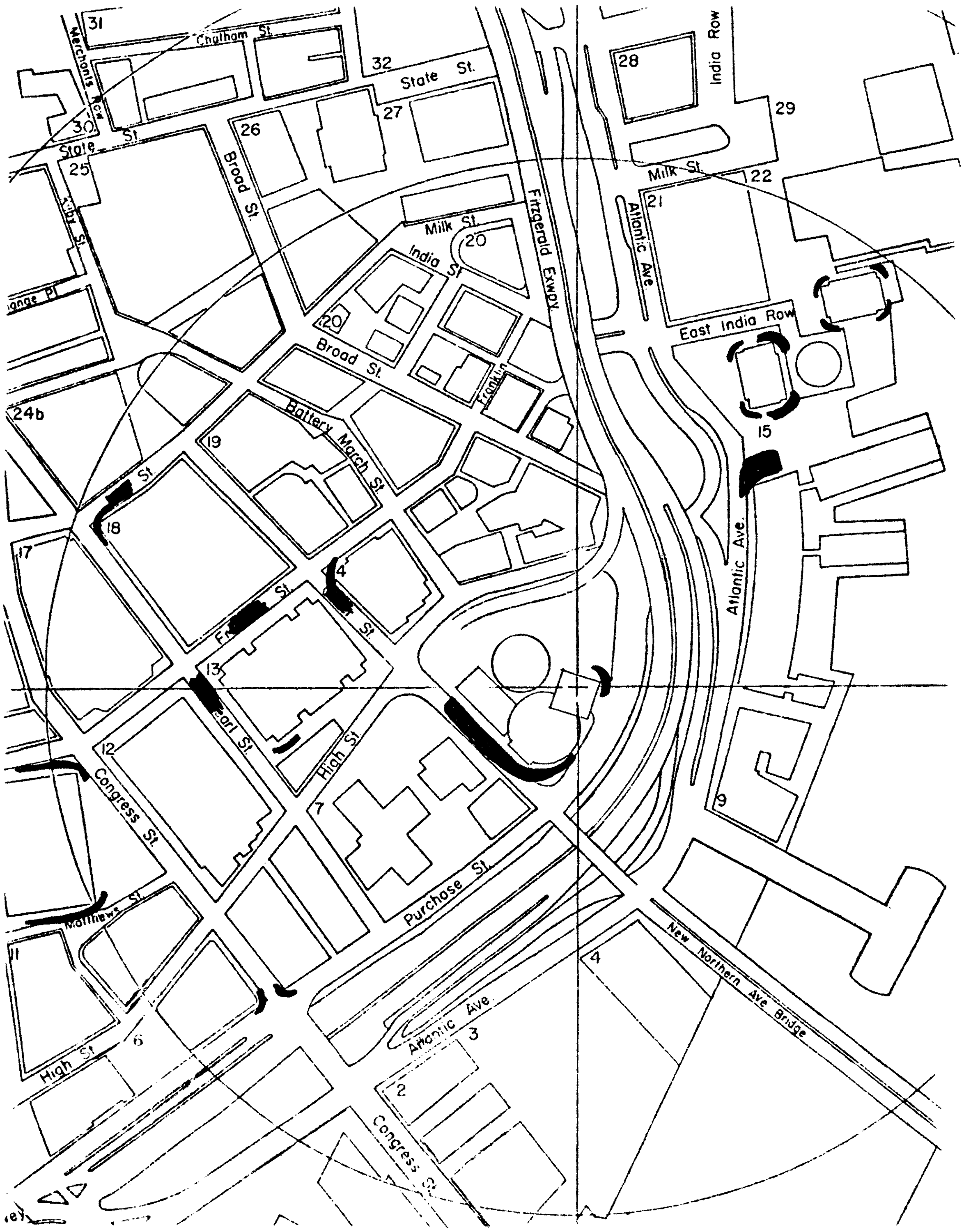

Figure 9b. High Velocity Areas for Configuration PH1

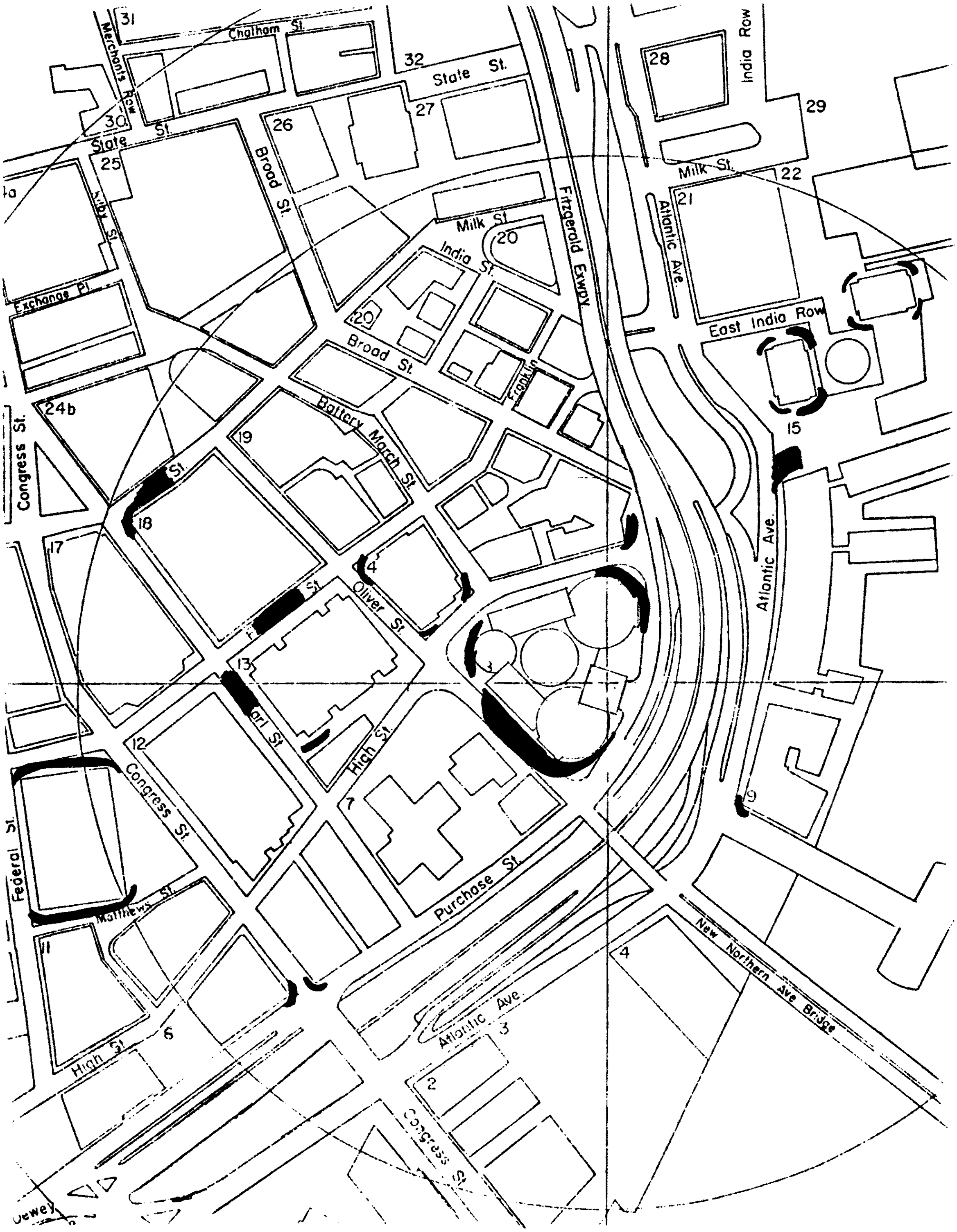

Figure 9c. High Velocity Areas for Configuration PH2

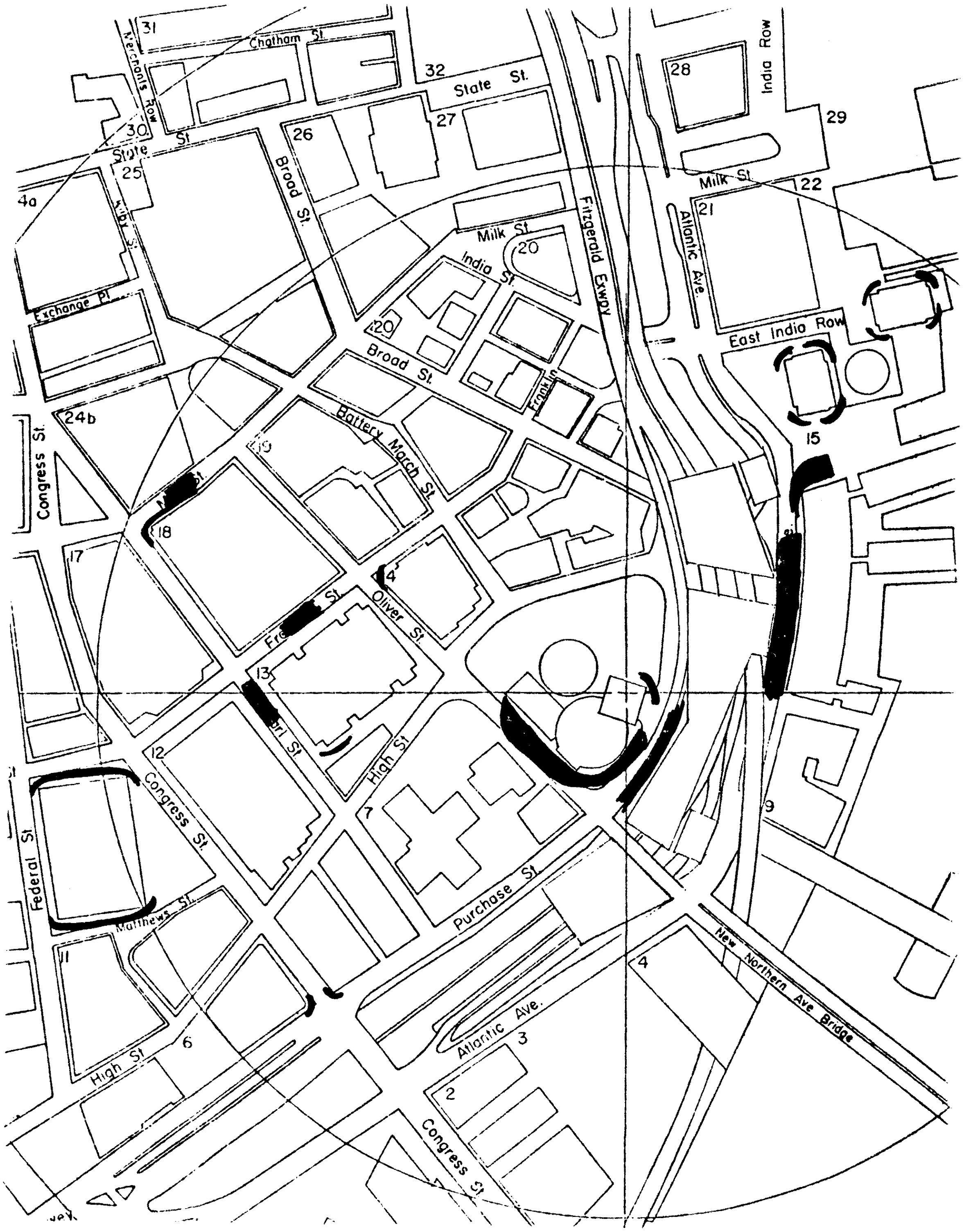

Figure 9d. High Velocity Areas for Configuration PH1F

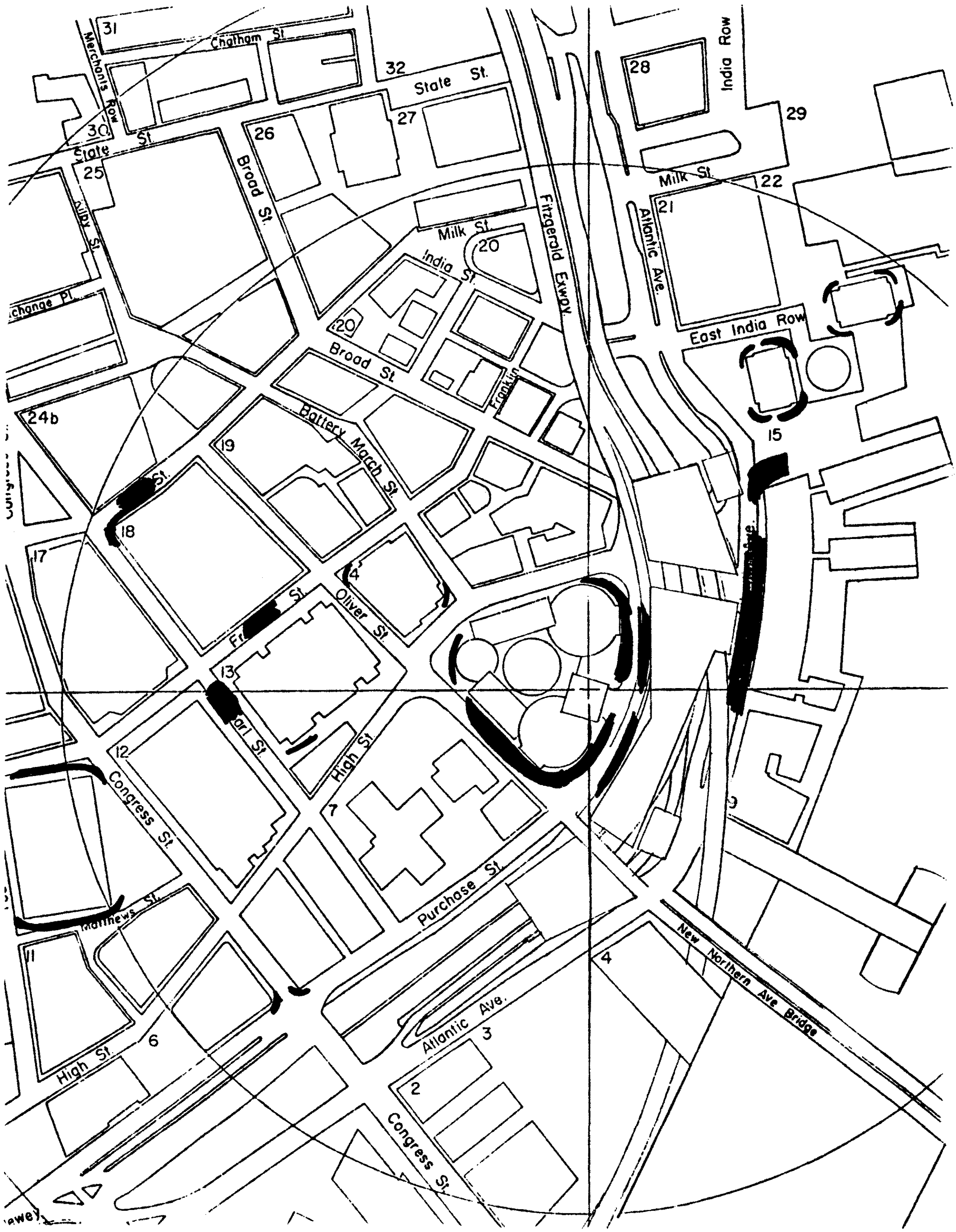

Figure 9e. High Velocity Areas for Configuration PH2F

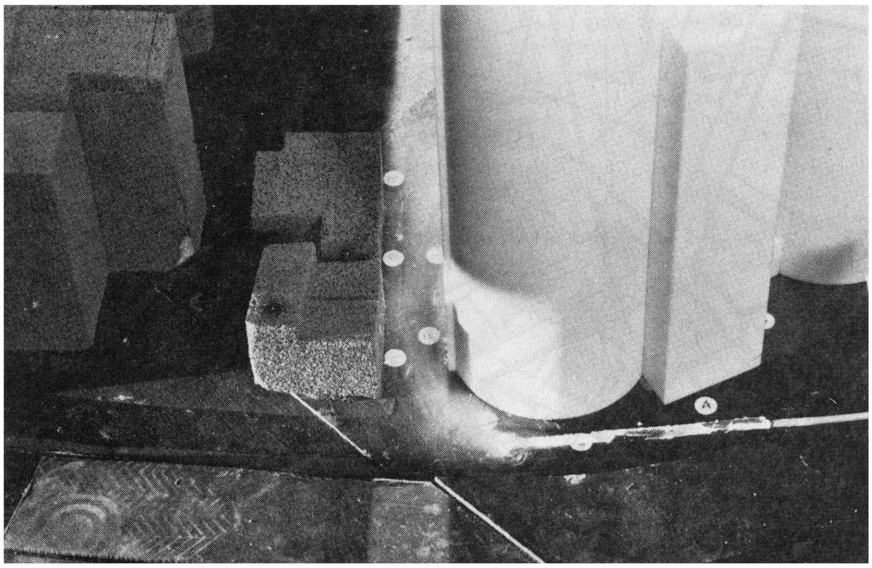

Figure 10. Flow Visualization of a high Wind Area on the Project Site for an East Wind

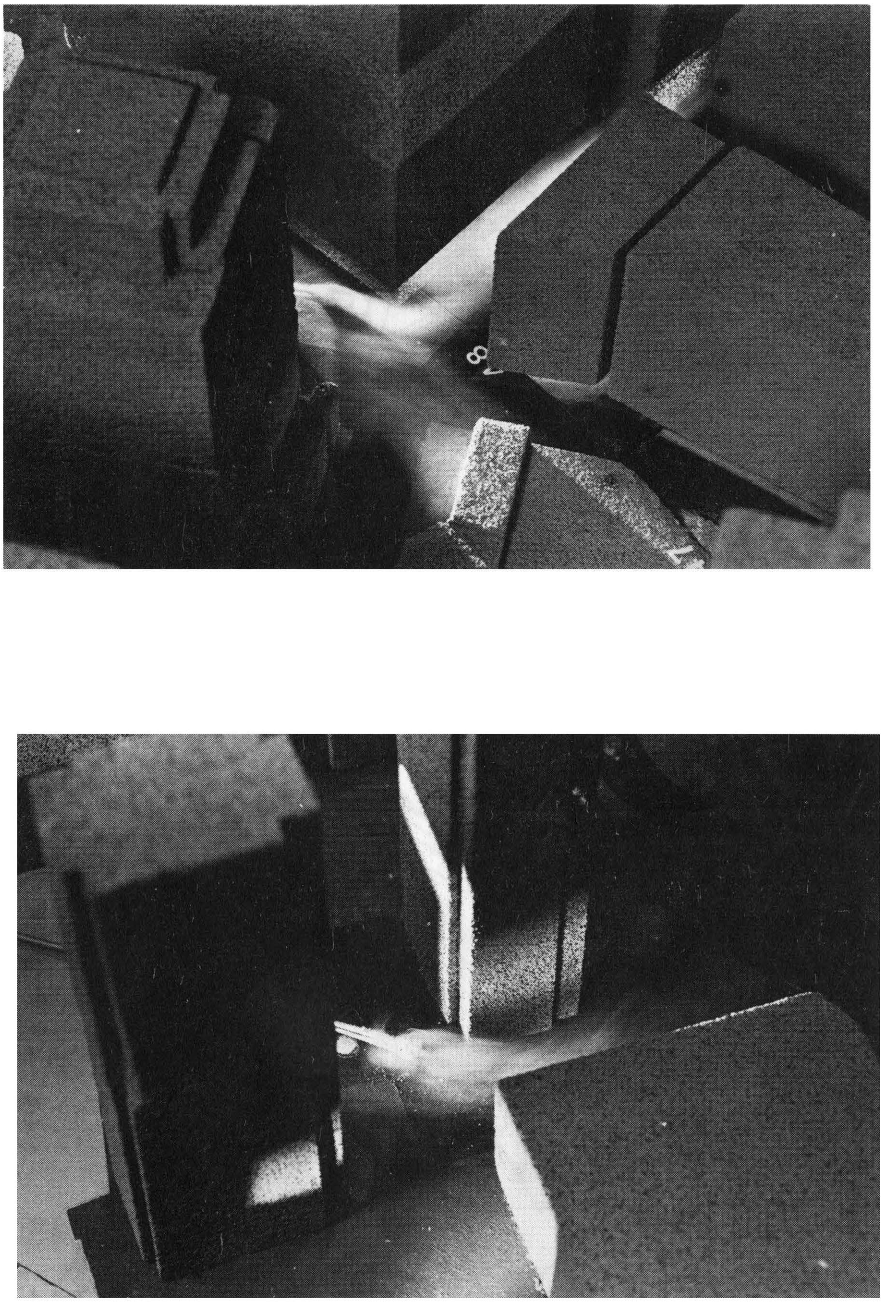

Figure 11. Flow Visualization of Two High-Wind Areas Away from the Projected Site for an East Wind

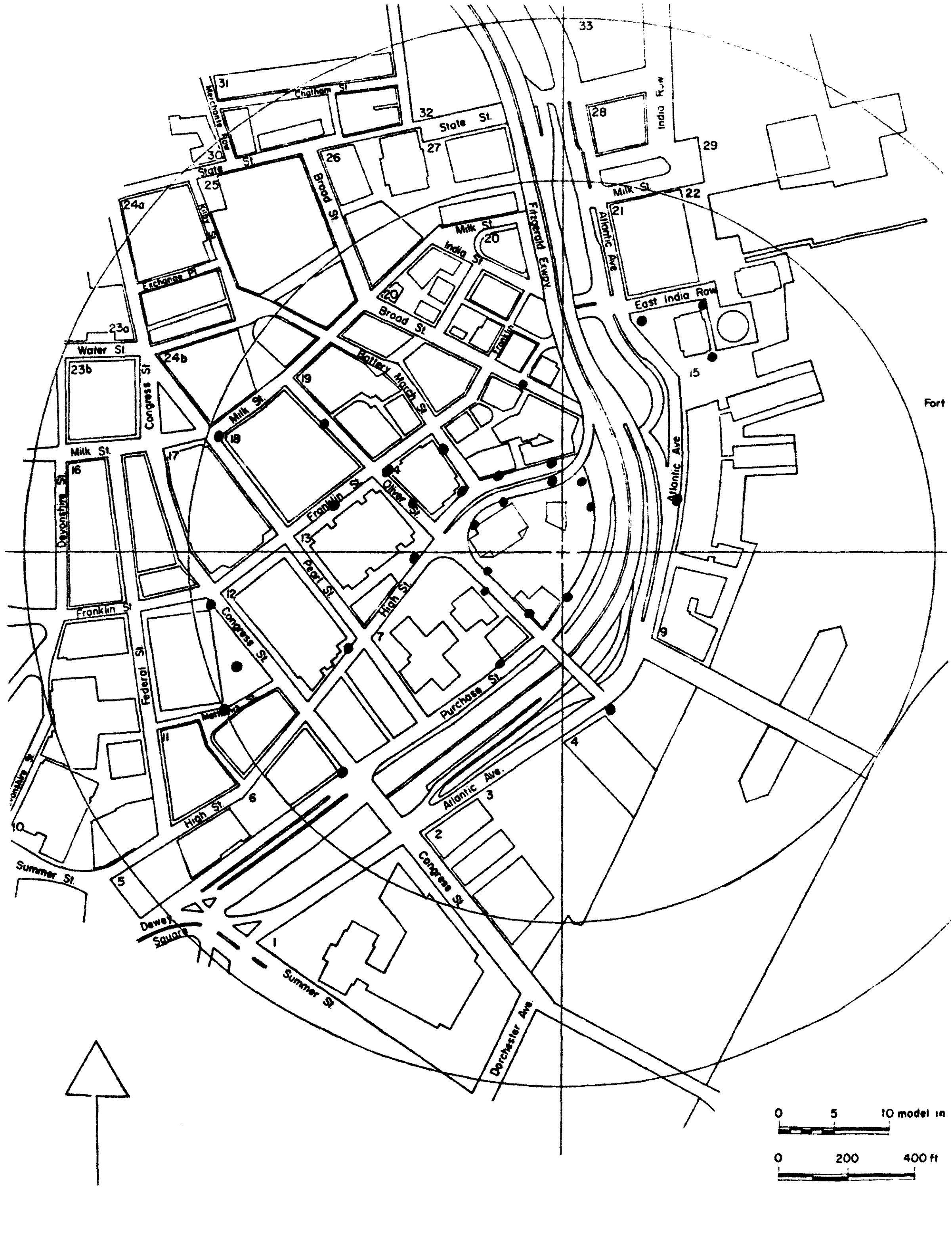

Figure 12. Proposed Locations for Quantitative Wind Analysis

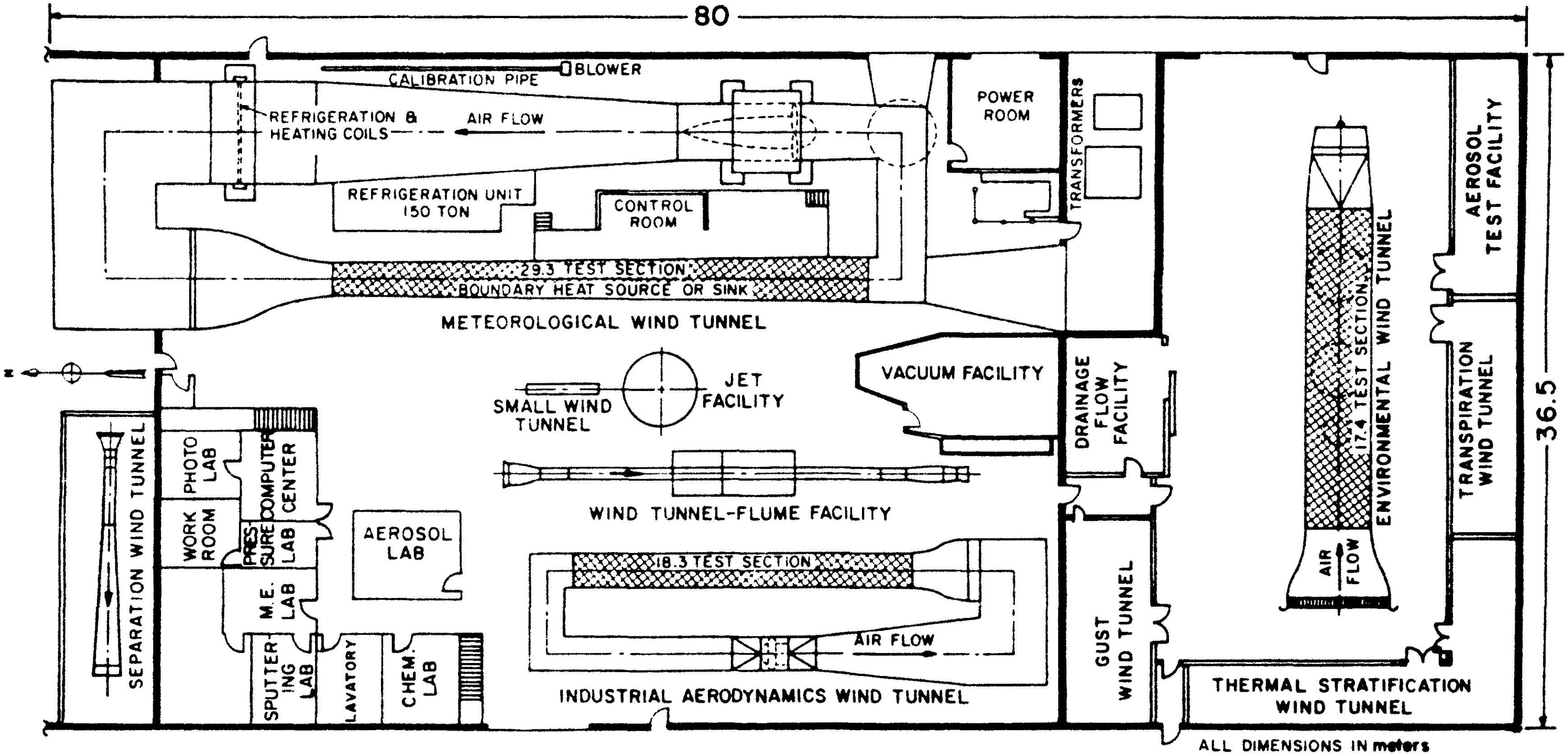

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Figure A1. Fluid Dynamics and Diffusion Laboratory

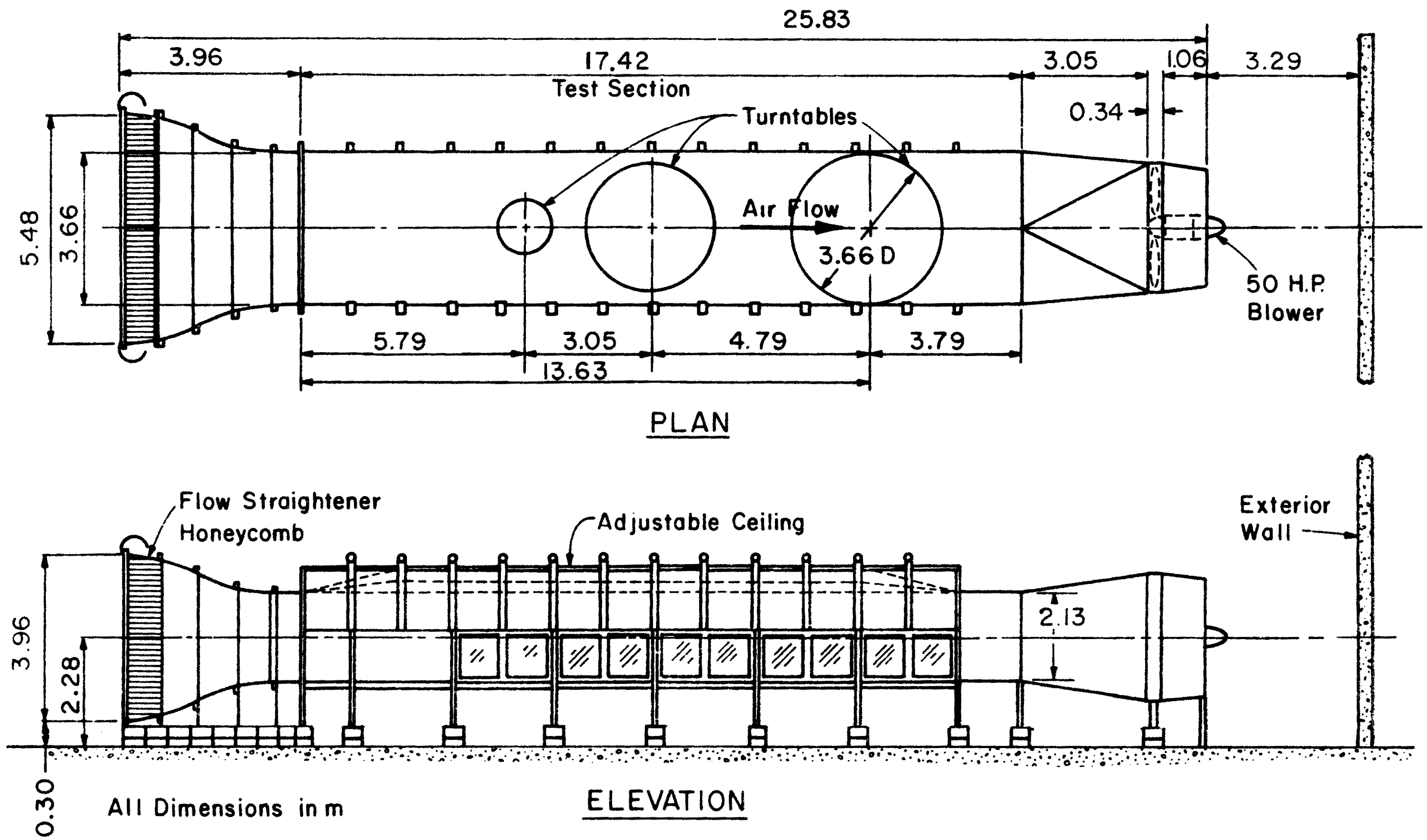

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Figure A2. Wind Tunnel Configuration

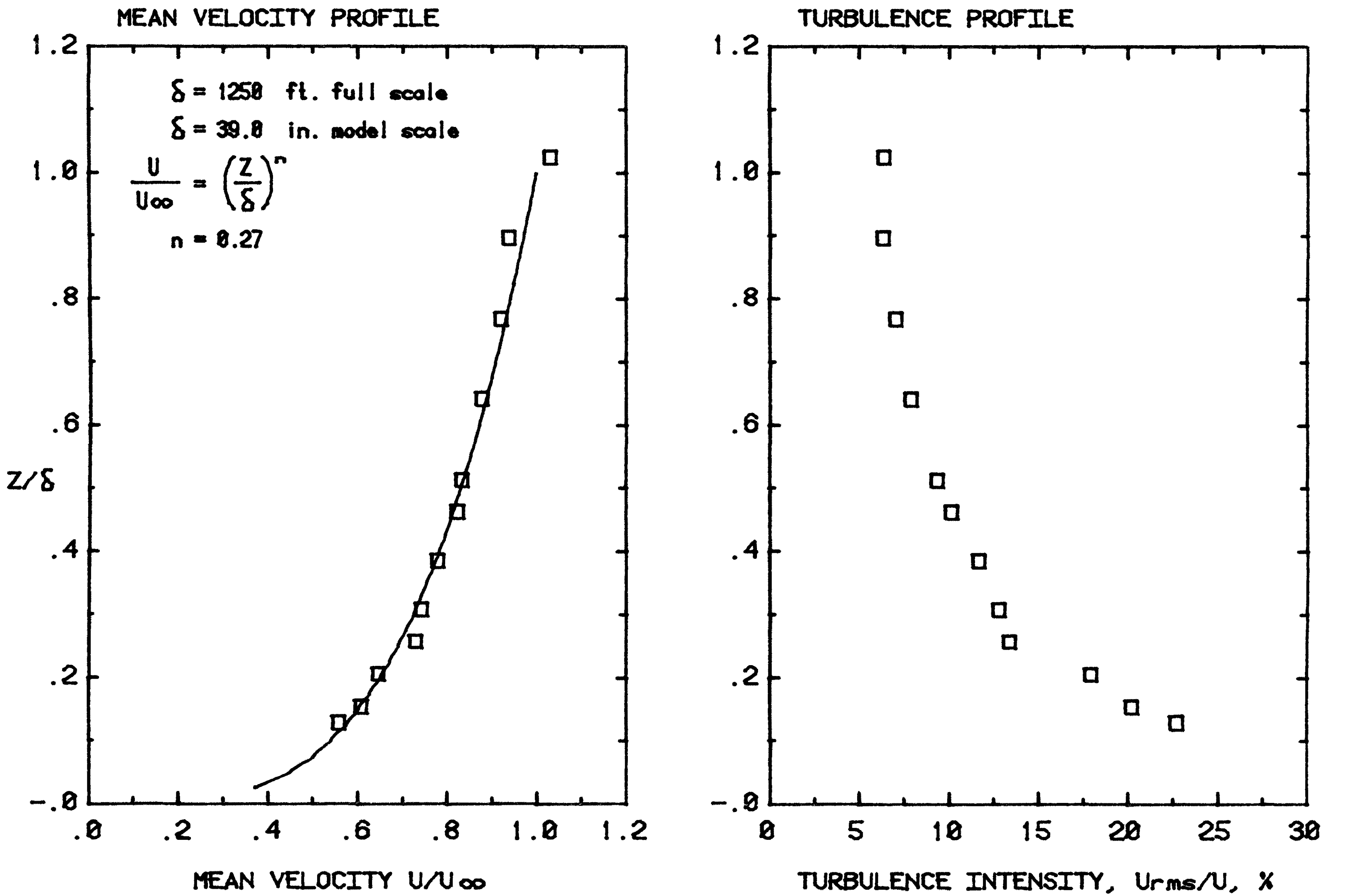

Figure A3. Approach Wind Profile Characteristics