An Experimental Study on Vehicular Emission Dispersion Through double Storied Building Model Configurations

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ABSTRACT*-In this paper line source dispersion around urban buildings has been investigated by physical modelling using arrays of buildings- like obstacles at scale 1:100 in boundary layer wind tunnel for double storied buildings and compared with field data. The particular effect of obstacle width- to - height ratio (S/H) was examined for a fixed obstacle plan area density. In comparison, experimentally observed σ_z values are below the field values. Again, wind tunnel double storied inline array configuration data appears to be more convective and /or less diffusive than the field data. In addition concentration measured in the wind tunnel was consistently larger than field data measurement. This may be due to different roughness conditions simulated in wind tunnel from that of field. Even with quantitative differences, the inline and staggered array results showed the same general trend.Study concluded that despite some quantitative differences, the field result and wind tunnel showed the same general trend of vertical dispersion parameter*.

Key words: Atmospheric Boundary Layers, wind tunnel study, vehicular emission dispersion, array of building obstacles.

1. INTRODUCTION

Dispersion in the urban near field environment is quite complex and involves the details of the interaction of the plume and the flow field with several obstacles. Physical modeling is the best way to obtain sensible results and to study the influence of the various parameters relevant to the problem which is not solvable by computational means. While using any line source model for prediction of pollutants in any urban/suburban area, it is imperative that the model should be capable of accounting for building effects. There is greater scope to understand systematically the influences of important varying parameters on dispersion mechanisms through arrays of obstacles. For the study of these types of local parametric influences, a boundary layer wind tunnel is a convenient tool to investigate the effects of these potential parameters.

The dispersion is dependent on different source parameters and surface layer micro-meteorological parameters such as wind speed, wind direction, roughness conditions etc. In addition, the influence of the nearby buildings and other structures of different terrain categories cause further complexity in the dispersion phenomenon. Hosker (1984), Hunt (1975) and Meroney (1995) have discussed the complex diffusion mechanisms in the wake of building arrays. Until fairly recently the literature on this topic has been quite sparse; for example the review by Hosker (1984) was mainly concern with flow and dispersion around individual or small groups of obstacles, with only handful of relevant field and wind tunnel experiments have appeared.

Meroney (1995) and Hosker (1984) provided excellent reviews on the main characteristics of flow and dispersion around single or small groups of obstacles. Several experiments have been carried out in model and real urban canopies and wind tunnel using tracer gases. Davidson et al. [1995], Theurer et al. (1996), and Macdonald et al. (1998) investigated diffusion around a building in field experiment in suburban area in Sapporo. They found that high concentrations were observed both upwind and downwind of the source on the roof. Macdonald et al. (1998) confirmed that at short distances from the source, concentration profiles in the obstacle arrays are quite variable. Mavroidis and Griffiths (1996) examined the flow and dispersion through arrays of obstacles. The results suggested that enhanced mixing and dispersion occur within array. Recently, dispersion of atmospheric pollutants in the vicinity of isolated obstacles of different shape and orientation with respect to the mean wind direction has been examined in scaled field and wind tunnel experiments. It has been found that the presence of taller obstacles results in a reduction of ground level concentrations. It is now widely acknowledged that the greatest damage to human health is caused in the near- field of toxic releases from line sources within the urban region. Complex flows around the obstacles in urban canopy pose difficult challenges to research. Thus, it is essential to address these challenges and develop methods to model the impact of contaminants at short distance from the source within urban region.

The main aim of the present paper is to investigate experimentally, the vehicular emission (which are treated as line source) dispersion phenomenon in simulated terrain conditions and to understand the dispersion pattern through double storied building model configurations in the near- field of roadway.

2, EXPERIMENTAL SETUP

2.1. Simulation of ABL Flow

Artificially thickened Atmospheric Boundary Layers (ABLs) have been produced in the Environmental Wind Tunnel (EWT) by the combination of the passive devices such as Counihan’s spires, tripping barrier and roughness blocks on the wind tunnel floor. The entire floor of the EWT was covered with roughness elements of 23 x 23 x 23 mm with a spacing of 70 mm (ABL-I). Three number of elliptic vortex generators (Counihan spires) of 940 mm height were placed symmetrically at the entrance of the test section of EWT with roughness elements (ABL-II). Further, a tripping barrier of 300 mm high was placed after the Counihan spires at 1.25 m from the Counihan spires with roughness elements

(ABL-III). The design of cubical blocks has been carried out as per Counihan (1969), Gartshore and De Cross (1977) Gowda (1999).

2.2. Details of physical modelling dispersion experiments

In the present study a near-field terrain buildings model arrangements have been selected. The set of experiments were carried for a geometric model scale of 1:100, which represent a real buildings height of 7 m (double storied buildings). For this case inline and staggered buildings model configuration were selected.

Physical modelling dispersion experiments were carried out one of the simulated ABL-III which represent centre of large city in the near field of roadway in the EWT. Measurements were taken to obtain vertical tracer gas concentration profiles for double storied building at pre-selected downwind distances from centre of the line source as per the scheme shown in Fig. 1. These measurements were observed at selected vertical height of (Z) 1.4H, 2.9H and 4.2H for double storied buildings model for selected lateral width of tunnel from the tunnel floor. For this tracer experiments were carried out for 90^{o}.

Lateral concentration measurements (along width of the test section) for pre selected lateral width of 4H, 8H, and 12H for double storied buildings model for all the downwind distances on either sides of the centreline. Further repeatability checks were carried out for all the experimental observations.

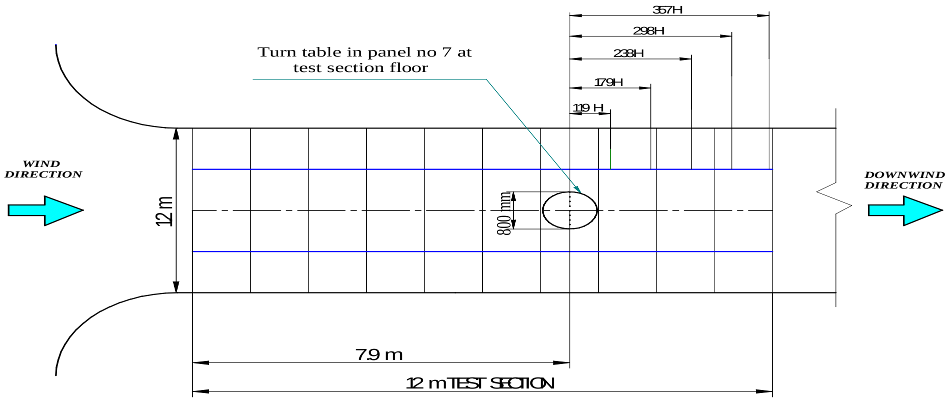

Fig. 1. Schematic showing downwind distances for tracer gas concentration measurement in the E WT

2.3. Experimental configuration in the wind tunnel

For the present study, buildings model made of wood cubical in shape had been arranged on the floor of the tunnel from line source to entire downwind section of the tunnel. The buildings model had been arranged downwind direction of the line source such that the row of buildings was at 70 mm (1H) for double storied buildings. This arrangement ensured that the line source was located in amidst of the buildings model.

Macdonald et al. (1997) characterised the buildings arrangement for arrays of cubical elements by plan area density, λ_{ar}. For regular arrays of cubic elements, the plan area density λ_{ar} is related to the gaps between cubes S and their height H by (eq 1)

$$\lambda_{ar} = \frac{1}{(1+S/H)^2}. \tag{1}$$

Where, S= Space between two consecutive array element

Based on plan area density different flow regimes have been defined for arrayed cubical blocks arrangement. The characteristics of these main flow regimes are presented in Table.1. The present studies have been conducted an isolated roughness flow regime for double storied buildings for the plan area density as per the Table 2.

Table. 1. Characteristic of the flow regime (Macdonald et al. [1997])

Flow regime	Array spacing	Plan Area density (%)
Isolated Roughness flow	S/H>2.0-2.5	λ<8-11
Wake Interference Flow	1.0-1.5<S/H<2.0-2.5	8-11< λ <16-25
Skimming Flow	S/H<1.0-1.5	16-25< λ

Table. 2. Characteristic of the flow regime for the double storied buildings model

Sl. No.	Average real building height (m)	Scale	*S/H* (>2.0–2.5)	λ_{ar} (%) (<8–11)	Width	Prototype cubical model *H* (mm)
1	7	1:100	2.00	11.0	*W*=*H*	70

For double storied buildings, cubical blocks having a height (*H*) of 70 mm with a spacing (*S*) between elements of 140 mm, and the plan area density was found to be 11.0% (or *S*/*H*=2.0). As per the flow regime suggested by Macdonald and Griffiths (1997) in Table 2, the prototype cubical models used for the experiment are made of wood at a geometric model scale of 1:100, which represents a real building's height of 7 m. Dimensions of the models are 70 mm (*L*) × 70 mm (*W*) × 70 mm (*H*). The size for both the inline and staggered array configurations was 6×6 arrays. Figs. 2 and 3 show a plan view of experimental buildings arrangement for inline and staggered array for double storied buildings, respectively.

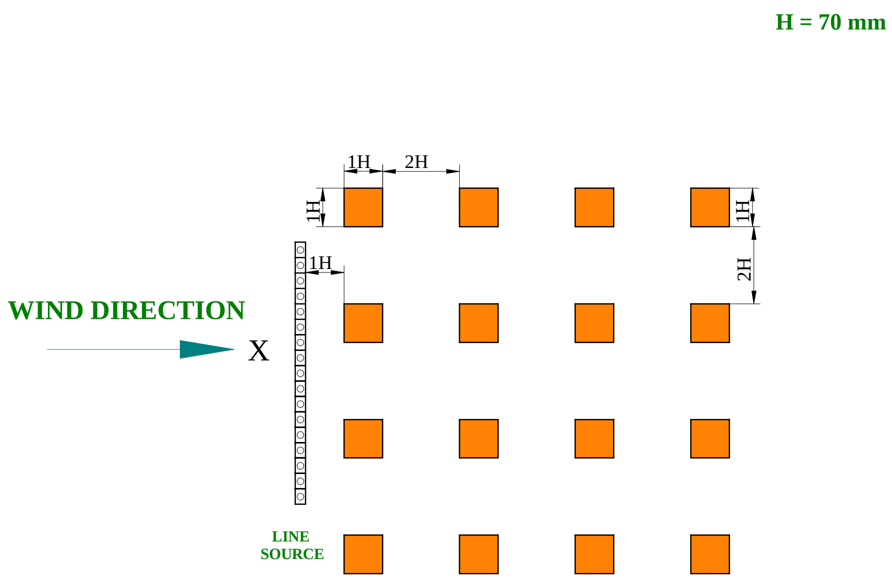

Fig. 2. Plan view of experimental buildings model inline array arrangement for double storied buildings

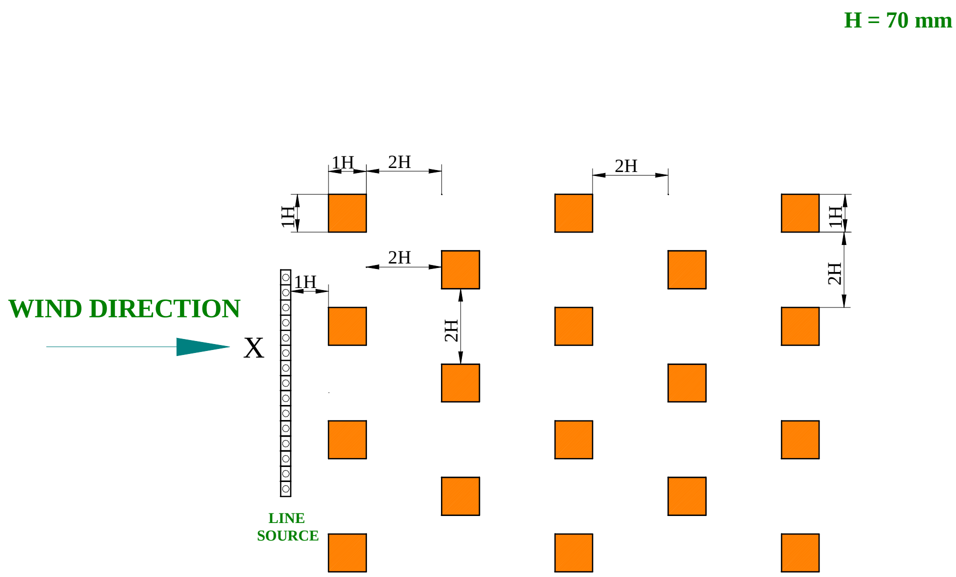

Fig. 3. Plan view of experimental buildings model staggered array arrangement for double storied buildings

3, RESULTS AND DISCUSSIONS

3.1 Comparison of vertical concentration profiles between inline and staggered array configurations for the double storied buildings model

The vertical tracer gas concentration profiles were compared at selected downwind distances of 119*H*, 179*H*, 238*H*, 298*H* and 357*H* from the centre of the line source at each of the selected lateral widths of *Y*=4*H*, *Y*=8*H* and *Y*=12*H* for the double storied buildings model. Figs. 4–8 depict the comparison of normalized concentration C/C_0 with vertical height *Z*/*H* above the tunnel floor for inline and staggered array configuration. From the figures, it is revealed that vertical concentration values for staggered array configuration are relatively higher than that of inline array configuration at different downwind distances measured. This may be attributed to higher recirculation region and "blocking" effect [Macdonald and Griffiths (1997), Mavroidis and Griffiths (1996) and Gowda (1999)], which might have produced as a result of another cube located between the obstacles in the staggered array configuration. It can be seen that C/C_0 showed a decreasing trend with increase in height for both the inline and staggered array configurations. In other words, the tracer concentration is maximum at the tunnel floor than at higher elevations.

The experimental results showed that there were significant differences between non-dimensional concentrations measured in the downwind of the obstacles in inline and staggered array. It was concluded that C/C_0 showed a decreasing trend with increase in height for both the inline and staggered array configurations of the double storied buildings model. Study also concluded that vertical concentration values for staggered array configuration are relatively higher than that of inline array configuration at different downwind distances measured. Even with quantitative differences, the inline and staggered array results showed the same general trend.

a) Y=4H *b) Y=8H* *C)Y=12H*

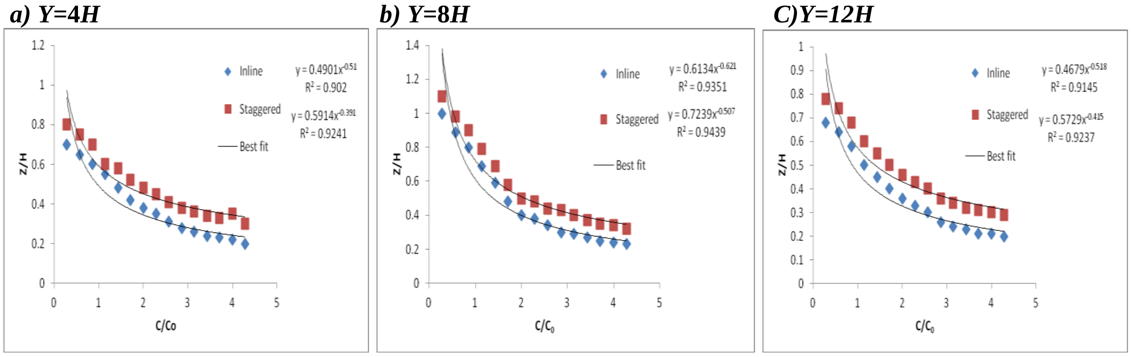

Fig. 4.Vertical concentration profiles comparison between inline and staggered array configurations for the double storied buildings model at *X*=119*H*.

a) Y=4H *b) Y=8H* *c) Y=12H*

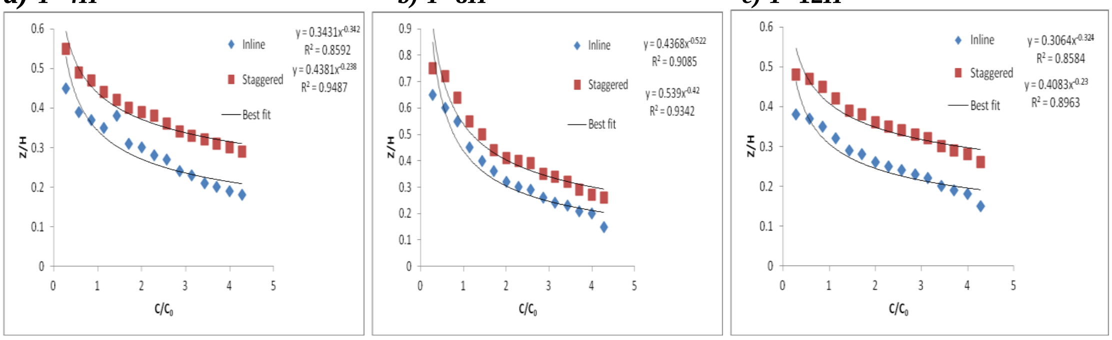

Fig. 5.Vertical concentration profiles comparison between inline and staggered array configurations for the double storied buildings model at *X*=179*H*.

a) Y=4H *b) Y=8H* *c) Y=12H*

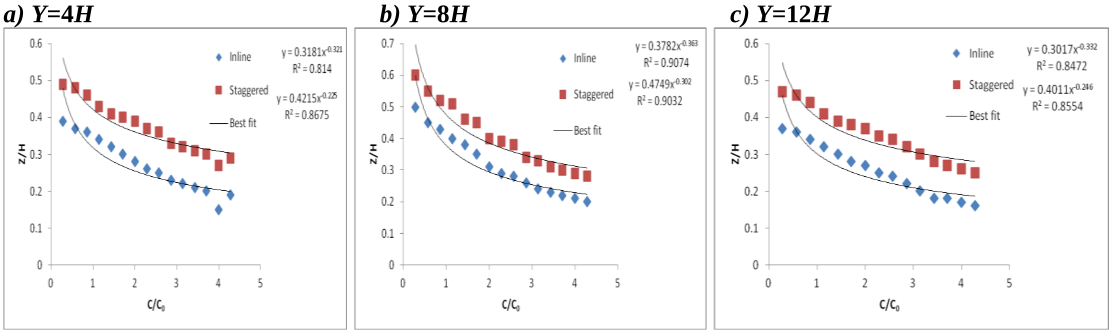

Fig. 6.Vertical concentration profiles comparison between inline and staggered array configurations for the double storied buildings model at *X*=238*H*.

a) Y=4H *b) Y=8H* *c) Y=12H*

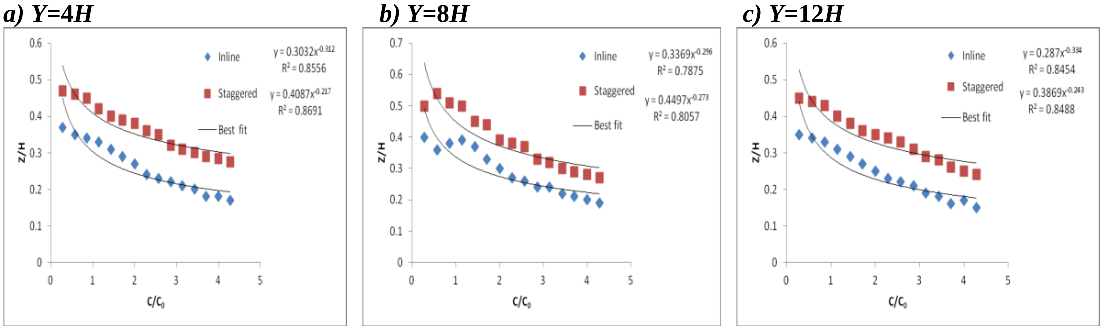

Fig. 7.Vertical concentration profiles comparison between inline and staggered array configurations for the double storied buildings model at *X*=298*H*

a) Y=4H *b) Y=8H* *c) Y=12H*

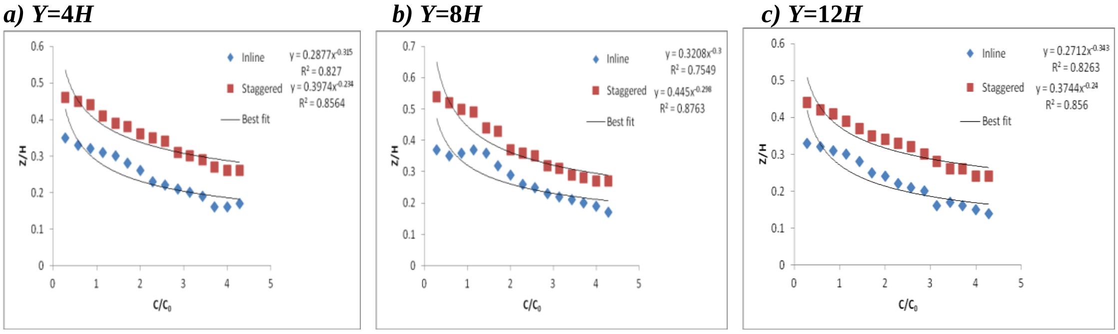

Fig. 8.Vertical concentration profiles comparison between inline and staggered array configurations for the double storied buildings model at *X*=357*H*

3.2 Comparison of vertical spread parameter (σz) for double storied inline array configuration with field data

Fig .9 shows a comparison of vertical spread parameter (σ_z) values obtained for double storied inline array configuration with reported field data. Experimentally obtained non-dimensionalized concentration with cubic height (*H*) (i.e., σ_z/H) values was plotted against downwind distances (*X*). Experimentally obtained values of σ_z/H for the double storied buildings model of inline array configuration have been compared with the field data reported by Macdonald et al. (1998).

In comparison, experimentally observed σ_z values are below the field values reported by Macdonald et al. (1998). They were best fitted with power-law profiles. In case of inline array configuration of double storied buildings model, non-dimensional concentrations were typically twice larger compared to the field data reported by Macdonald et al. (1998). This is attributed to the fact that the tracer material is quite concentrated in the recirculation region in inline array configuration of the double storied buildings model.

However, it was concluded that concentration is consistently larger in wind tunnel for in double storied inline array configurations compared to the field data reported by Macdonald et al. (1998). Again, wind tunnel double storied inline array configuration data appear to be more convective and/or less diffusive than the field data. In addition, the concentration measured in the wind tunnel was consistently larger than the field data measurement. This may be due to different roughness conditions simulated in wind tunnel from that of field. Compared to the wind tunnel double storied inline array configuration, there was more scatter in the field result due to the effect of larger scales of turbulence (Macdonald et al. 1998). The study concluded that, despite some quantitative differences, the field result and wind tunnel showed the same general trend of vertical dispersion parameter.

a) *Y*=4*H* **b) *Y*=8*H*** **c) *Y*=12*H***

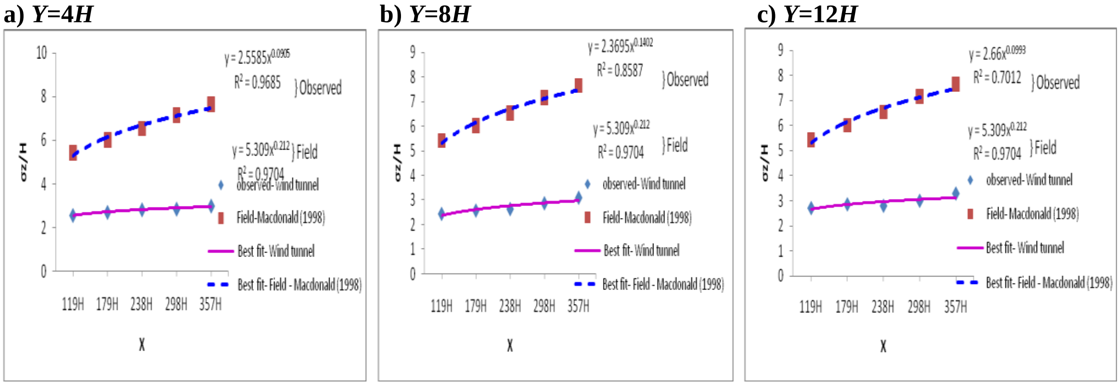

Fig. 9 Comparison of σ_z values for double storied inline array configuration with field data.

3.3 Comparison of vertical spread parameter (σz) for double storied staggered array configuration with field data

Fig.10 shows a comparison of vertical spread parameter (σ_z) values obtained for double storied staggered array configuration with reported field data. Experimentally obtained non-dimensionalized concentration with cubic height (*H*) (i.e., σ_z/H) values was plotted against downwind distances (*X*). Experimentally obtained values of σ_z/H for double storied buildings model of staggered array configuration have been compared with the field data

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reported by Macdonald et al. (1998). Experimentally observed σ_z values are below the field values reported by Macdonald et al. (1998). They were best fitted with power-law profiles. Values of staggered array configuration of double storied buildings model, non-dimensional concentrations were typically twice larger compared to the field data reported by Macdonald et al. (1998).

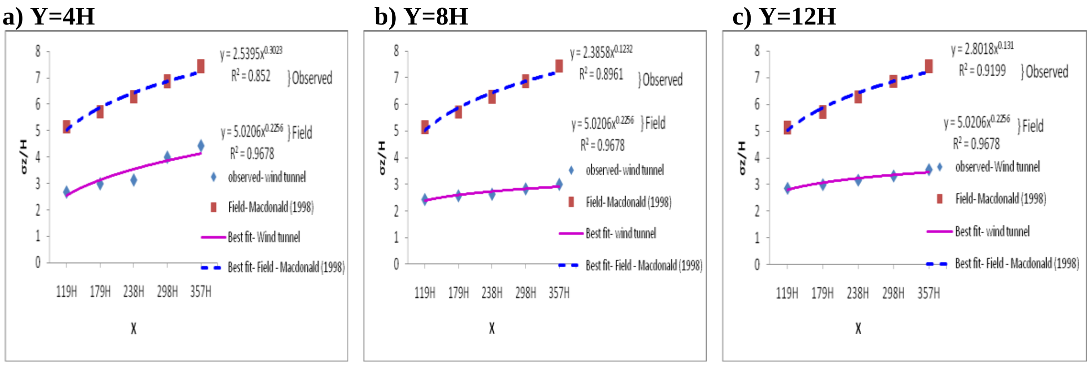

Fig. 10 Comparison of σ_z values for double storied staggered array configuration with field data.

IV, CONCLUSIONS

Concentrations are higher at tunnel floor compared to the elevated height for the inline and staggered array configuration of the double storied buildings model. This is attributed to the fact that both higher recirculation region and blocking effect are predominated in the double storied buildings model of inline and staggered array configuration. Vertical concentration values for staggered array configuration are relatively higher than that of inline array configuration at different downwind distances measured for the double storied buildings model. Even with quantitative differences, the inline and staggered array results showed the same general trend. Vertical spread parameter (σ_z) for the double storied buildings model of inline and staggered array configuration behaved more or less in a similar trend with a quantitative difference between centerline and either side of centerline at lateral locations. Concentration is consistently larger in wind tunnel compared to the field data reported by Macdonald et al. (1998). Again, wind tunnel double storied inline array configuration data appear to be more convective and/or less diffusive than the field data. In addition, concentration measured in the wind tunnel was consistently larger than field data measurement. This may be due to different roughness conditions simulated in wind tunnel from that of field. Values of vertical spread parameters (σ_z) for staggered array configuration of double storied buildings model, non-dimensional concentrations were typically twice larger compared to the field data reported by Macdonald et al.(1998).

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