



REVIEW OF AS/NZS1170.2 SECTION 6.3.2 - AWES RESEARCH PROJECT

WD200-13-REV0 REVIEW OF CROSS-WIND
DECEMBER 7, 2018

Prepared for:

Australasian Wind Engineering Society

Attn: Dr Matthew Mason

DOCUMENT CONTROL

Date	Revision History	Issued Revision	Prepared By
December 5, 2018	Initial Draft	0	Tony Rofail

The work presented in this document was carried out in accordance with the Windtech Consultants Quality Assurance System, which is based on International Standard ISO 9001.

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EXECUTIVE SUMMARY

The main driver behind this study is to investigate the reason for the significant differences often found between the predictions for cross-wind response by AS/NZS 1170.2:2011 and the ISO 4354: 2009. In some cases the AS/NZS 1170.2:2011 tended to underestimate the cross-wind response when compared against the results of wind tunnel model studies, even in cases where interference excitation effects have been ruled out. We agree with the observation by Holmes (2013) that the along-wind response predictions in AS/NZS 1170.2:2011 closely match wind tunnel results, more than other standards, including ASCE 7.

A set of 26 cases were carefully selected to represent towers of aspect ratios $h:b:d$ of 3:1:1, 6:1:1, 6:2:1 and 6:1:2. The cases selected for analysis are those that are not affected by the following exclusion criteria:

- Towers of irregular or substantially curved forms
- Towers likely to be affected by interference excitation for the direction of interest
- Towers that had aspect ratios greater than 2:1 in plan.

With regards to the last exclusion criterion, we found that towers that had plan aspect ratio of 3:1 or more were subject to much more significant cross-wind response than what is estimated from the cases provided in the current standard. Hence we recommend the addition of Clause 6.1(b)(i)(D) for tall buildings with plan aspect ratio of 1:3 or more.

After a thorough comparison between AS/NZS 1170.2:2011 and the ISO 4354: 2009 it was concluded that neither standard is substantially more consistent with the wind tunnel results than the other. It was concluded that it is best to stay with the format of AS/NZS 1170.2:2011 as it reflects more clearly the mechanics of wind-structure interactions. However, we propose that the C_{fs} curves for tower aspect ratios 6:1:1, 6:2:1 and 6:1:2 be modified slightly to provide a reasonable envelope of cross-wind responses from real world cases.

Our wind tunnel results have also shown that apart from the 3:1:1 cases, there is no consistent trend separating the responses of towers that fall within the lower-bound and upper-bound upstream turbulence intensities. Hence we recommend merging of these into a single curve.

References:

AS/NZS 1170.2:2011, "Structural Design Actions, Part 2: Wind Actions", Standards Australia and Standards New Zealand.

ISO 4354: 2009, "Wind actions on structures", International Standard.

Holmes, J., 2013, "Along-wind response of a generic tall building – comparison of consensus wind-tunnel data with codes and standards", The 12th Americas Conference on Wind Engineering, Seattle, Washington, USA June 16-20, 2013.

1 METHODOLOGY

When comparing against the ISO 4354: 2009 the actual base moment was computed for each case of reduced velocity then the equivalent C_{fs} value as defined in AS/NZS1170.2:2011 was calculated. The same approach was adopted for the wind tunnel results.

Wind tunnel results are obtained using either the high-frequency force balance (HFFB) or high frequency pressure integration (HFPI) technique. The accuracy of Windtech's HFFB measurement system has been verified in the benchmark study reported in Holmes and Tse (2012). Also due to Windtech's proprietary pressure measurement system, which allows for a high sampling rate (typically over 1000Hz) and an unbiased response over a frequency range of 0-300Hz. The close match between the HFFB and HFPI techniques has been demonstrated on a complex building by Truong and Rofail (2015). All wind tunnel tests are in compliance with the AWES-QAM-01.

A set of 26 cases were carefully selected to represent towers of aspect ratios $h:b:d$ of 3:1:1, 6:1:1, 6:2:1 and 6:1:2. Multiple angles of incidence each were analysed from each case, each within 10 degrees of the principal axis. The cases selected for analysis are those that are not affected by the following exclusion criteria:

- Towers of irregular or substantially curved forms
- Towers likely to be affected by interference excitation for the direction of interest
- Towers that had aspect ratios greater than 2:1 in plan.

With regards to the last exclusion criterion, we found that towers that had plan aspect ratio of 3:1 or more were subject to much more significant cross-wind response than what is estimated from the cases provided in the current standard. Hence we recommend the addition of Clause 6.1(b)(i)(D) for tall buildings with plan aspect ratio of 1:3 or more.

References:

AWES-QAM-01, "Quality Assurance Manual for Wind Tunnel Testing", Australasian Wind Engineering Society, 2000.

Holmes, J.D. and Tse, T.K.T., 2012, International high-frequency base balance benchmark study", 2012 World Congress on Advances in Civil, Environmental, and Materials Research, 26-29 August 2012, Seoul.

Truong N., Rofail A.W., 2015, "Wind Engineering for a Complex Structure", 14th International Conference on Wind Engineering, Porto Alegre.

2 RESULTS AND RECOMMENDATIONS

The comparative results are presented in Annexures 1 to 5. These annexures present comparative values of the crosswind force spectrum coefficient (C_{fs}) as a function of the reduced velocity (V_n). As can be seen at the end of Annexure 1, interference excitation effects are generally not significant for buildings having a 3:1:1 aspect ratio. Annexure 5 demonstrates that interpolation is appropriate. Excluding a case where there is a significant recess in plan, the C_{fs} curves proposed from this study generally envelope the various cases.

The 3:1:1 cases generally fell within the C_{fs} curves for respective turbulence intensities. There was only one case for each turbulence cases where there was an exceedance at the lower end of the reduced velocity range. This does not give sufficient weight for a revision of the C_{fs} curves for the 3:1:1 case. The AS/NZS 1170.2:2011 also performed significantly better overall than the ISO 4354: 2009 for the 3:1:1 case. For the other cases there was no consistent trend in terms of the effect of the background turbulence intensity. Also there is a consistent pattern of exceedances at the lower range of reduced velocities for the 6:1:1 case; for reduced velocities in the range 4.5 to 7 and above 12 for the 6:2:1 case; and for the entire range particularly are the lower and higher parts of the range of reduced velocities for the 6:1:2 case.

Based on the above it is proposed that the crosswind force spectrum coefficients be modified as follows:

a) For a 3:1:1 square section ($h:b:d$), where V_n is in the range 2 to 16:

(i) For turbulence intensity of 0.12 at $2h/3$ (no change):

$$\text{Log}_{10} C_{fs} = 0.000353V_n^4 - 0.0134V_n^3 + 0.15V_n^2 - 0.345V_n - 3.109 \quad 6.3(5)$$

(ii) For turbulence intensity of 0.2 at $2h/3$ (no change):

$$\text{Log}_{10} C_{fs} = 0.00008V_n^4 - 0.0028V_n^3 + 0.199V_n^2 + 0.13V_n - 2.985 \quad 6.3(6)$$

b) For a 6:1:1 square section ($h:b:d$), where V_n is in the range 2 to 16:

$$\text{Log}_{10} C_{fs} = 0.00037V_n^4 - 0.0145V_n^3 + 0.17V_n^2 - 0.49V_n - 2.5 \quad 6.3(7)$$

c) For a 6:2:1 square section ($h:b:d$), where V_n is in the range 2 to 16:

$$\text{Log}_{10} C_{fs} = \frac{-0.00045V_n^4 + 0.065V_n^2 - 3.05}{0.00015V_n^4 - 0.018V_n^2 + 1} \quad 6.3(8)$$

d) For a 6:1:2 square section ($h:b:d$), where V_n is in the range 2 to 16:

$$\text{Log}_{10} C_{fs} = 0.0957V_n - 2.59 \quad 6.3(9)$$

Given that it is often unclear which way to interpolate, it is recommended that for intermediate values of $h:b$, $b:d$, the highest C_{fs} value is adopted rather than linear interpolation of $\text{log}_{10} C_{fs}$.

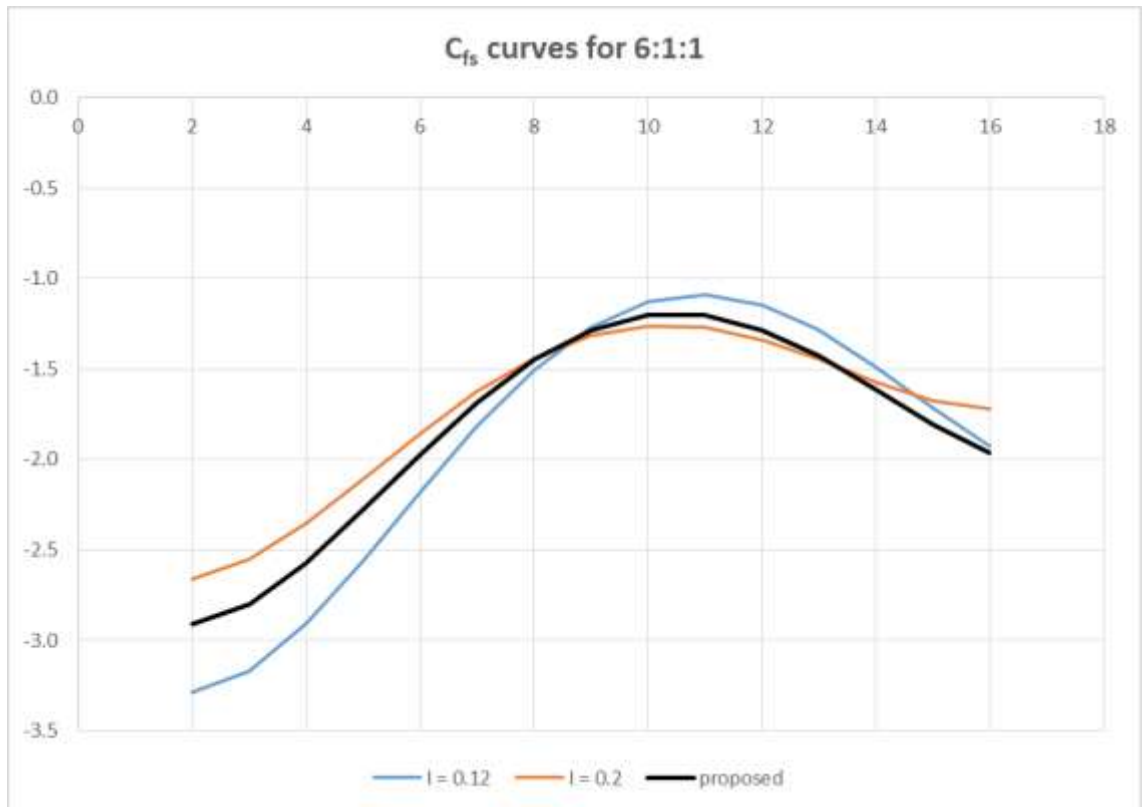


Figure 1a: Proposed C_{fs} curves for tall buildings of aspect ratio 6:1:1

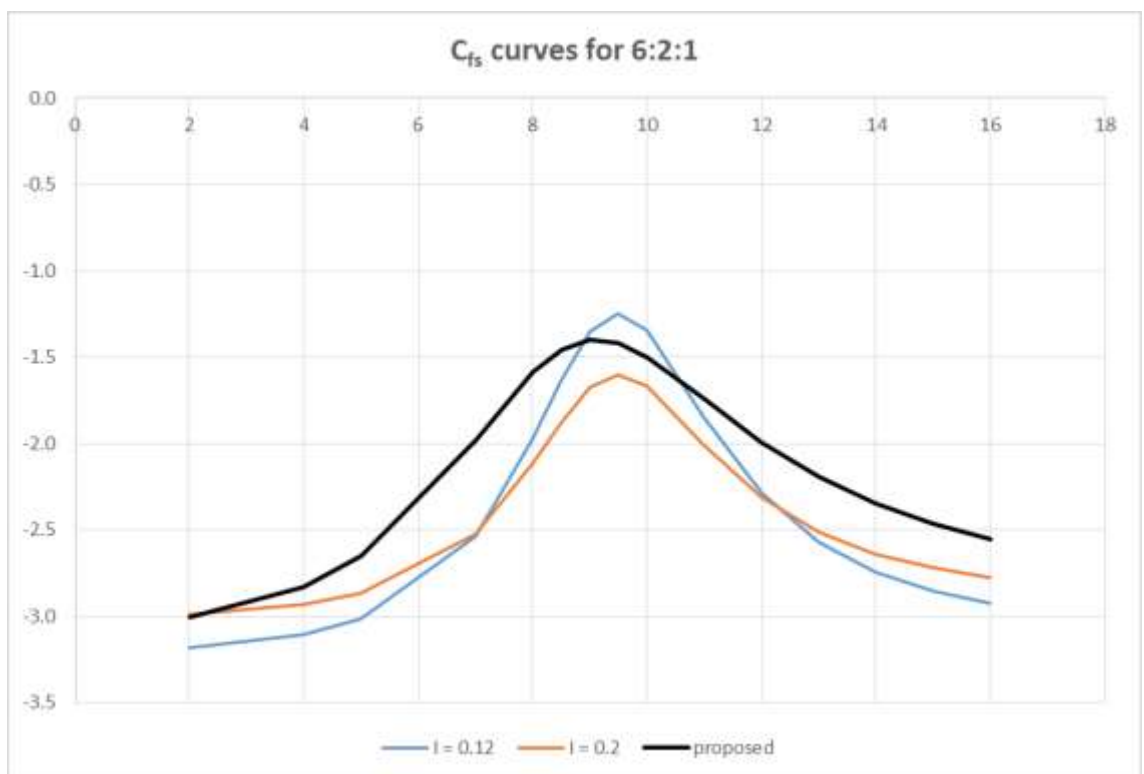


Figure 1b: Proposed C_{fs} curves for tall buildings of aspect ratio 6:2:1

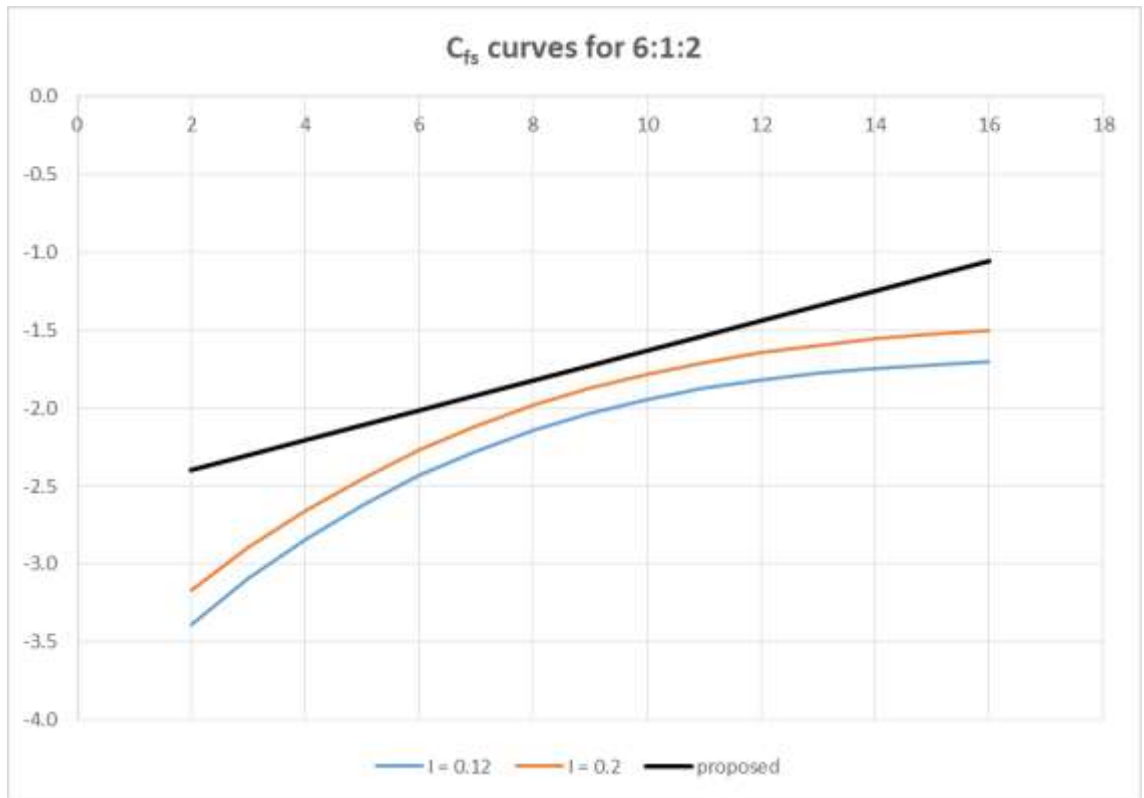


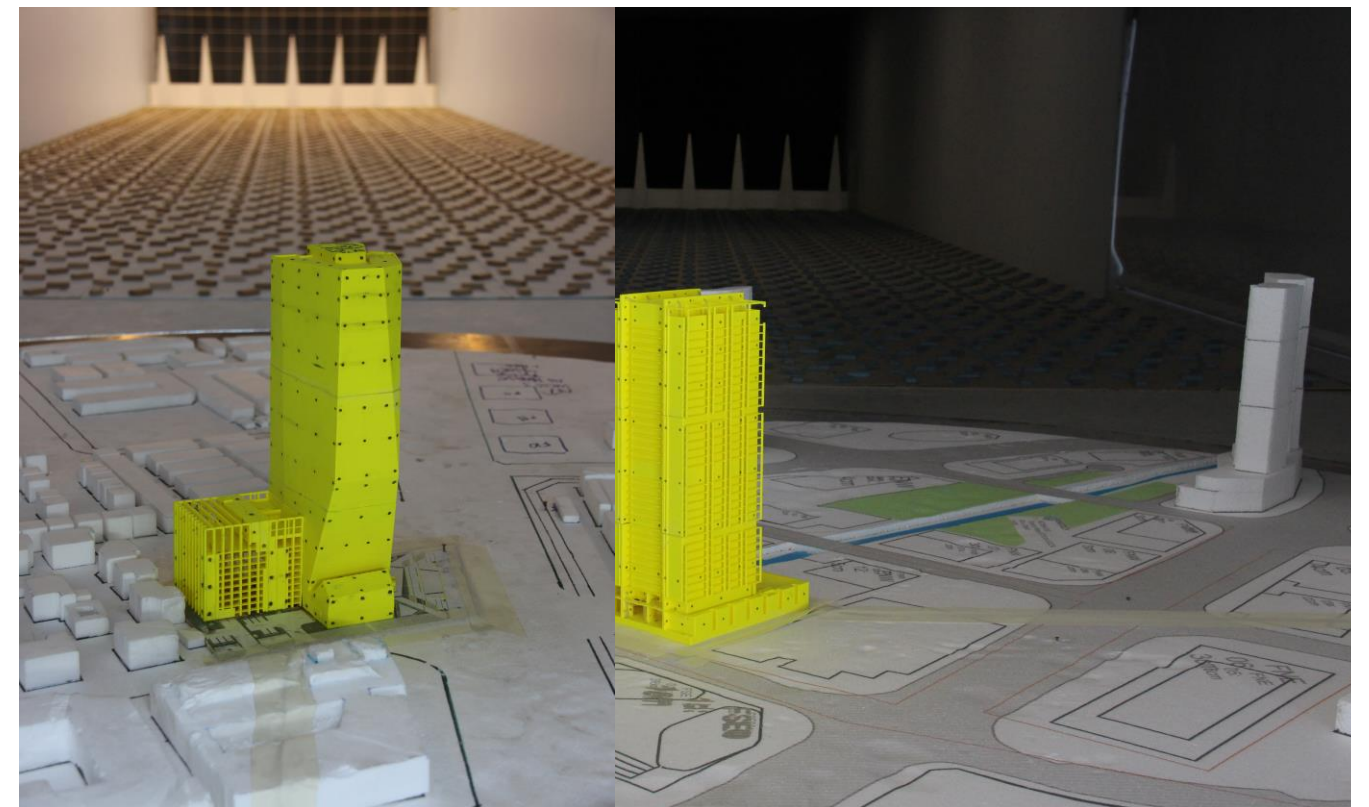
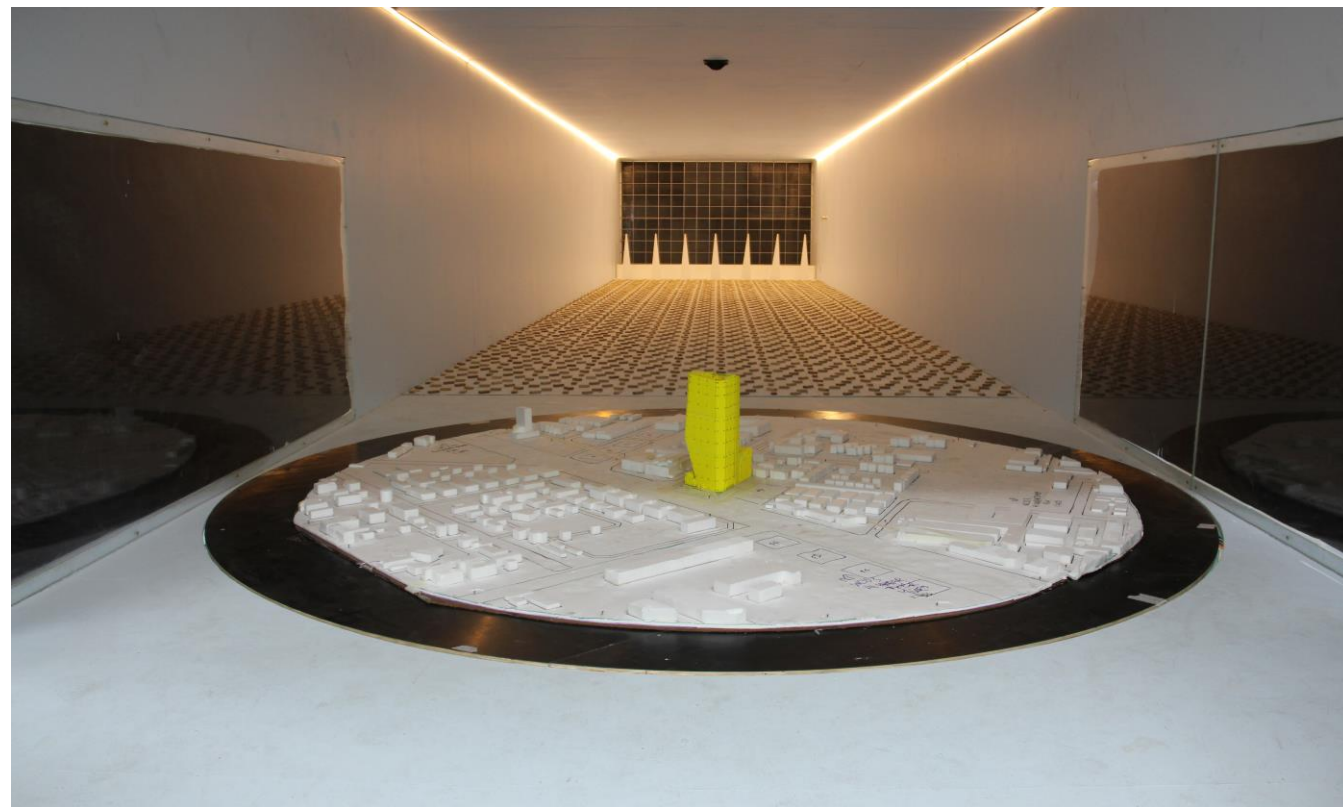
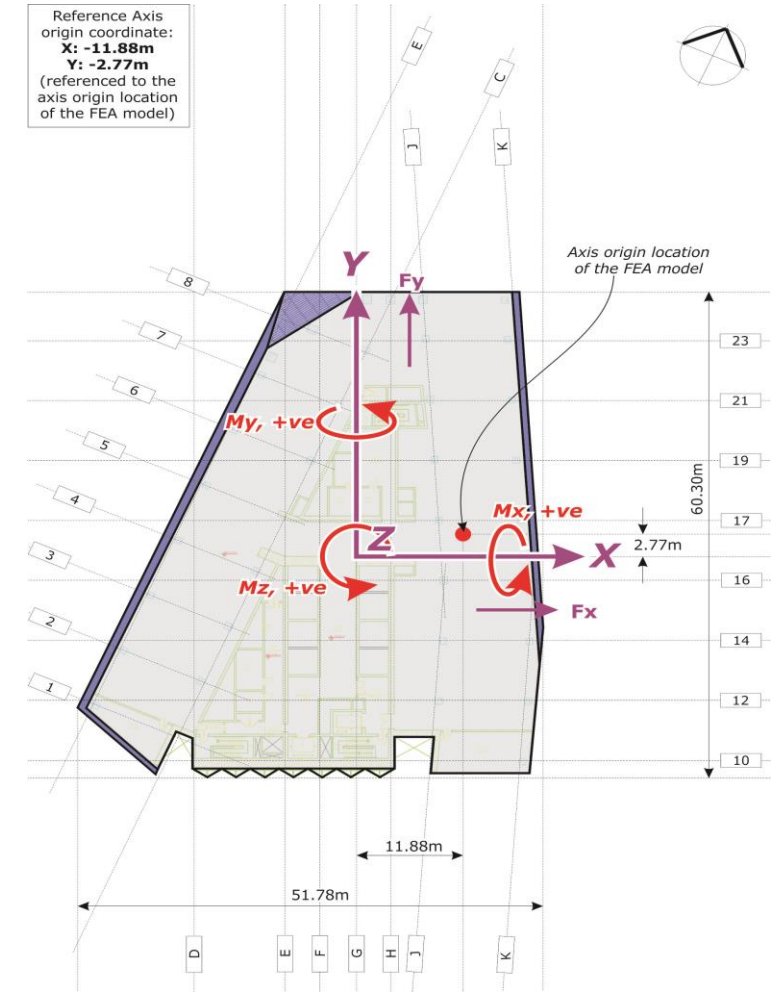
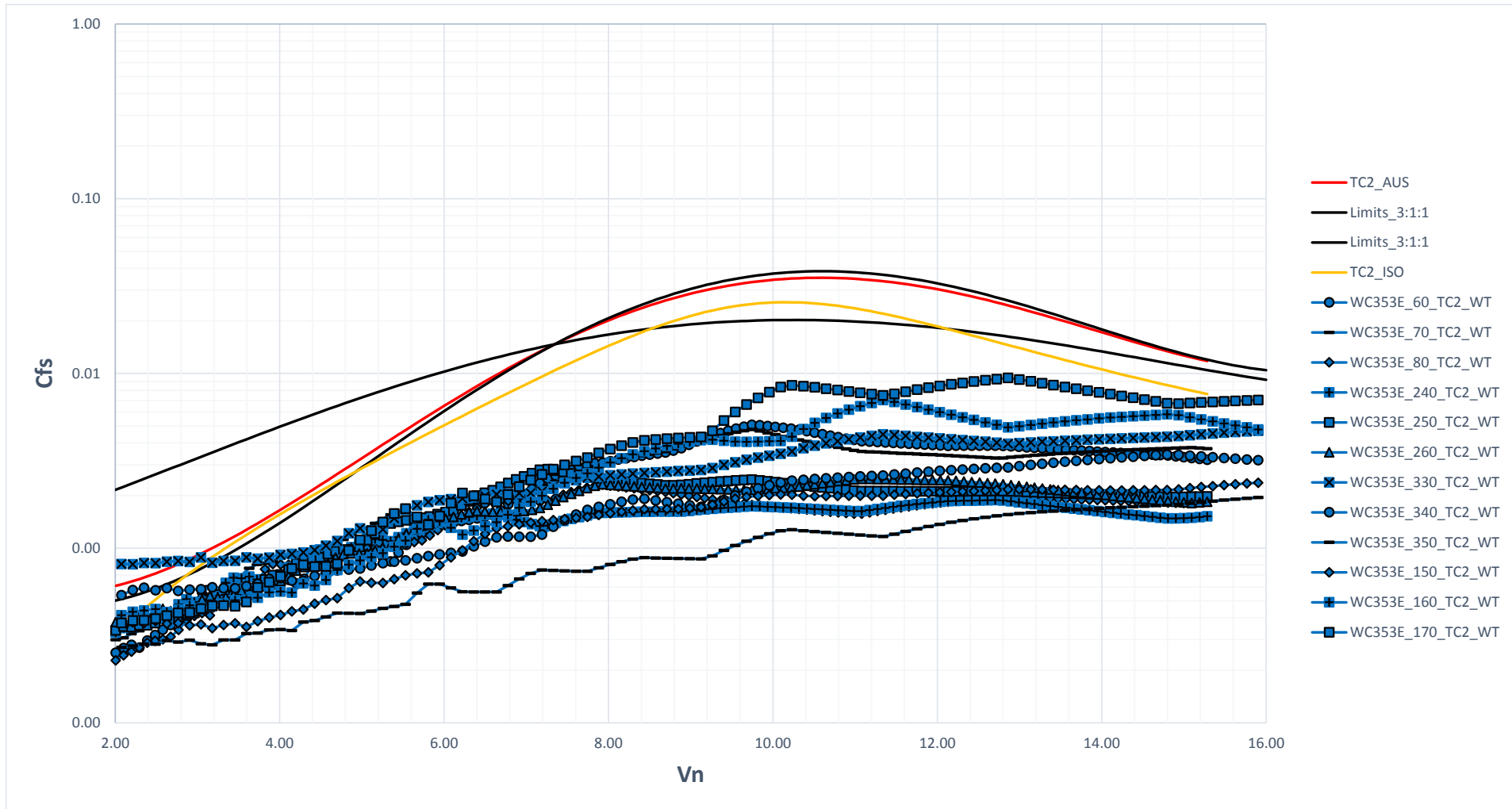
Figure 1c: Proposed C_{fs} curves for tall buildings of aspect ratio 6:1:2

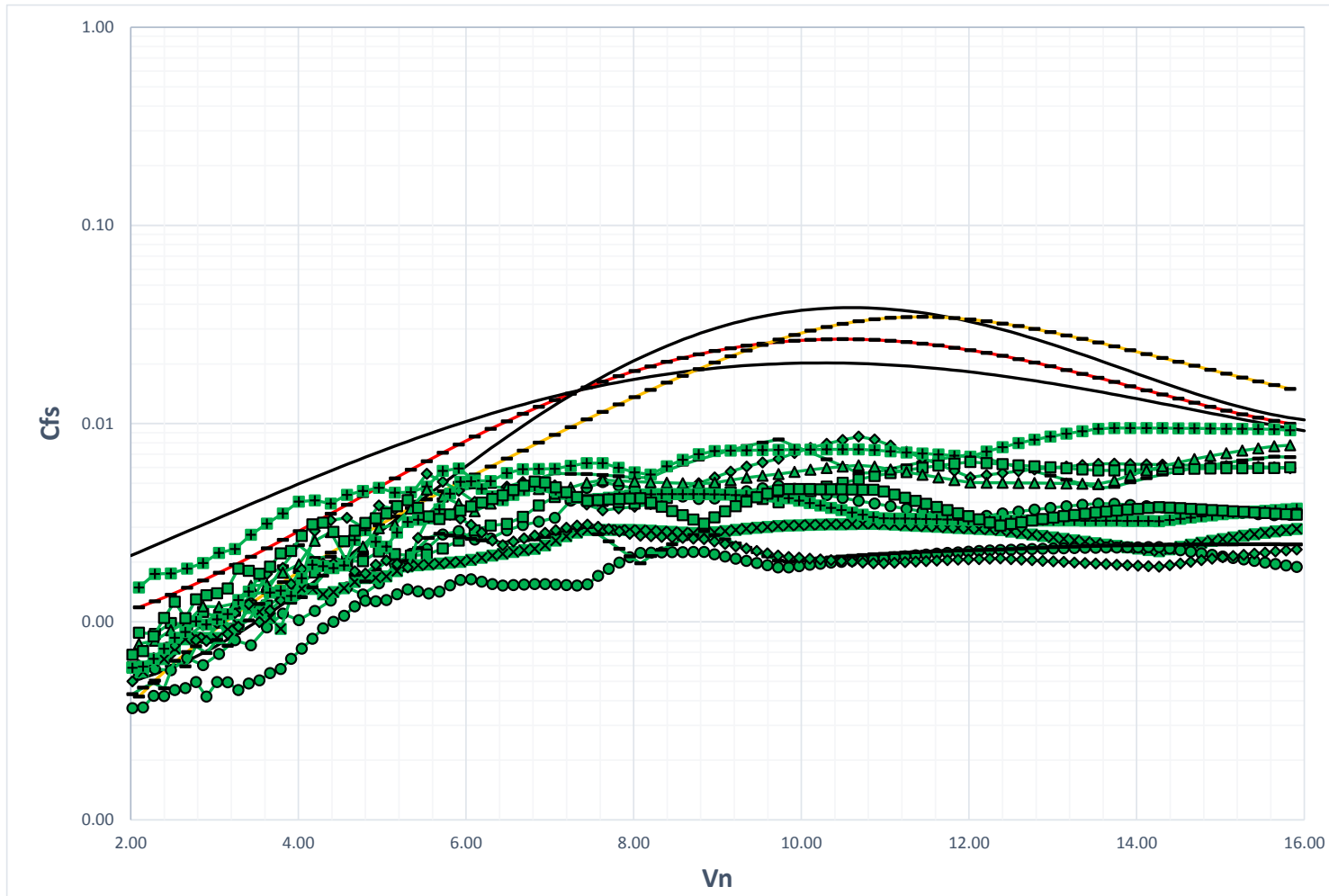
3 ACKNOWLEDGEMENTS

The author wishes to acknowledge the subsidy towards this study, received in February 2018 from the Australasian Wind Engineering Society.

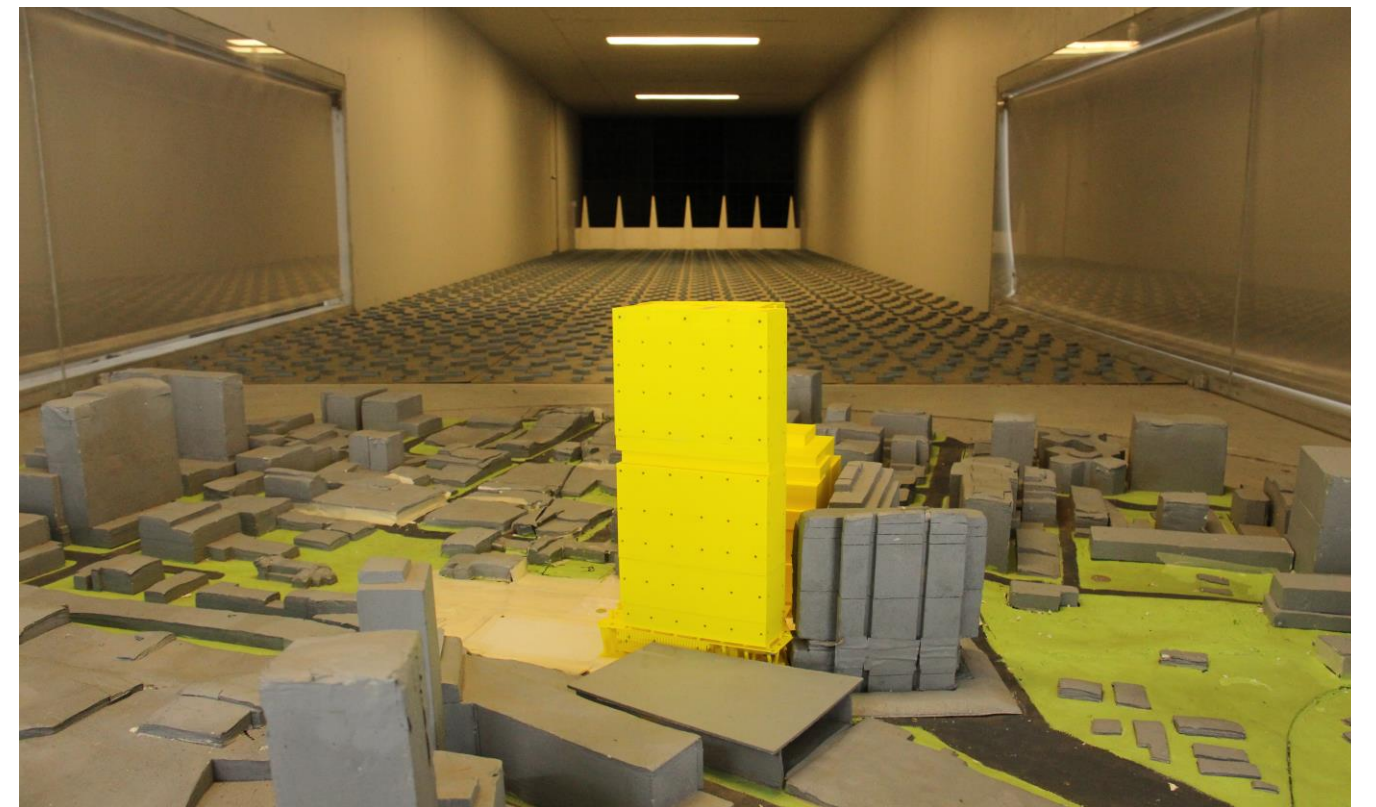
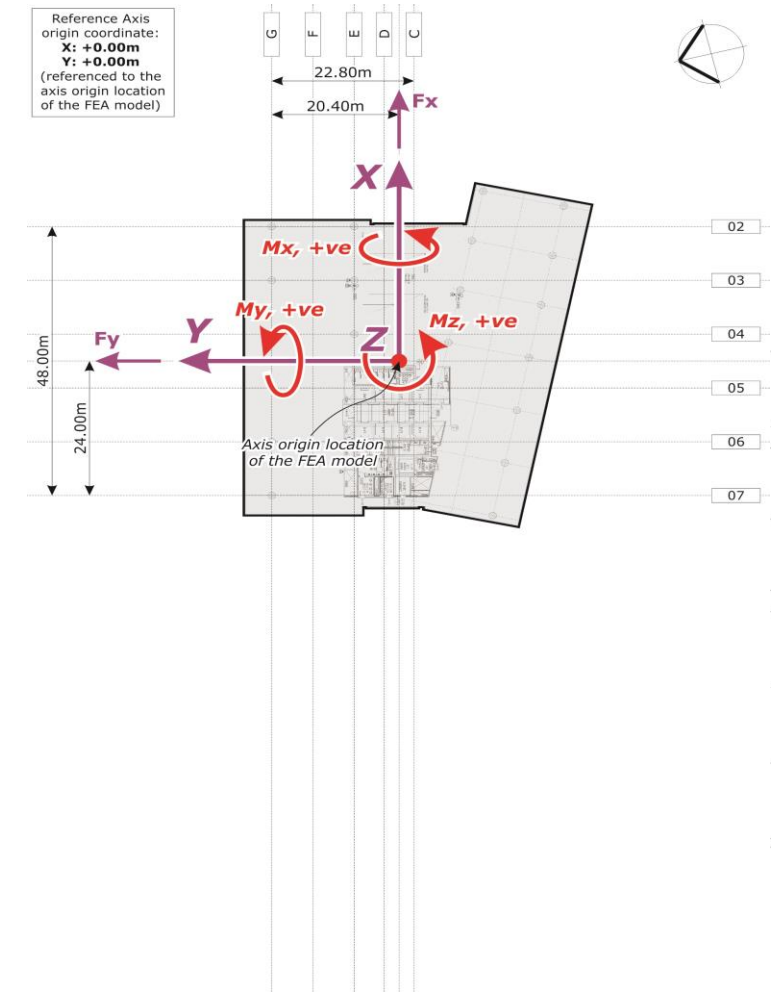
The author wishes to also acknowledge the innumerable hours spent by Todd Davies scouring through hundreds of past projects and running the analyses to compile the C_{fs} data used for this study. Credit also goes to Dr Nicholas Truong for his valuable input into the project.

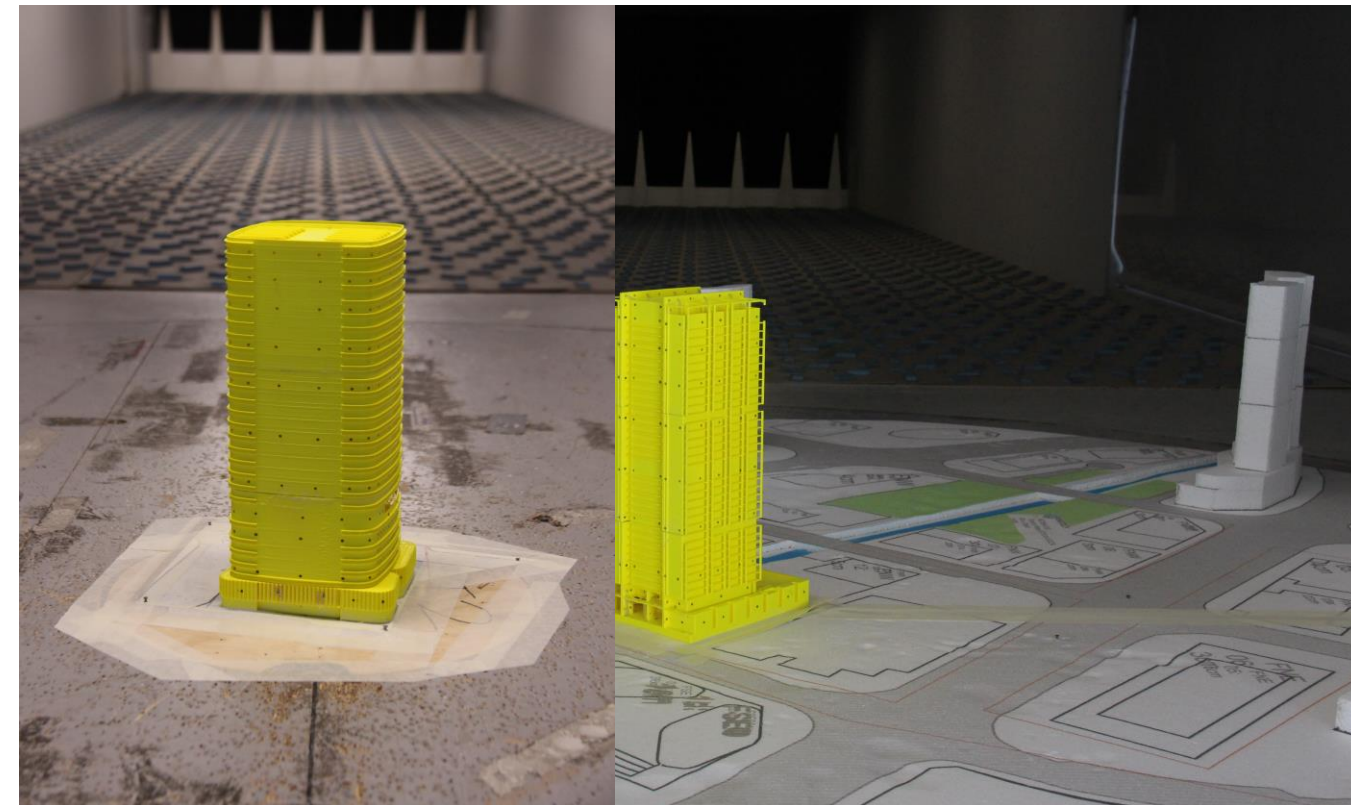
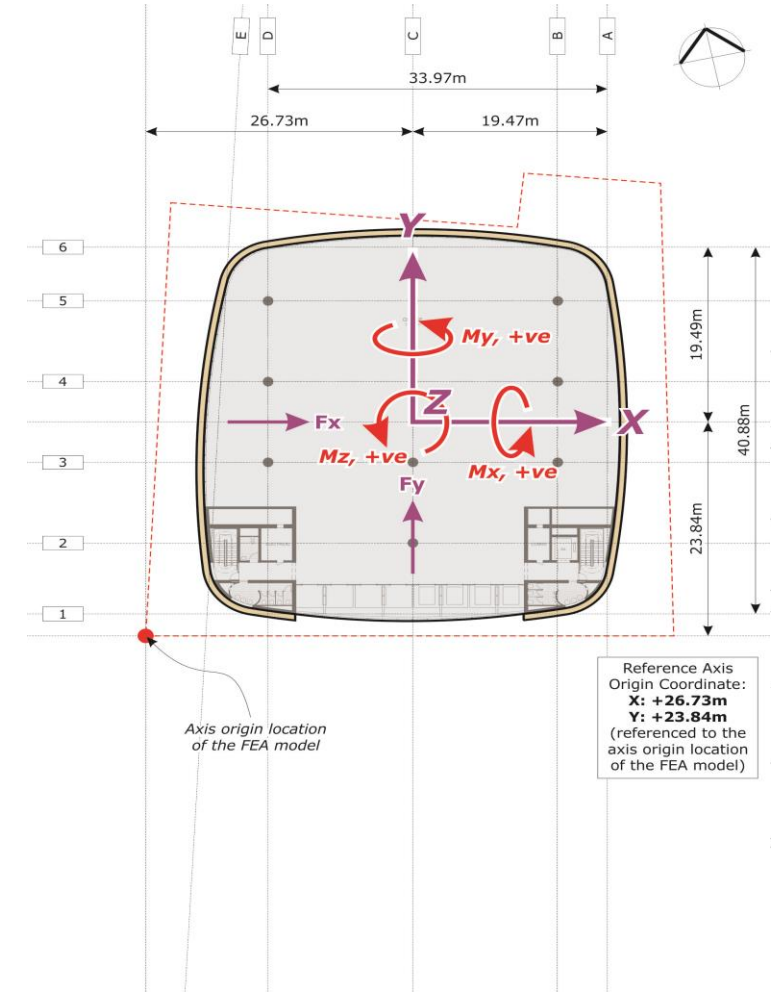
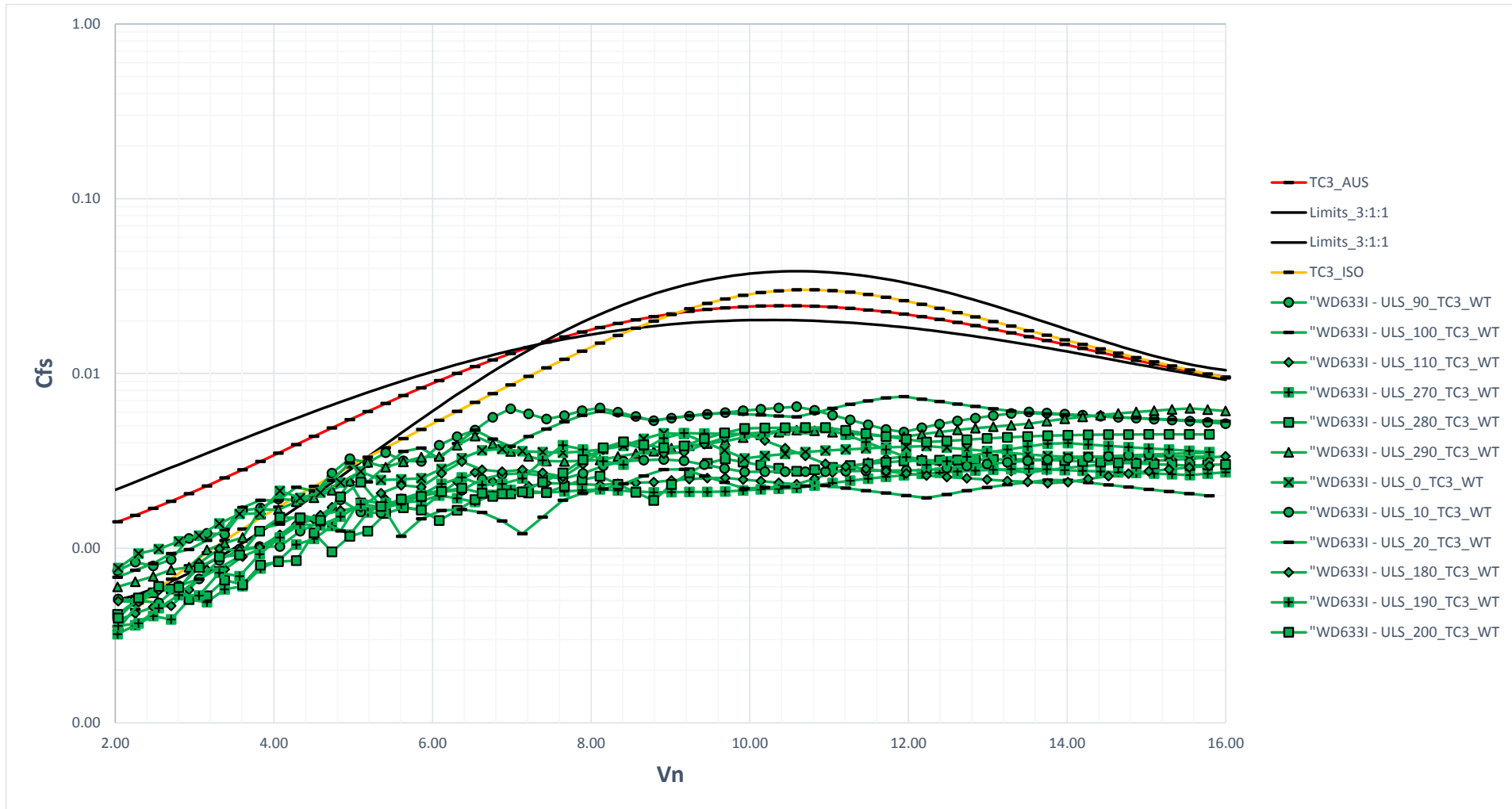
ANNEXURE 1 – COMPARATIVE RESULTS for $h:b:d$ of 3:1:1

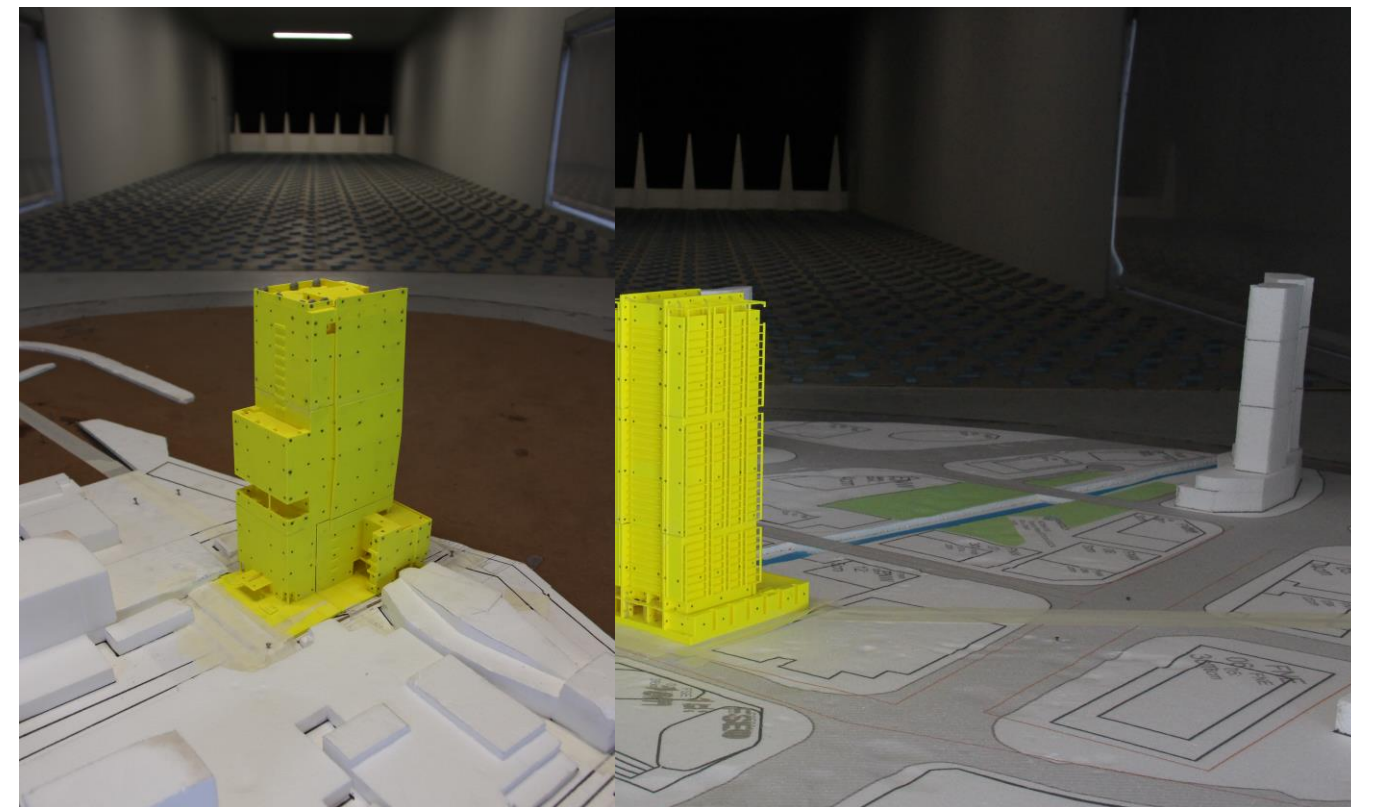
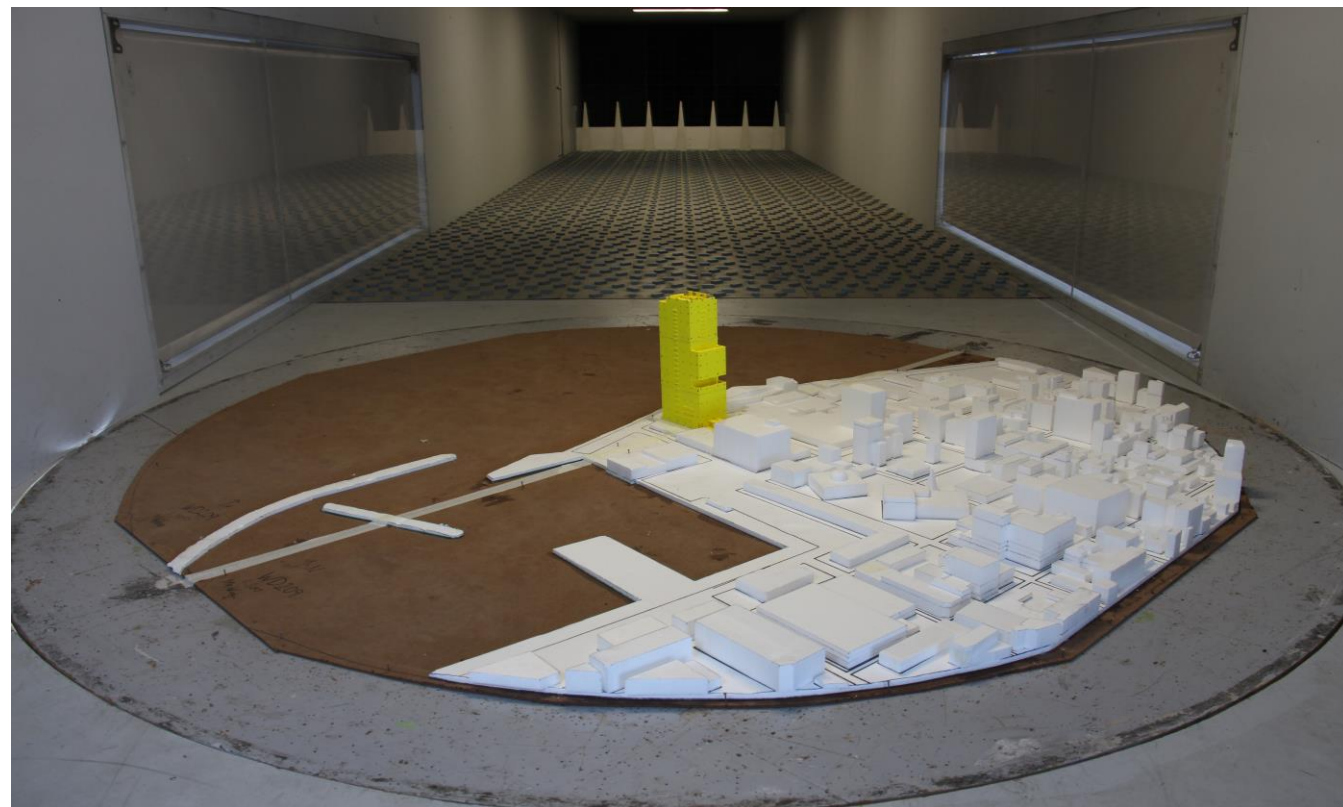
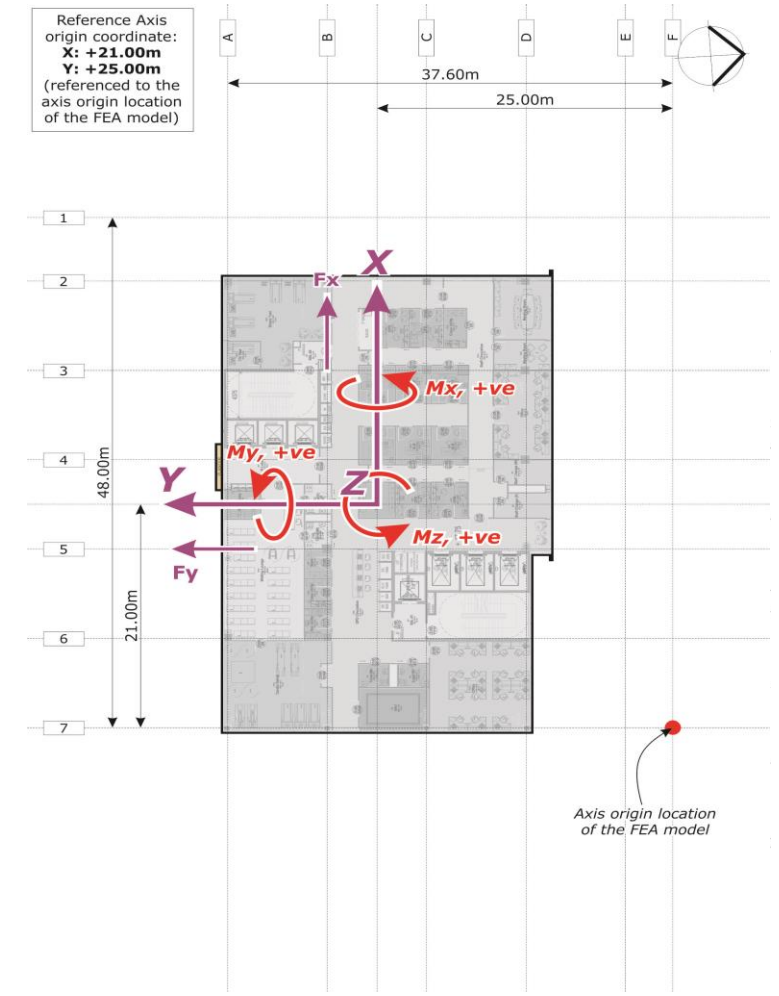
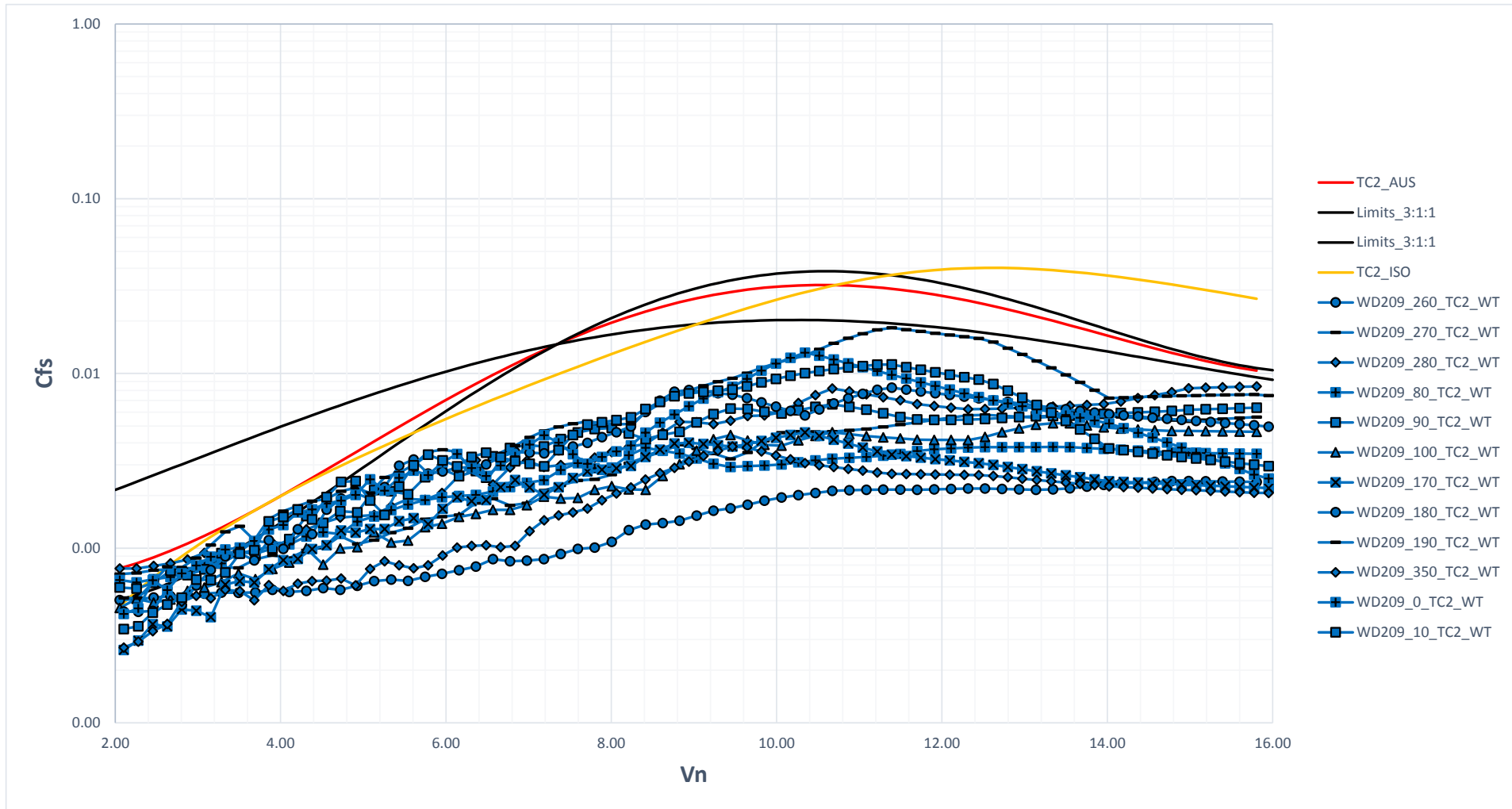


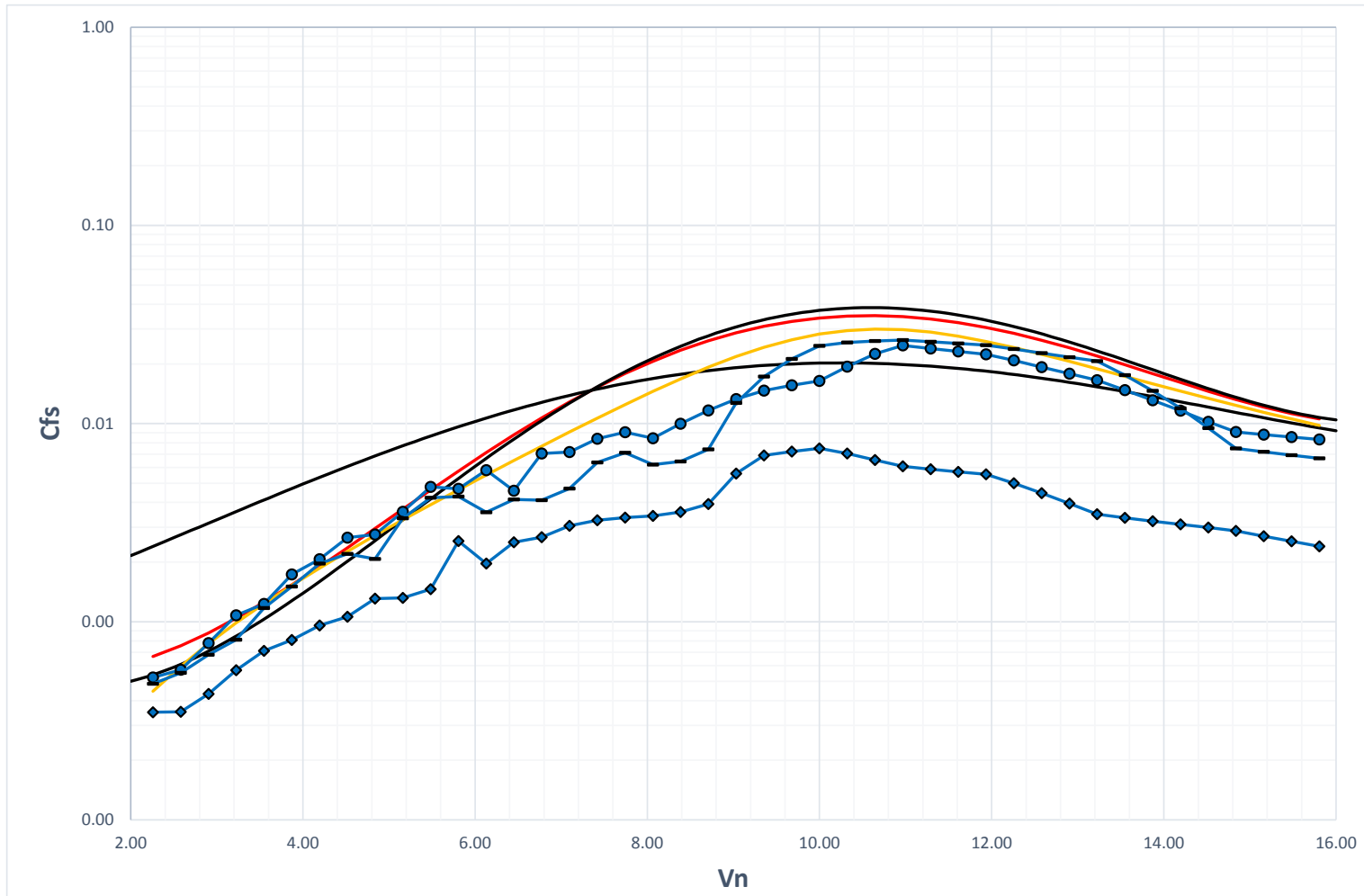


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- TC3_ISO
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- WC585E - ULS - 1000yr@2_100_TC3_WT
- WC585E - ULS - 1000yr@2_110_TC3_WT
- WC585E - ULS - 1000yr@2_270_TC3_WT
- WC585E - ULS - 1000yr@2_280_TC3_WT
- WC585E - ULS - 1000yr@2_290_TC3_WT
- WC585E - ULS - 1000yr@2_0_TC3_WT
- WC585E - ULS - 1000yr@2_10_TC3_WT
- WC585E - ULS - 1000yr@2_20_TC3_WT
- WC585E - ULS - 1000yr@2_180_TC3_WT
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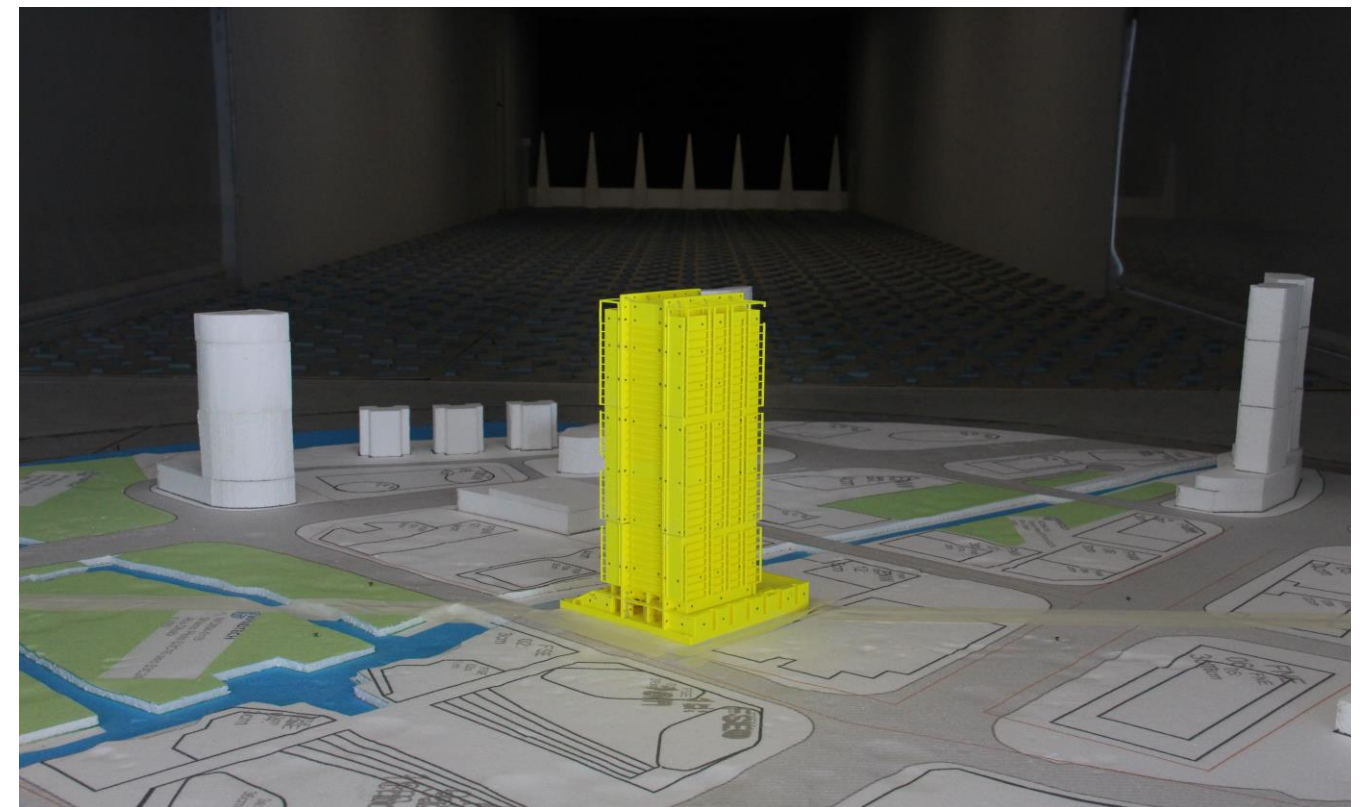
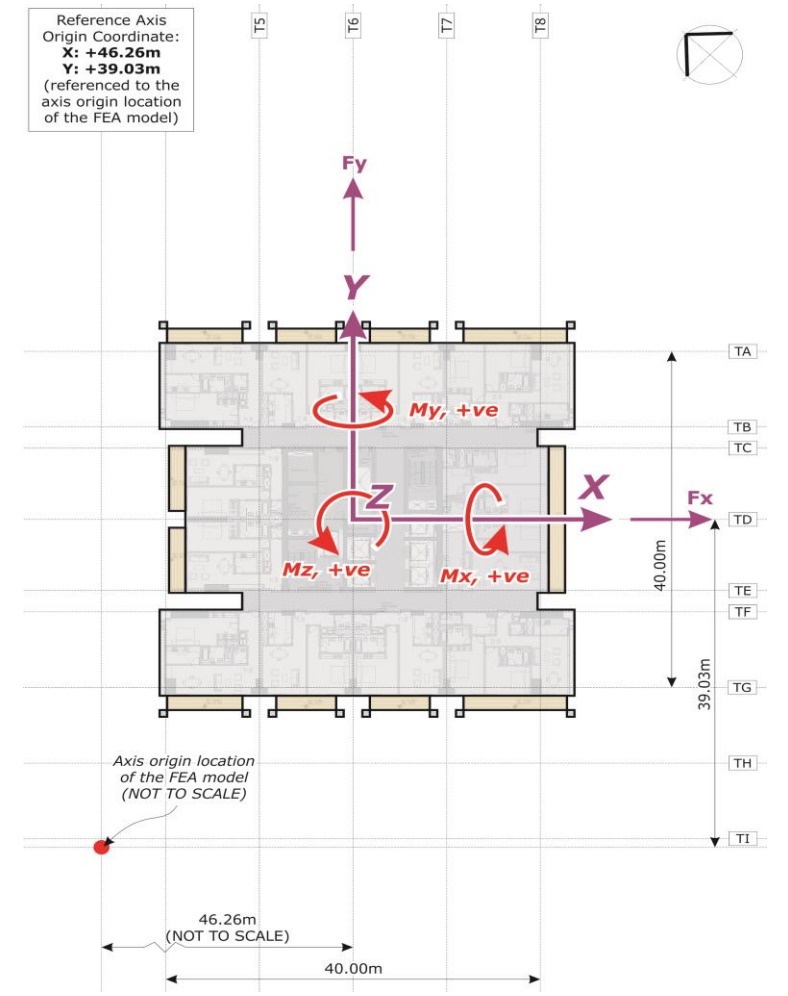


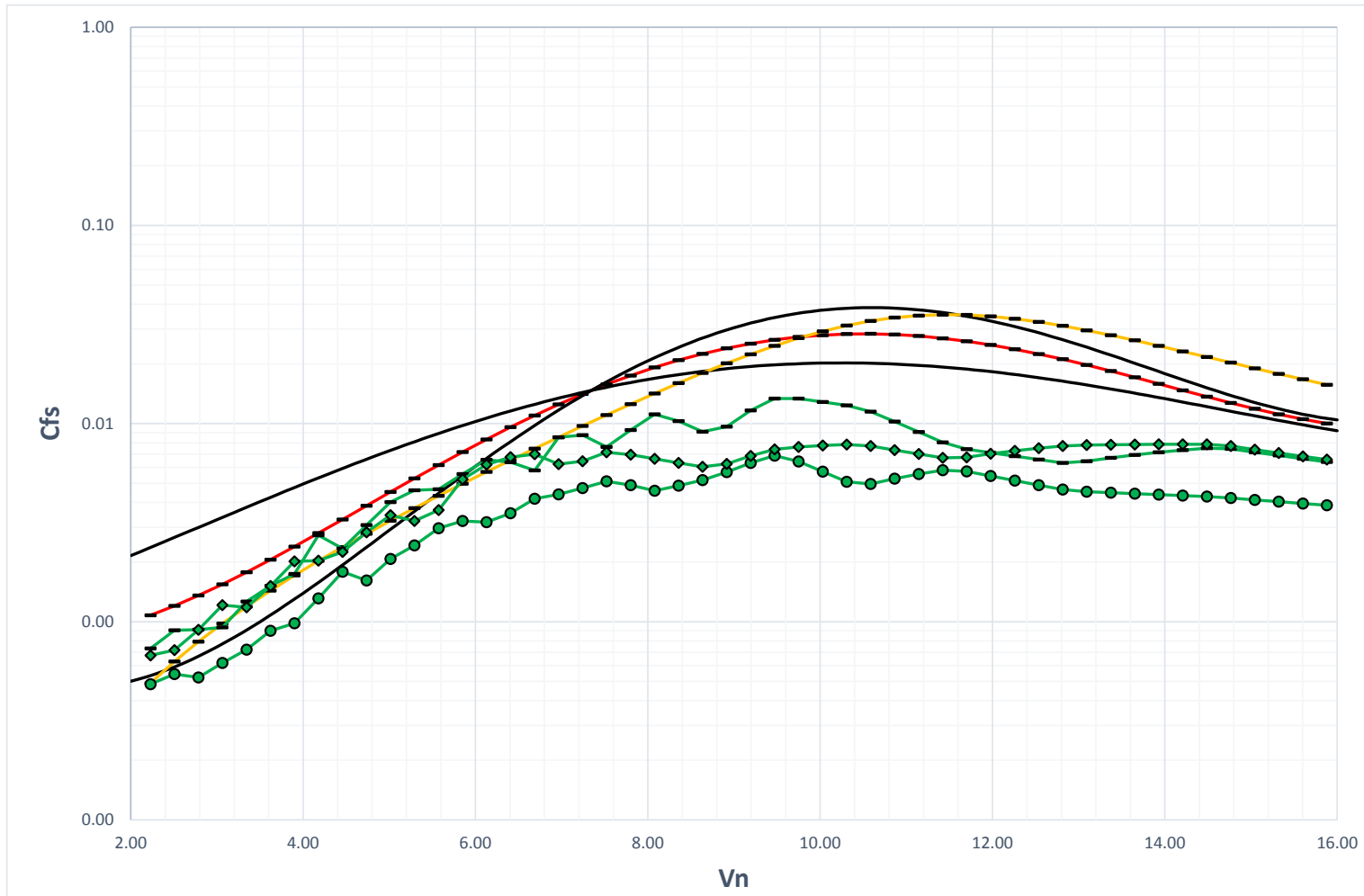




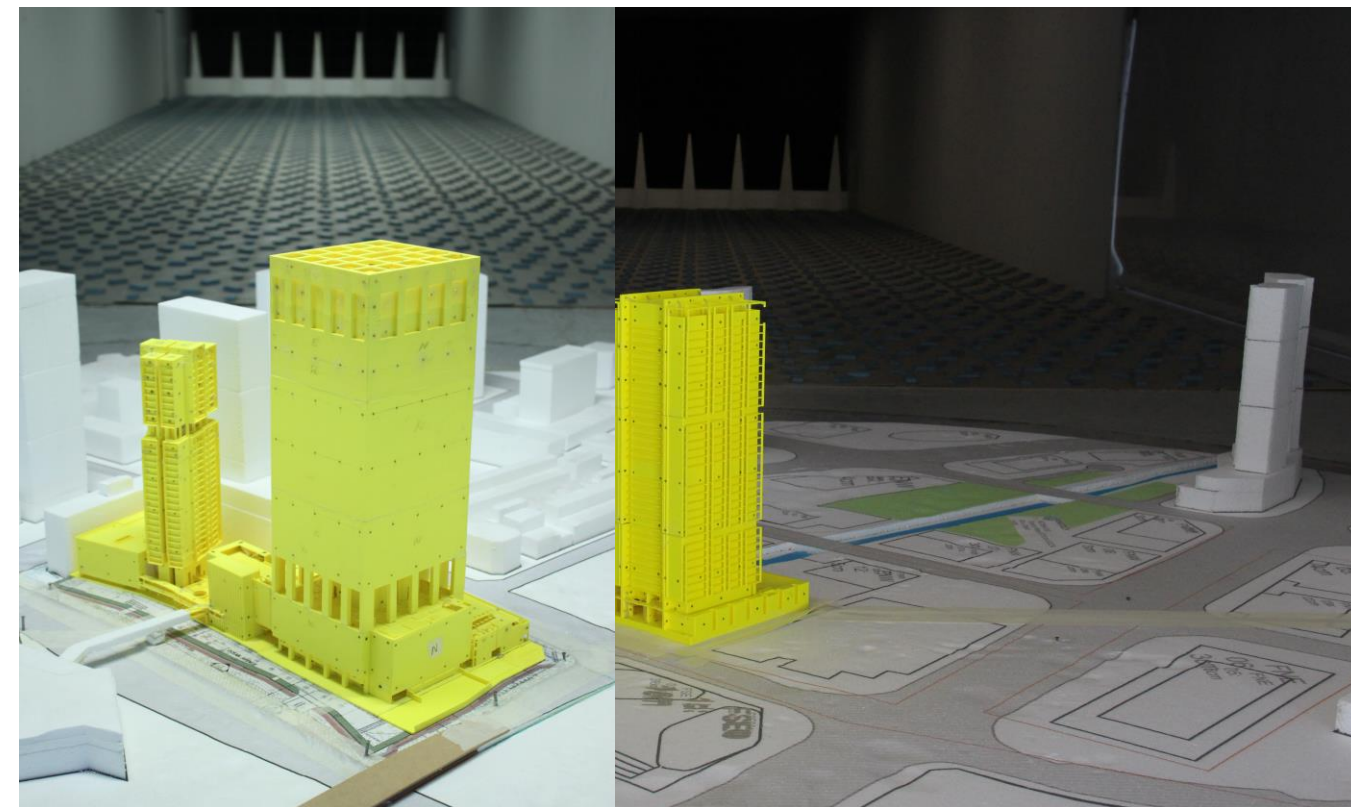
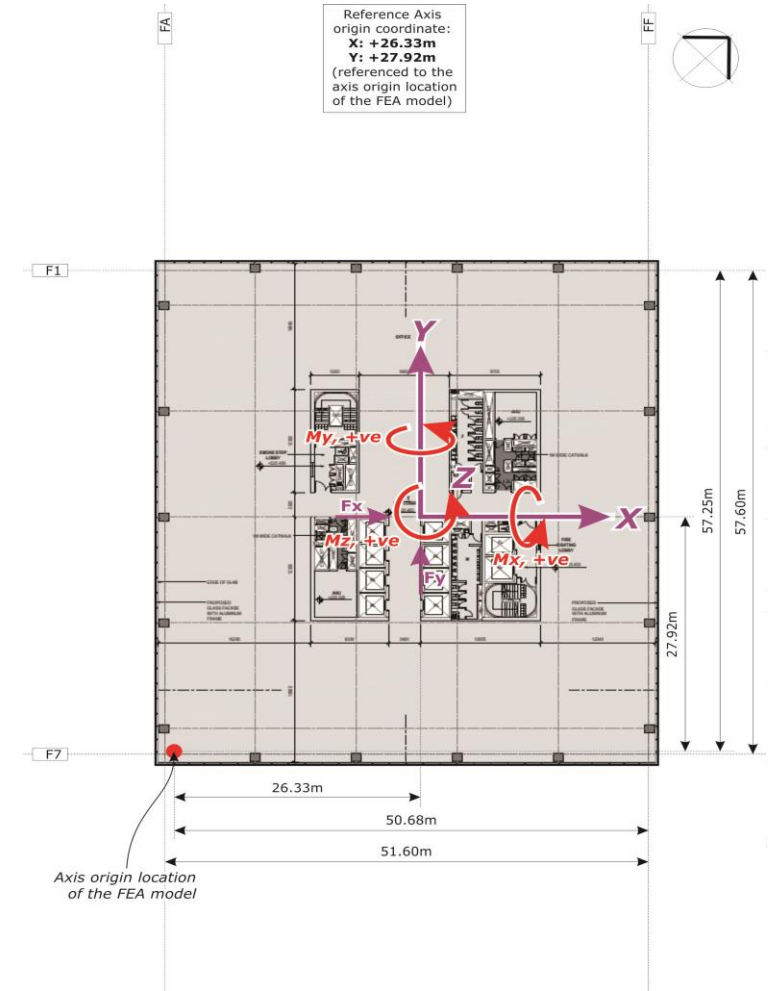


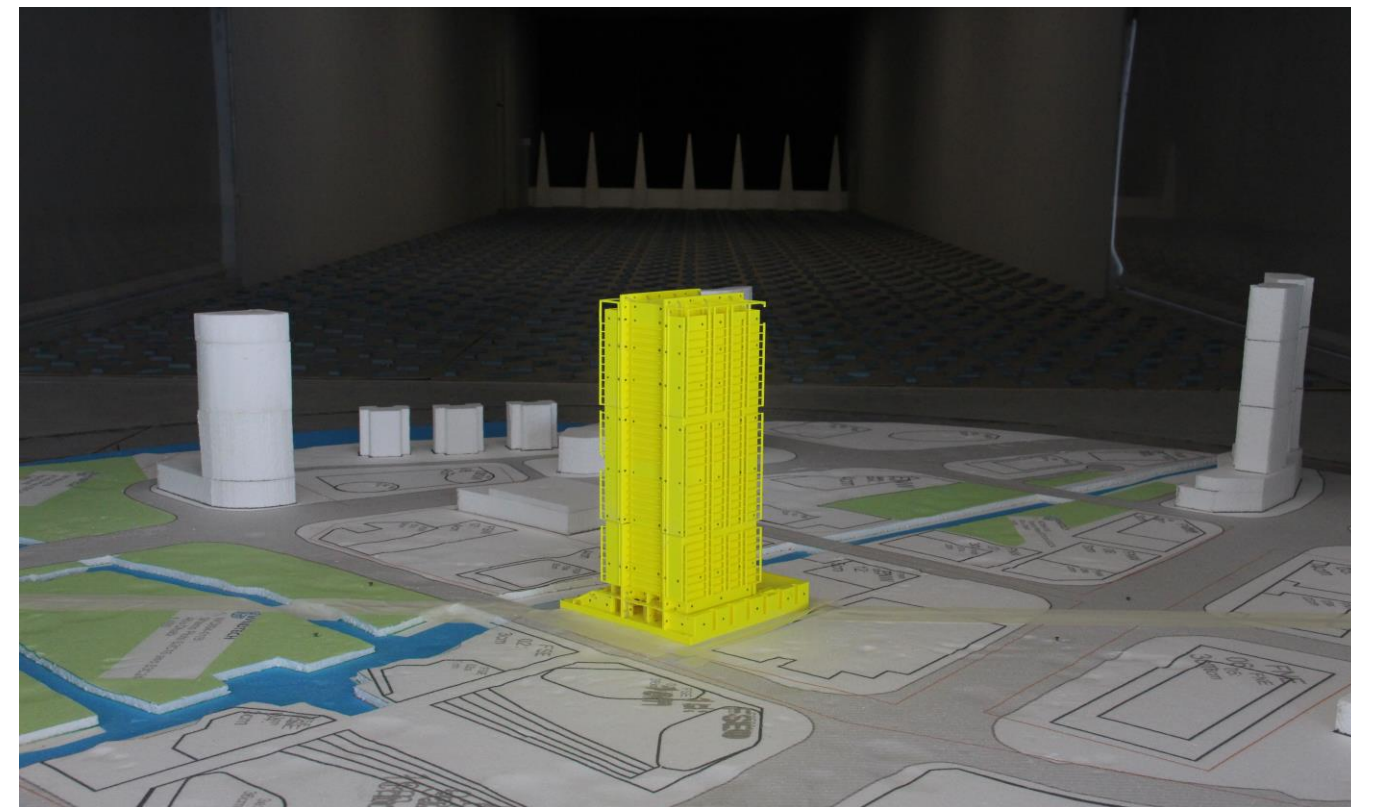
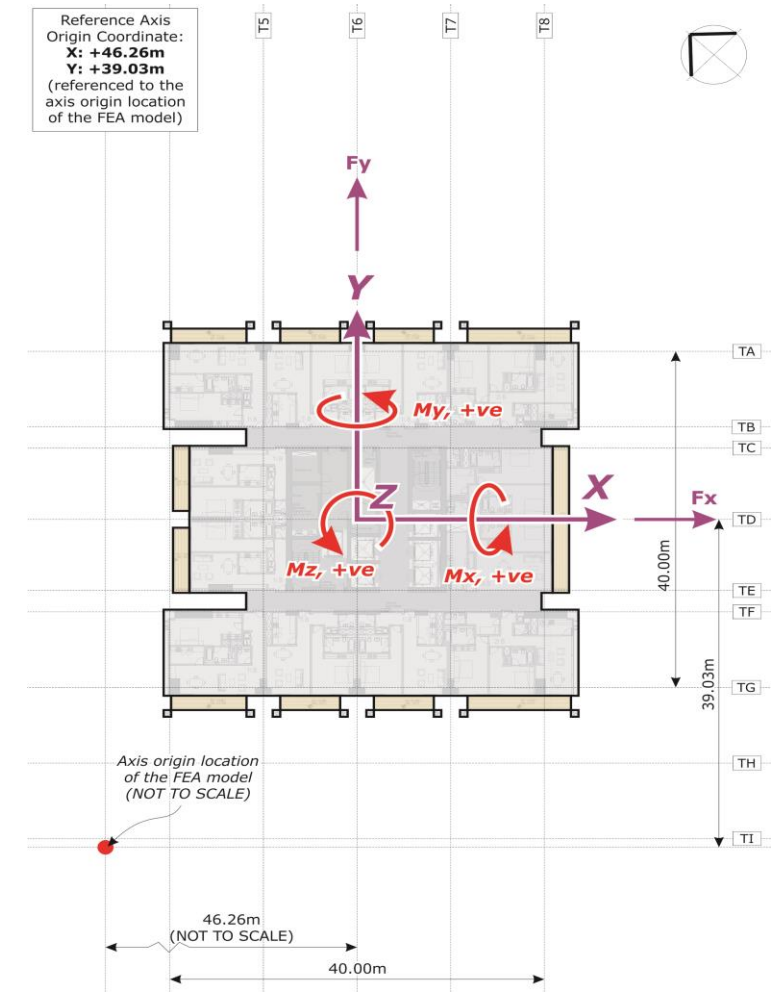
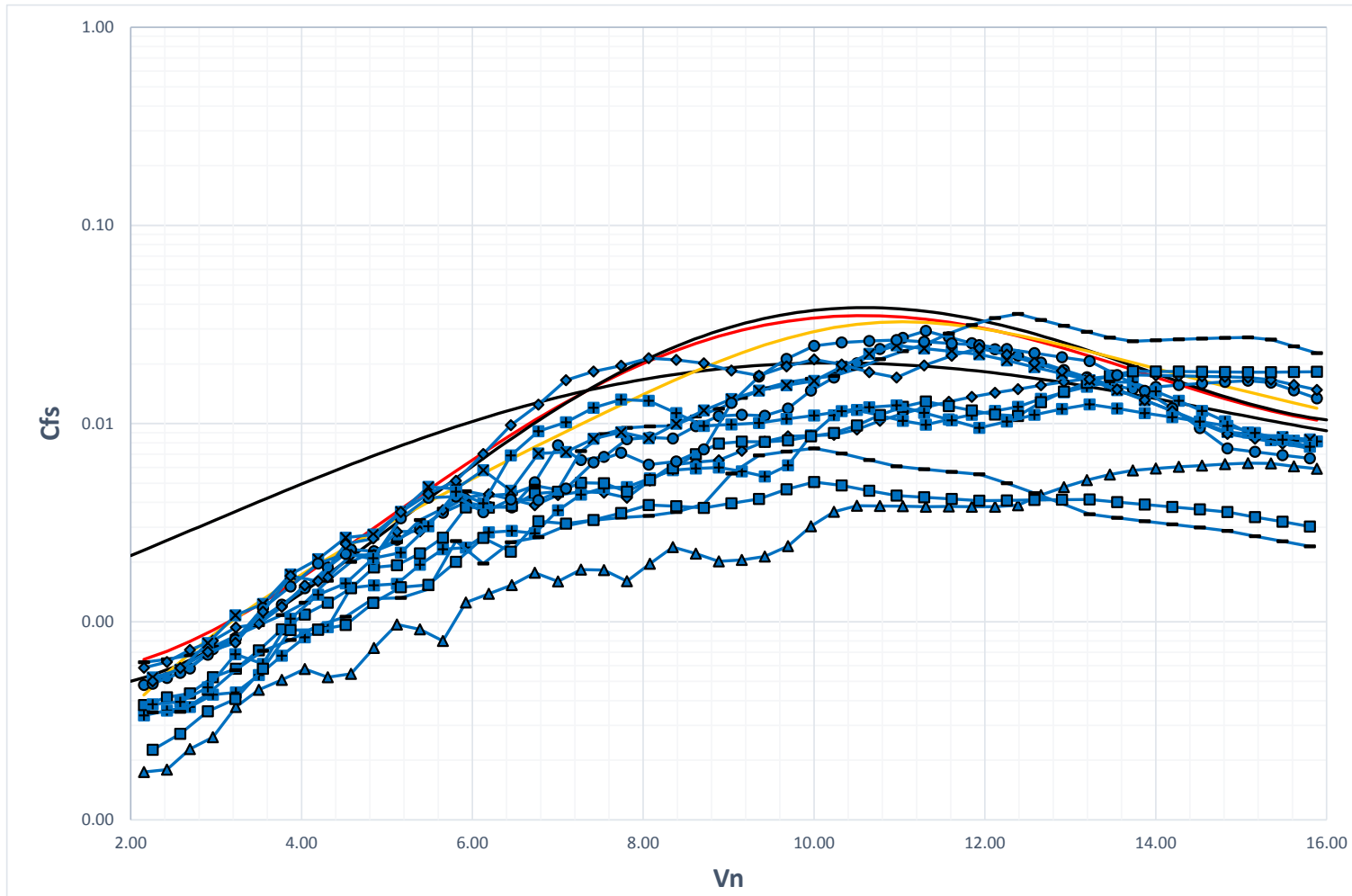
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- TC2_ISO
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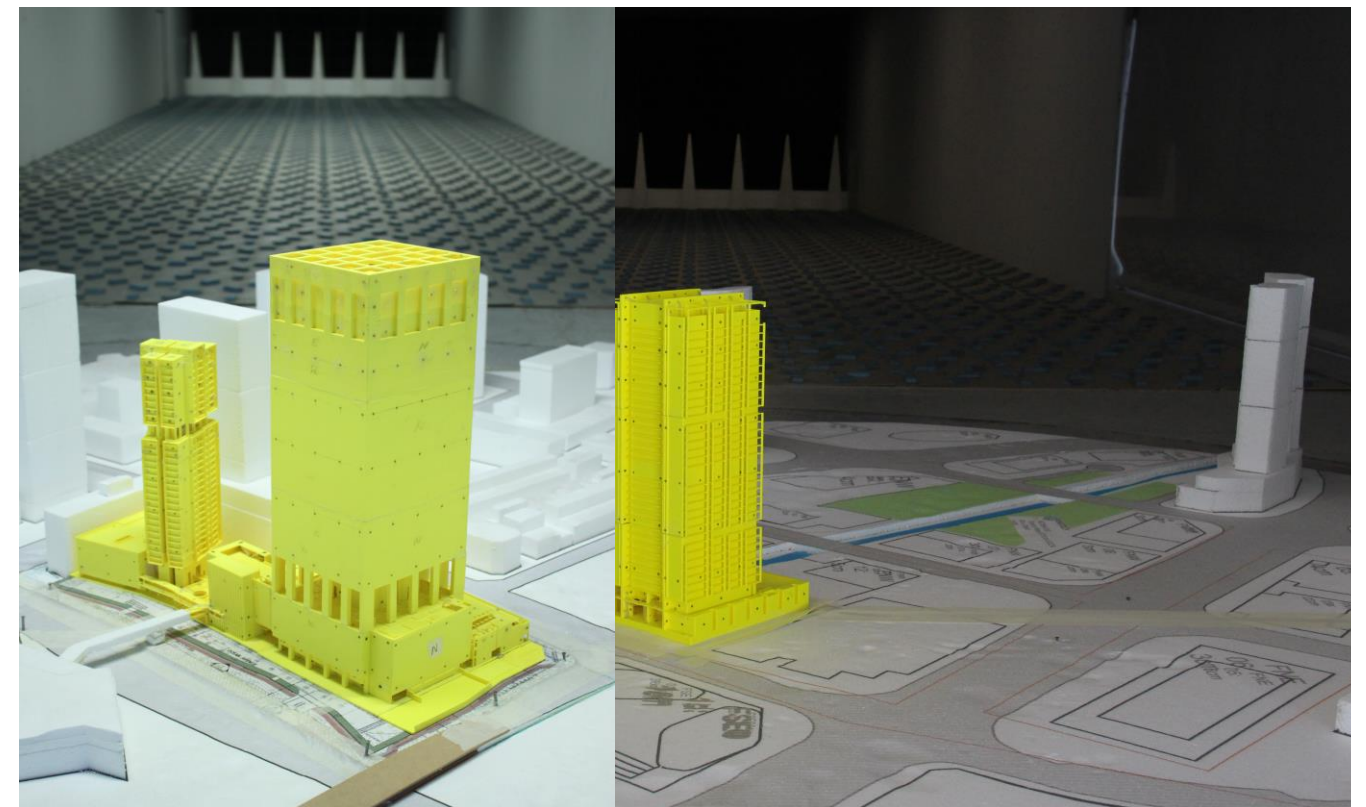
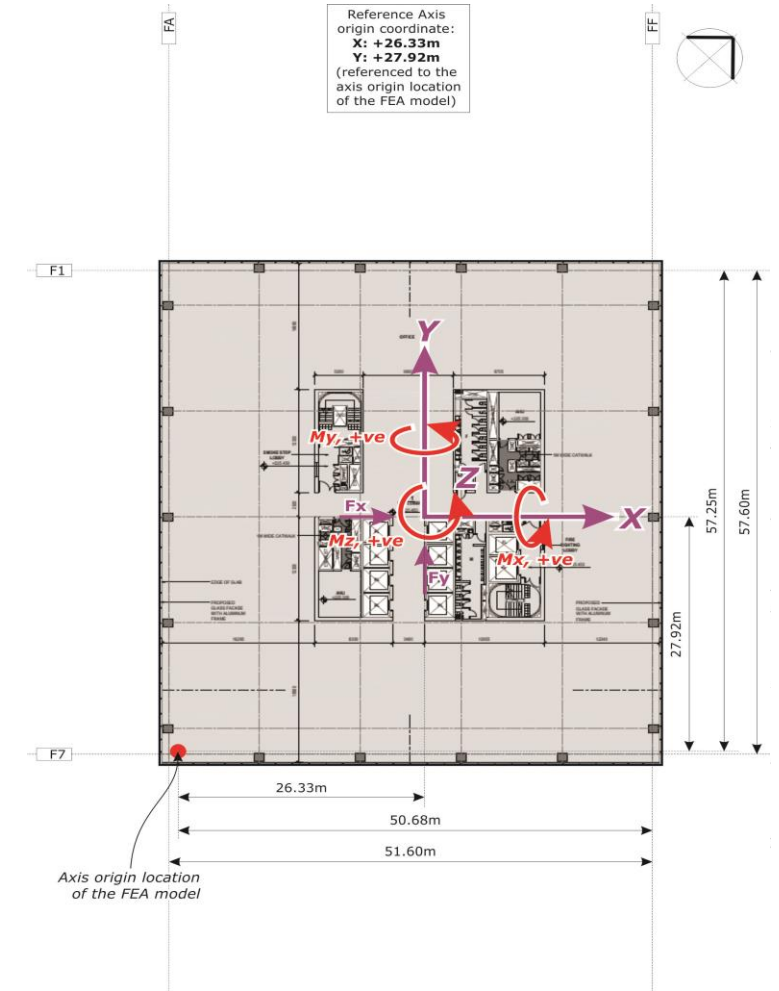
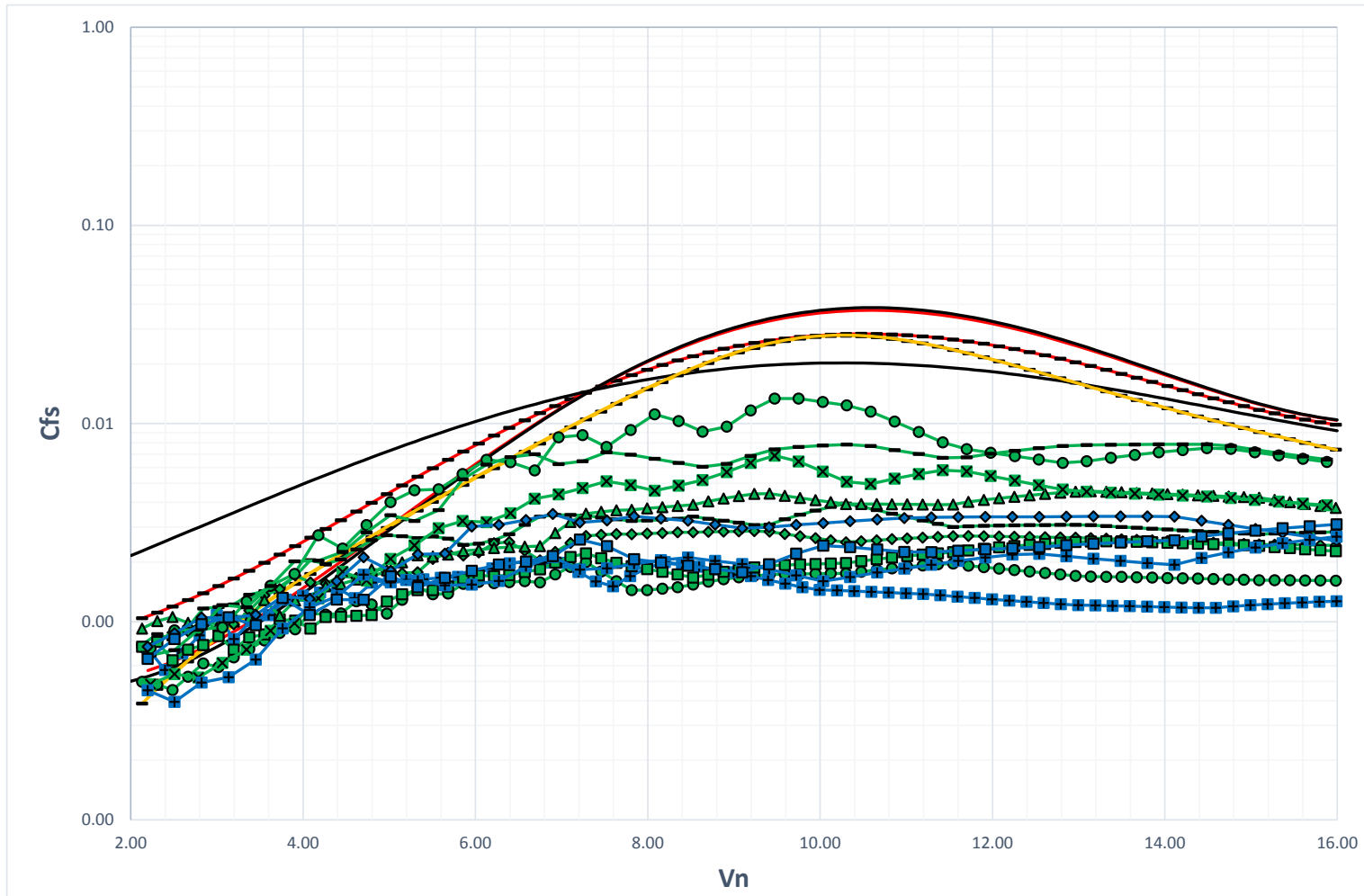




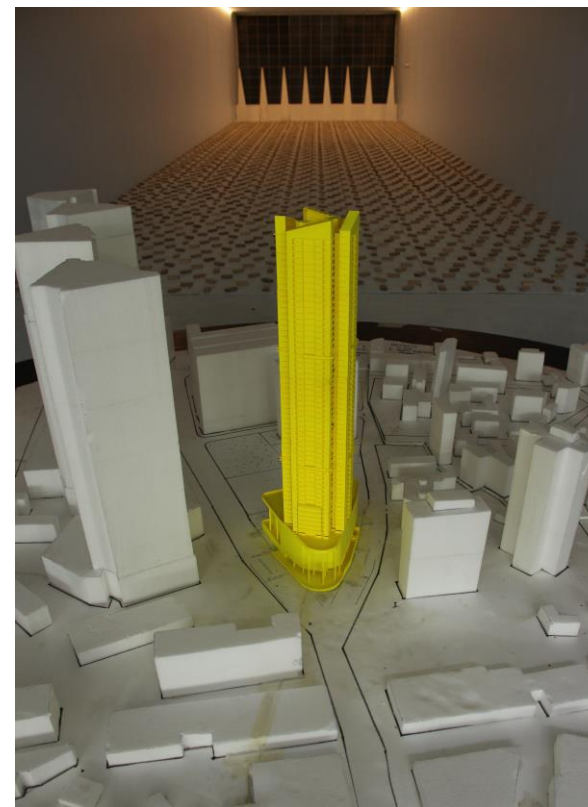
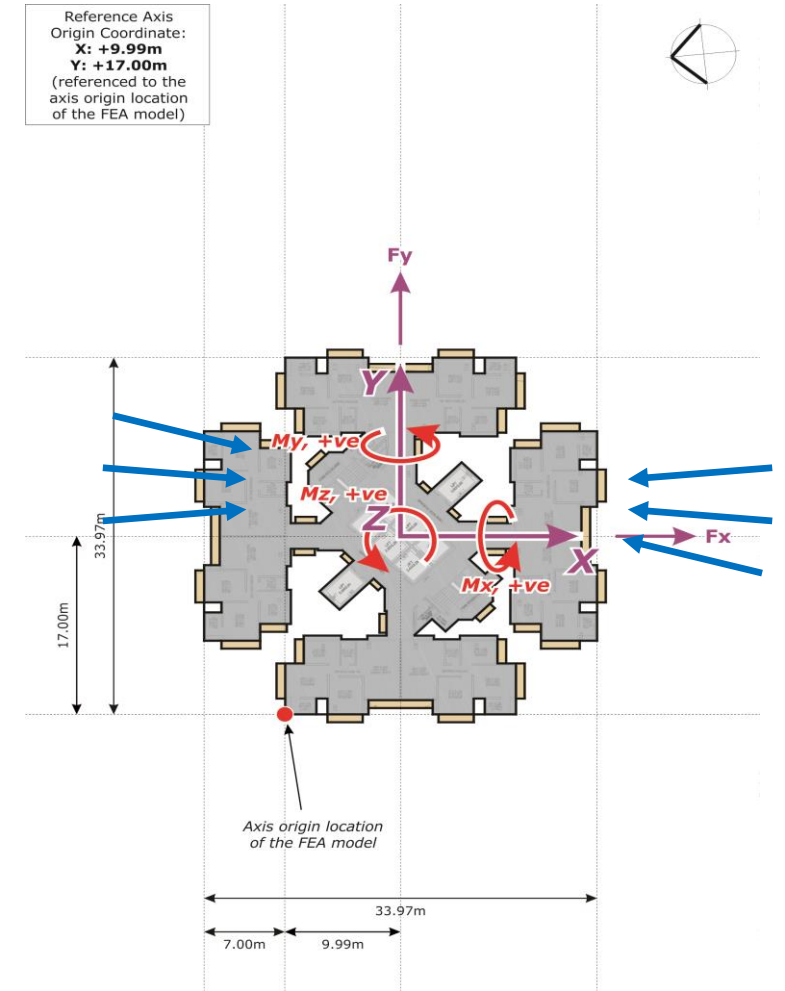
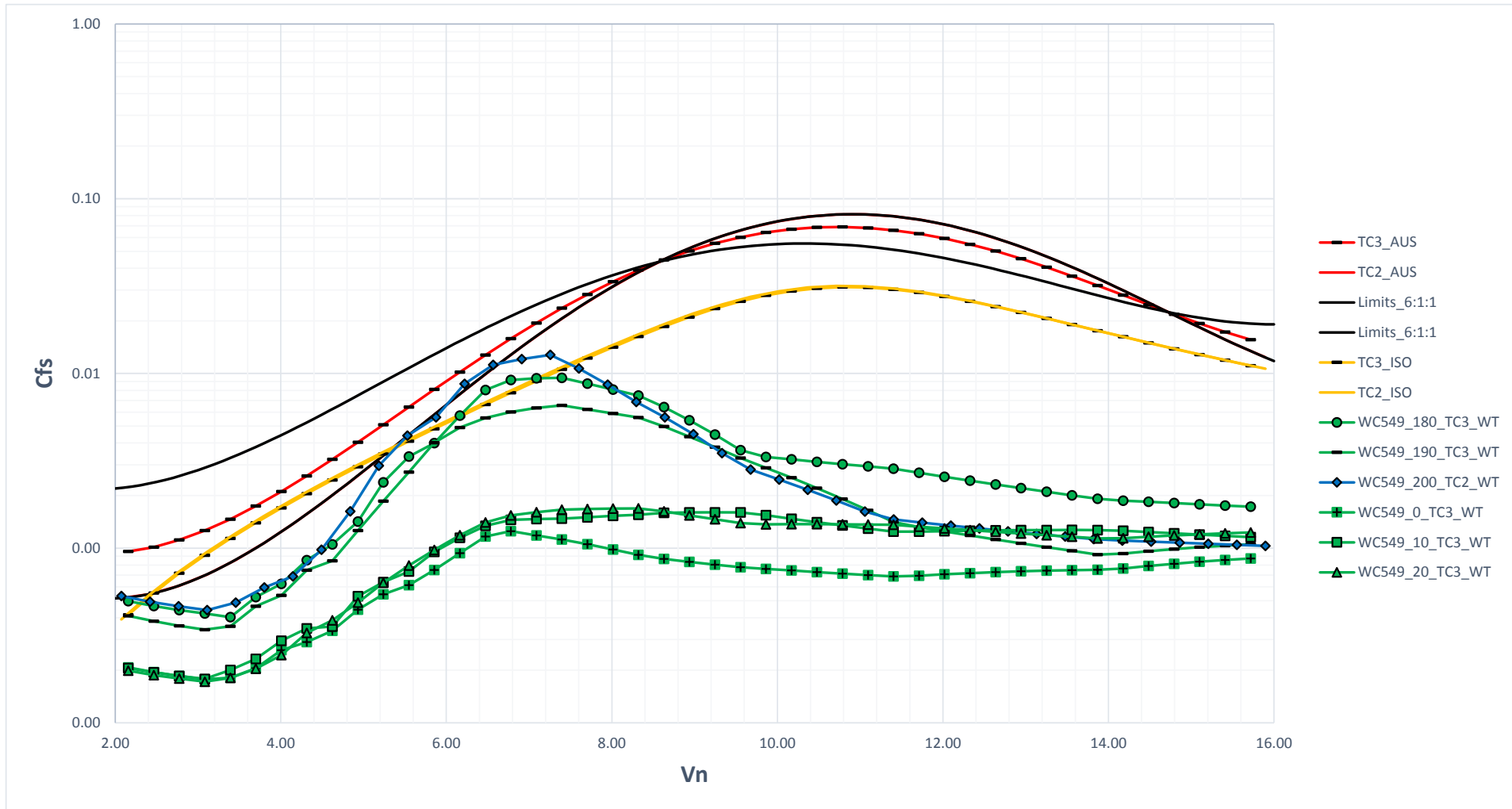
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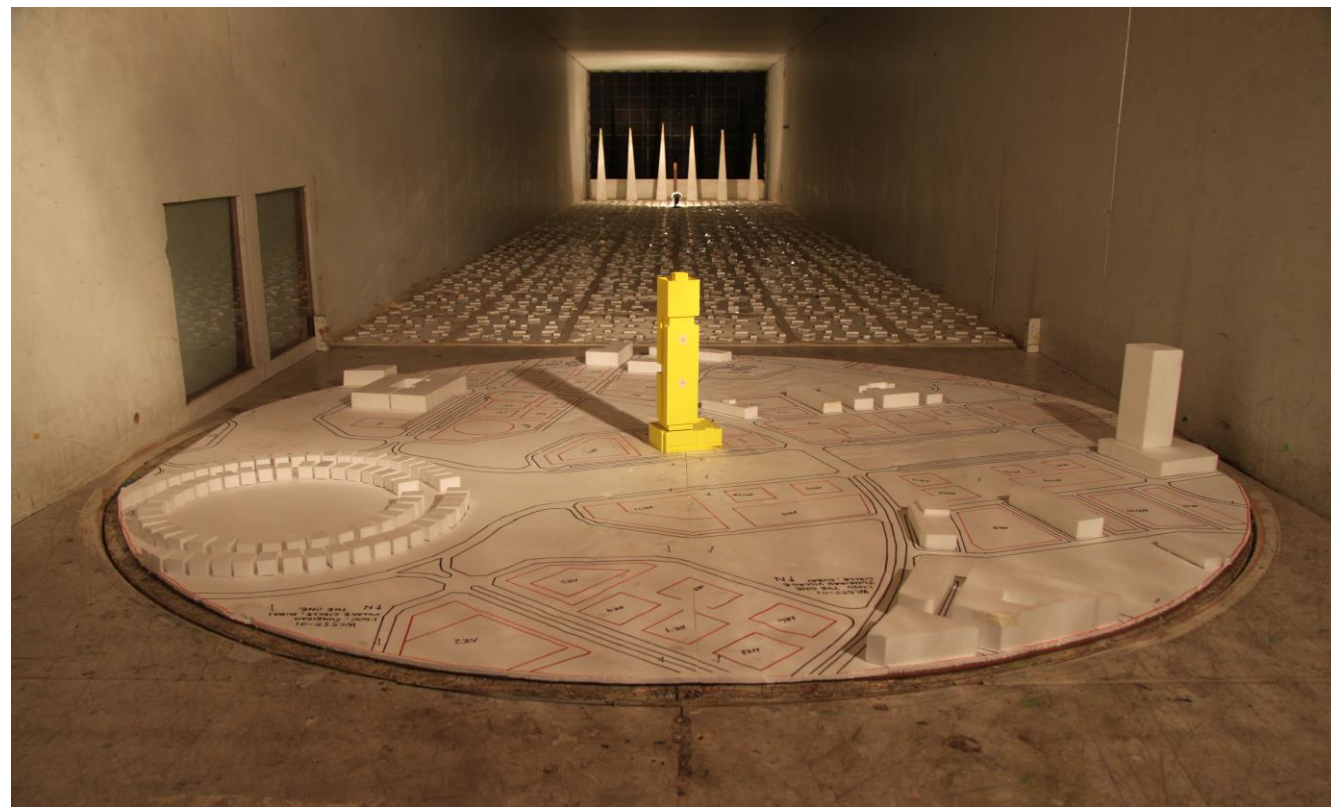
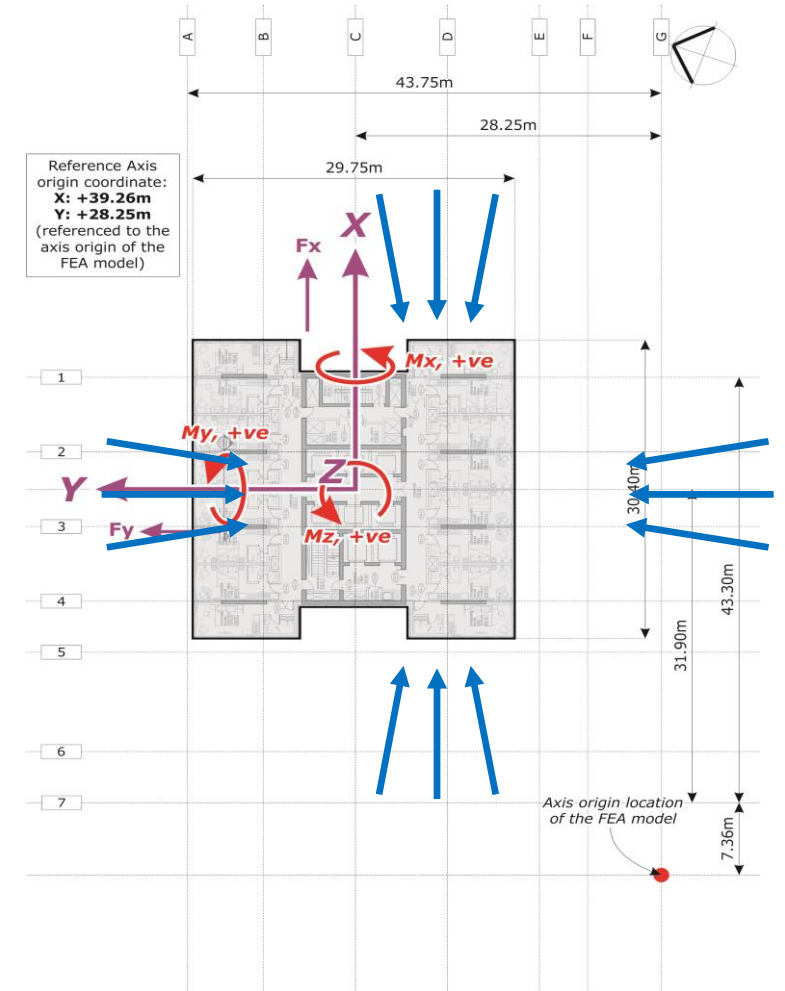
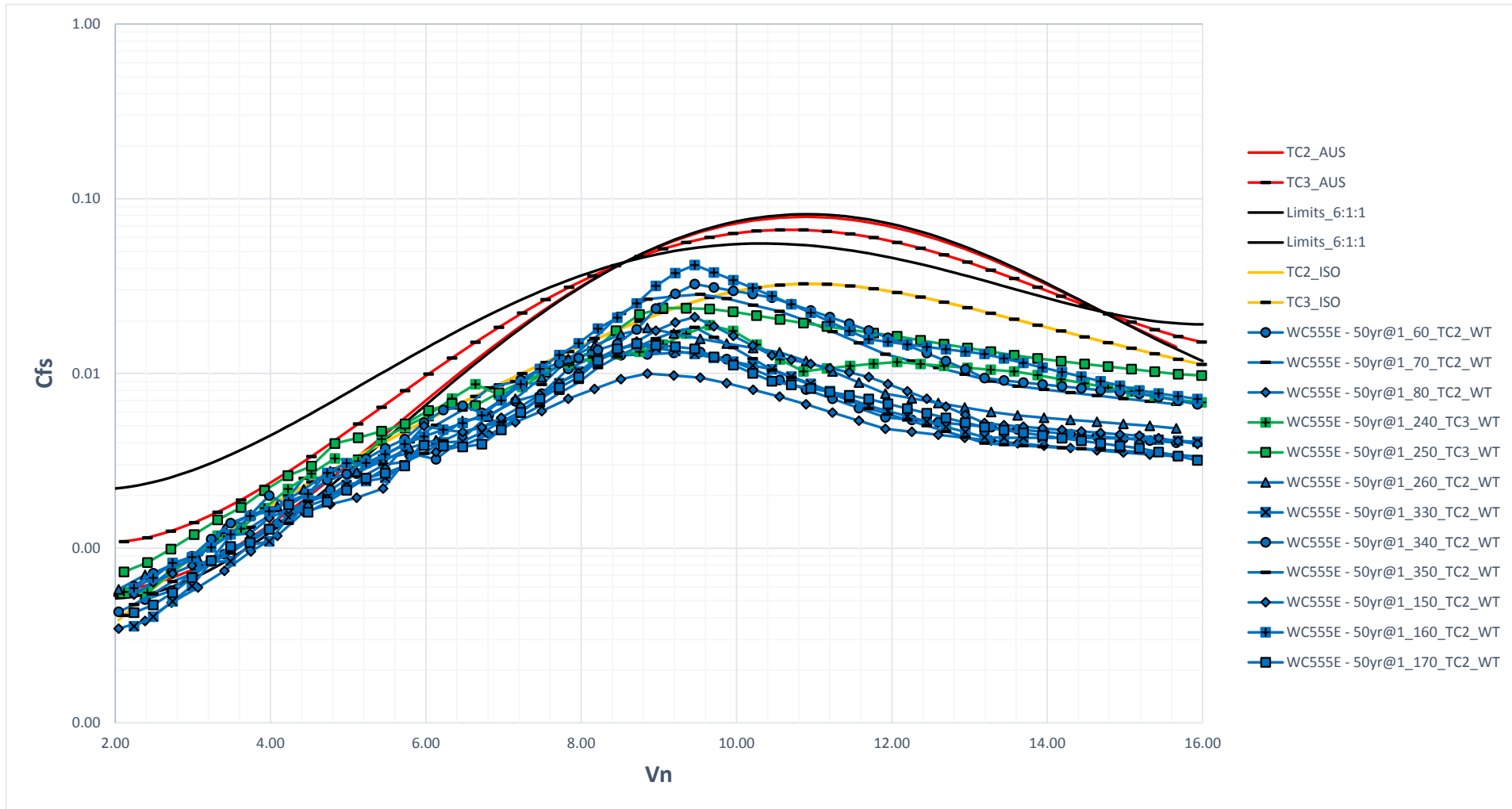


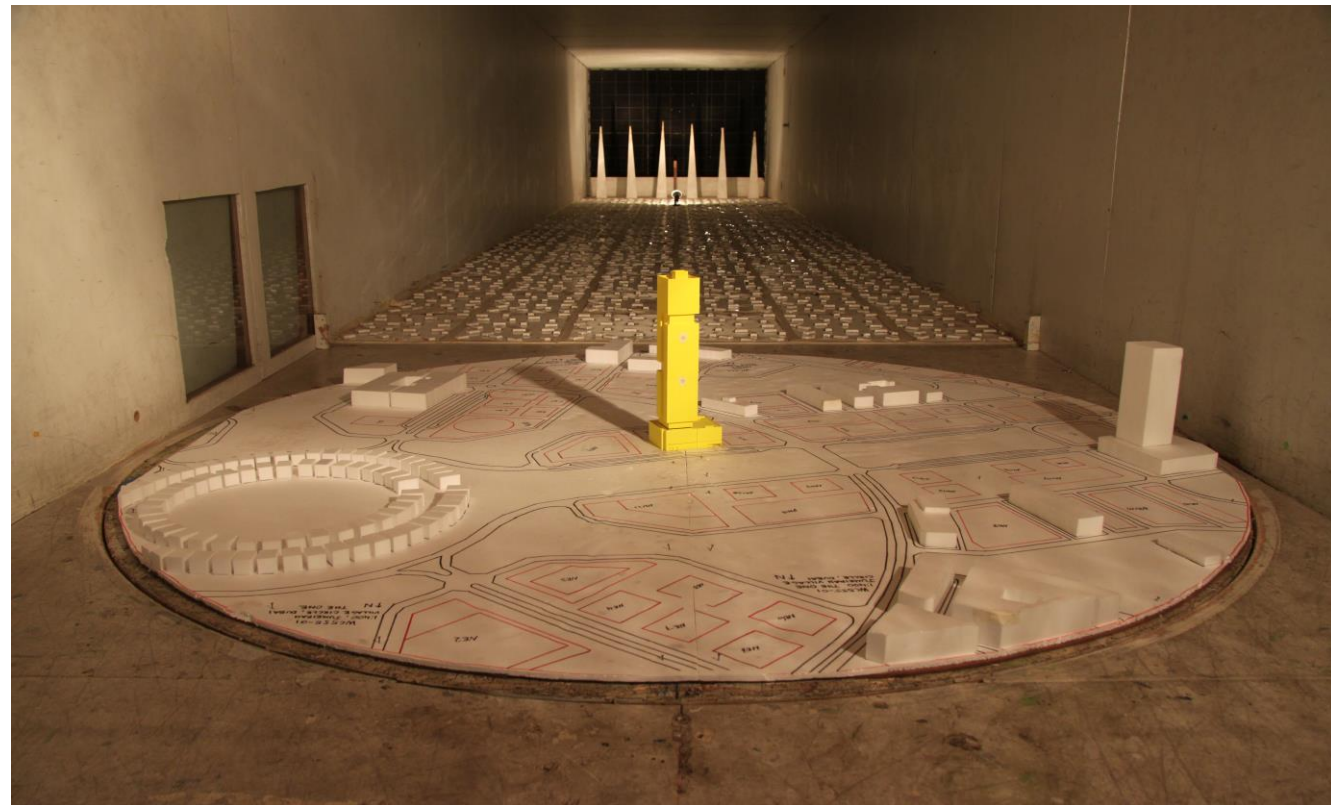
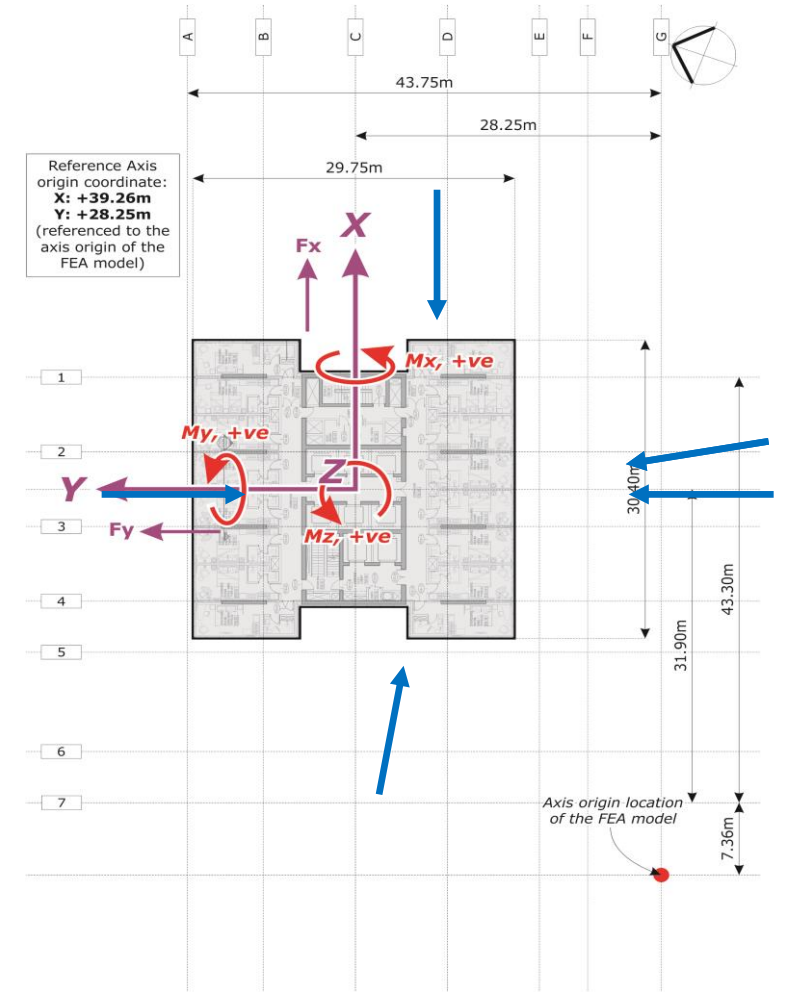
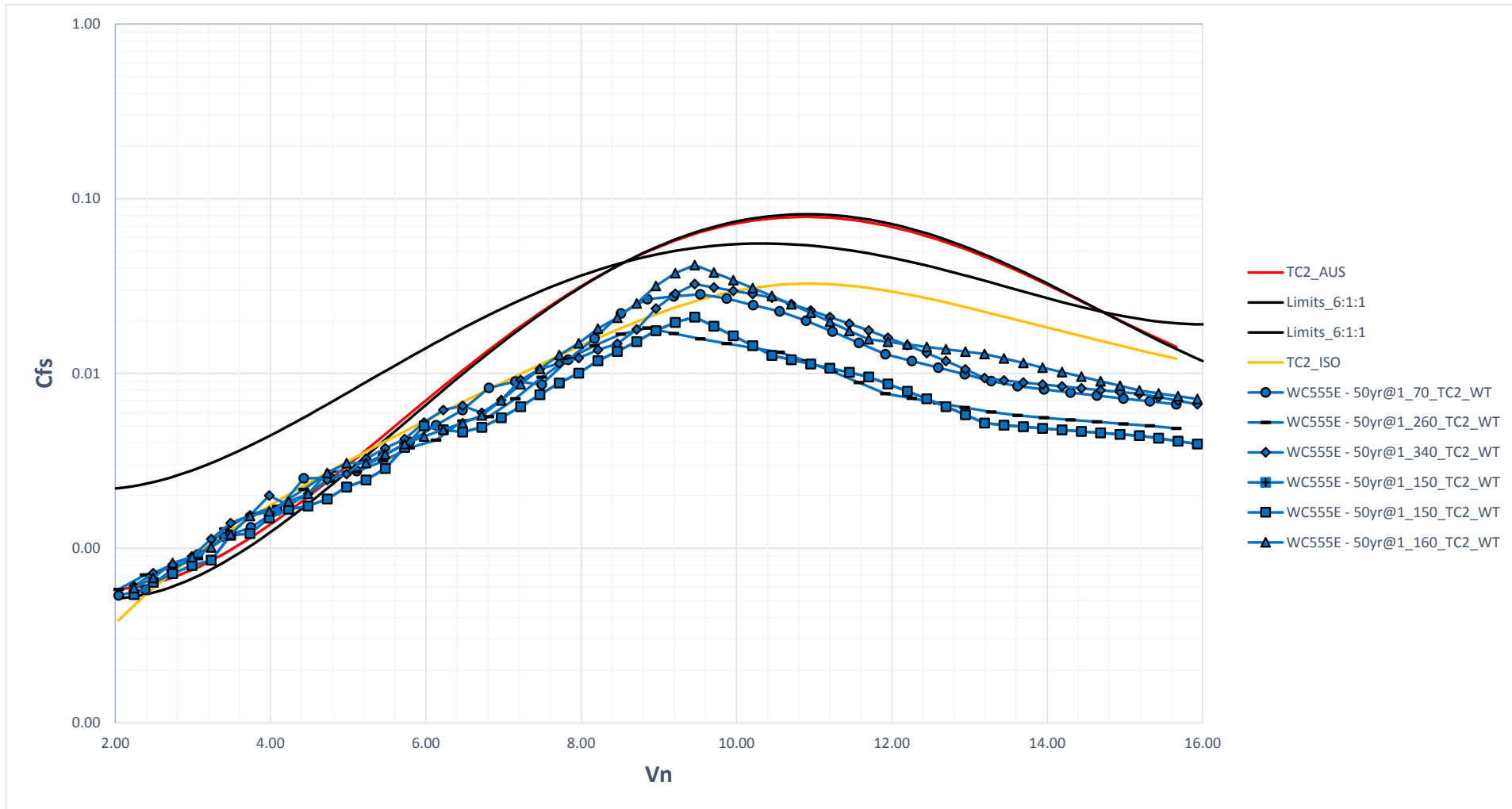


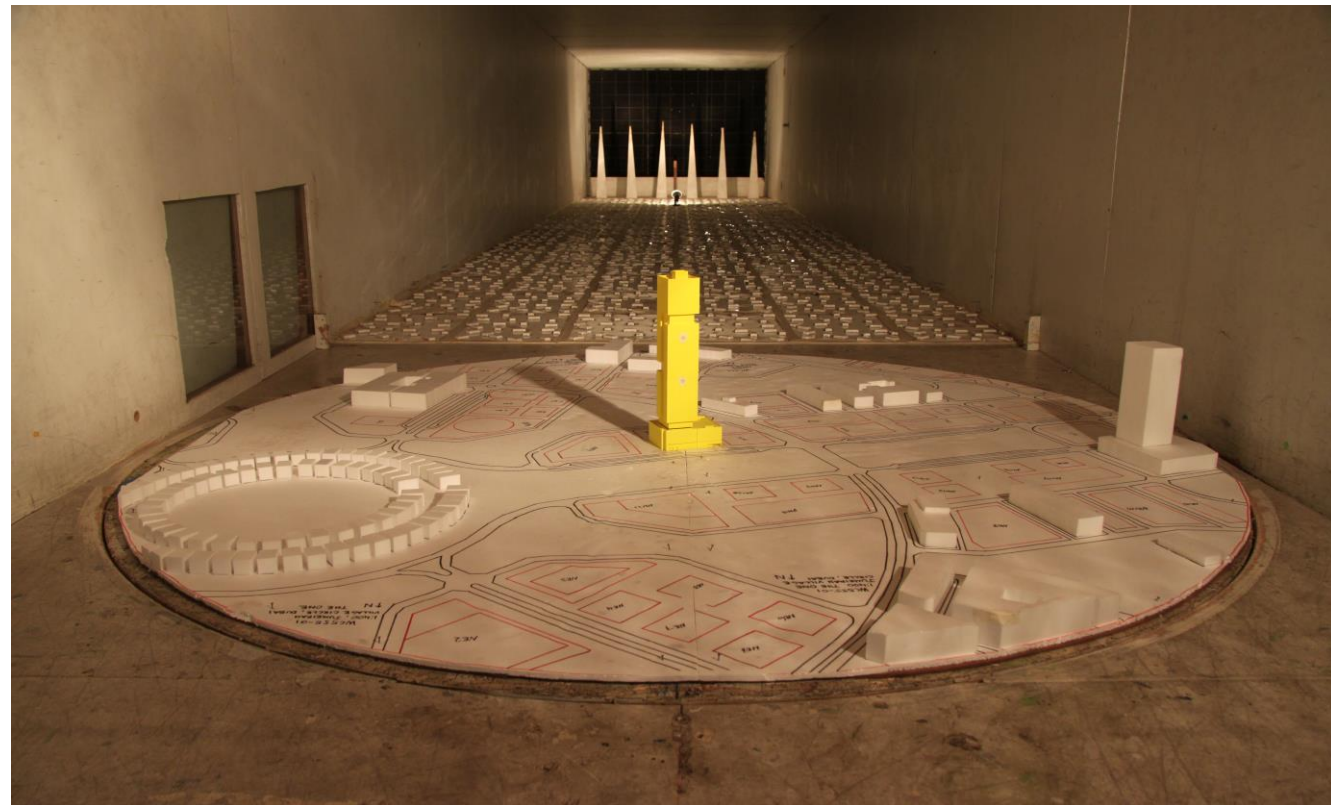
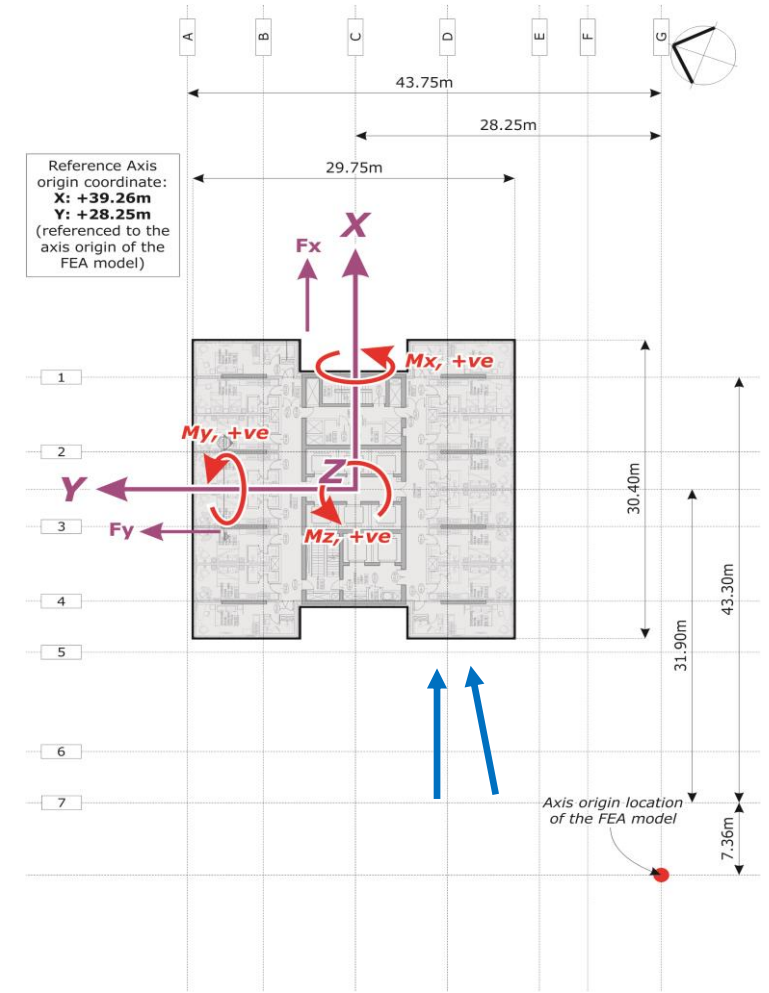
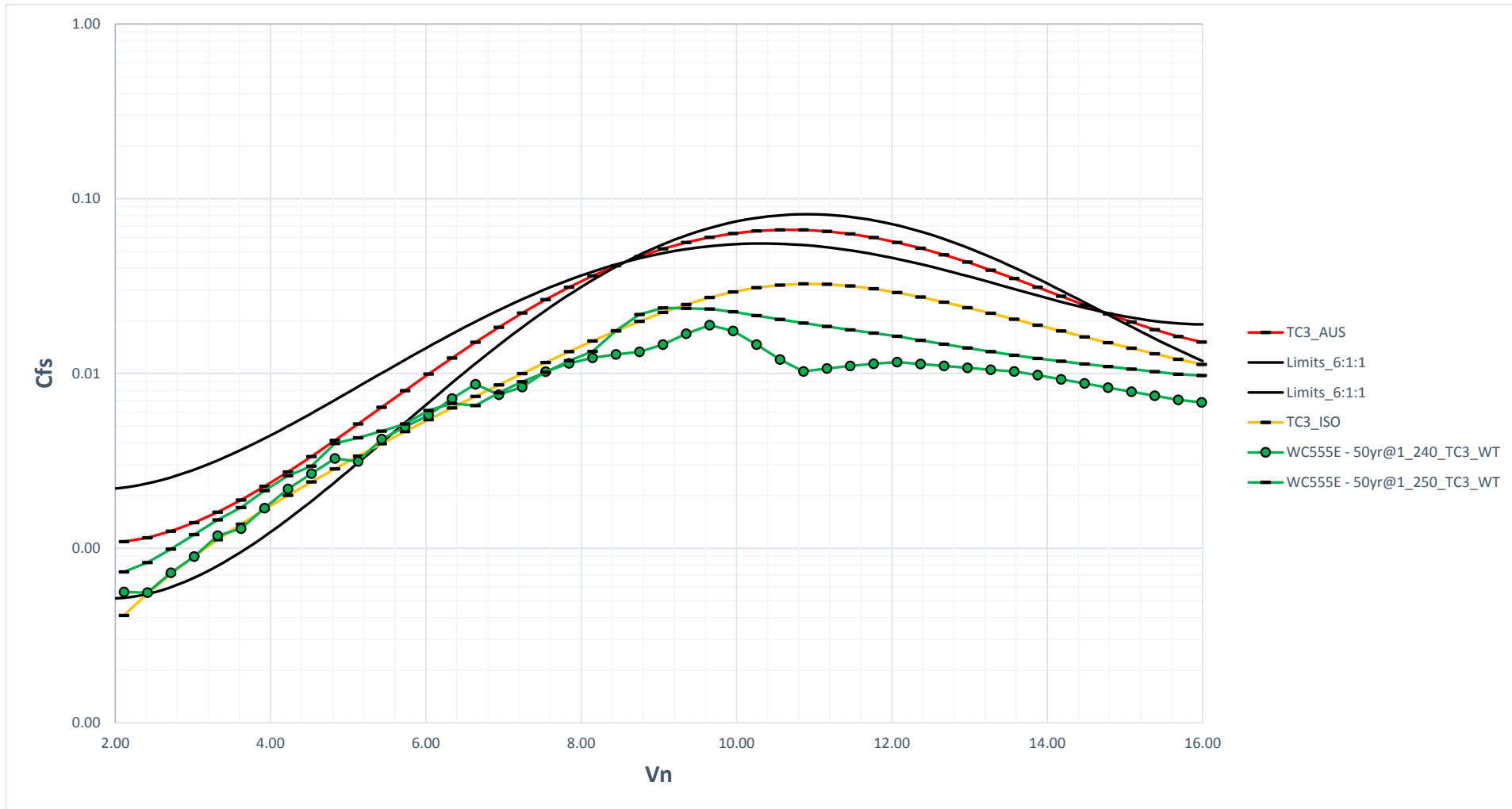


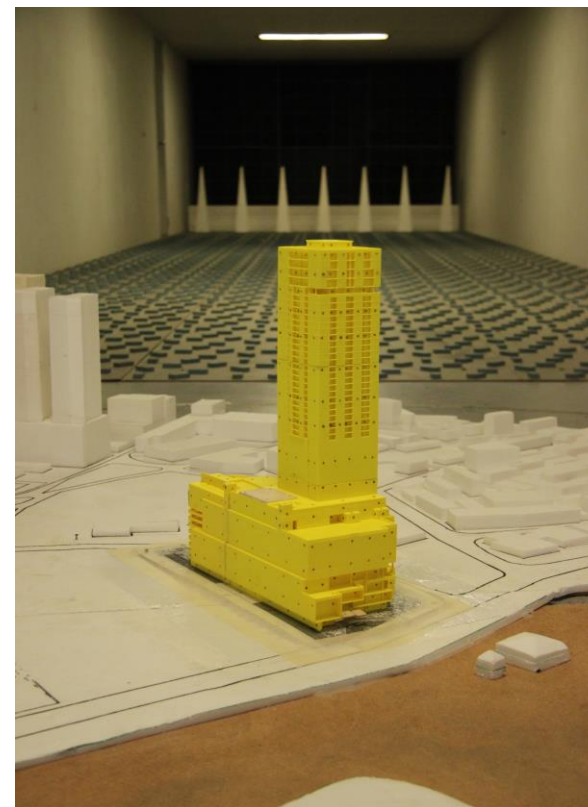
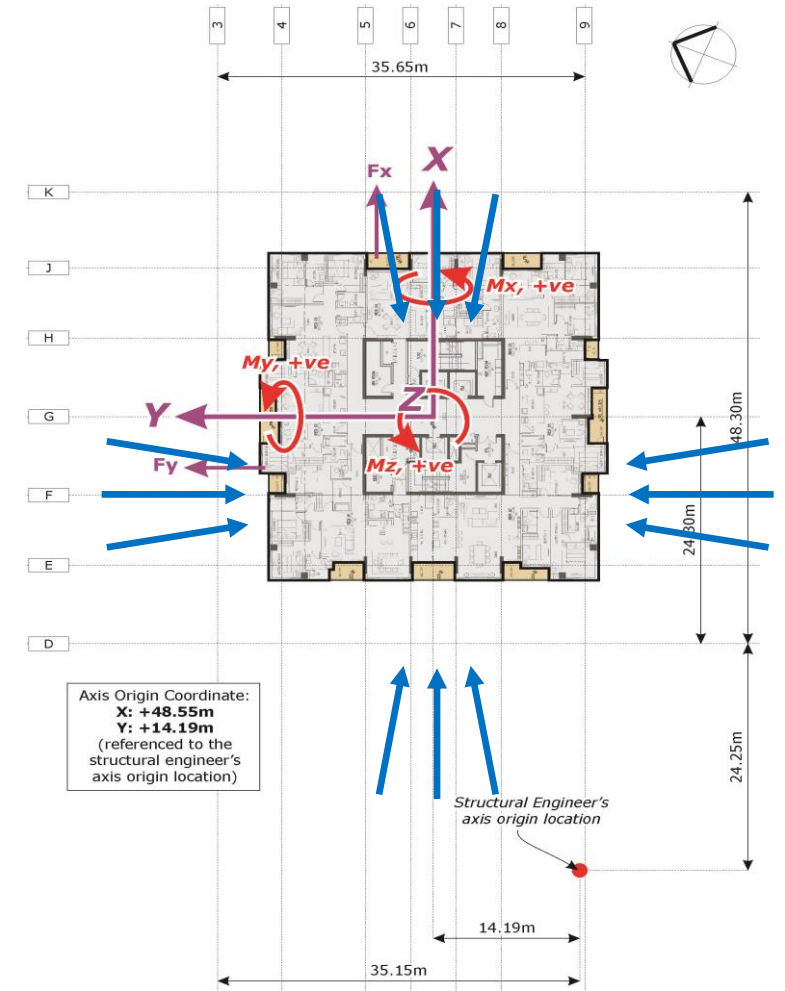
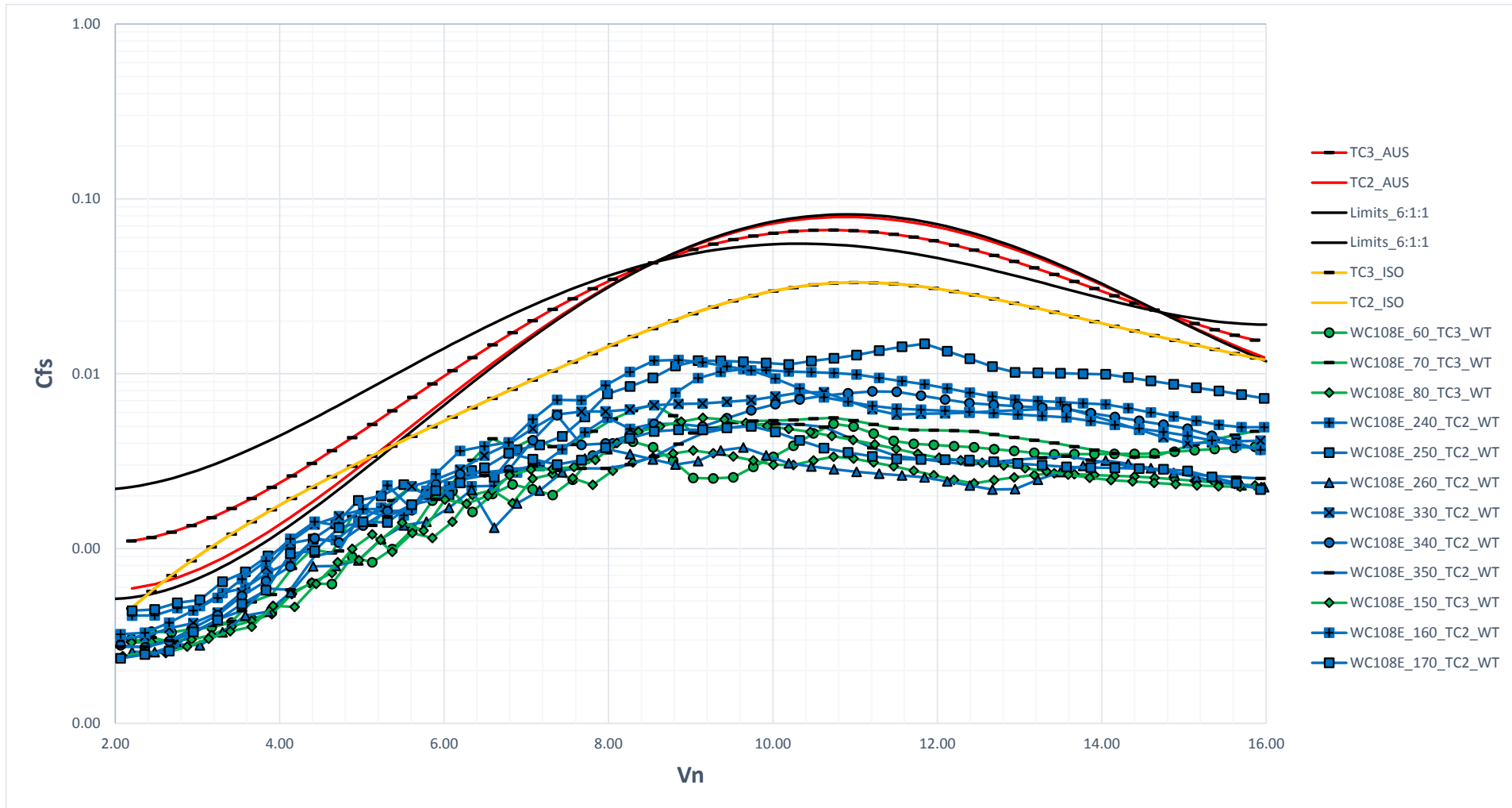
ANNEXURE 2 – COMPARATIVE RESULTS for $h:b:d$ of 6:1:1

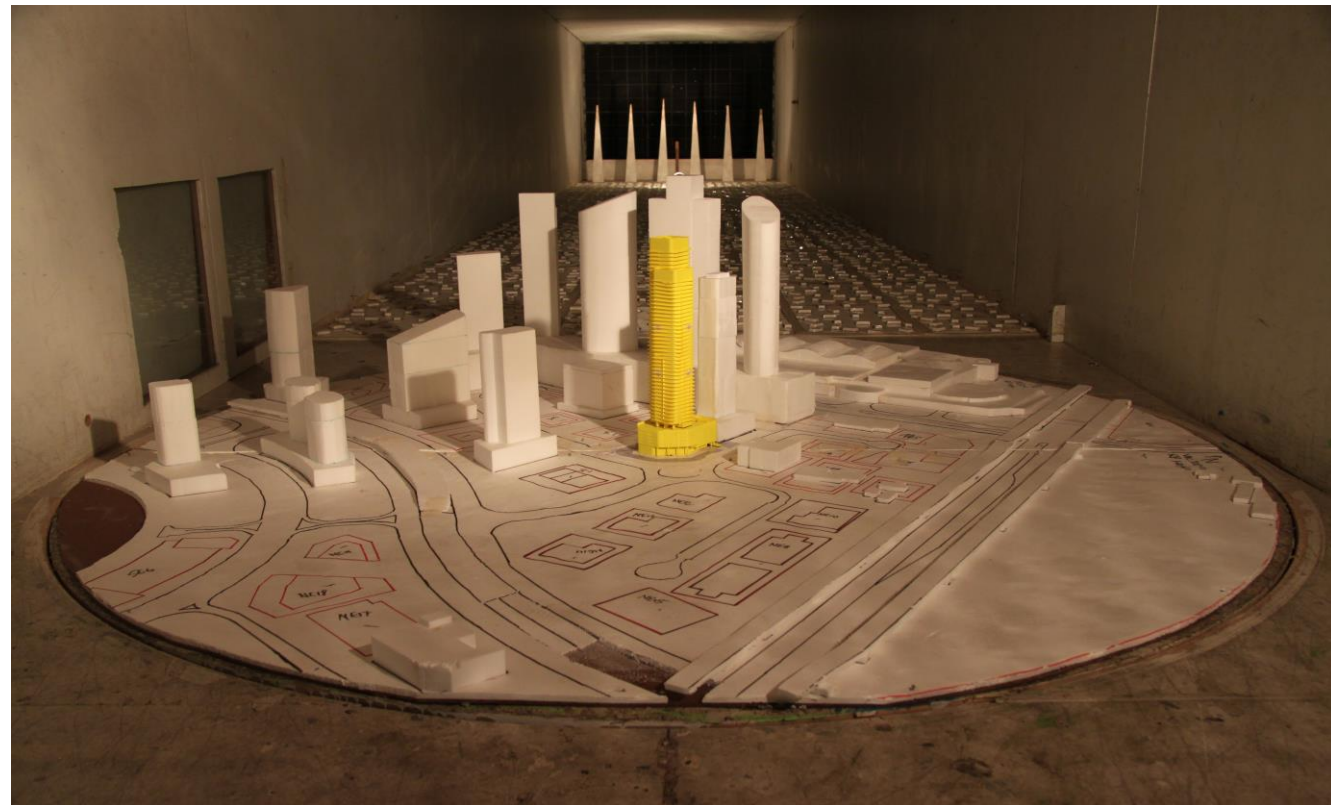
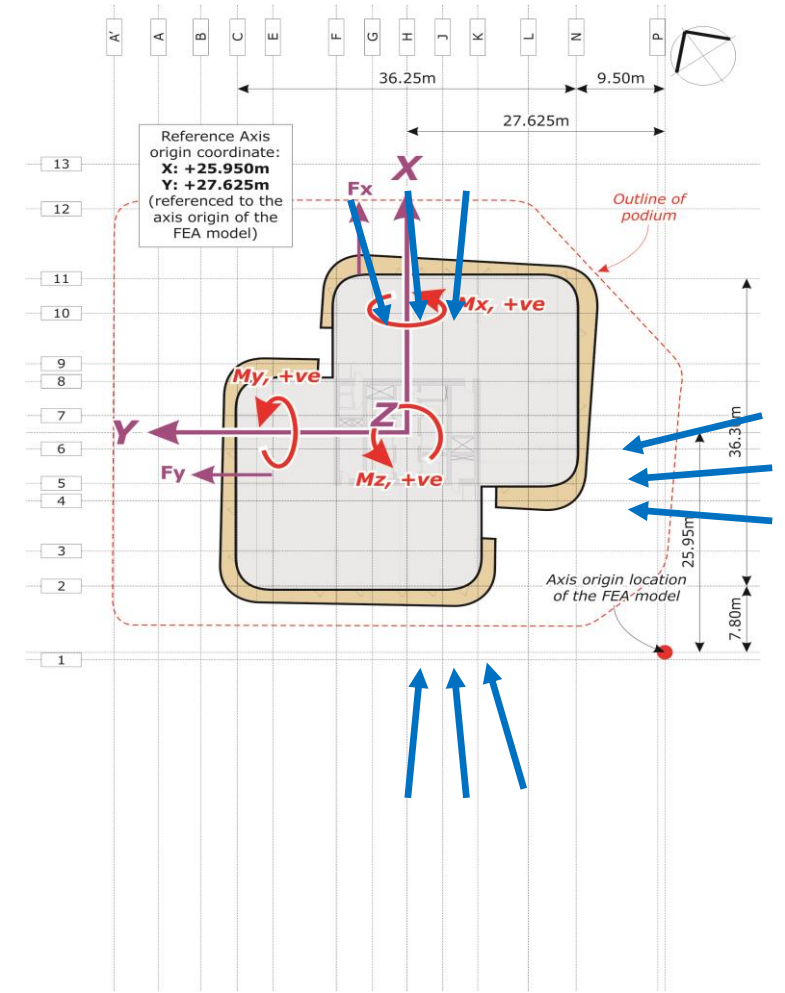
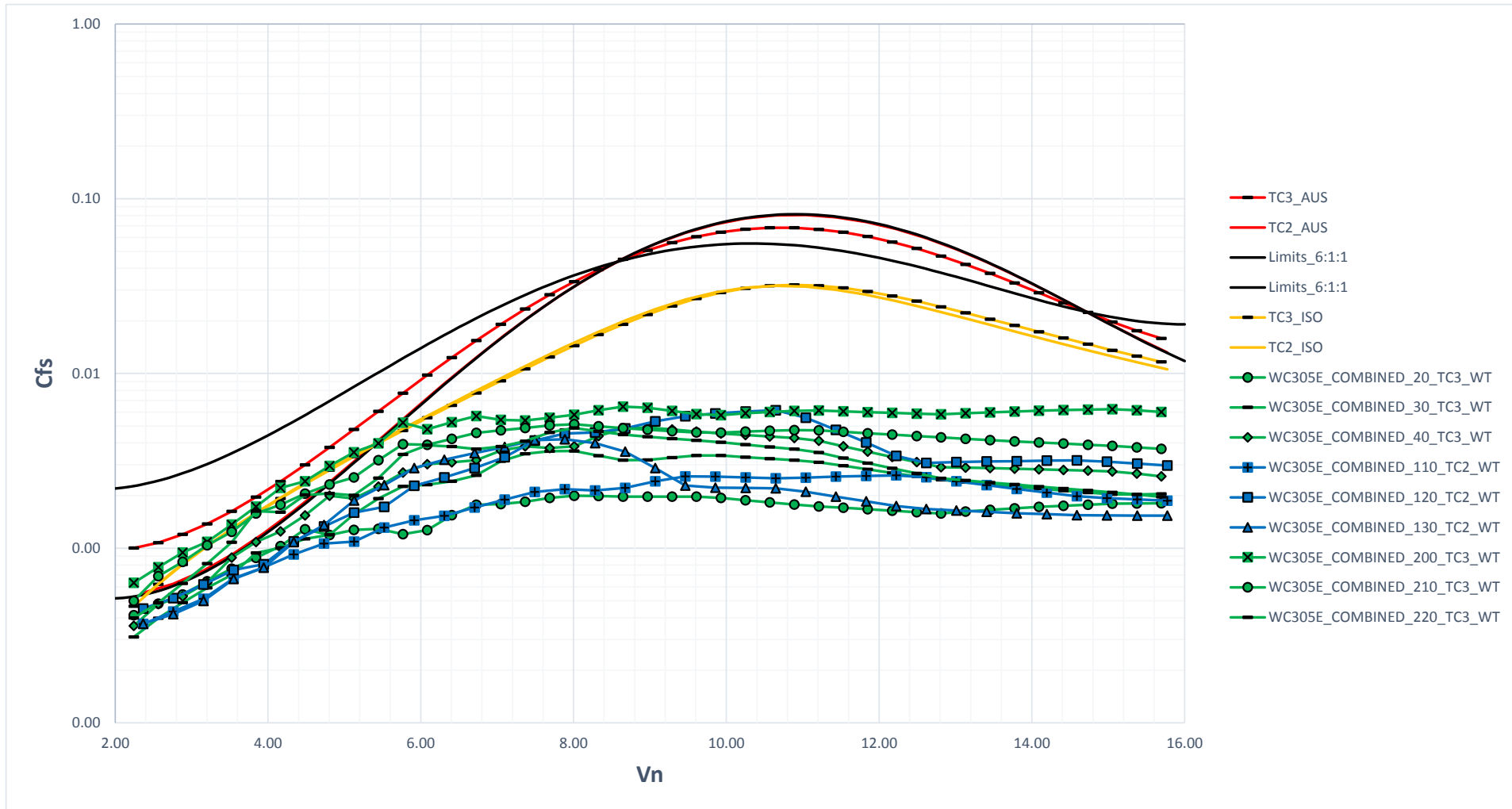




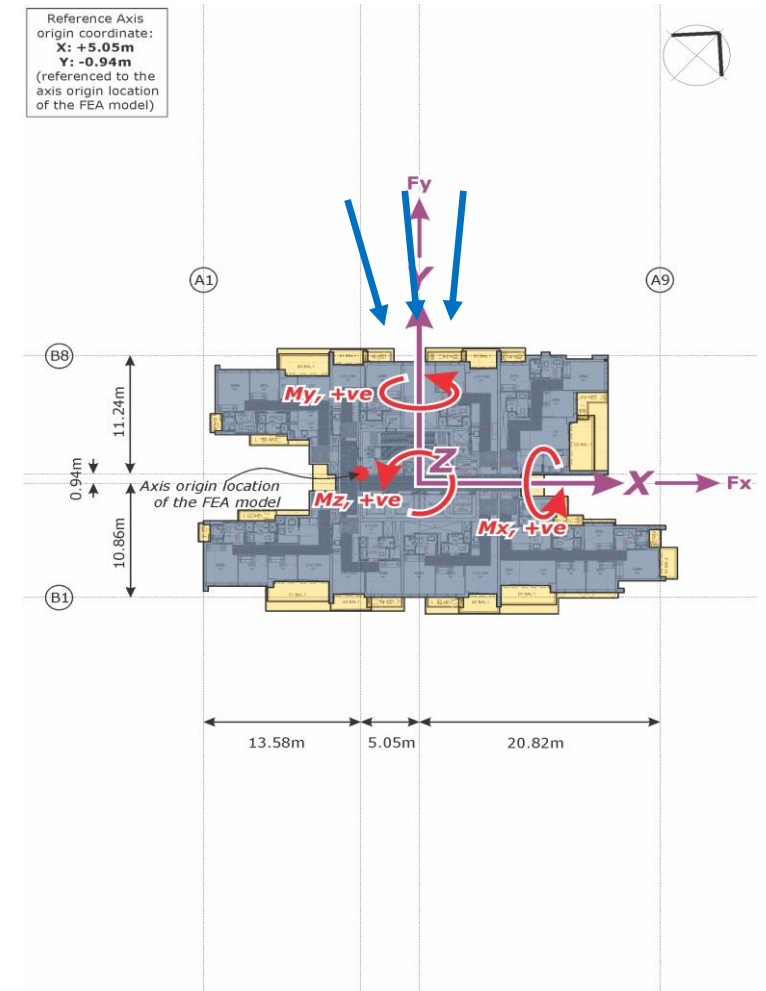
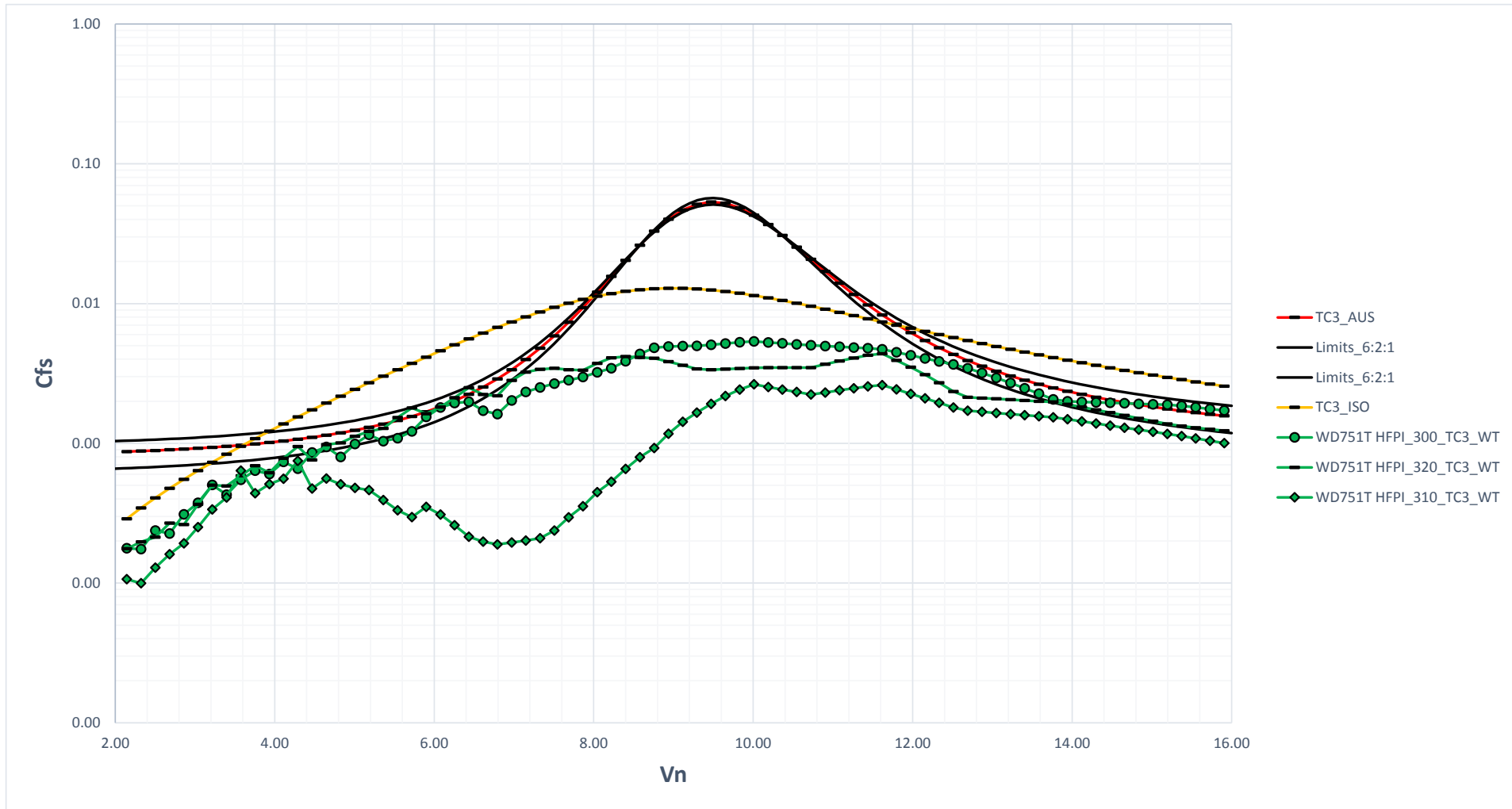


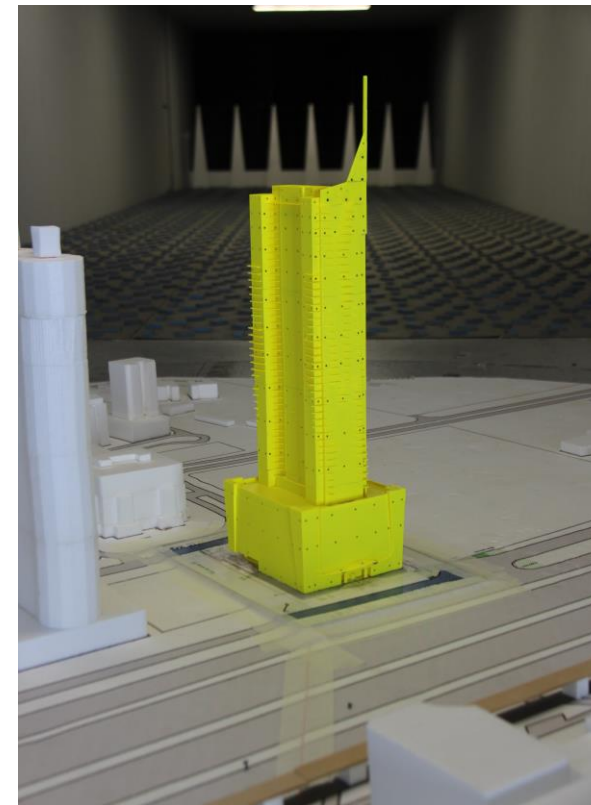
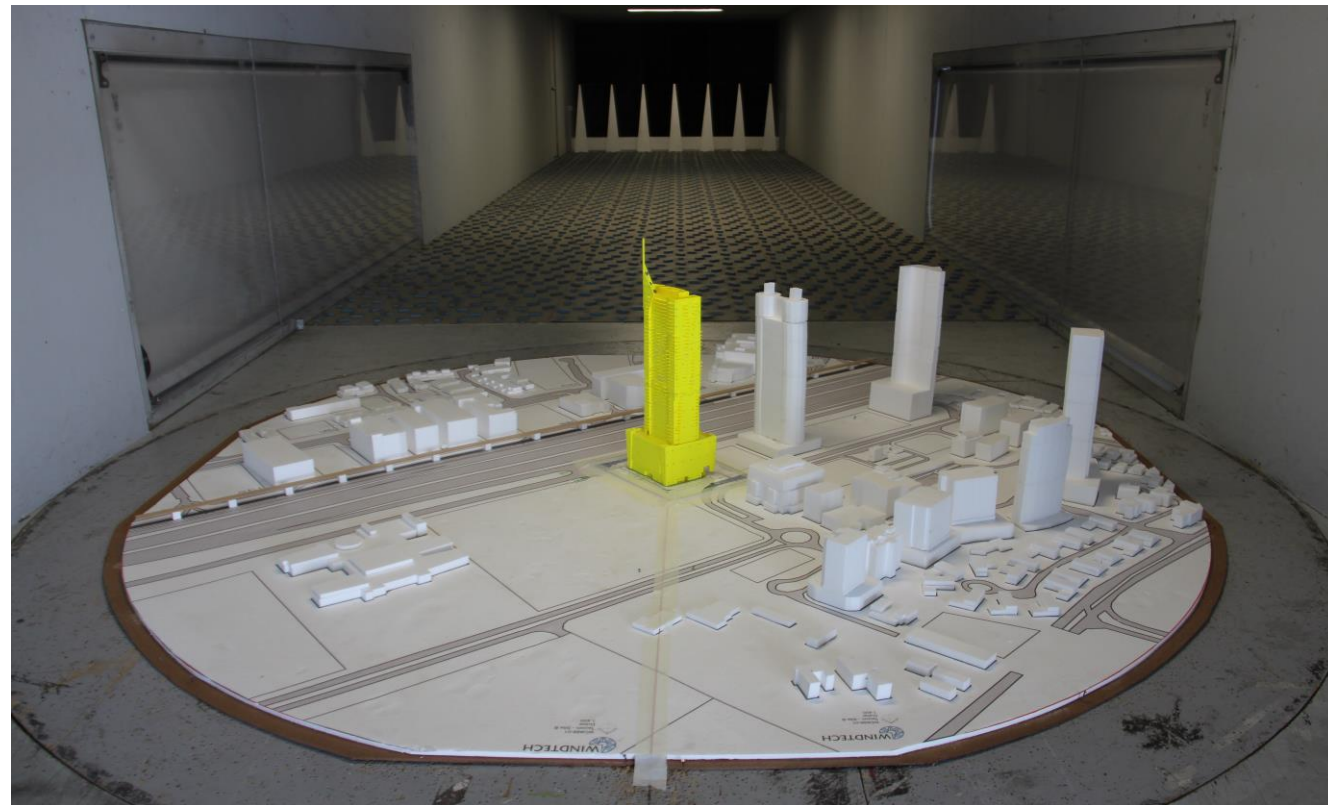
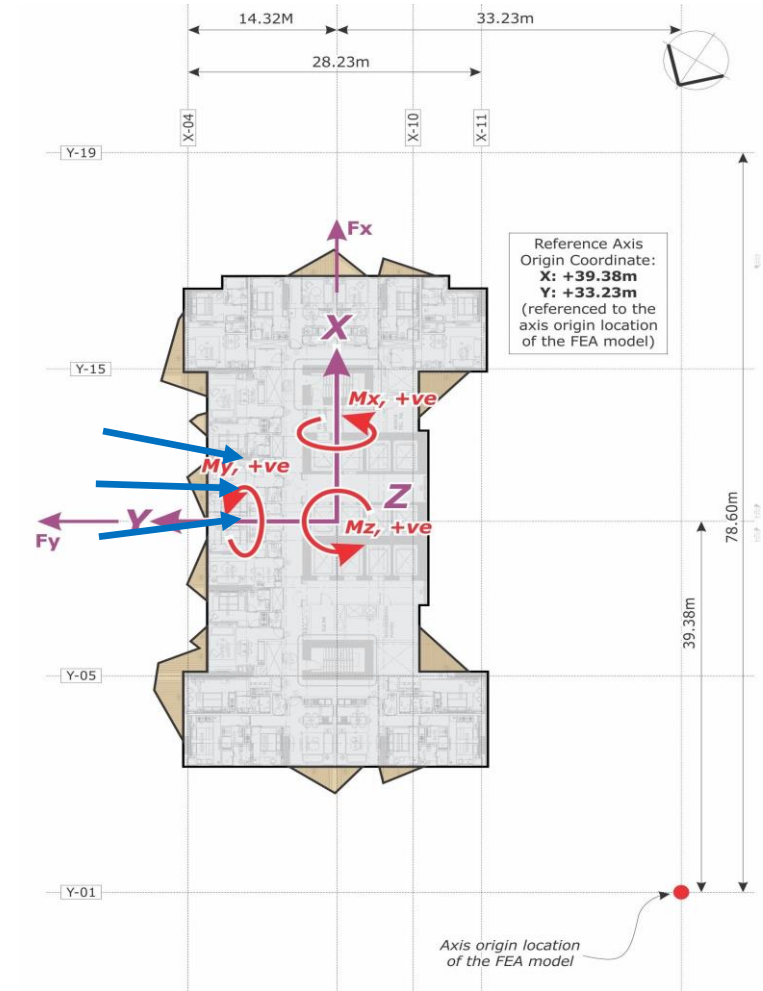
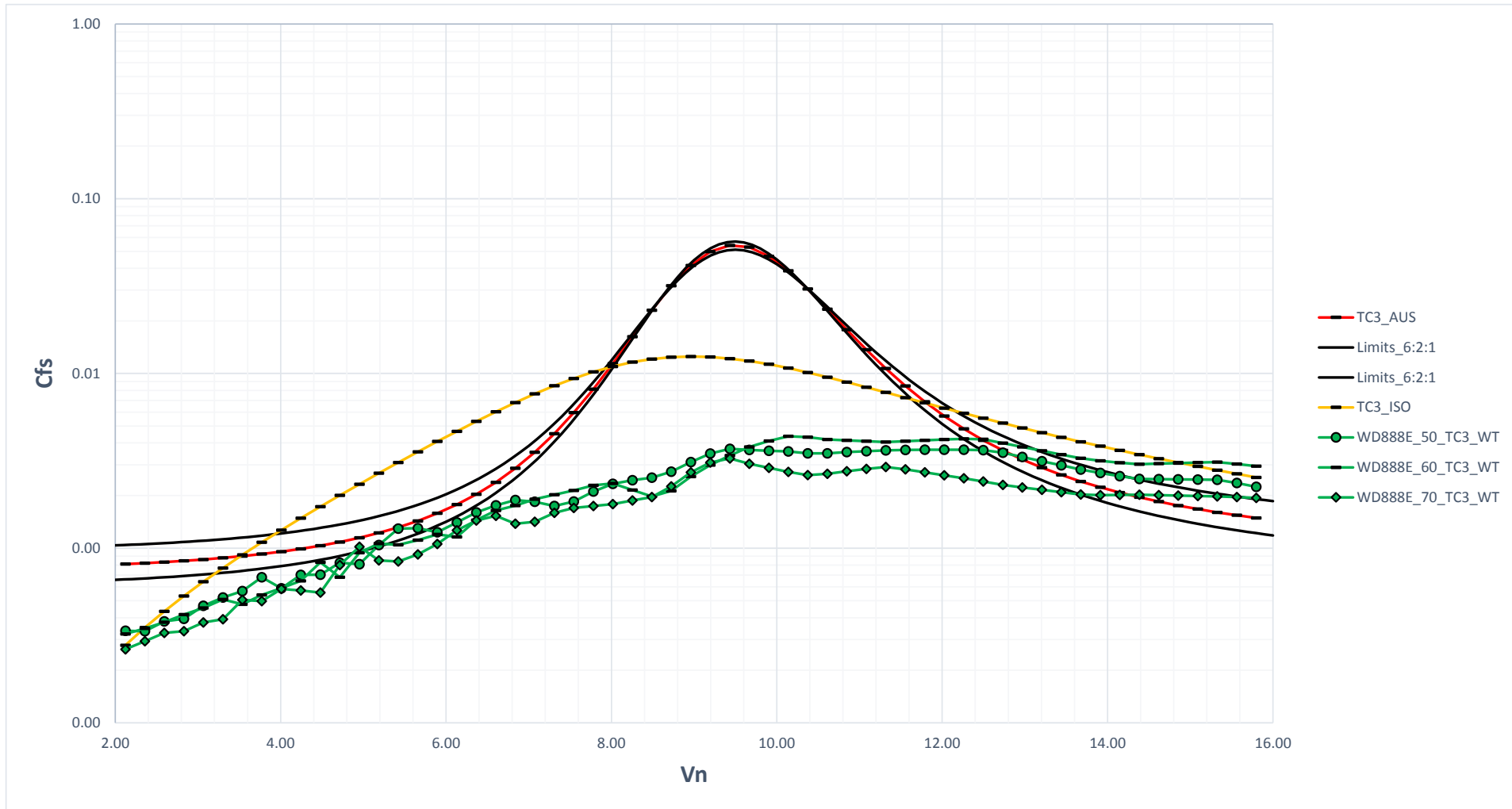


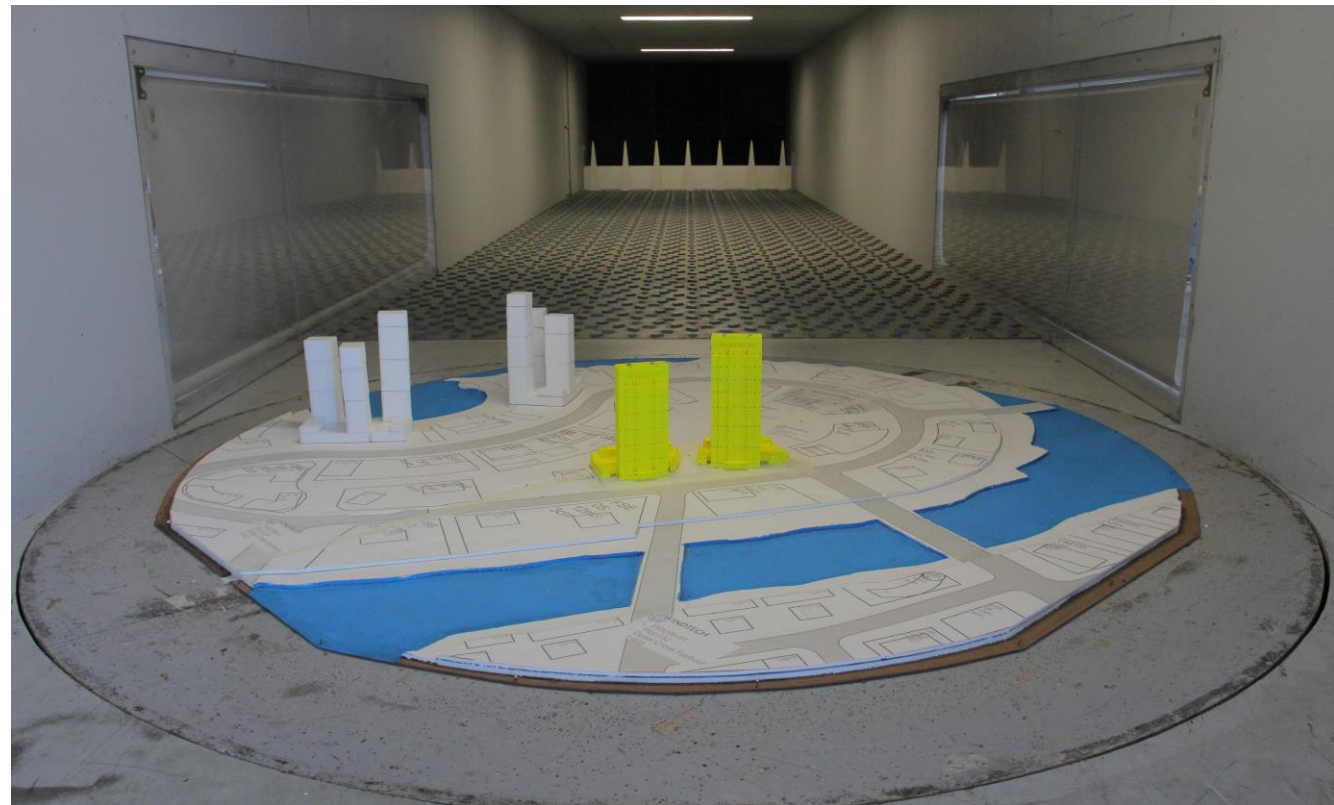
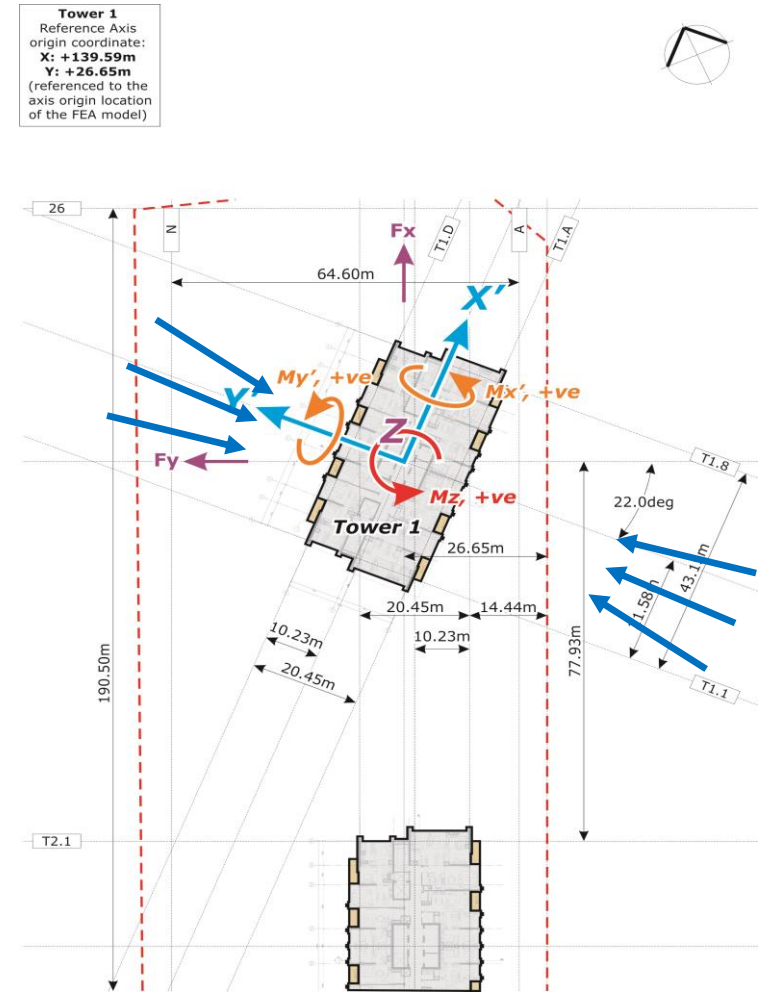
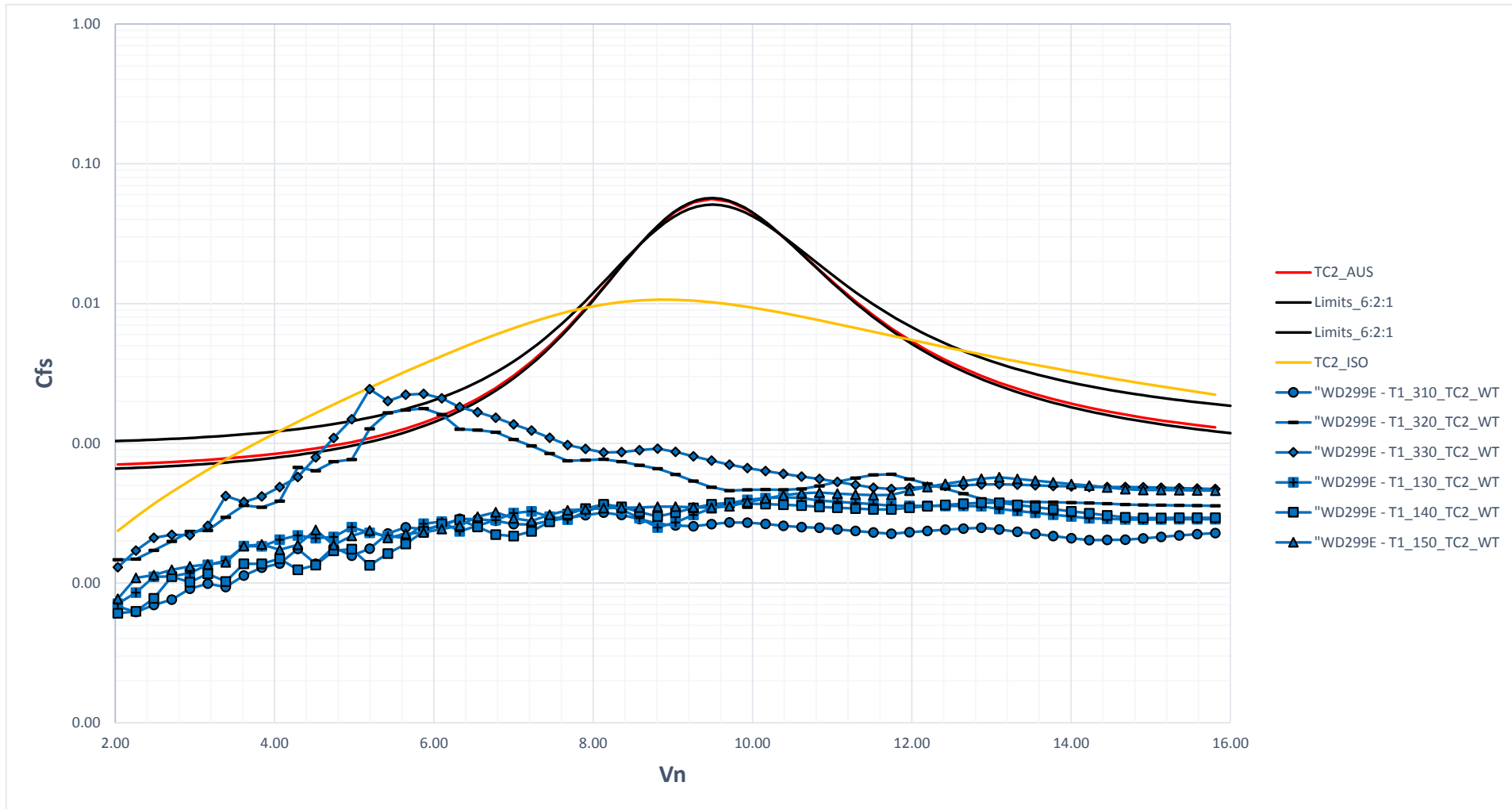


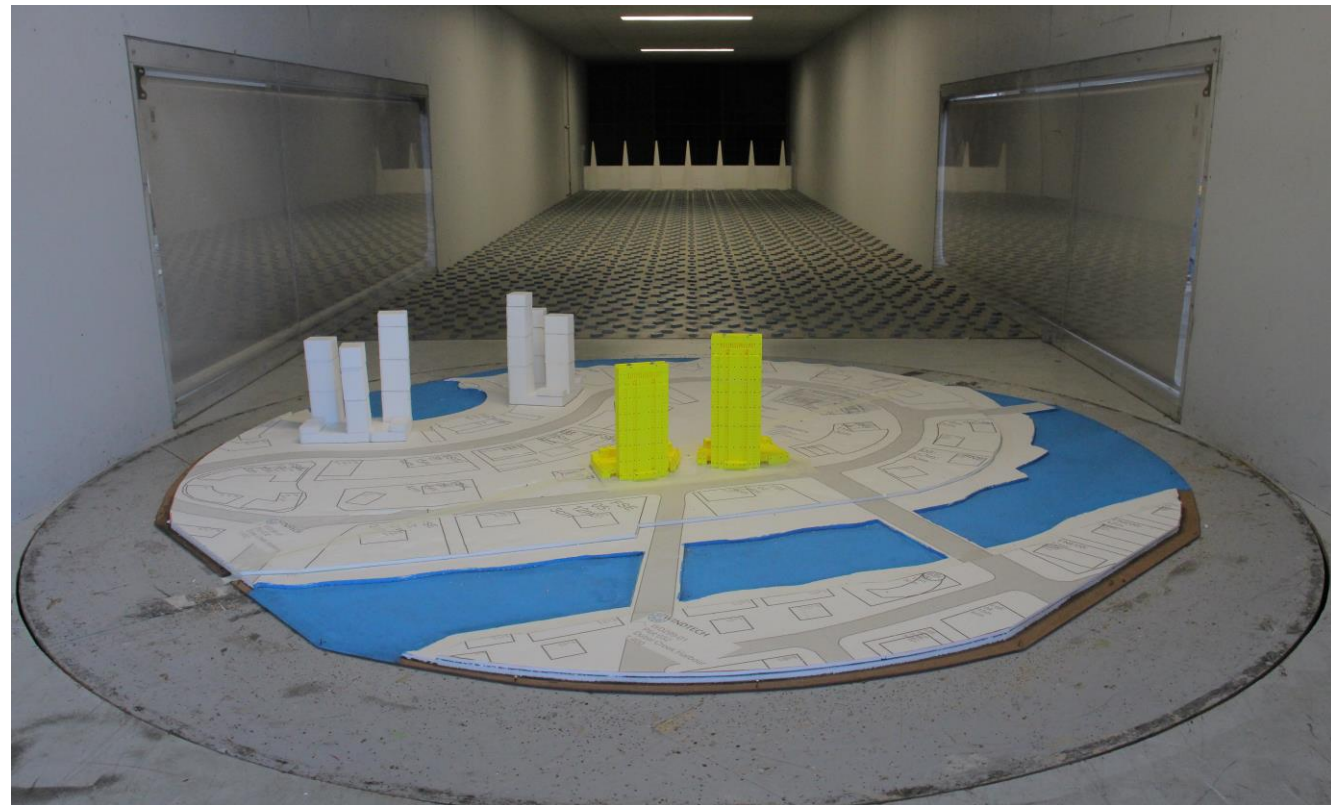
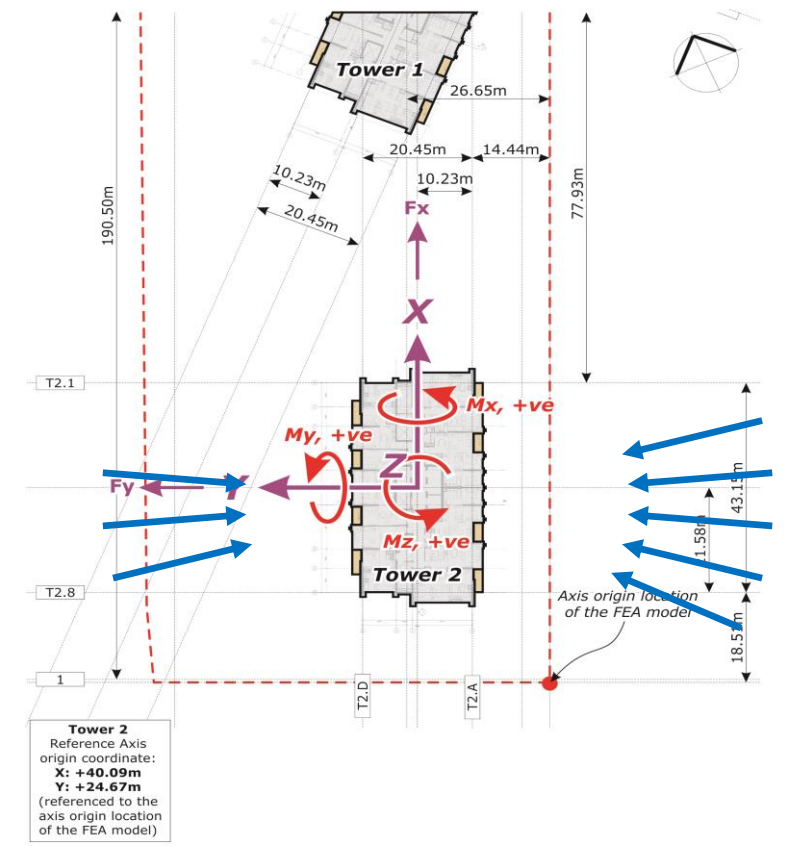
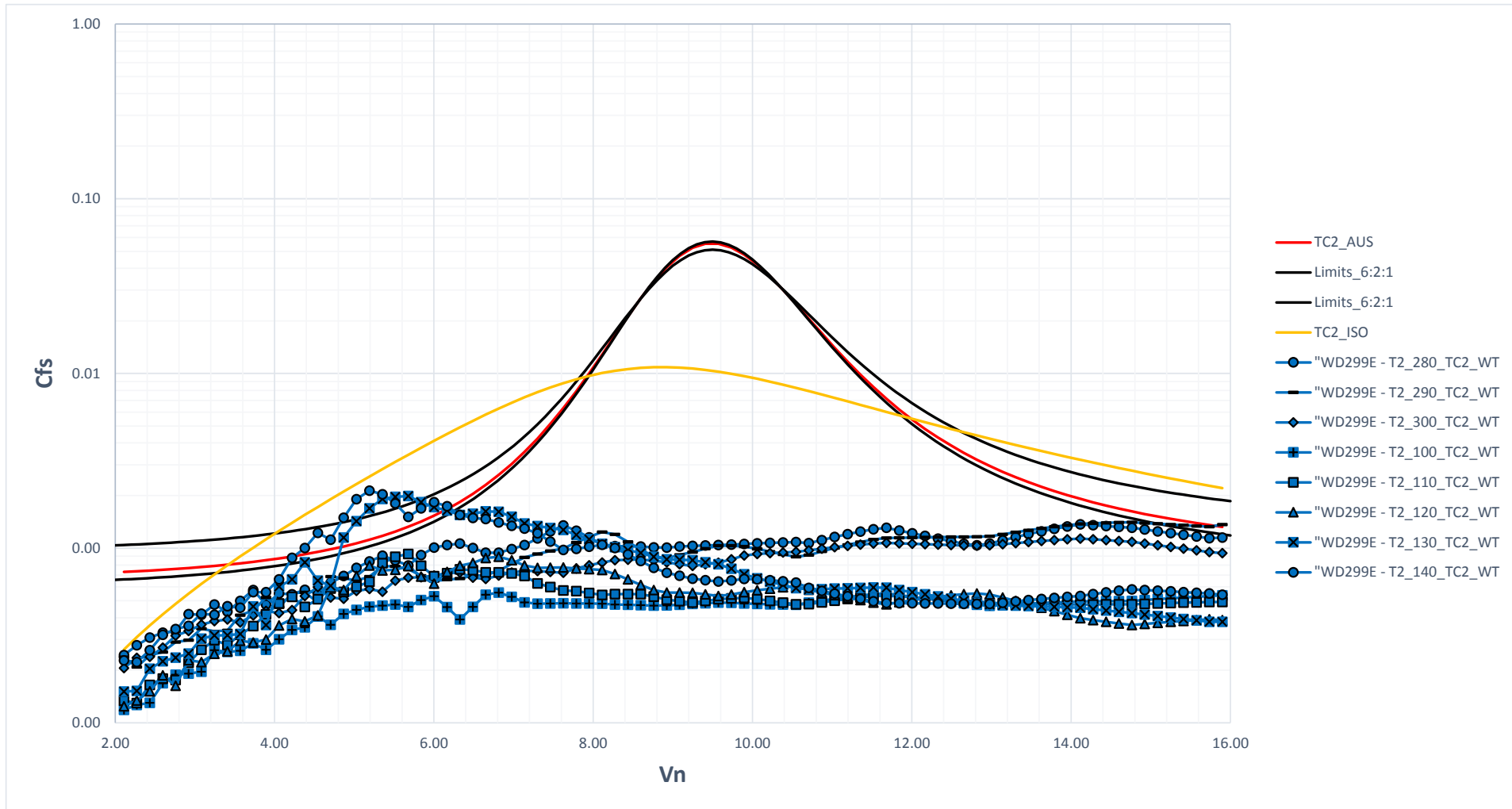


ANNEXURE 3 – COMPARATIVE RESULTS for $h:b:d$ of 6:2:1

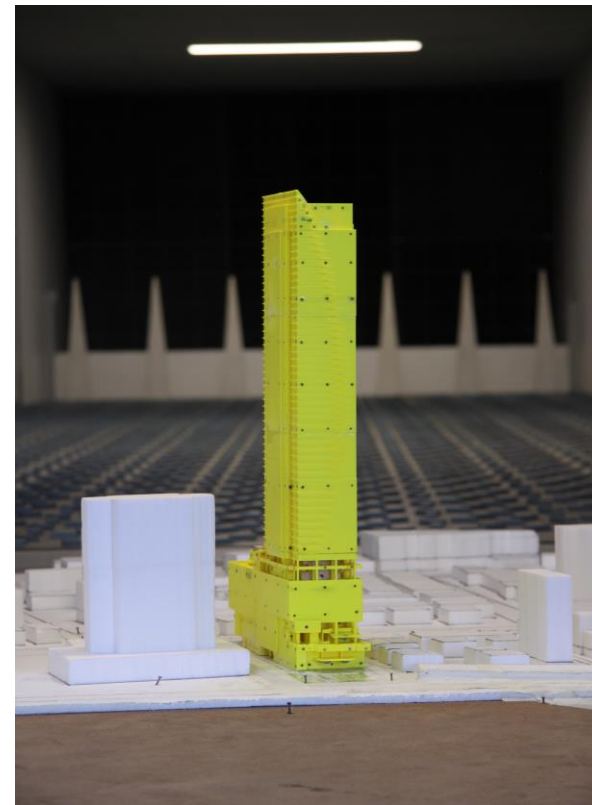
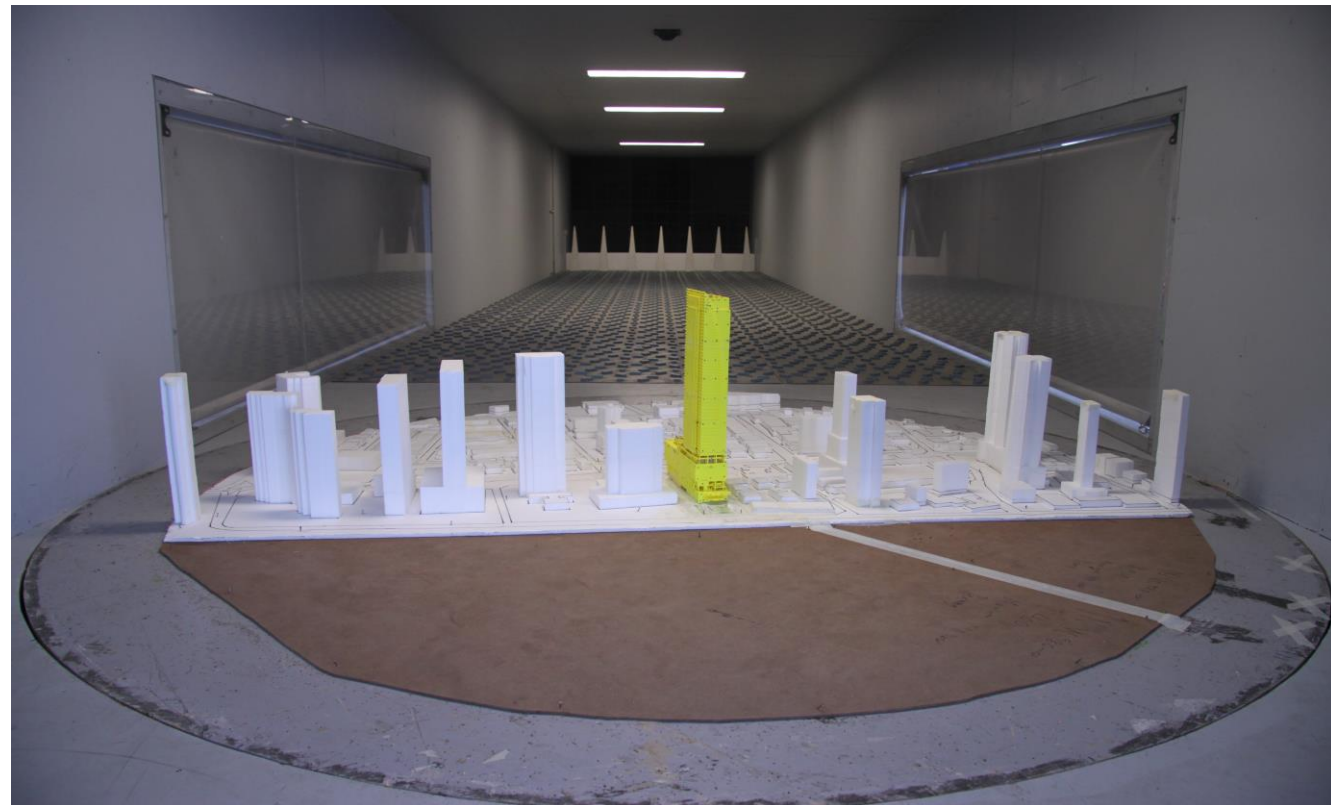
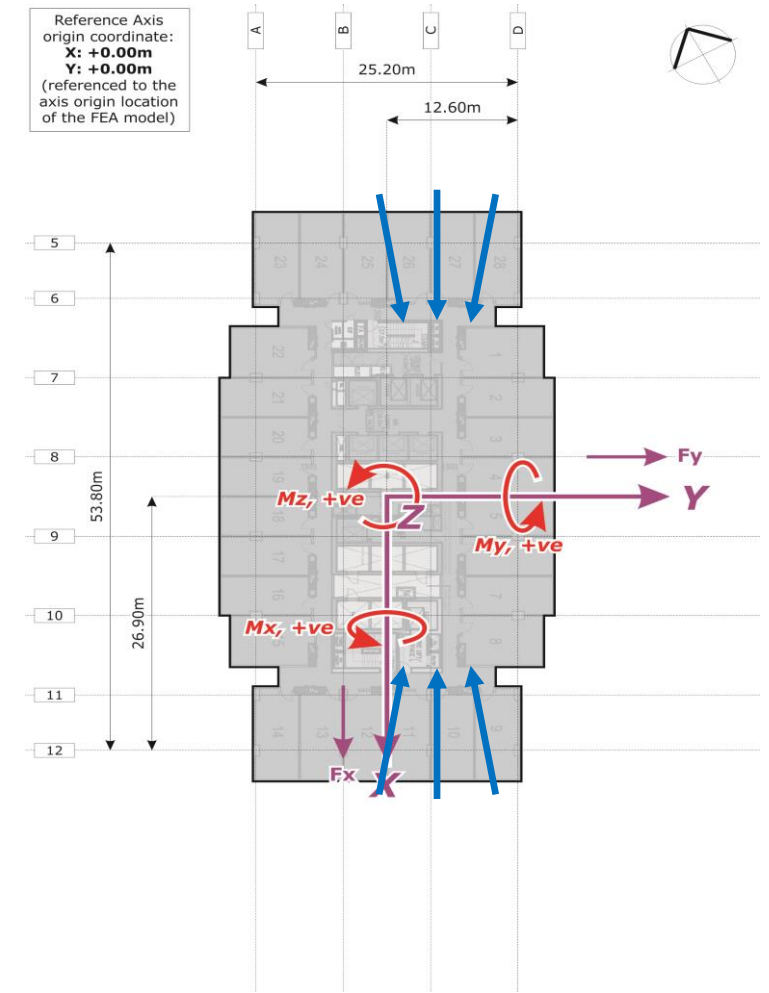
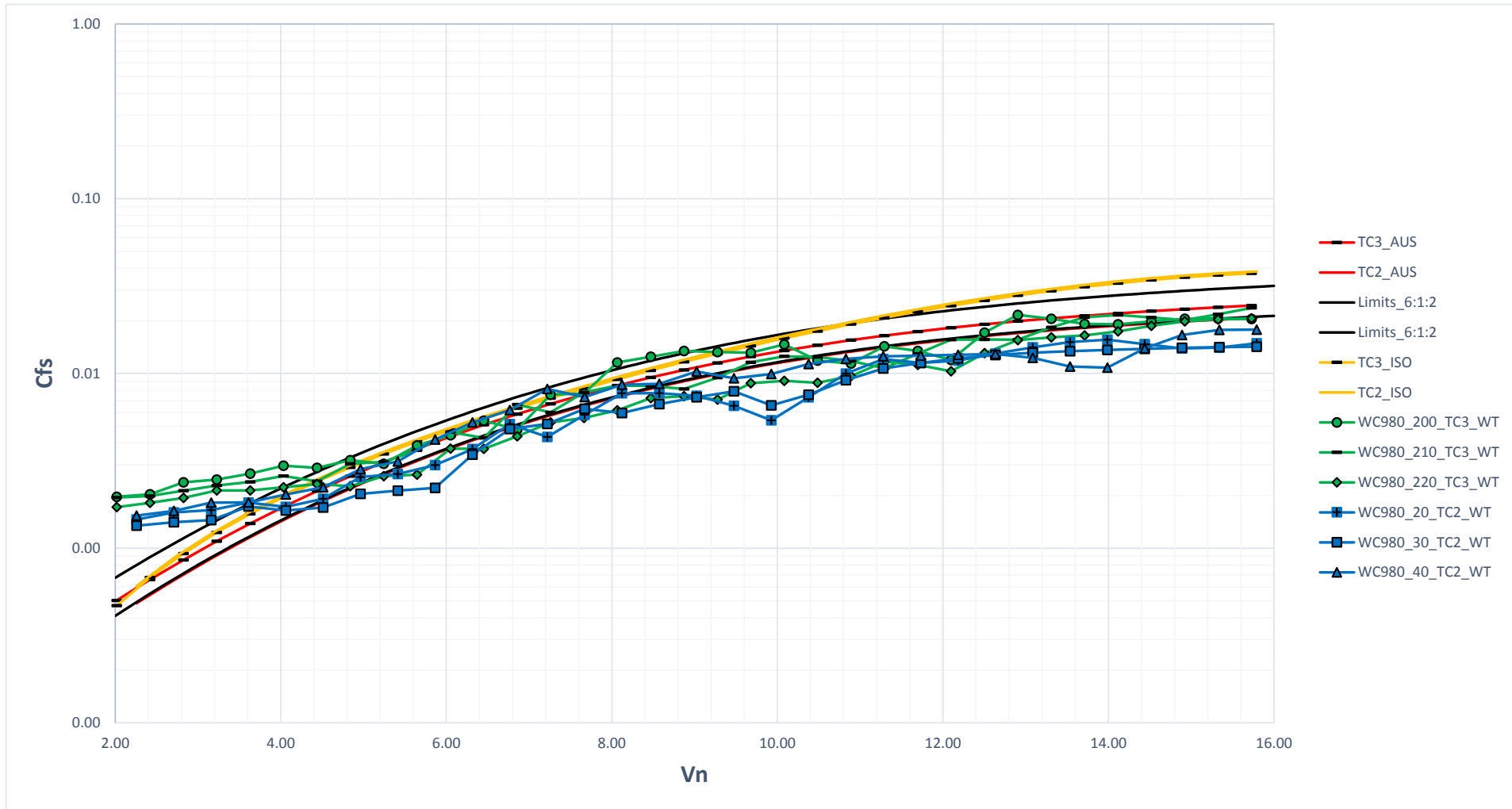


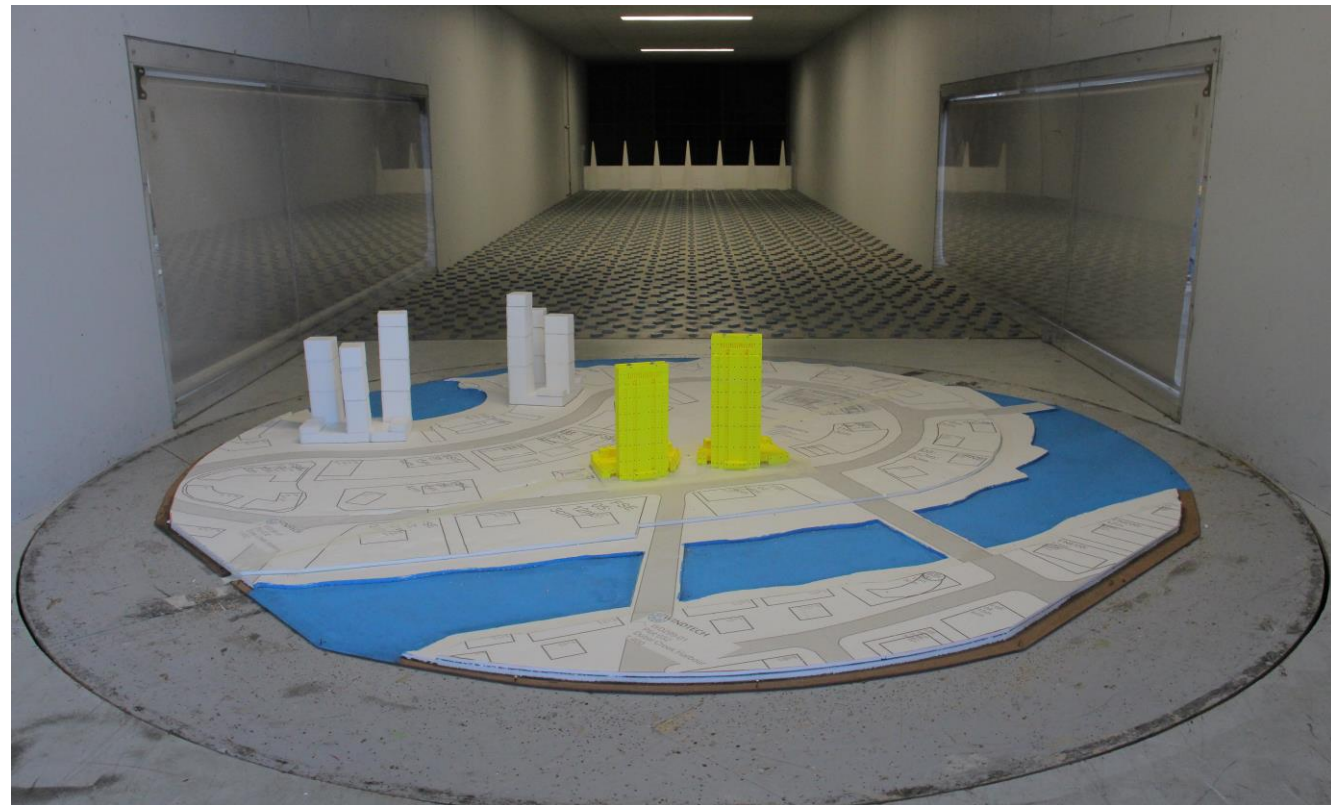
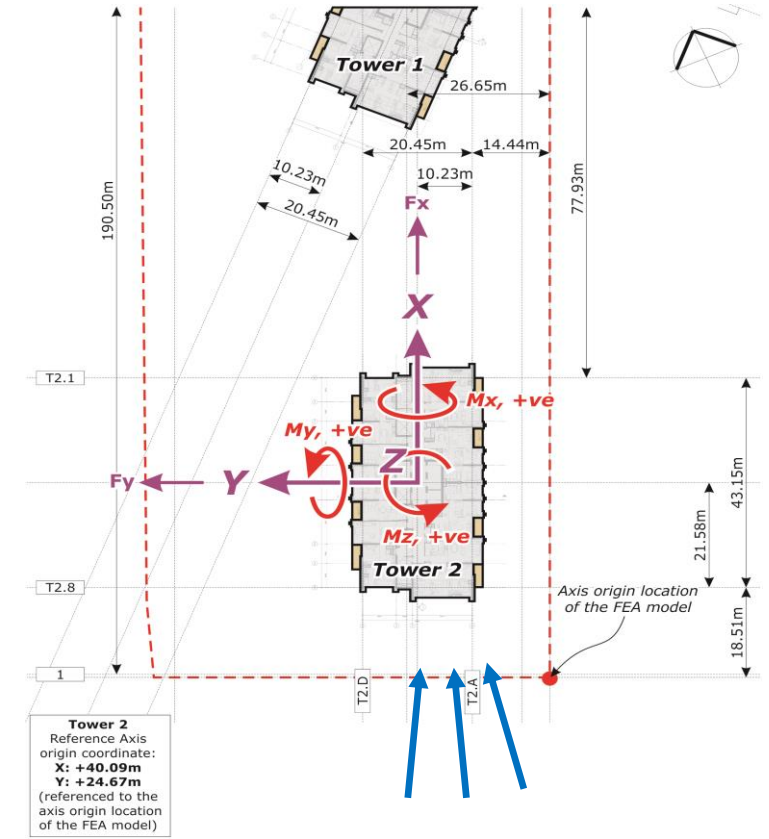
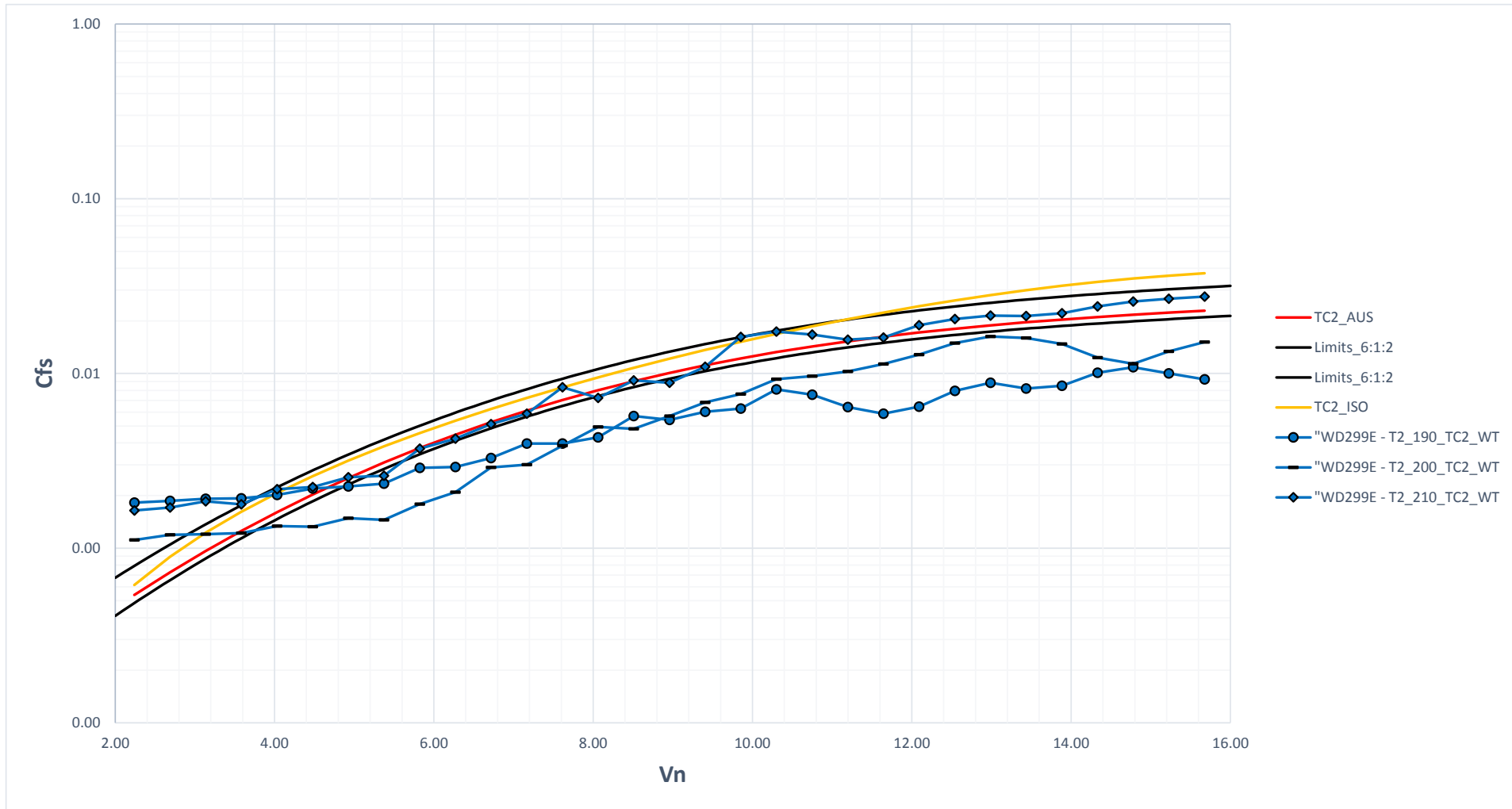


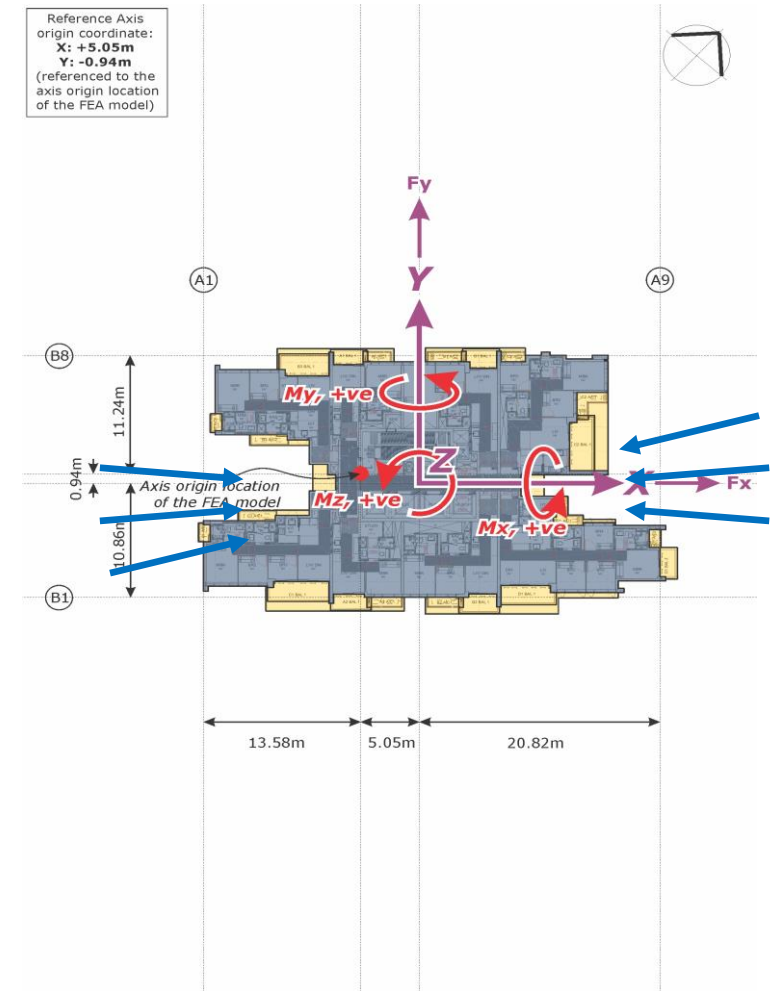
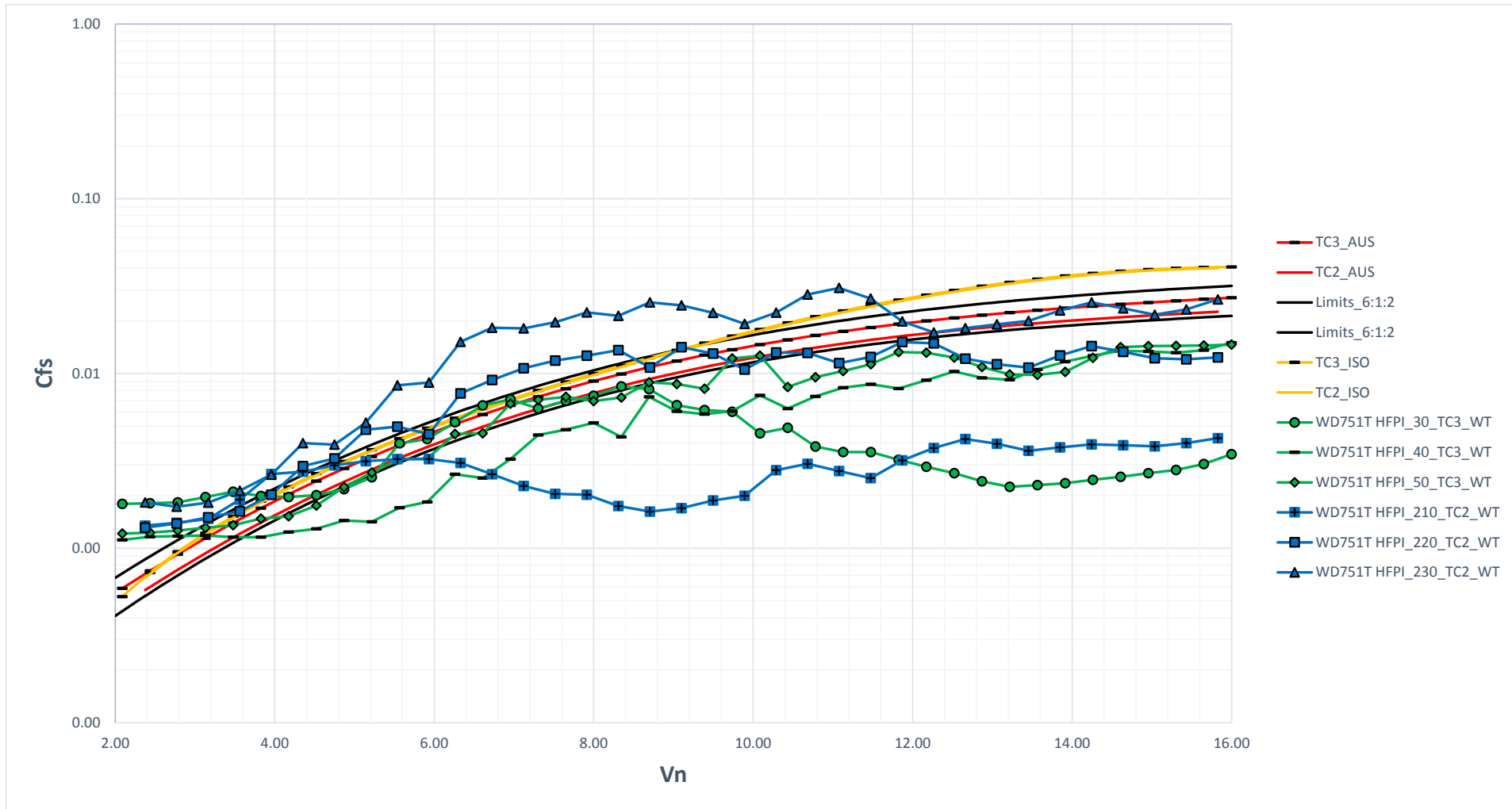


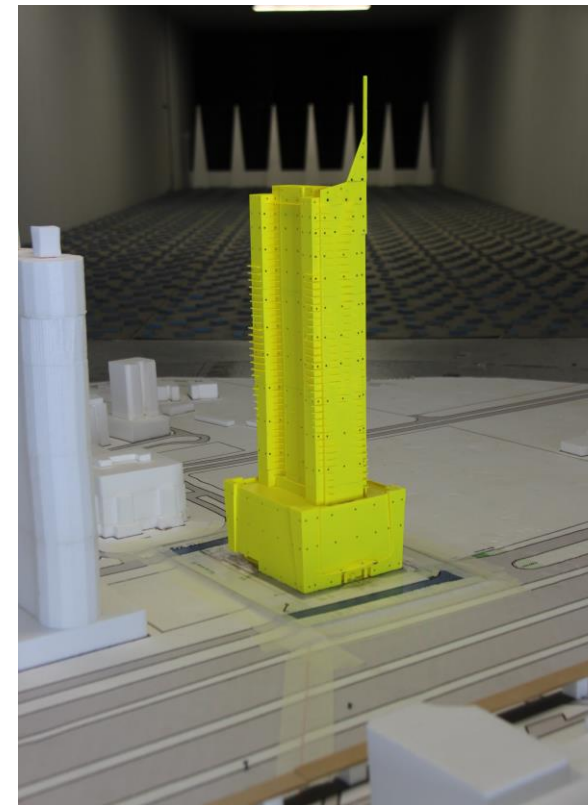
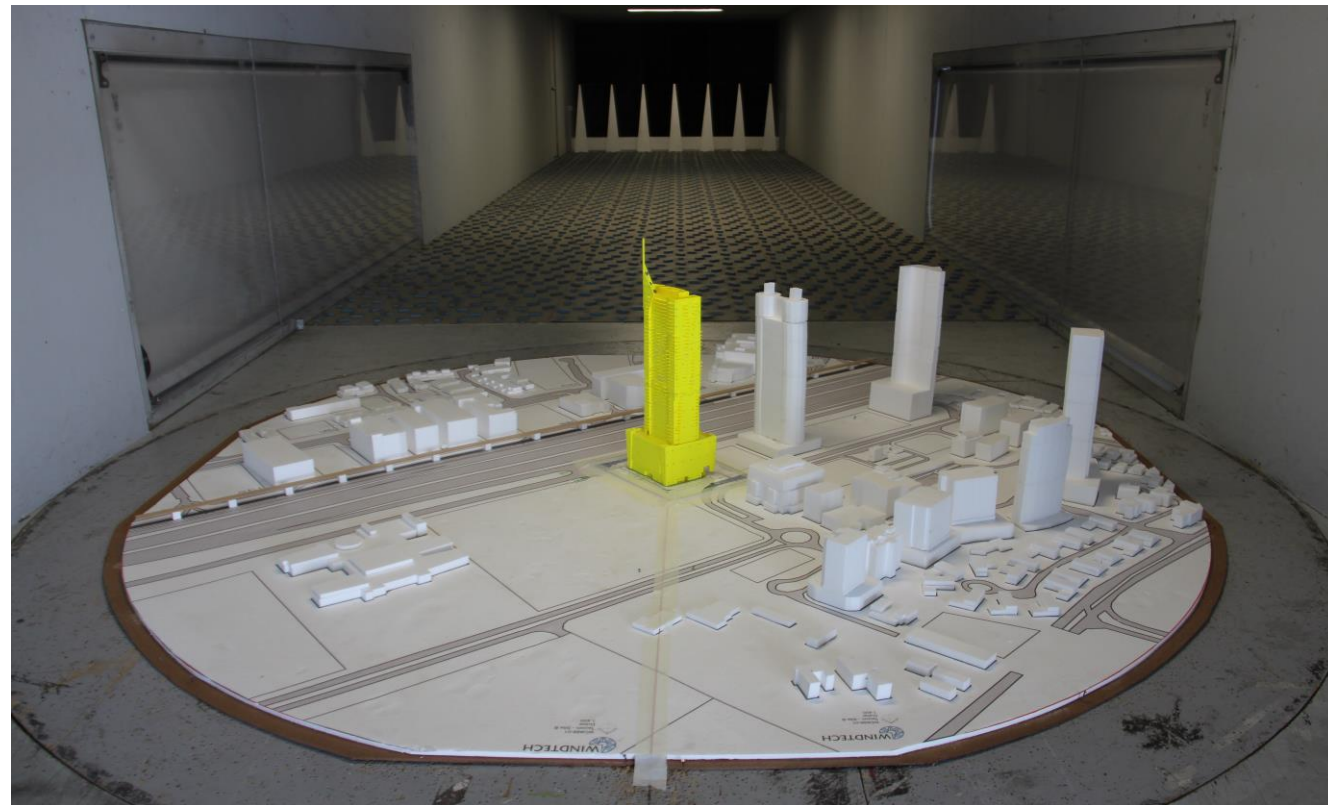
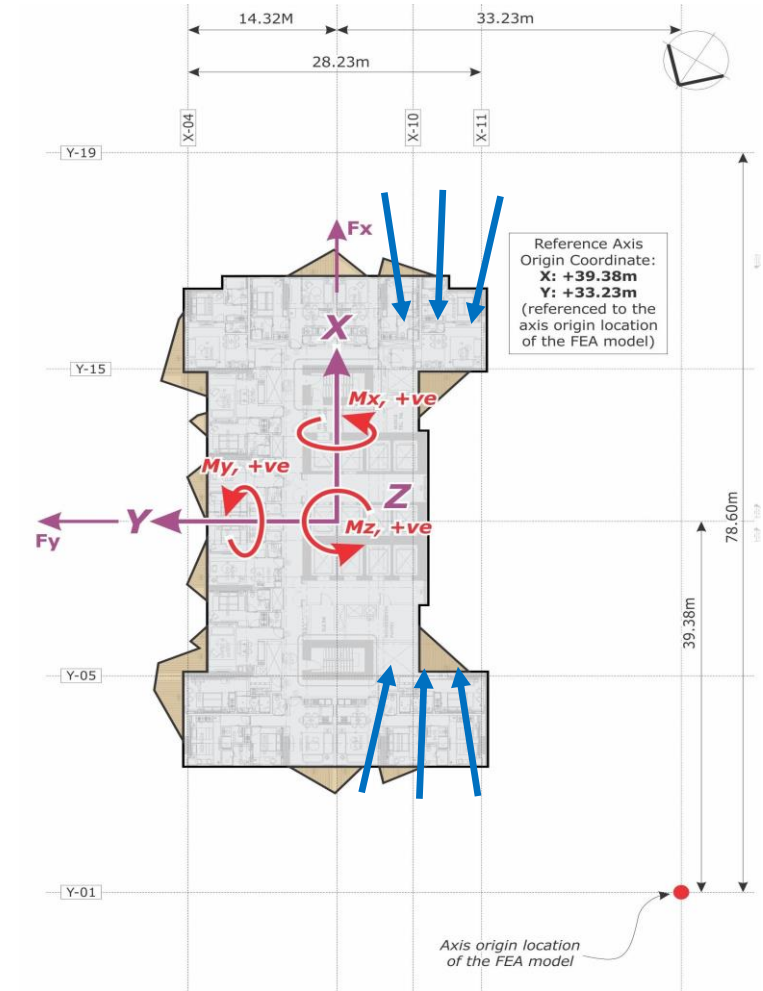
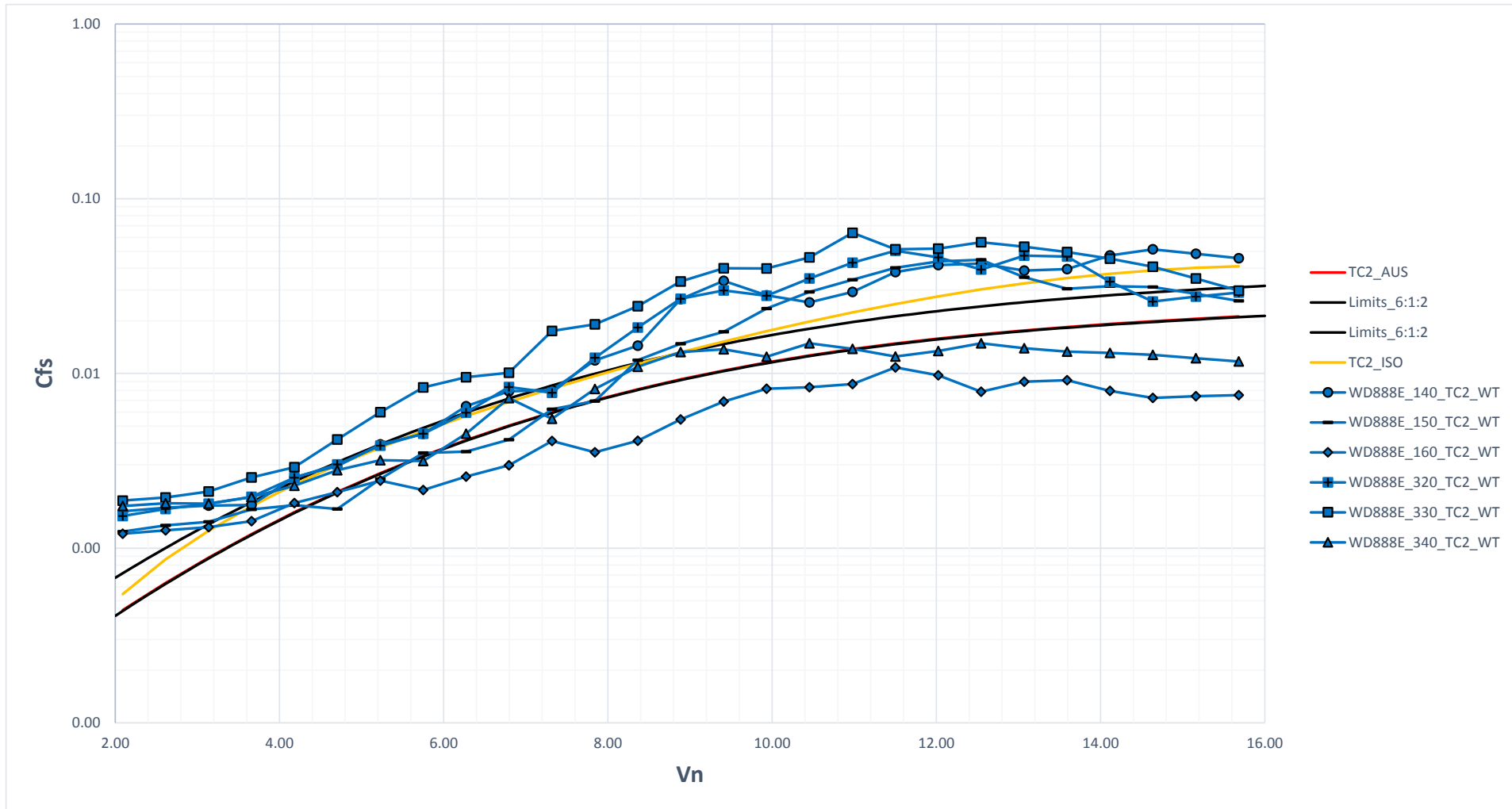


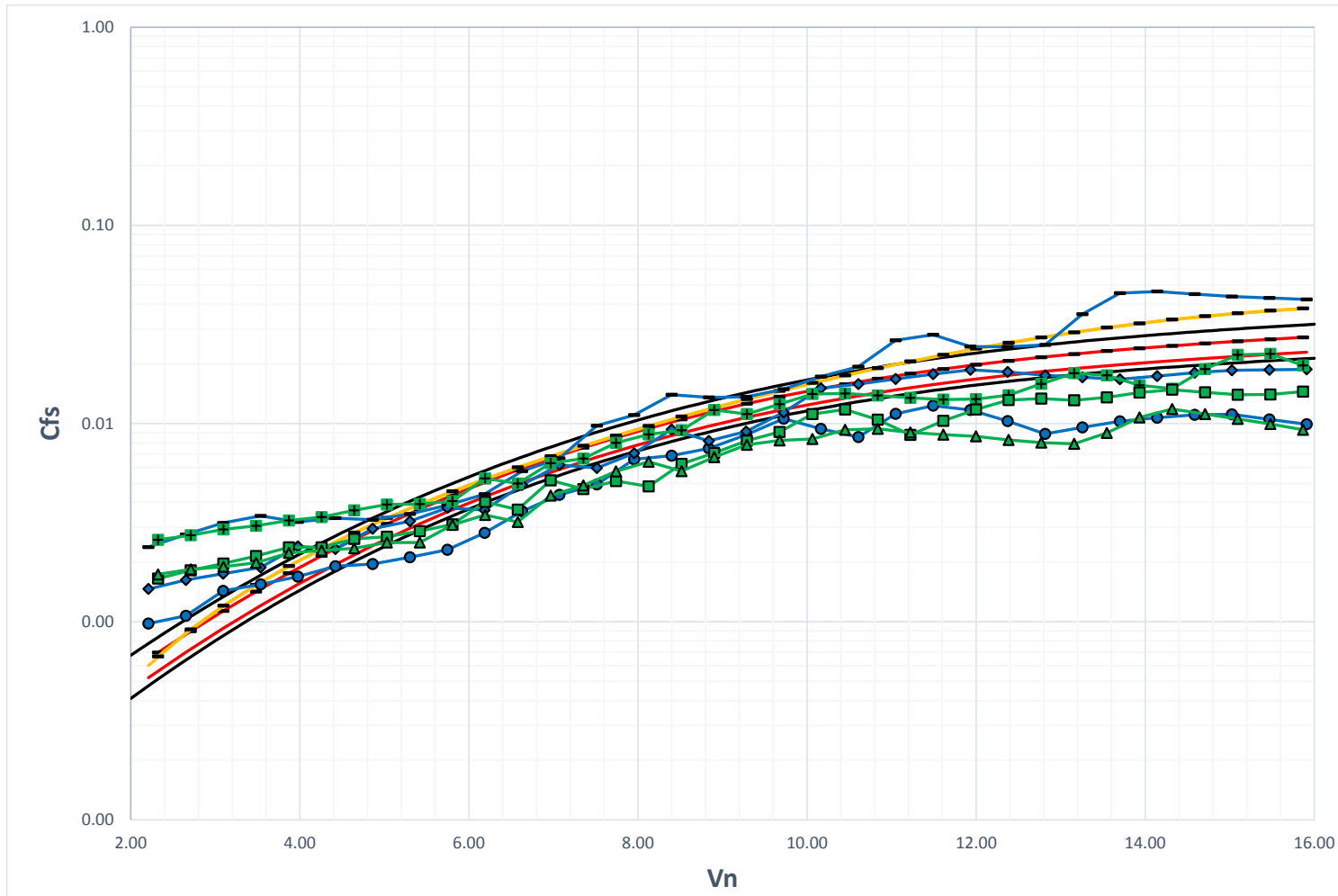
ANNEXURE 4 – COMPARATIVE RESULTS for $h:b:d$ of 6:1:2



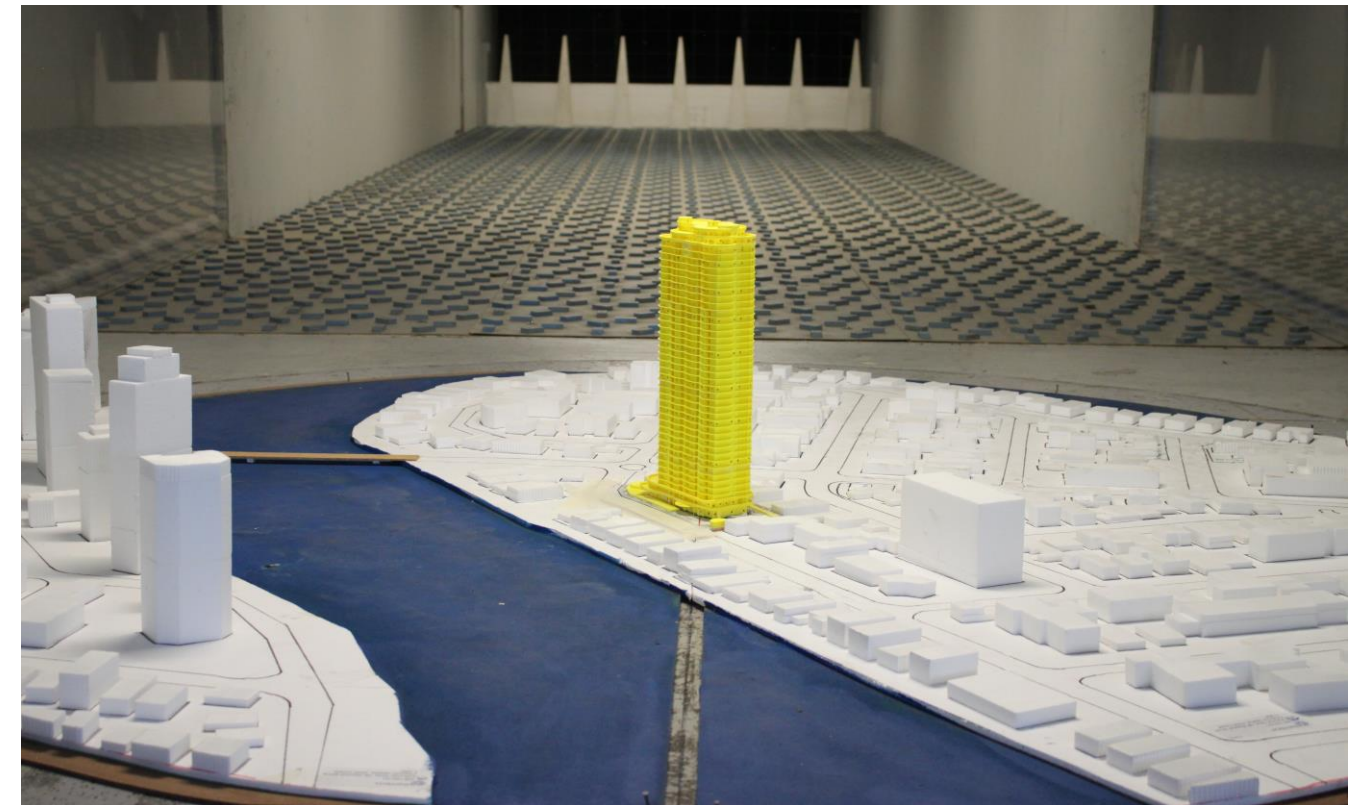
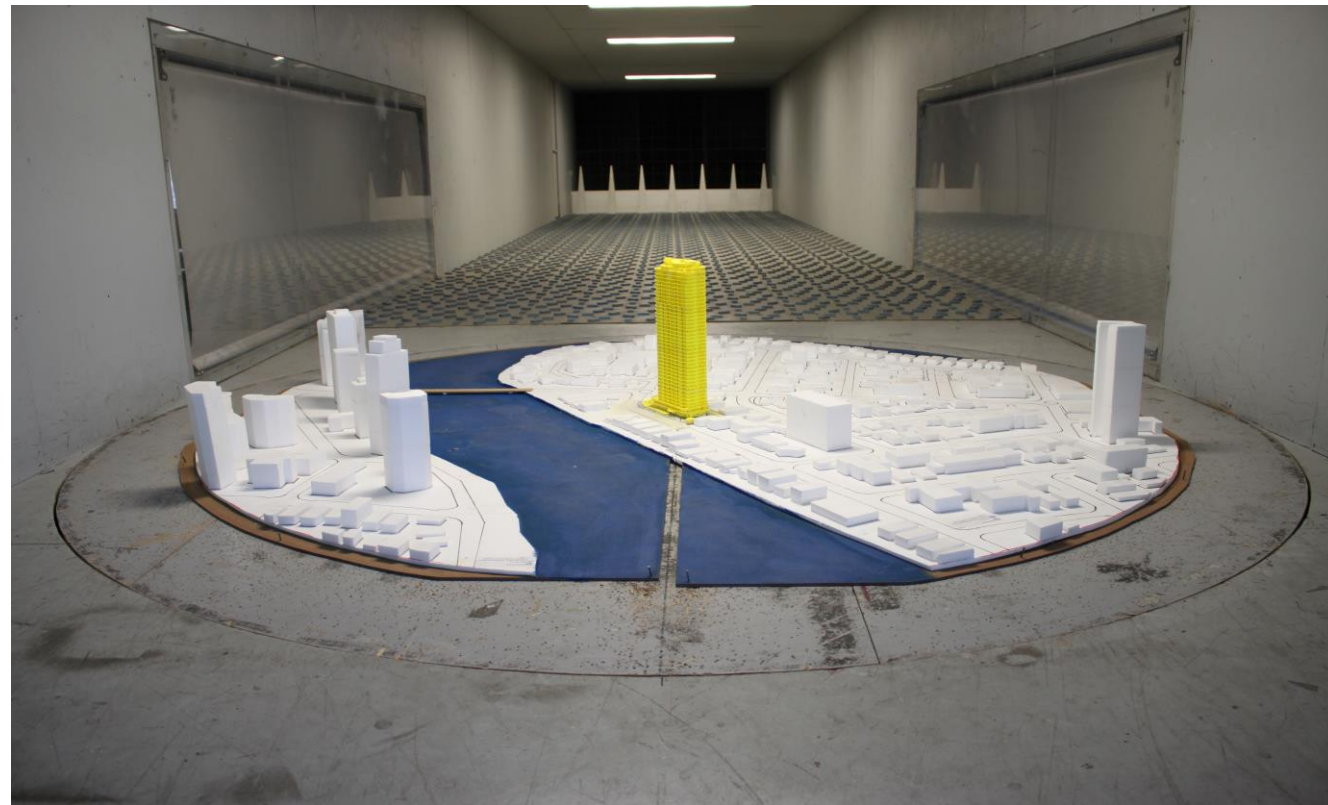
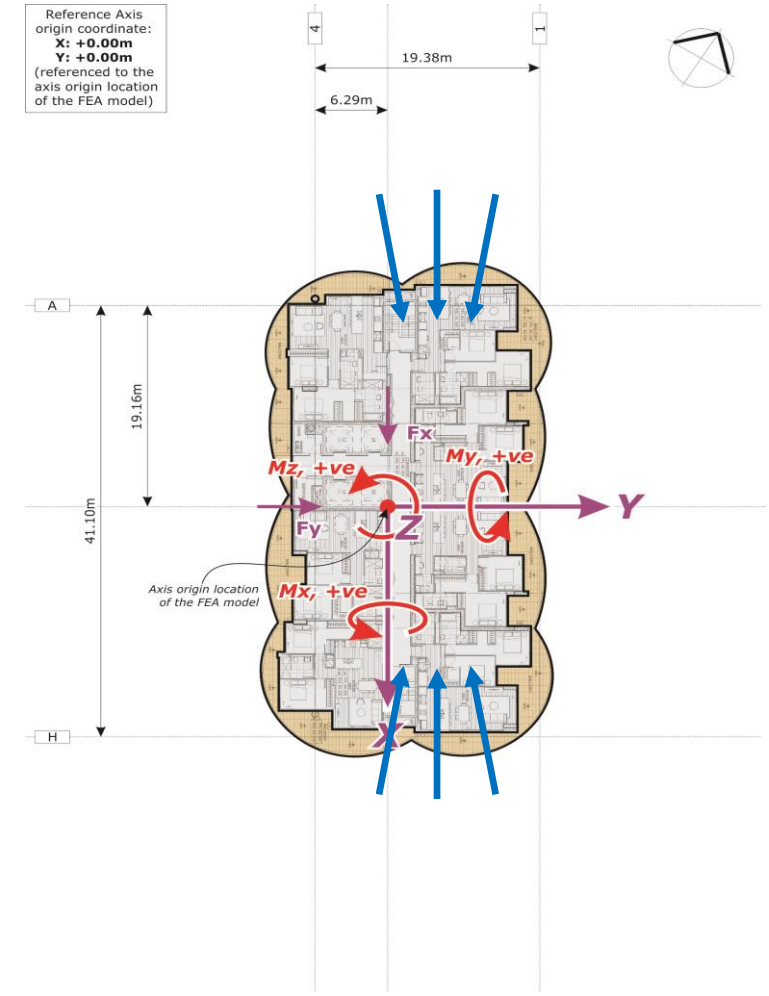


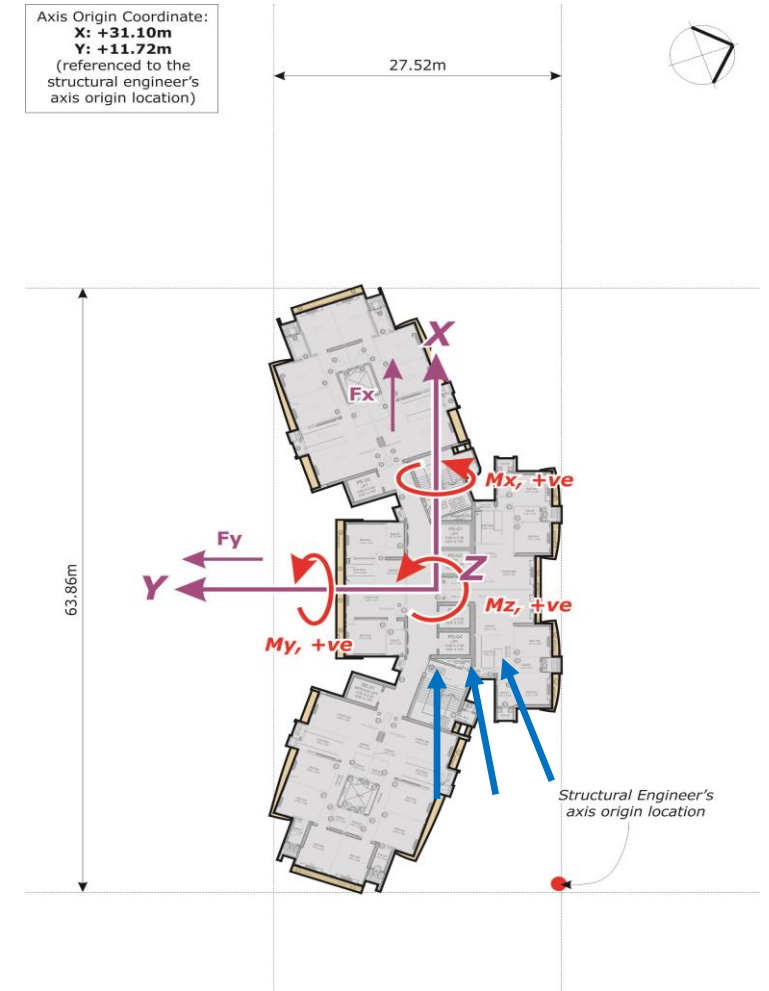
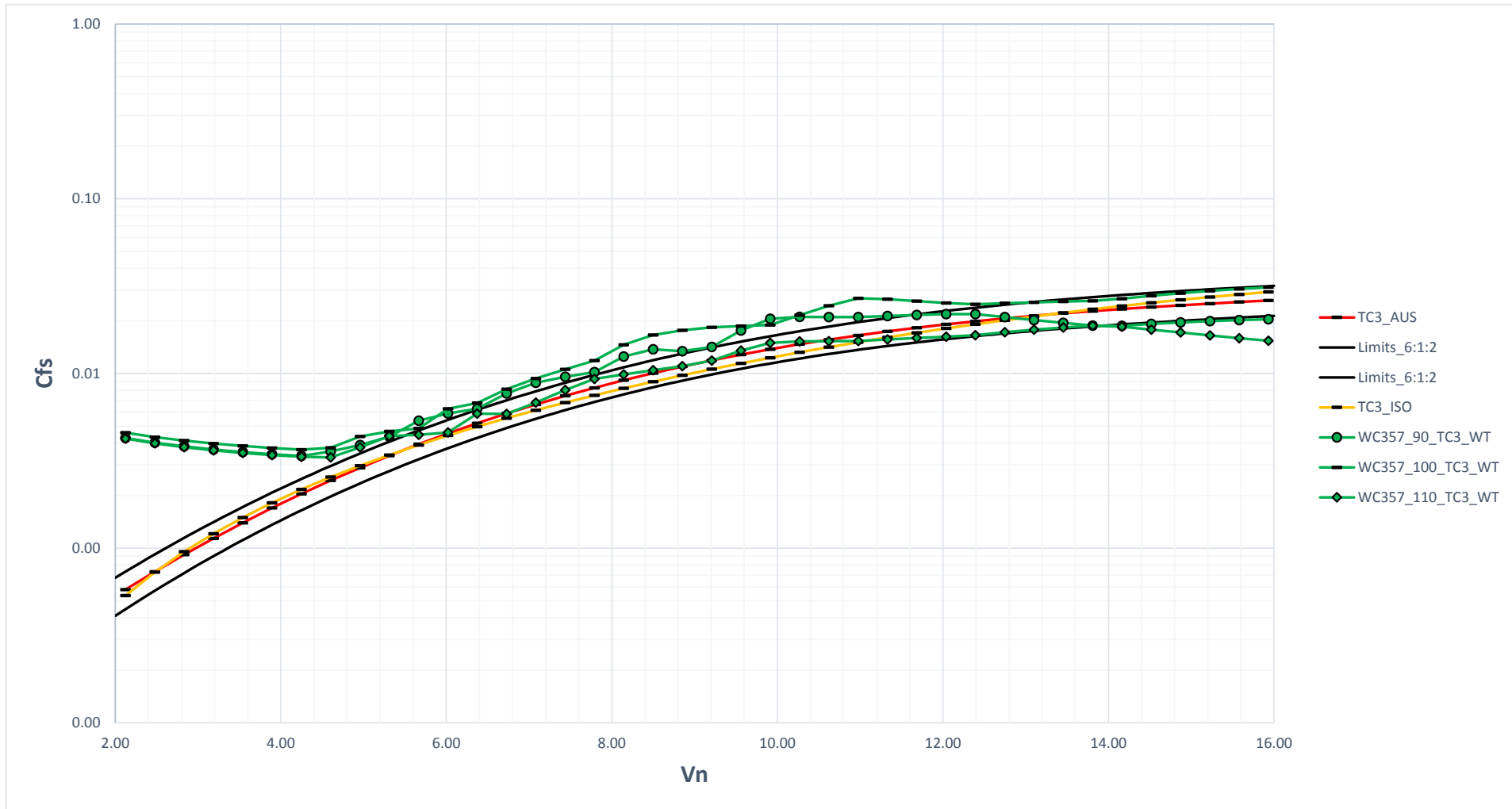


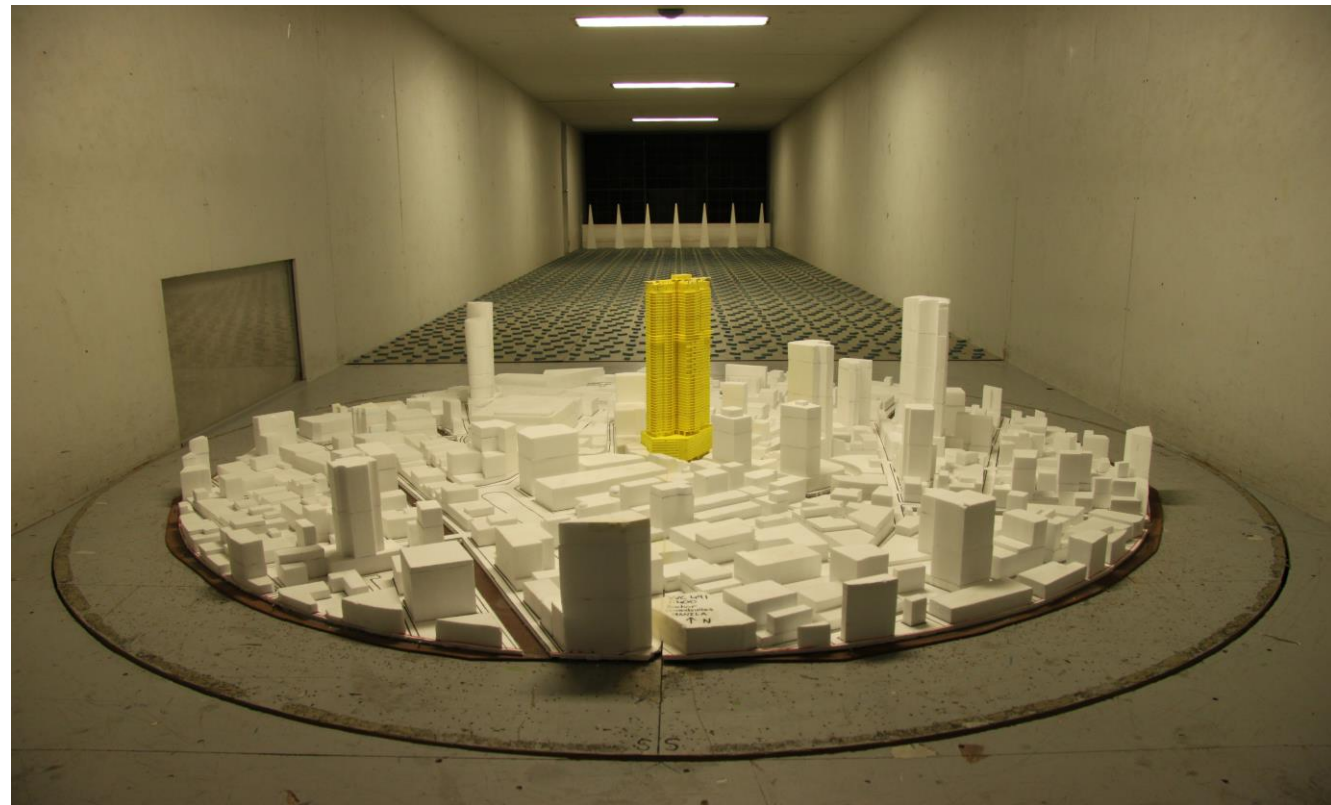
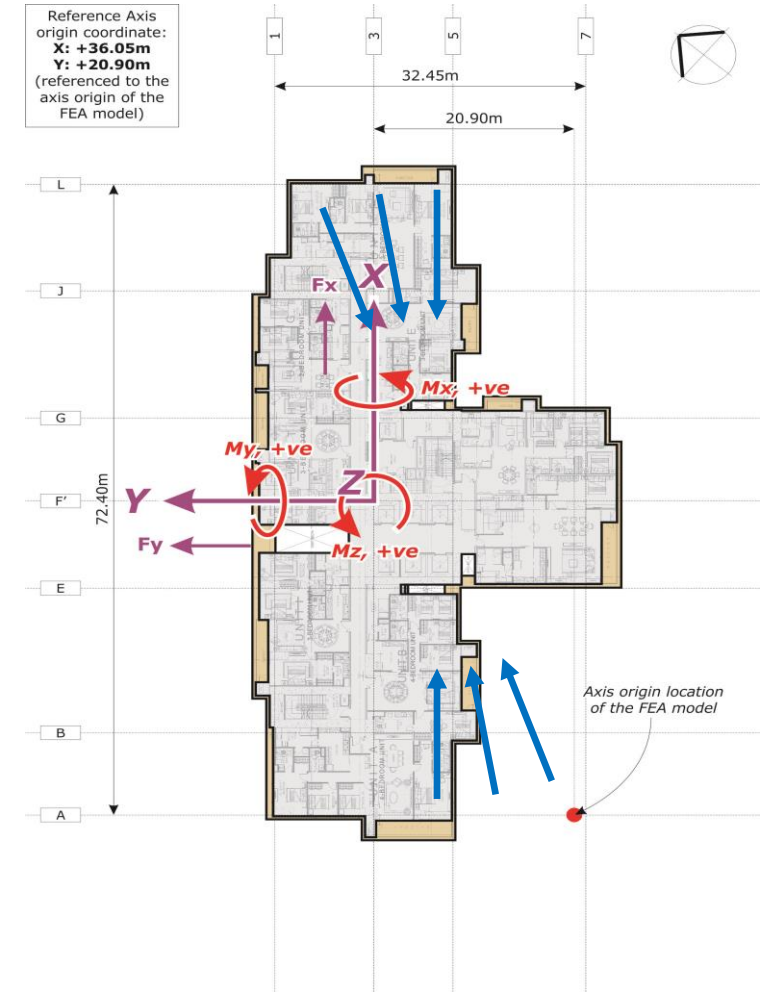
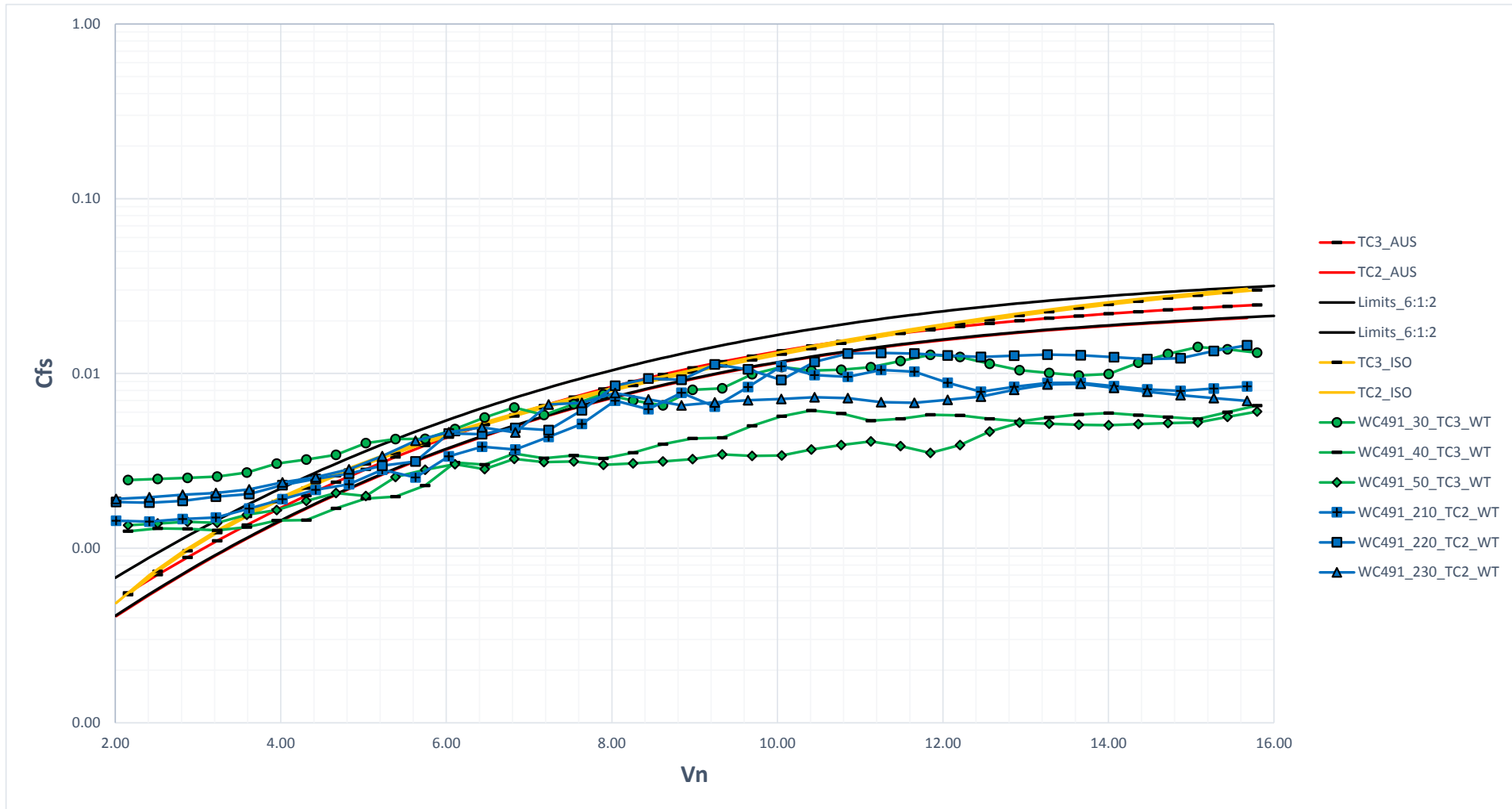




- TC2_AUS
- TC3_AUS
- Limits_6:1:2
- Limits_6:1:2
- TC2_ISO
- TC3_ISO
- WE152E - ULS - 500yr@2_140_TC2_WT
- WE152E - ULS - 500yr@2_150_TC2_WT
- ◆ WE152E - ULS - 500yr@2_160_TC2_WT
- WE152E - ULS - 500yr@2_320_TC3_WT
- WE152E - ULS - 500yr@2_330_TC3_WT
- ▲ WE152E - ULS - 500yr@2_340_TC3_WT







ANNEXURE 5 – COMPARATIVE RESULTS for $h:b:d$ of 6:1.5:1 & 6:1:1.5

