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CONSULTING ENGINEERS & SCIENTISTS

Agaogla Maslak EGYO Project

Istanbul, Turkey

Draft Report – Tower C10

Cladding Pressures

RWDI # 1300132
January 17, 2014

SUBMITTED TO

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1. INTRODUCTION

Rowan Williams Davies & Irwin Inc. (RWDI) was retained by Yapi Teknik to study the wind loading on the proposed Agaogla Maslak EGYO Project in Istanbul, Turkey. The Agaogla Maslak EGYO Project is a multi-tower development comprised of four phases, with hotel, residential, office, retail and conference facilities. The objective of this study was to determine the wind loads for design of the exterior envelope of tower C10.

The following table summarizes relevant information about the design team, results of the study and the governing parameters:

Project Details:		
	Architect	Leach Rhodes Walker Architects
Key Results and Recommendations:		
	Recommended Cladding Design Wind Loads Negative Pressures Positive Pressures	 Figures 4 to 8 Figures 9 to 13
	Range of Negative Pressures Range of Positive Pressures	-1.0 kPa to -1.75 kPa +1.0 kPa to +2 kPa
Selected Analysis Parameters:		
	Internal Pressures	+0.18 kPa, -0.18 kPa
	Basic Wind Speed per FBC 2001	36m/s 3-second Gust Speed at 10m in open terrain
	Importance Factor on Wind Speed	1.0

The wind tunnel test procedures met or exceeded the requirements set out in Chapter 31 of the ASCE 7-10 Standard. The following sections outline the test methodology for the current study, and discuss the results and recommendations. Appendix A provides additional background information on the testing and analysis procedures for this type of study. For detailed explanations of the procedures and underlying theory, refer to RWDI's Technical Reference Document - Wind Tunnel Studies for Buildings (RD2-2000.1), which is available upon request.

2. WIND TUNNEL TESTS

2.1 Study Model and Surroundings

A 1:400 scale model of the proposed development was constructed using the architectural drawings listed in Table 1. The model was instrumented with 280 pressure taps and was tested in the presence of all surroundings within a full-scale radius of 480 m, in RWDI's 2.4 m × 2.0 m boundary layer wind tunnel facility in Dunstable, Bedfordshire.

Photographs of the scale model in the boundary layer wind tunnel are shown in Figure 1. An orientation plan showing the location of the study site is given in Figure 2.

2.2 Upwind Profiles

Beyond the modeled area, the influence of the upwind terrain on the planetary boundary layer was simulated in the testing by appropriate roughness on the wind tunnel floor and flow conditioning spires at the upwind end of the working section for each wind direction. This simulation, and subsequent analysis of the data from the model, was targeted to represent the following upwind terrain conditions. Wind direction is defined as the direction from which the wind blows, measured clockwise from true north.

Upwind Terrain	Wind Directions (Inclusive)
Urban/Suburban terrain – varying lengths of suburban and urban fetch immediately upwind of the surrounding model, with open terrain or water beyond.	10° to 360°

3. WIND CLIMATE

In order to predict the full-scale wind pressures acting on the building as a function of return period, the wind tunnel data were combined with a statistical model of the local wind climate. The wind climate model was based on local surface wind measurements taken at Ataturk International Airport, Istanbul.

The magnitude of the wind velocity for the 50 year return period corresponded to a 3-second gust wind speed of 36m/s at a height of 10 m in open terrain. This value is consistent with that identified for Istanbul in the TS498 Turkish Standard.

The wind climate for Istanbul is illustrated by the plots in Figure 3. The upper two plots show, based on the wind climate model, the strength of the wind versus wind direction. The lower plot shows the wind speeds from the data set as a function of return period.

4. DETERMINING CLADDING WIND LOADS FROM WIND TUNNEL TEST RESULTS

For design of cladding elements, the net wind load acting across an element must be considered. The results provided in this report include the contributions of the wind loads acting on both the external surface (measured directly on the scale model during the wind tunnel test) and internal surface of the element (determined through analytical methods and the wind tunnel test data).

For elements exposed to wind on the external surface only, an internal pressure allowance must be applied to the measured external pressure in order to determine the net pressure applicable for design. In strong winds, the internal pressures are dominated by air leakage effects. Important sources of air leakage include uniformly distributed small leakage paths over the building's envelope.

The wind loads provided are net pressures which include an allowance for wind-induced internal pressure based on a building without any large or significant openings. The resulting internal pressure allowance values were ±0.18 kPa. Note that this allowance doesn't include any consideration of pressures induced by auxiliary mechanical systems.

To obtain the net peak negative pressure on the building's cladding, the negative exterior pressures were augmented by an amount equal to the positive internal pressure. Likewise, the net peak positive pressures were obtained by augmenting the exterior positive pressure by an amount equal to the magnitude of the negative internal pressure.

For elements exposed to wind on opposite surfaces such as parapets, fins and canopies, the net pressure acting on the element was determined by measuring the instantaneous pressure difference across the element.

5. RECOMMENDED CLADDING DESIGN WIND LOADS

It is recommended that the wind loads presented in Figures 4 through 13 be considered for the 50-year return period. The drawings in these figures have been zoned using 0.25 kPa increments so that the pressure indicated is the maximum pressure in that particular zone. For example, a 1.5 kPa zone would have pressures ranging from 1.26 kPa to 1.5kPa.

Wind loads have been provided for the elevation walls of the tower and separately for the fin features (figures 7 and 12). In these cases the local recommended pressures shown are differential pressures measured across the fins.

Note that the recommended wind loads are for cladding design for resistance against wind pressure, including an allowance for internal pressures. Design of the cladding to the provided wind loads will not necessarily prevent breakage due to impact by wind borne debris.

Note that the wind loads provided in this report include the effects of the directionality in the local wind climate. These loads do not contain safety or load factors and are to be applied to the building's cladding system in the same manner as would wind loads calculated by code analytical methods.

"Negative pressure" or suction is defined to act outward normal to the building's exterior surface and "positive pressure" acts inward. The largest recommended negative cladding wind load was -1.75 kPa, which occurred on the Roof Plan (Figure 8). The majority of the negative wind loads were -1.0 kPa. The largest recommended positive cladding wind load was +2 kPa, which occurred on both the Internal and External Front Wall (Figures 9 and 12, respectively). The majority of the positive wind loads were +1.0kPa.

6. APPLICABILITY OF RESULTS

6.1 The Proximity Model

The cladding design wind loads determined by the wind tunnel tests and aforementioned analytical procedures are applicable to the particular configuration of surroundings modeled. The surroundings model used for the wind tunnel tests reflected the current state of development at the time of testing and include, where appropriate, known off-site structures expected to be completed in the near future. If, at a later date, additional buildings besides those considered in the tested configuration are constructed or demolished near the project site, then some load changes could occur. To make some allowance for possible future changes in surroundings, our final recommended cladding design wind loads do not go below a minimum of ±1.0kPa.

6.2 Study Model

The results presented in this report pertain to the scale model of the proposed development, constructed using the architectural information listed in Table 1. Should there be any design changes that deviate substantially from the above information; the results for the revised design may differ from those presented in this report. Therefore, if the design changes, RWDI should be contacted and requested to review the impact on the wind loads.

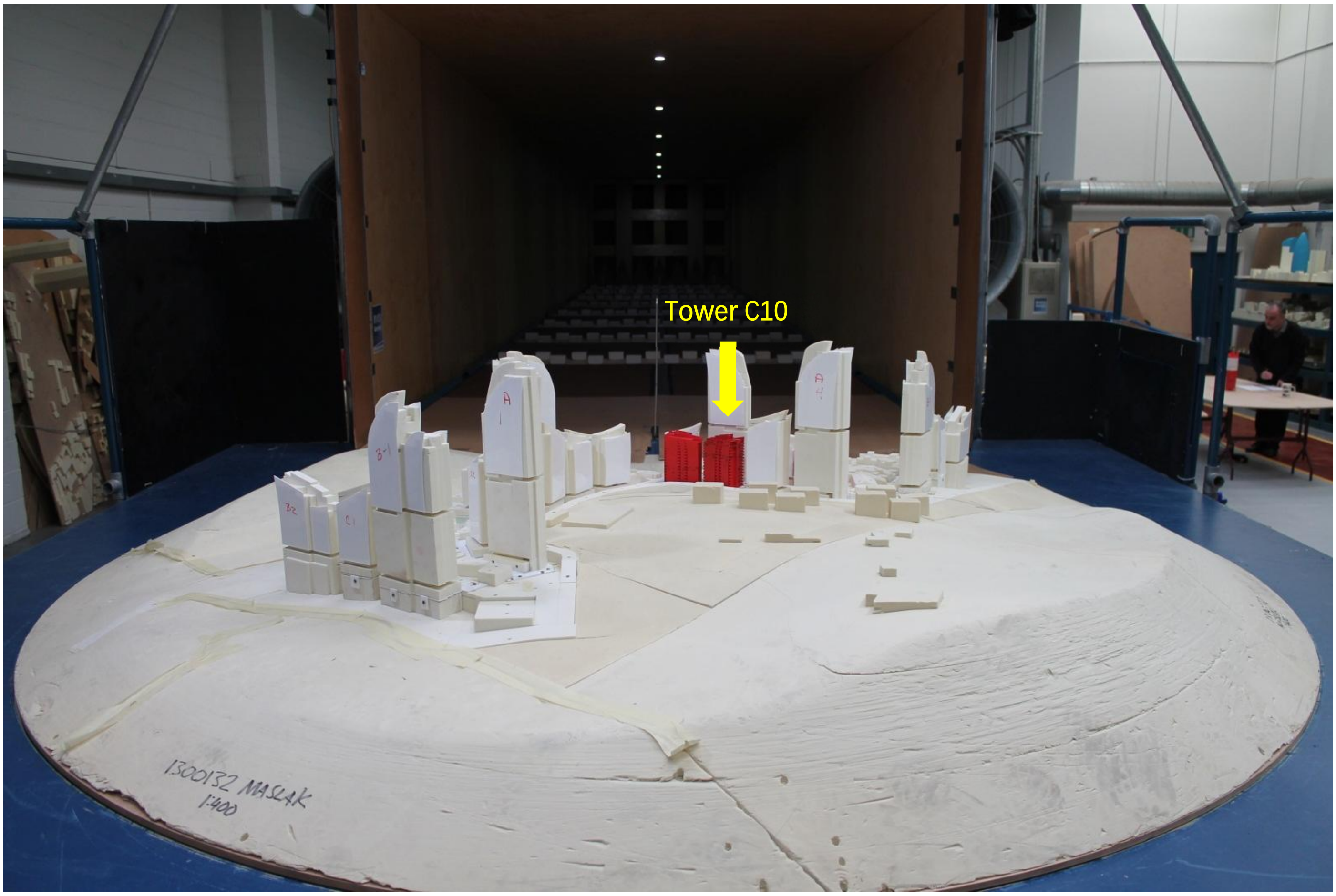
TABLES

TABLE 1: DRAWING LIST FOR MODEL CONSTRUCTION

The drawings and information listed below were received from Leach Rhodes Walker Architects and were used to construct the scale model of the proposed Agaogla Maslak EGYO Project. Should there be any design changes that deviate from this list of drawings, the results may change. Therefore, if changes in the design area made, it is recommended that RWDI be contacted and requested to review their potential effects on wind conditions.

File Name	File Type	Date Received
AgaogluAyazaga-10	.dwg	13/01/03
AgaogluAyazaga-10	.skp	13/01/03

FIGURES



Wind Tunnel Study Model
Tower C10

Agaogla Maslak EGYO Project – Istanbul, Turkey

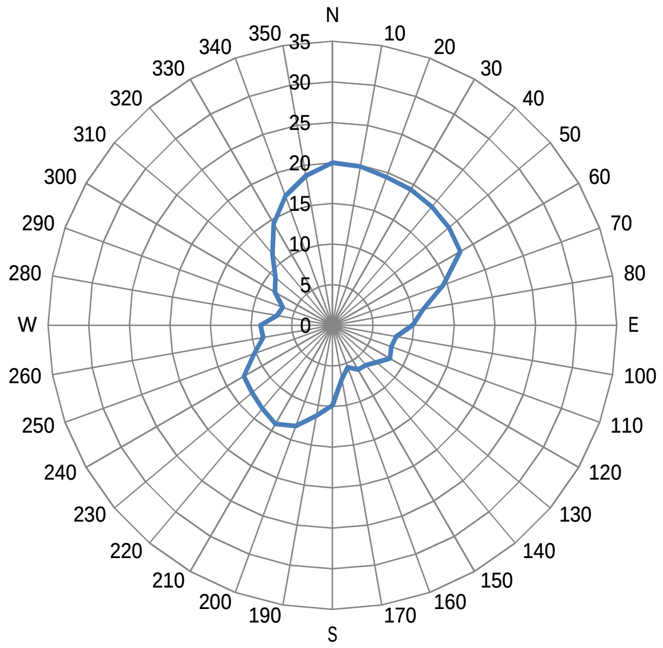
Project #1300132

Figure: 1

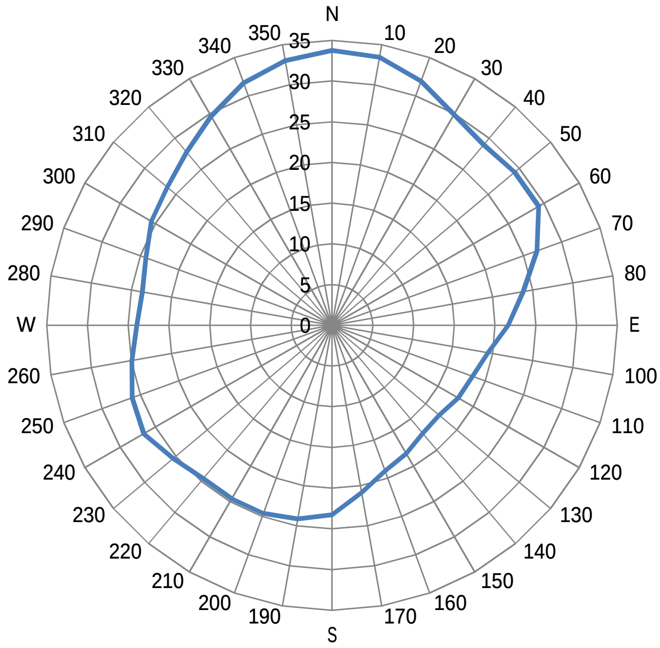
Date: January 15, 2014

RWDI

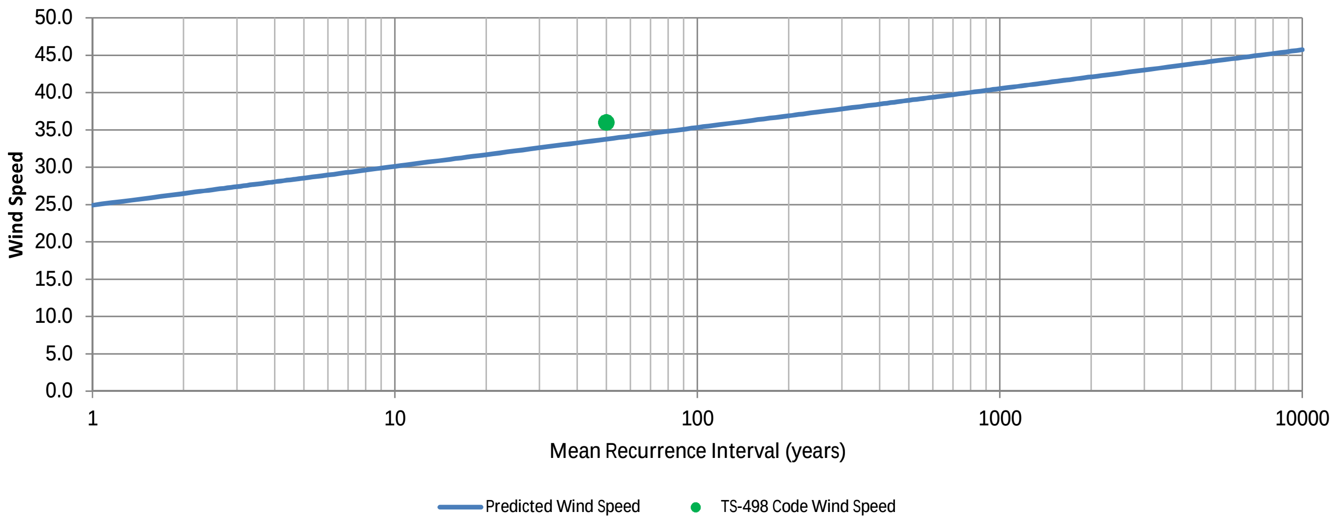
Site Plan	True North	Drawn by: ck	Figure: 2
		Approx. Scale: 1:2000	
Agaogla Maslak EGYO Project - Istanbul, Turkey	Project #1300132	Date Revised: Jan. 16, 2014	



Common Winds
Corresponding to a 1-month return period



Extreme Winds
Corresponding to a 50-year return period



Note: Wind Speeds shown are 3-second Gust Wind Speeds (m/s) at 10 m height in Open Terrain

Directional Distribution of Local Wind Speeds

Figure No. 3

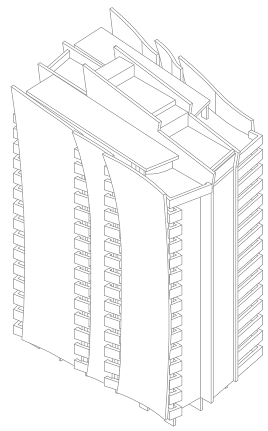
Agaogla Maslak EGYO Project - Istanbul

Project # 1300132

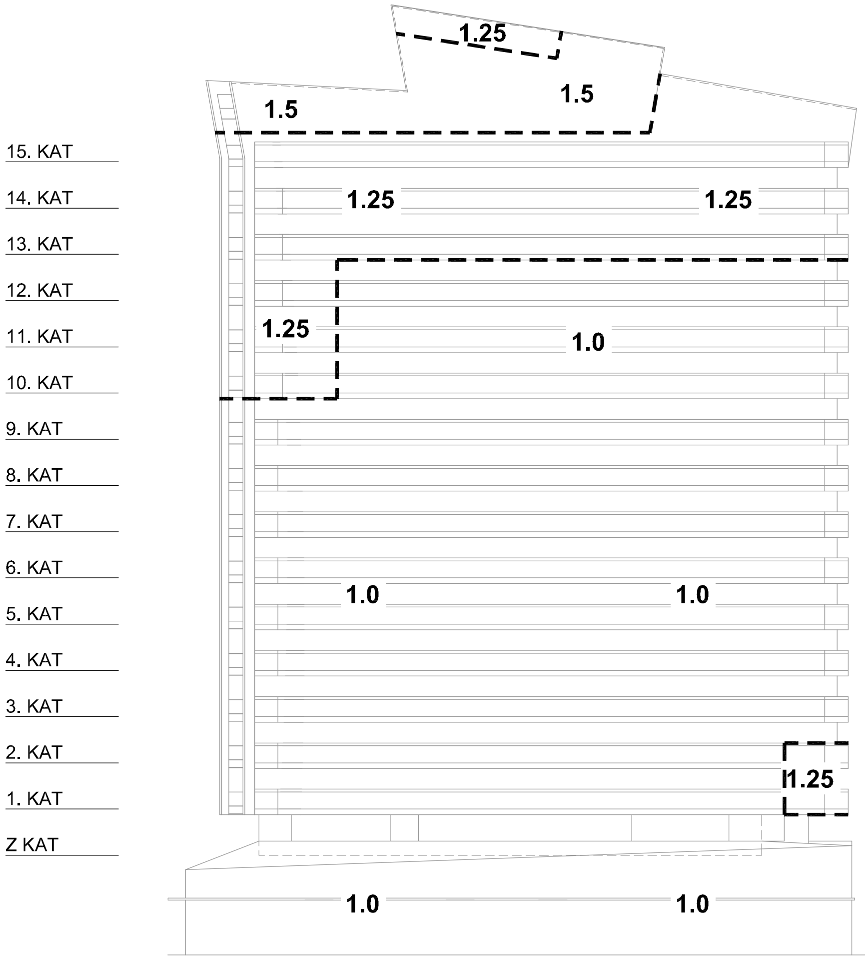
Date: Jan. 13, 2014

RWDI

Note:
The wind loads presented **do not** contain load or safety factors. The loads are to be applied to the building's cladding system in the same manner as would wind loads calculated by building code analytical methods.



Representation of Tower C10

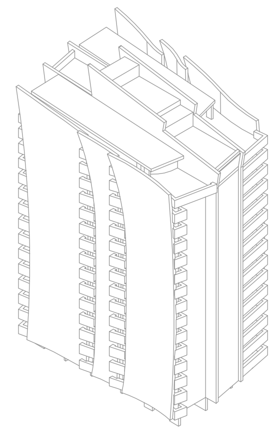


C10 - FRONT (INSIDE WALL)

0 10 20m

Recommended Wind Loads for Cladding Design (kPa)	Drawn by: ck	Figure: 4
Peak Net Negative Pressures (Negative External Pressure with Positive Internal Pressure Where Applicable) 50-Year Basic Wind Speed = 36 m/s (3 second gust), Importance Factor = 1	Approx. Scale: 1:500	
Agaogla Maslak EGYO Project - Istanbul, Turkey — Project #1300132	Date Revised: Jan. 16, 2014	

Note:
The wind loads presented **do not** contain load or safety factors. The loads are to be applied to the building's cladding system in the same manner as would wind loads calculated by building code analytical methods.



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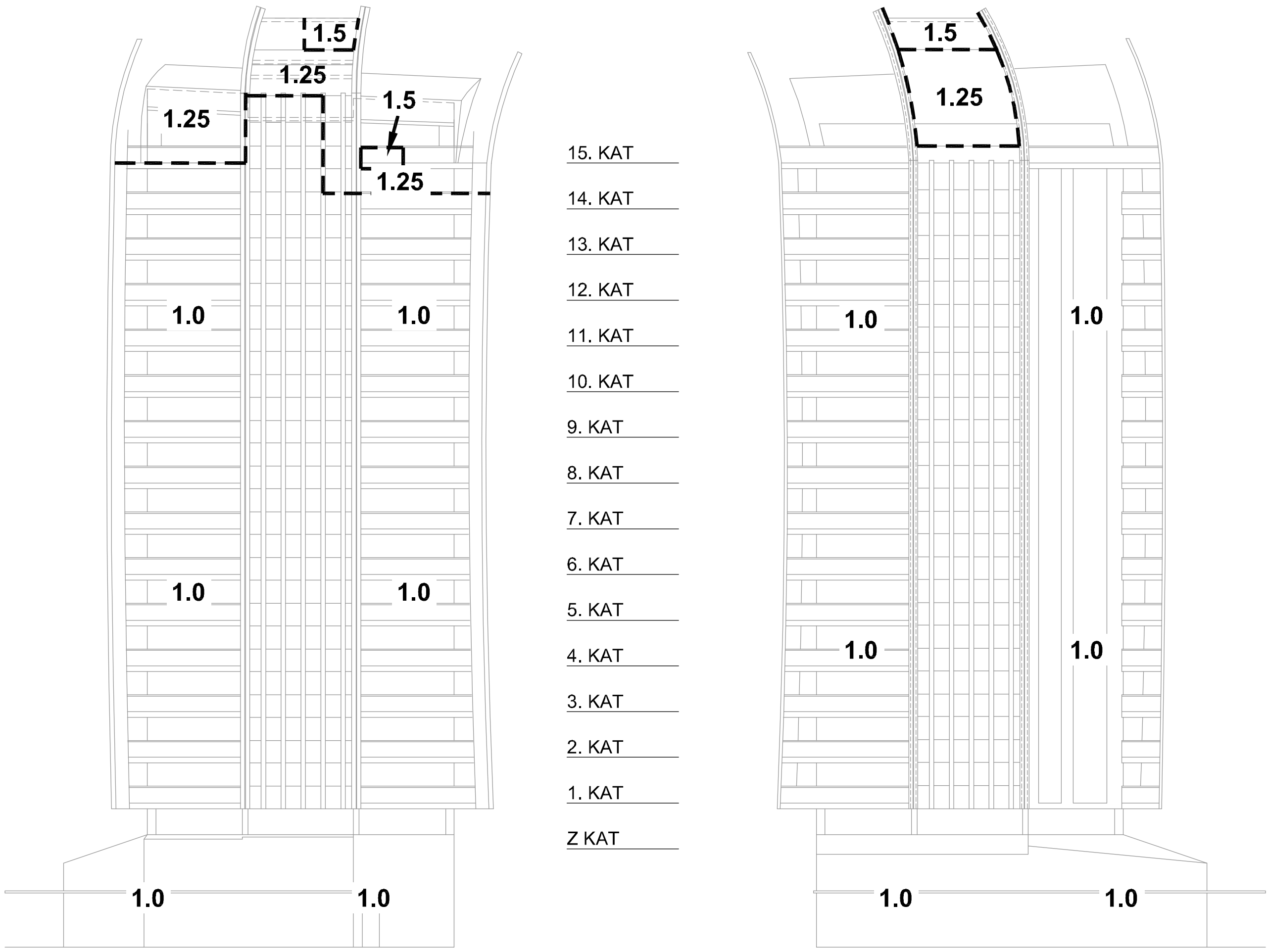


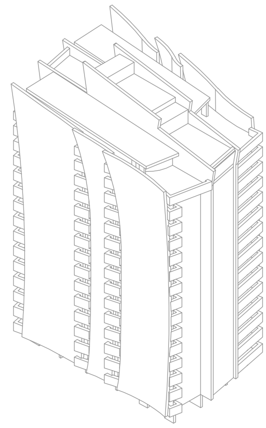
C10 - RIGHT SIDE

C10 - LEFT SIDE

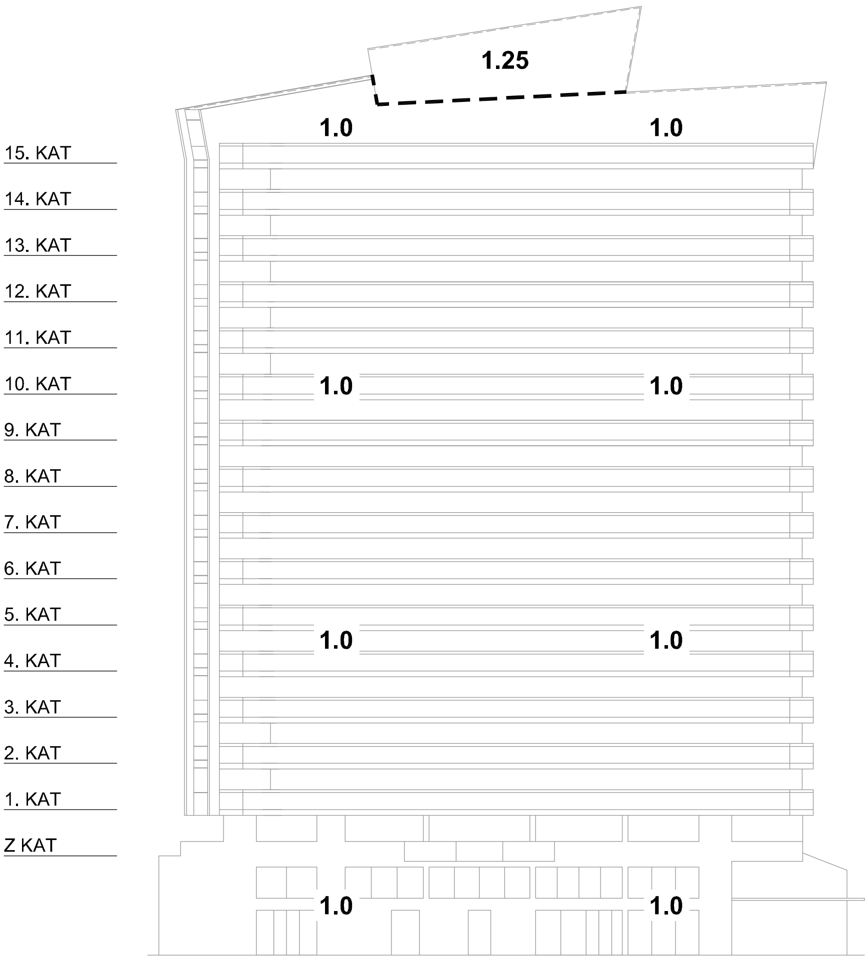
0 10 20m

Recommended Wind Loads for Cladding Design (kPa) Peak Net Negative Pressures (Negative External Pressure with Positive Internal Pressure Where Applicable) 50-Year Basic Wind Speed = 36 m/s (3 second gust), Importance Factor = 1	Drawn by: ck	Figure: 5	RWDI
	Approx. Scale: 1:500		
Agaogla Maslak EGYO Project - Istanbul, Turkey Project #1300132	Date Revised: Jan. 16, 2014		

Note:
The wind loads presented **do not** contain load or safety factors. The loads are to be applied to the building's cladding system in the same manner as would wind loads calculated by building code analytical methods.



Representation of Tower C10



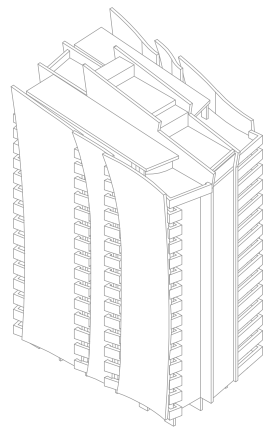
C10 - REAR (INSIDE WALL)

0 10 20m

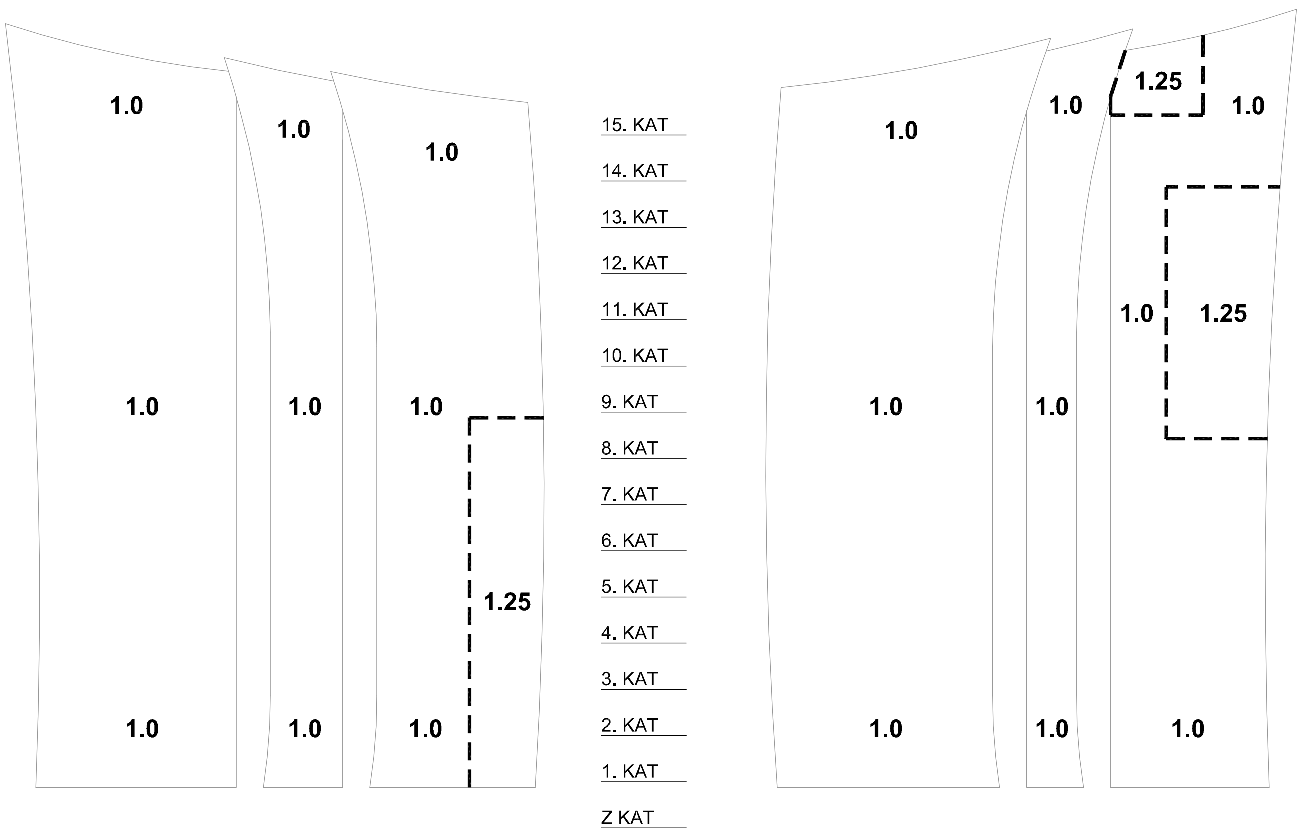
Recommended Wind Loads for Cladding Design (kPa) Peak Net Negative Pressures (Negative External Pressure with Positive Internal Pressure Where Applicable) 50-Year Basic Wind Speed = 36 m/s (3 second gust), Importance Factor = 1	Drawn by: ck	Figure: 6
Agaogla Maslak EGYO Project - Istanbul, Turkey — Project #1300132	Approx. Scale: 1:500	
	Date Revised: Jan. 16, 2014	

RWDI

Note:
The wind loads presented **do not** contain load or safety factors. The loads are to be applied to the building's cladding system in the same manner as would wind loads calculated by building code analytical methods.



Representation of Tower C10



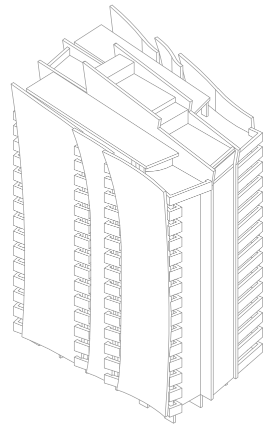
C10 - FRONT (EXTERNAL WALL)

C10 - REAR (EXTERNAL WALL)

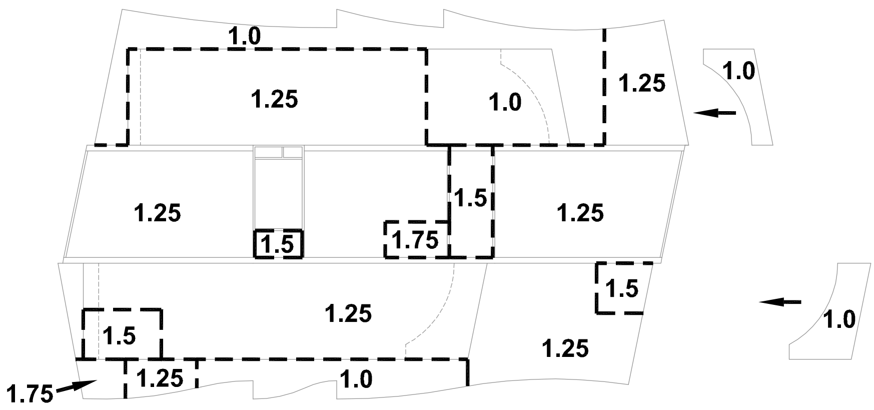
0 10 20m

Recommended Wind Loads for Cladding Design (kPa) Peak Net Negative Pressures (Negative External Pressure with Positive Internal Pressure Where Applicable) 50-Year Basic Wind Speed = 36 m/s (3 second gust), Importance Factor = 1 Agaogla Maslak EGYO Project - Istanbul, Turkey Project #1300132	Drawn by: ck	Figure: 7
	Approx. Scale: 1:500	
	Date Revised: Jan. 16, 2014	

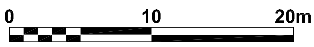
Note:
The wind loads presented **do not** contain load or safety factors. The loads are to be applied to the building's cladding system in the same manner as would wind loads calculated by building code analytical methods.



Representation of Tower C10

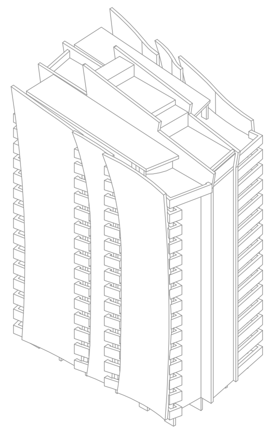


C10 - ROOF PLAN

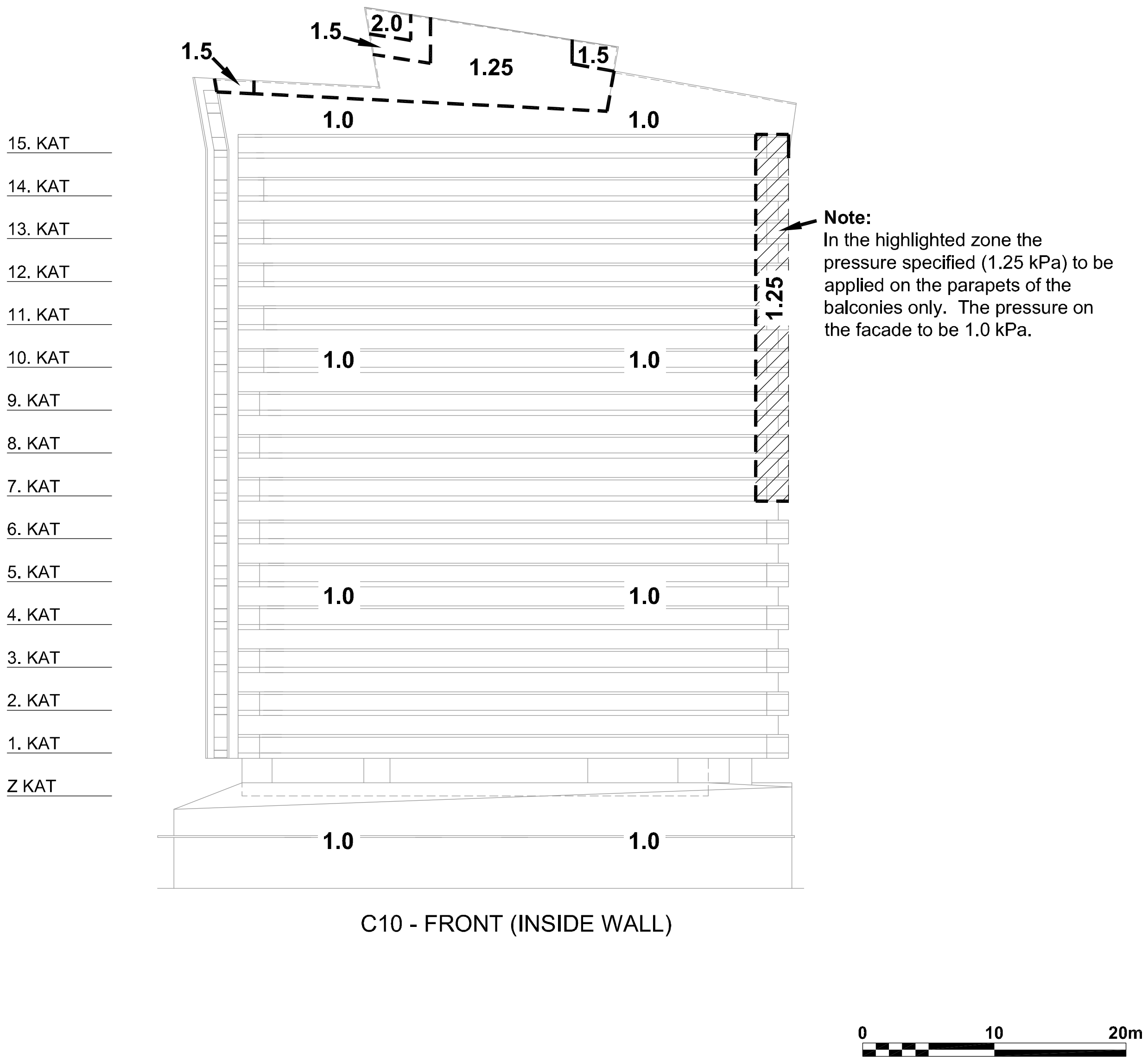


Recommended Wind Loads for Cladding Design (kPa) Peak Net Negative Pressures (Negative External Pressure with Positive Internal Pressure Where Applicable) 50-Year Basic Wind Speed = 36 m/s (3 second gust), Importance Factor = 1	True North	Drawn by: ck	Figure: 8
		Approx. Scale: 1:500	
Agaogla Maslak EGYO Project - Istanbul, Turkey	Project #1300132	Date Revised: Jan. 16, 2014	

Note:
The wind loads presented **do not** contain load or safety factors. The loads are to be applied to the building's cladding system in the same manner as would wind loads calculated by building code analytical methods.



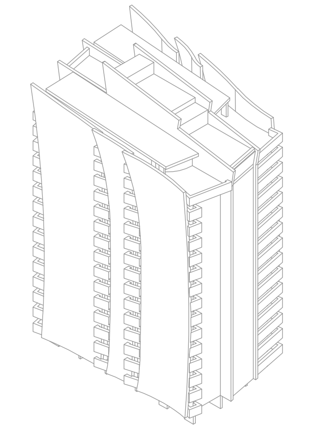
Representation of Tower C10



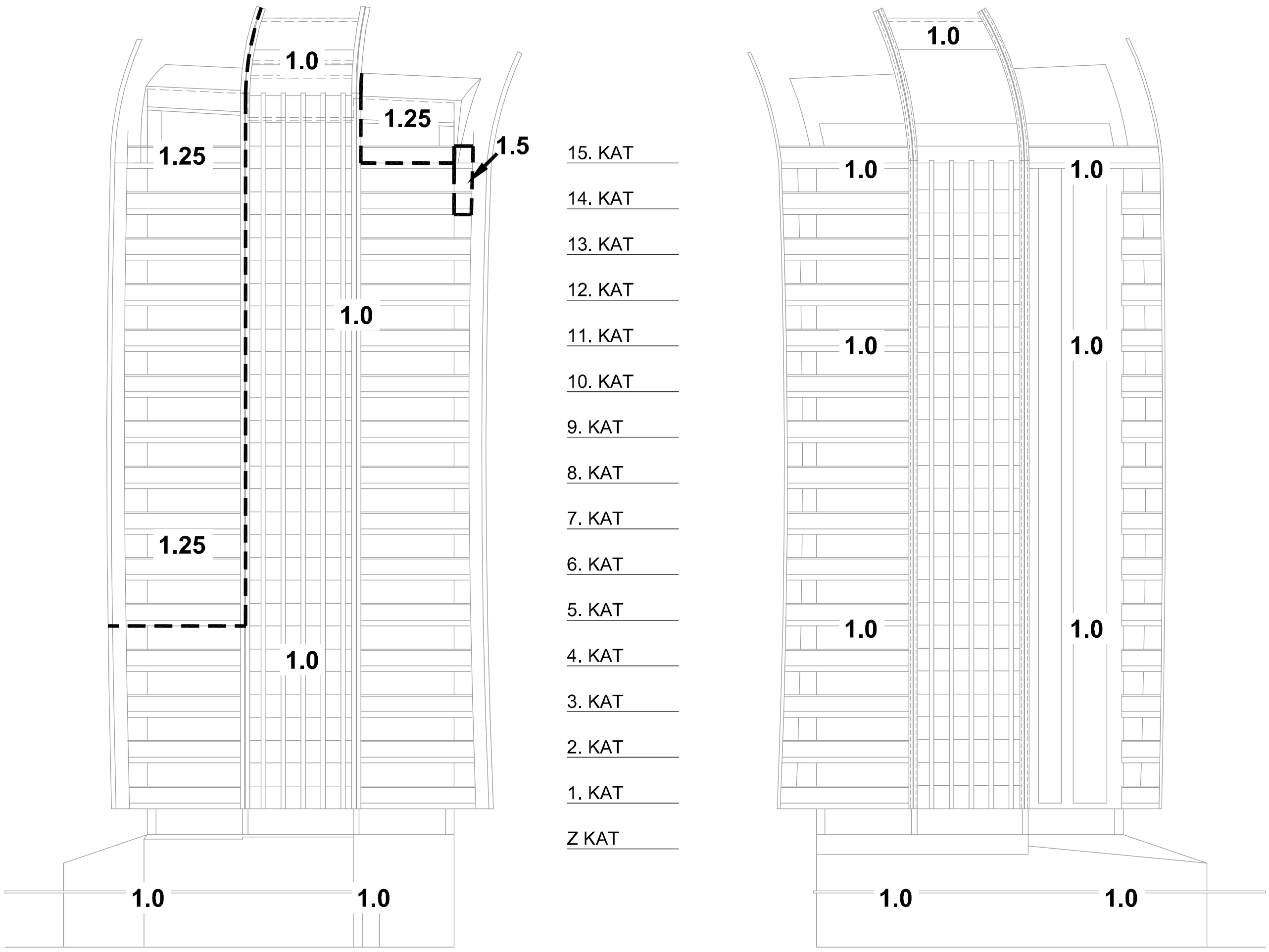
C10 - FRONT (INSIDE WALL)

Recommended Wind Loads for Cladding Design (kPa) Peak Net Positive Pressures (Positive External Pressure with Negative Internal Pressure Where Applicable) 50-Year Basic Wind Speed = 36 m/s (3 second gust), Importance Factor = 1	Drawn by: ck	Figure: 9	RWDI
	Approx. Scale: 1:500		
Agaogla Maslak EGYO Project - Istanbul, Turkey — Project #1300132	Date Revised: Jan. 16, 2014		

Note:
The wind loads presented **do not** contain load or safety factors. The loads are to be applied to the building's cladding system in the same manner as would wind loads calculated by building code analytical methods.



Representation of Tower C10



C10 - RIGHT SIDE

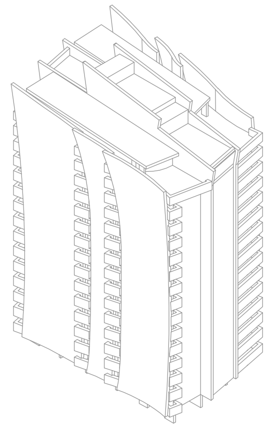
C10 - LEFT SIDE

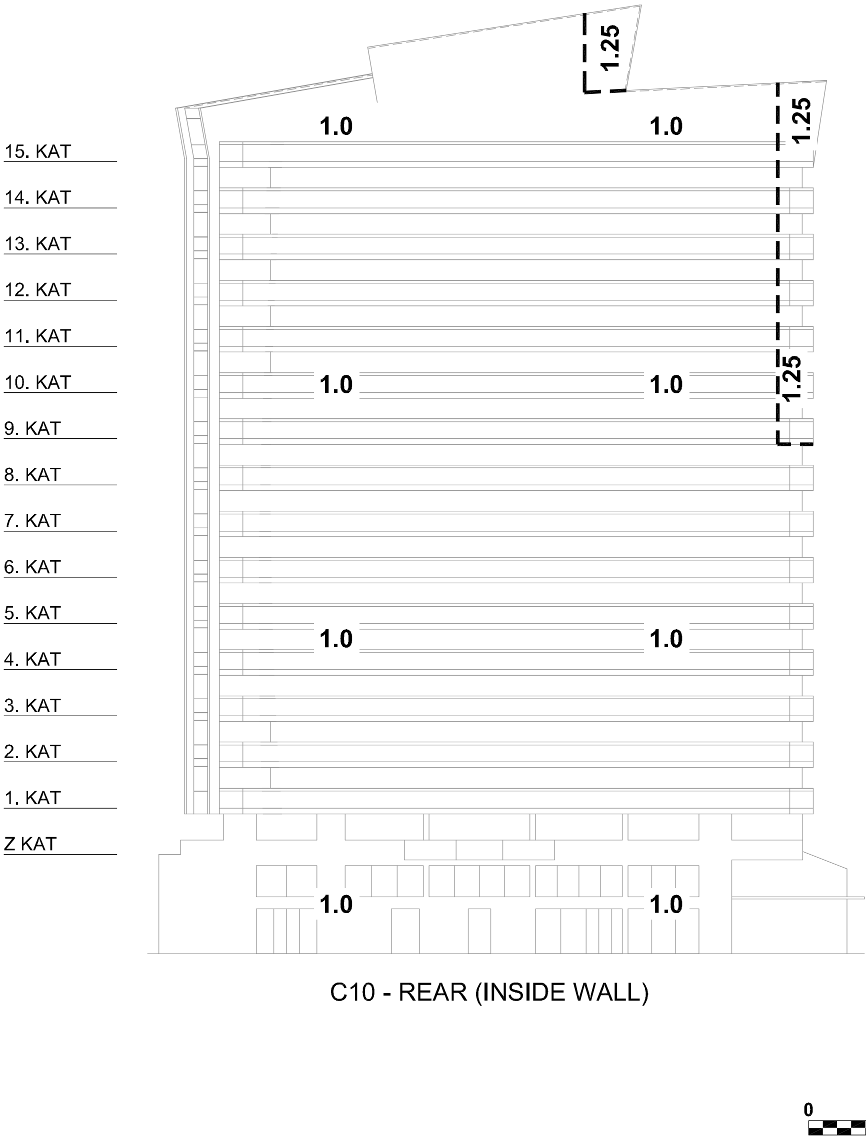
0 10 20m

Recommended Wind Loads for Cladding Design (kPa) Peak Net Positive Pressures (Positive External Pressure with Negative Internal Pressure Where Applicable) 50-Year Basic Wind Speed = 36 m/s (3 second gust), Importance Factor = 1	Drawn by: ck — Figure: 10
	Approx. Scale: 1:500
Agaogla Maslak EGYO Project - Istanbul, Turkey — Project #1300132	Date Revised: Jan. 16, 2014

RWDI

Note:
The wind loads presented **do not** contain load or safety factors. The loads are to be applied to the building's cladding system in the same manner as would wind loads calculated by building code analytical methods.

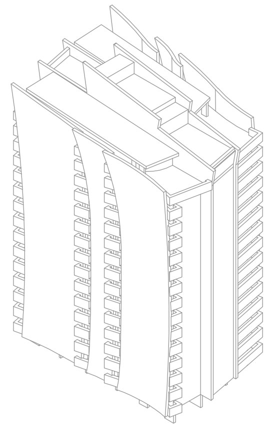

Representation of Tower C10



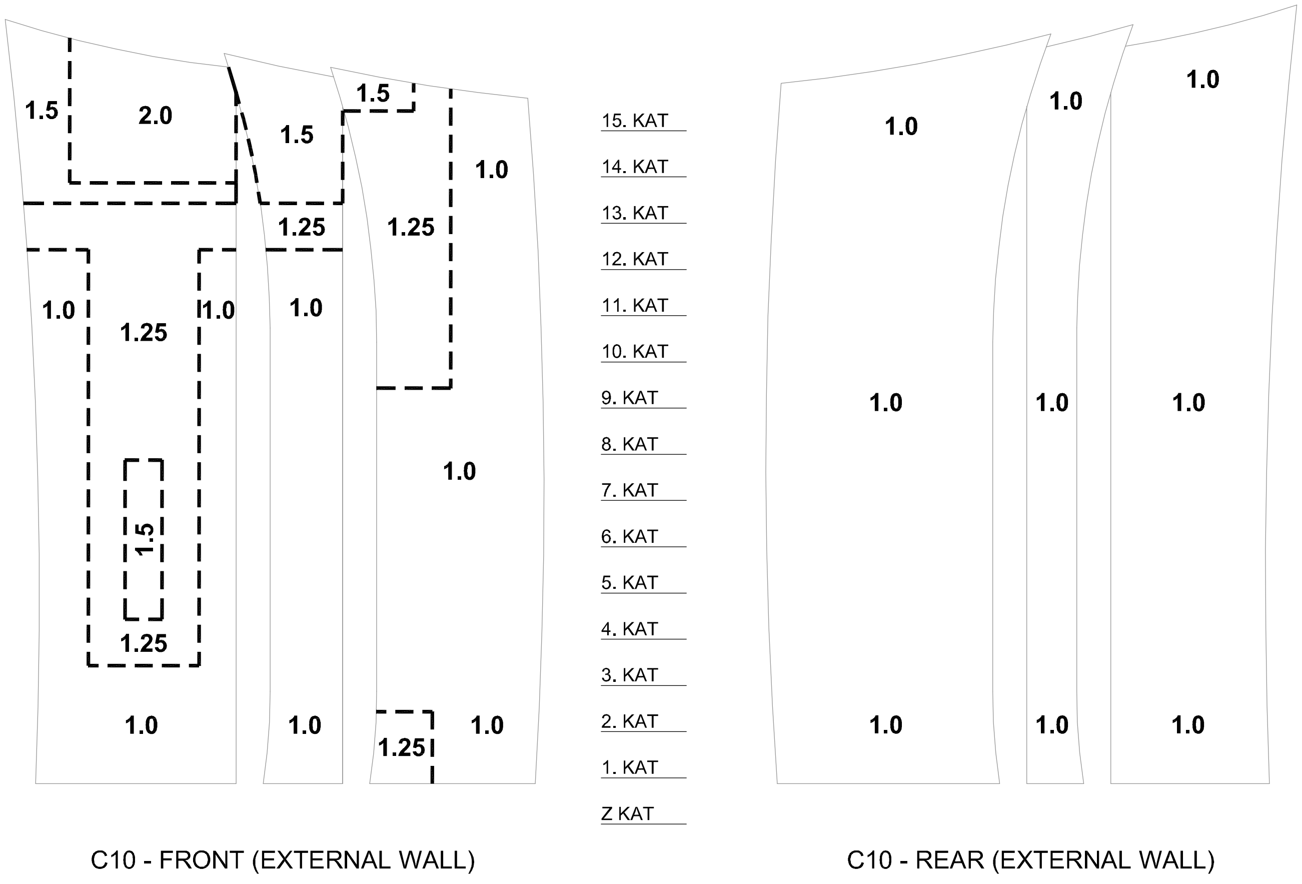
C10 - REAR (INSIDE WALL)

Recommended Wind Loads for Cladding Design (kPa)	Drawn by: ck	Figure: 11
Peak Net Positive Pressures (Positive External Pressure with Negative Internal Pressure Where Applicable) 50-Year Basic Wind Speed = 36 m/s (3 second gust), Importance Factor = 1	Approx. Scale:	1:500
Agaogla Maslak EGYO Project - Istanbul, Turkey — Project #1300132	Date Revised:	Jan. 16, 2014

Note:
The wind loads presented **do not** contain load or safety factors. The loads are to be applied to the building's cladding system in the same manner as would wind loads calculated by building code analytical methods.



Representation of Tower C10



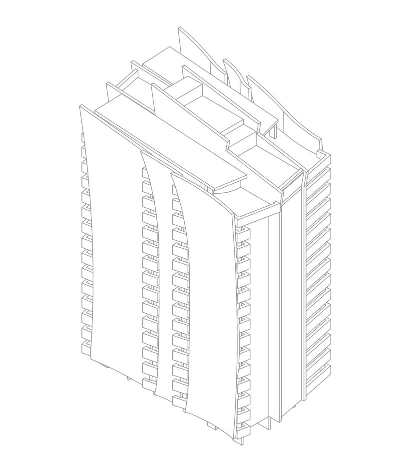
Recommended Wind Loads for Cladding Design (kPa)
Peak Net Positive Pressures
(Positive External Pressure with Negative Internal Pressure Where Applicable)
50-Year Basic Wind Speed = 36 m/s (3 second gust), Importance Factor = 1

Agaogla Maslak EGYO Project - Istanbul, Turkey
Project #1300132

Drawn by: ck	Figure: 12
Approx. Scale: 1:500	
Date Revised: Jan. 16, 2014	

RWDI

Note:
The wind loads presented **do not** contain load or safety factors. The loads are to be applied to the building's cladding system in the same manner as would wind loads calculated by building code analytical methods.



Representation of Tower C10

C10 - ROOF PLAN

0 10 20m

Recommended Wind Loads for Cladding Design (kPa)
Peak Net Positive Pressures
(Positive External Pressure with Negative Internal Pressure Where Applicable)
50-Year Basic Wind Speed = 36 m/s (3 second gust), Importance Factor = 1

Agaogla Maslak EGYO Project - Istanbul, Turkey

True North

Project #1300132

Drawn by: ck

Figure: 13

Approx. Scale: 1:500

Date Revised: Jan. 16, 2014

RWDI

APPENDIX A

APPENDIX A: WIND TUNNEL PROCEDURES

OVERVIEW OF WIND TUNNEL PROCEDURES FOR THE PREDICTION OF CLADDING WIND LOADS

A.1 Wind Tunnel Test and Analysis Methods

A.1.1 Wind Tunnel Tests

RWDI's boundary layer wind tunnel facility simulates the mean speed profile and turbulence of the natural wind approaching the modeled area by having a long working section with a roughened floor and specially designed turbulence generators, or spires, at the upwind end. Floor roughness and spires have been selected to simulate four basic terrain conditions, ranging from open terrain, or water, to built-up urban terrain. During the tests, the upwind profile in the wind tunnel is set to represent the most appropriate of these four basic profiles, for directions with similar upwind terrain. Scaling factors are also introduced at the analysis stage to account for remaining minor differences between the expected wind speed and turbulence properties, and the basic upwind flow conditions simulated in the wind tunnel. The full-scale properties are derived using the ESDU methodology[1, 2] for predicting the effect of changes in the earth's surface roughness on the planetary boundary layer. For example, this procedure distinguishes between the flows generated by a uniform open water fetch upwind of the site, versus a short fetch of suburban terrain immediately upwind of the site with open water in the distance.

Wind direction is defined as the direction from which the wind blows in degrees measured clockwise from true north. The test model (study model and surroundings) is mounted on a turntable, allowing any wind direction to be simulated by rotating the model to the appropriate angle in the wind tunnel. The wind tunnel test is typically conducted for 36 wind directions at 10° intervals.

It is prudent to take steps to ensure that the safety of a structure is not entirely dependent on specific surrounding buildings for shelter. Building codes often contain specific provisions to address this. These may include requirements to test with the more significant surrounding buildings removed, and/or lower limits on the reduction that is permitted compared to the code analytical approach.

A.1.2 Measurement Techniques

This study addresses the local wind pressures that act on the exterior envelope of the building. Predictions of these loads are required in order that the cladding system can be designed to safely resist the wind loads. The technique that is used to make these predictions consists of conducting a wind pressure study. The basis of the approach is to instrument a rigid wind tunnel model of the building with pressure taps that adequately cover the exterior areas exposed to wind. The mean pressure, the root-mean-square of pressure fluctuations and the peak negative and peak positive pressures are measured at each tap using a system capable of responding to pressure fluctuations as short as 0.5 to 1 second at full scale. The measured data are converted into pressure coefficients based on the measured upper level mean dynamic pressure in the wind tunnel. Time series of the simultaneous pressures are also recorded for post-test processing if required. A typical example of an instrumented wind tunnel study model is provided in Figure 1.

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[1] Wind speed profiles over terrain with roughness changes for flat or hilly sites. Item No. 84011, ESDU International London, 1984 with amendments to 1993.

[2] Longitudinal turbulence intensities over terrain with roughness changes for flat or hilly sites. Item No. 84030, ESDU International London, 1984 with amendments to 1993.

A.1.3 Consideration of the Local Wind Climate

Carrying out the procedures described in the previous sections determines the peak local external pressure coefficients expected for a given wind direction. However, in order to account for the varying likelihood of different wind directions and the varying strengths of winds that may be expected from different directions, the measured pressure coefficients are integrated with statistical records of the local wind climate to produce predicted peak pressures as a function of return period. In the case of cladding loads, it is appropriate to consider peak loads associated with return periods comparable to the design life of the structure. The choice of return period will be governed by local code requirements that consider the intended use of the building. For Allowable Stress Design, return periods of 50 or 100 years are often used for cladding design, to which appropriate load or safety factors are applied. For Limit States Design, return periods of 700 or 1700 years, without load or safety factors, are used to represent the ultimate state loading.

Wind records taken from one or more locations near to the study site are generally used to derive the wind climate model. In areas affected by hurricanes or typhoons, Monte Carlo simulations are typically used to generate a better database since full scale measurements, if available for a given location, typically provide an inadequate sample for statistical purposes. The data in either case are analysed to determine the probabilities of exceeding various hourly mean wind speeds from within each of 36 wind sectors at an upper level reference height, typically taken to be 600 m (2000 ft) above open terrain. This coincides with the height used to measure the reference dynamic pressure in the wind tunnel.

In order to predict the cladding wind loads for a given return period, the wind tunnel results are integrated with the wind climate model. There are two methods typically used by RWDI to perform this integration. In one method, the historical (or simulated as is the case with hurricanes or typhoons) wind record is used to determine the full-scale cladding wind pressures for each hour, given the recorded wind speed and direction and the wind tunnel predictions for that direction. By stepping through the wind speed and direction data on an hour-by-hour basis, a time history of the resulting peak pressure is generated. Then, through the use of extreme value fitting techniques, statistically valid peak responses for any desired return period are determined.

The second method is the Upcrossing Method as described by Irwin[3] and Irwin and Sifton[4]. In simple terms, this can be thought of as an analytical representation of the first method, in which a fitted mathematical model of the wind statistics is used in place of the detailed wind records themselves. The time history method (first method described above) is typically used by RWDI for cladding wind load studies where the extent and quality of the wind records permit it. In areas of shorter records and lower quality records RWDI typically reverts to the Upcrossing Method since it enables a smoothing of erratic behaviour of the wind statistics to be more readily implemented and is thus more robust.

A.1.4 Internal Pressure Allowances Considering Localized Breaches in the Building Façade

In strong winds, air leakage effects dominate the internal pressures. Other factors that influence them, but are usually of less significance, are the operation of mechanical ventilation systems and the stack effect. Important sources of air leakage include uniformly distributed small leakage paths over the

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[3] Irwin, P.A., "Pressure Model Techniques for Cladding Loads", Journal of Wind Engineering and Industrial Aerodynamics 29 (1988), pg. 69-78.

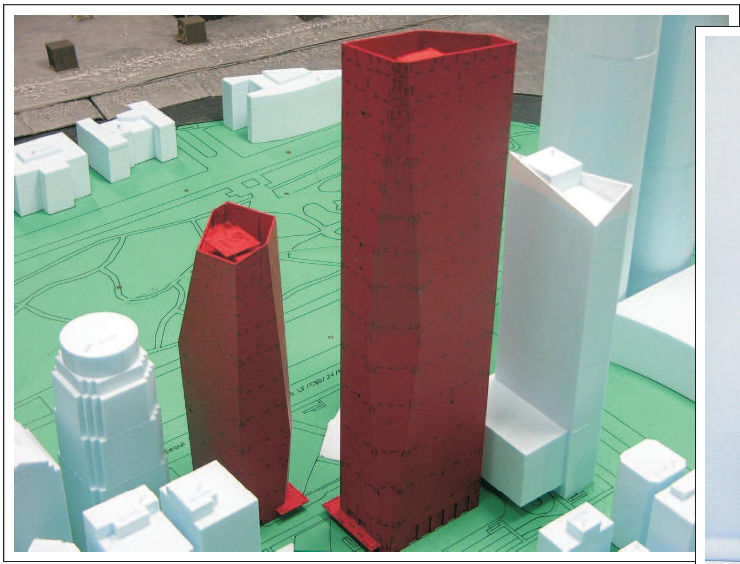
[4] Irwin, P.A. and Sifton, V. L., "Risk Considerations for Internal Pressures", Journal of Wind Engineering and Industrial Aerodynamics, 77 & 78 (1998), pg. 715-723.

building's envelope and larger leakage paths. These larger leakage paths include window breakage due to airborne debris in a windstorm and open doors or windows, in cases where they are operable. The internal pressure allowances can be influenced by many factors including the size and location of potential glass breakage, the internal compartmentalization of the building and the internal volumes. During a major storm event, glass breakage can be different sizes and occur at various locations. There are many types of projectiles that typically cause glass breakage, ranging in size from small rocks to tree branches. Larger projectiles impacting the building would be rare events.

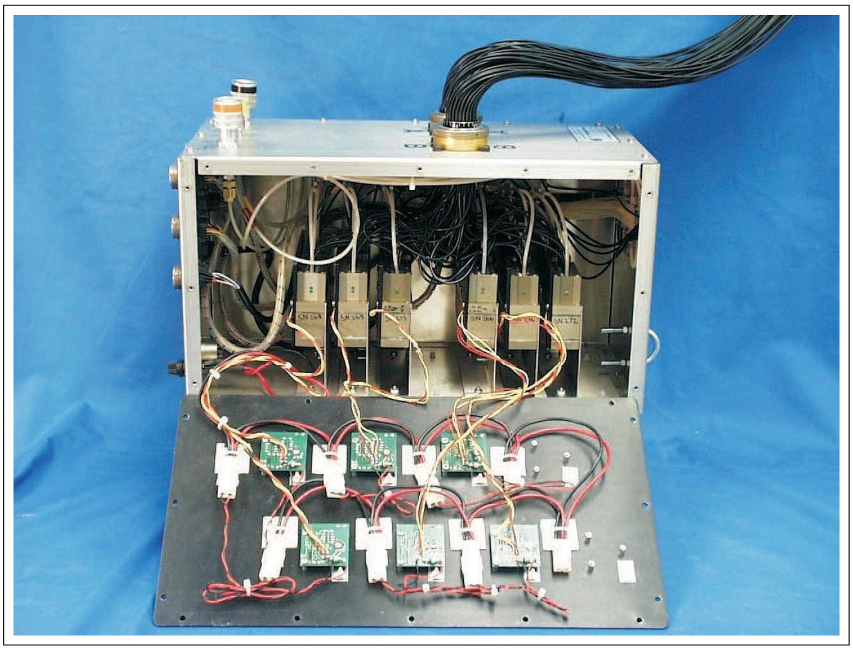
To evaluate the internal pressures resulting from dominant openings in the building envelope, simultaneous measurements are taken during the wind tunnel test between pairs of pressure taps located on building walls that share the same internal volume. Of particular interest are measurements taken in areas where large pressure differences can occur such as those that are generated at the corners of the floor plate. A single opening (worst case) scenario is typically considered since multiple leakage sources tend to reduce the magnitude of the internal pressure. Using an in-house approach, these data are analyzed to determine the range of internal pressures that may occur at selected opening locations and for a range of probabilities of these openings occurring. Lower probabilities are used in lower wind speed areas (i.e., – non-hurricane/non-typhoon areas), and higher probabilities are used in higher wind speed areas (i.e., – hurricane/typhoon areas) or for buildings that have a large number of operable windows or doors. Using these dominant opening probabilities, internal pressures are determined for the same level of risk as that assumed for the external pressures.

For buildings that use large missile impact resistant glazing everywhere, and do not have operable windows, the potential for breakage due to windborne debris is very low. As a result, the probability of an opening is also very low, and the internal pressures used are at or near the minimum considerations of a nominally sealed building.

The internal pressure allowances are applied to help reduce the possibility of subsequent facade failures due to pressure increases caused by localized breaches in the facade. Design of the cladding to the provided wind loads will not necessarily prevent breakage due to impact by wind borne debris.



(a) Typical Cladding Wind Load Study model



(b) Data Acquisition

Measurement Techniques for the Prediction of Cladding Wind Loads Appendix A - Wind Tunnel Procedures	Figure: 1	RWDI
	Date: October 1, 2007	