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EFFECTS OF WIND ON A 3 DIMENSIONAL STEEL STRUCTURE FOR THE CENTRAL CORRIDOR ROOF (CENTRAL SPINE) AT TCS CAMPUS AT SIRUSERI, CHENNAI (INDIA) - A CASE STUDY

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Abstract. *With the advent of high speed computers, 3D structural modeling and analysis have evolved to new heights. Equally exceptional user friendly finite element software tools have made the modeling exercise a lot easier than ever before. This paper will provide a case study on the evolution of the structural system for one of the modern architectural marvels of India. The authors, who were deeply involved in the various stages from concept to construction, will discuss in particular, the analysis and design of the central spine which resembles a* ***"Giant Wasp"*** *(as called by the concept architect). This paper will also discuss the structural system suitably provided for the huge cantilevers at the ends representing the tail, huge cantilevers at the sides representing wings, tall curved portals representing the legs and the pyramid shaped lattice girders representing the body of so called giant wasp. Also discussed in this paper, will be the behavior of the central spine structure due to wind.*

1 INTRODUCTION

The proposed techno park at Siruseri, Chennai, India is spread over a plot area of approximately 70 acres. It has 6 engineering blocks, customer care center, General services block, Training and library block and other facilities as in figure 1.

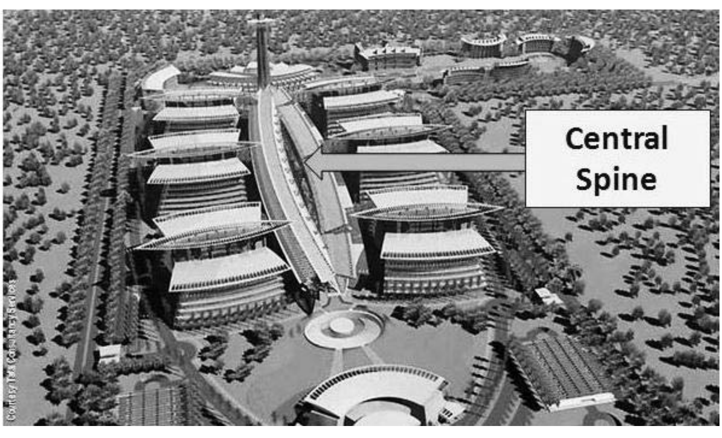

Figure 1: TCS campus showing central spine

This paper will discuss about the central corridor roof between the engineering blocks which is also known as the central spine. The central spine serves as the shelter for people movement. This also houses the landscape which consists of water body and other facilities. This is spread over a length of 400 m. The architectural concept is such that 2 giant wasps each of 8 pairs of legs and long tails are facing each other. The formation of the entire structure is by means of 3 dimensional curves. In both the side elevations it is symmetrical about vertical axis (refer figure 2). In top plan, it is symmetrical about both vertical and horizontal axes as in figure 2.

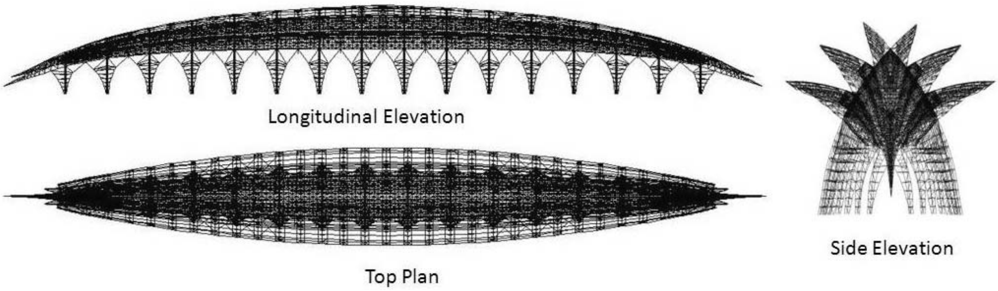

Figure 2: Views of central spine

1.1 Project team

Architect: Carlos Ott architects (Uruguay, South America); Resident architect: CRN architects (Chennai, India); Engineering Services: Potential Service Consultants (Bangalore, India); Review and Project Management Consultants: TCE Consulting Engineers (Bangalore, India)

2 STRUCTURAL SYSTEM

2.1 Main portals and arch bracings

Main portals are formed by intersecting gothic arches as in figure 3. They are the main supporting elements of the central spine in the vertical direction. They are made of two outer pipes and one inner pipe as in figure 3. These 3 pipes are connected by triangulated web members. They are further connected to the arch bracing members which are provided along the elevation. The outer and inner pipes form cantilever trusses called wings to support the purlins on them.

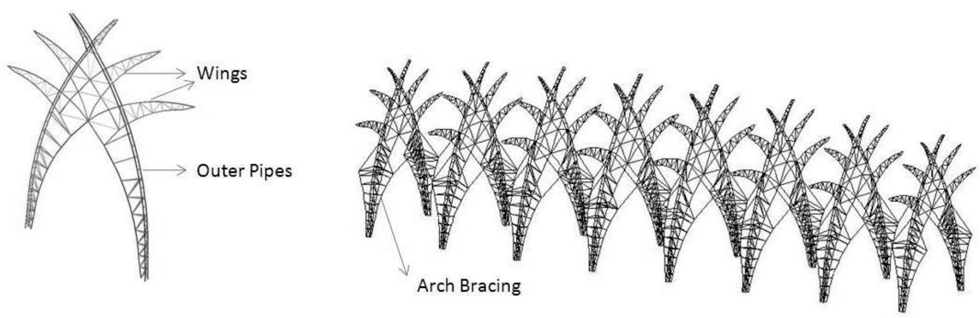

Figure 3: Main portals with arch bracing

2.2 Middle wings

To reduce the span of purlins a truss system known as middle wings (figure 4.) which are quite similar to the top part of main portals, are introduced in between the 2 portals. By this, the span of purlins is reduced to around 11 m which is reasonable. The middle wings are supported by the lattice and box girders running between the 2 main portals.

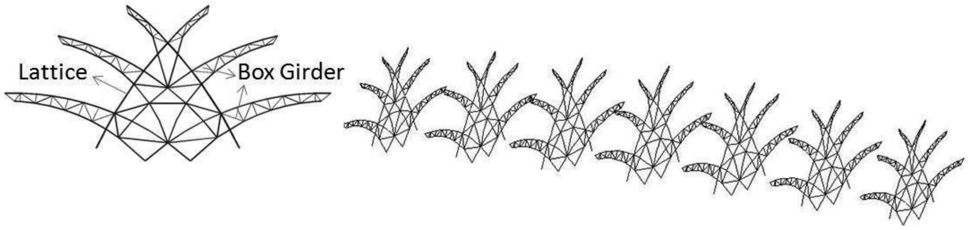

Figure 4: Middle wings

2.3 Lattice girder and Tail

The lattice girder as shown in figure 5 connects the main portals in the longitudinal direction. Between 2 consecutive main portals, at the centre it supports the middle wing. The lattice girder is connected at the bottom exactly at the centre to the arch bracing in each span. It is extended from the base of top wing to the bottom wing forming a curved pyramid. Tail is the continuation of lattice girder at both ends converging at a point. Space frame method is used to form this structure as in figure 6. It is an open structure without any roof covering making it very obvious so that it looks like the tail of the "Giant Wasp". The cantilever is about 35 m from the last portal. It is tied back to the 2^{nd} portal to control the deflection in the vertical direction and horizontal "X" bracings are provided at the bottom to control deflection due to wind.

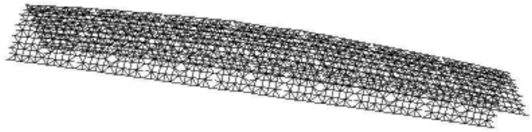

Figure 5: Lattice girder

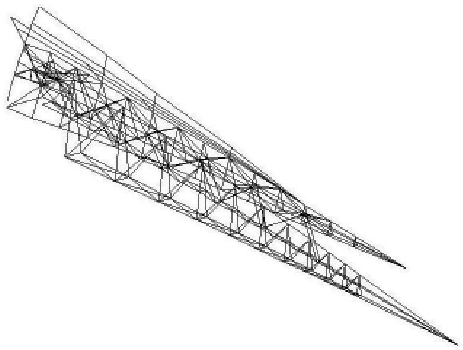

Figure 6: Tail of central spine

2.4 Foundation

The two legs of each portal consisting of five pipes (including the arch bracing) are connected to a base plate with required stiffeners. Base plate is further connected to the podium column capital by means of cast-in holding down bolts.

3 ANALYSIS AND DESIGN DATA

3.1 Loads

Dead loads and imposed loads have included the weight of all structural and architectural components on the basis of the unit weights as mentioned in the table 1. Wind loads are based on the code provisions mentioned in IS 875 [1]. The wind speed is calculated using the parameters in table 2.

Table 1: Dead loads and imposed loads [1]

Material	Weight
Unit weight of steel	78.5 kN/cum
Sheeting Weight	0.12 kN/sq.m
Louver Weight	0.4 kN/sq.m
Roof Sheeting area	0.4 kN/sq.m

Table 2: Wind load parameters [1]

Parameter	Value
Basic wind speed, Vb	50 mps
Risk Coefficient, K1	1.0
Terrain factor, K2	1.13
Topography factor, K3	1.0

3.2 Temperature loads and expansion joints

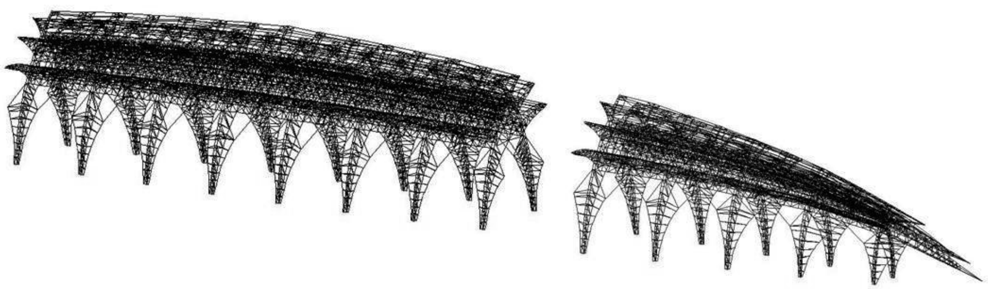

Figure 7: Central spine divided into central and tail part with expansion joint

Elongation due to differential temperatures is of importance in long steel buildings. It can be taken care by either providing expansion joints at an appropriate spacing or designing structural members for the additional moments caused by the temperature. Expansion gap between two structures shall be sufficient to accommodate temperature and shrinkage for effects due to wind. Expansion joints are provided at 2 locations along the length, breaking the whole structure into 3 parts known as Central part(1. no.) and Tail part (2. no.). Central part will have 7 spans. The final configuration of the whole structure is as shown in the figure 7.

3.3 Materials used

Structural steel confirming to IS: 2062 with minimum yield strength of 310 N/sq.mm is used for all structural members. For expansion joints approved Teflon sheet is provided.

4 WIND PRESSURE COMPUTATIONS

4.1 Configuration

Figure 8 shows the configuration of the central spine (CS) structure. There are sixteen bays of geometrically similar configuration of diminishing size from centre to ends. Each bay is around 21 m long. At the middle, the width is 35 m and height is 55 m, at the ends the width is 12 m and 18 m height.

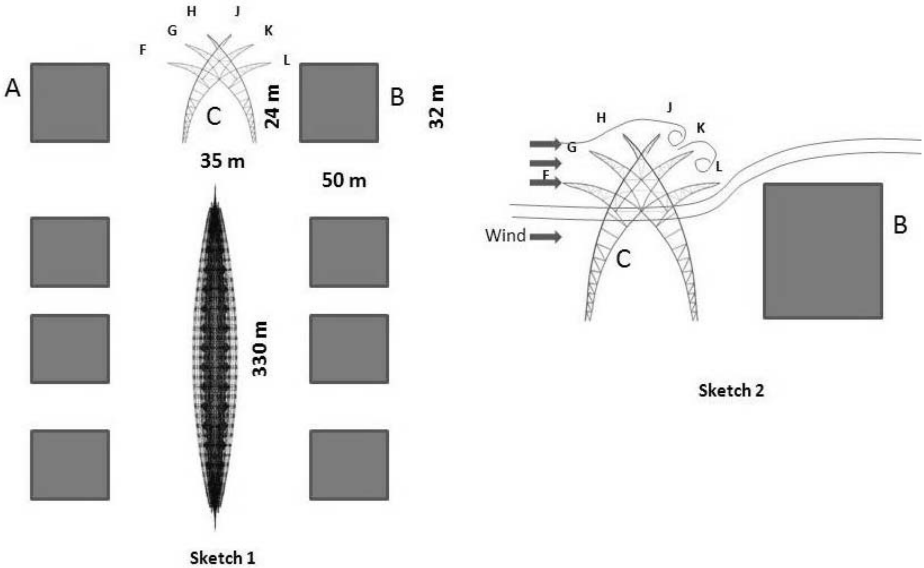

Figure 8: Configuration of central spine influencing wind pressure

The bays are open in the bottom, for example up to a height of 24 m at the centre, above which CS supports six wings symmetrically by the framework, which also supports Louvers (water barrier made of overlapping plates) at the roots of the wings with a porosity of 20%. The Louvers extend below F & L.

4.2 Types of wind loads

The following cases have been considered to analyze the structure:

Case 1: Wind from empty position of A to B

Case 2: Wind from the direction of B to A, with A absent

4.3 Wind loads with CS and building B only, wind from position A to B

As shown in sketch 2 of figure 8, the part of the wind below the point C will move on to B, gets diverted upwards and impacts to rear wing L. But wings K & L are partially shielded by F, G, H and their loads will be less than those values on G & H. Somewhat similar phenomenon occurs on the bottom of F, where the Louvers below F block the flow partially, creating a positive pressure. The Louvers between F & G and G & H also create positive pressure (or makes negative pressure, less so). The nearest configuration in the Indian wind code IS 875-1987 is Table 8 [1] for the wings F, G and H, J, K and L all with $\varphi = 1$. By considering shielding effect and the pressure build ups, the overall pressure coefficients with directions for all the wings and the Louvers are as in figure 9. The configurations of Table 13[1] and Table 14[1] can be used as guidance with $\theta = 0^0$. These are used for the analysis of the entire structure. The local pressure coefficients listed in table 3 are used for designing the purlins.

Table 3: Local pressure coefficients (Positive upwards)

Wing	Front 10% of length	Middle	Rear
F / L	1.5 / 2.6	0.8 / 1.6	-0.9 / -0.9
G / K	2.6 / 1.3	1.4 / 0.7	1.0 / 0.5
H / J	2.0 / 1.3	2.0 / 1.3	2.0 / 1.3

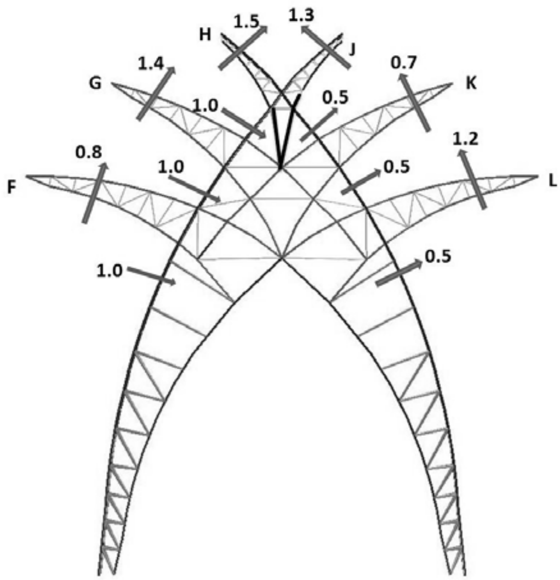

Figure 9: Overall wind pressure coefficients on portals

4.4 Wind loads with CS and building B only, wind from position B to A

Here, the bottom of wing L is above the building B & hence the flow will be similar to that as wing F with wind from A to B. Loads on K & J will be similar to those on G & H of the earlier case. However since F, G and H are fully shielded by L, K and J their loads will be half of the previous values including those on Louvers.

5 STRUCTURAL ANALYSIS AND DESIGN

Table 4: Sample results of analysis and design

BEAM RESULTS For Combination 25 (Units: Kn, Kn*meter)

Dl+ll+wly3 no sheet

Bm.	Node	Axial	V2	V3	MT	M2	M3
28411	6661	416.9	-14.5	-2.7	-3.6	18.2	-56.0
	6649	-413.9	15.0	3.6	3.6	1.3	-36.4
Maximum		416.9	15.0	3.6	3.6	18.2	-56.0
Beam no.		28411					

DESIGN	EQUATION	FACTORS	VALUES	RESULT
V2 Shear [6.4.2]	V/(Av*τva) <1.00 τva=0.4*fy	Av = 41.48	V = 14.95 τva = 124.00	0.03
M3 Moment [6.2.1]	$\frac{M}{Ze*0.66*fy} < 1.0$	Z = 593.21 Ze = 593.21	M = 55.96	0.46
V3 Shear [6.4.2]	V/(Av*τva) <1.00 τva=0.4*fy	Av = 41.48	V = 3.56 τva = 124.00	0.01
M2 Moment [6.2.5]	$\frac{M}{Ze*0.66*fy} < 1.0$	Z = 593.21 Ze = 593.21	M = 18.20	0.15
Deflection	$\frac{defl.}{L/325} < 1.00$		defl = 0.00365	0.19
Axial Force [5.1.1]	$\frac{P}{Ae*\sigma ac} < 1.00$	(kL/r)x =51 (kL/r)y =51 fcc = 758.91	P = 416.93 Ag = 69.13 σac = 155.45 Ae = 69.13	0.39
Combined Stresses Local-compr. [7.1.1-b]	$\frac{\sigma a}{0.6fy} + \frac{\sigma bx}{0.66fy} + \frac{\sigma by}{0.66fy} < 1.00$	at L = 0.00	σa = 60.31 σbx = 94.33 σby = 30.68	0.94

The structural analysis is carried out by creating a 3 dimensional space frame model using the commercially available software STRAP VER.11.5 for the load combinations as per IS 800 standards. Line elements are used in the finite element model with rigid nodes. Triangular surfaces were created to idealize the curved surface and pressure loads were applied perpendicular to the surface in the required direction. This method has helped in reducing the time that would have been spent for member load computation and its application on each member. In total, including both central and tail part, the structural model contains about 10,400 nodes, 36,700 members and 61,600 degrees of freedom.

Design of structural steel members is done using elastic method as per IS: 800 [2] with relevant allowable stresses. Each member is designed for combined stresses due to axial force, shear force and moments. Sample output for the analysis and design are shown in table 4.

6 CONCLUSIONS

It is observed that the load combinations involving the wind loads computed using the pressure coefficients shown in figure 9 govern the design of members of the central spine structure. Since the structure is very light, the earthquake forces do not have any influence on the design. For academic purpose, the load combinations including earthquake, wind loads on members, live and dead loads are studied. The deflected shapes of the main portals with some governing load combinations are shown in figures 10 and 11.

The pipe sizes used for the main portals are 350 mm diameter with thicknesses varying from 22 mm to 16 mm. For the other elements almost all available pipe sizes are used considering the most economical sizes and durability. The joints are connected by full strength butt welds. The thickness of base plate worked out to be between 70 to 80 mm for various portals by suitably providing the stiffener plates. Overall structural steel consumption is around 3000 Tons with a roof sheeting area of around 25,000 square meters. The central spine structure under construction is shown in figure 12.

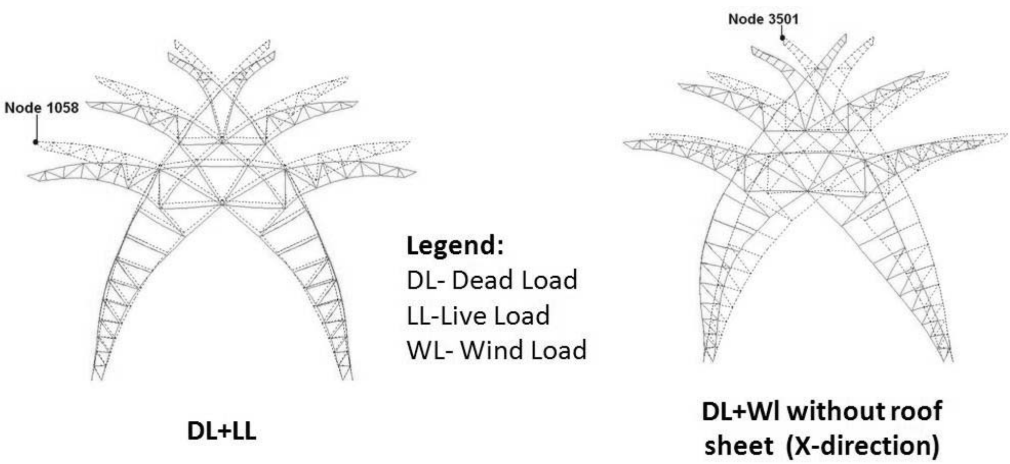

Figure 10: Deflected shapes for DL, LL and WL

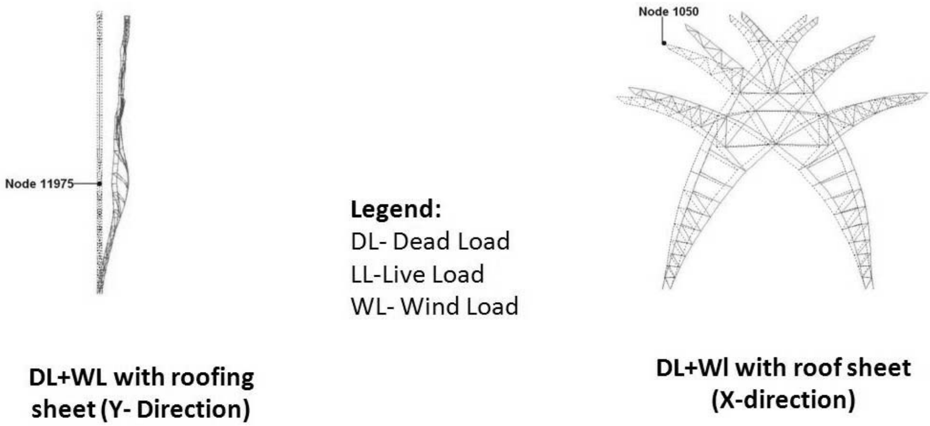

Figure 11: Deflected shapes due to DL and WL

Figure 12: Central Spine under construction

7 ACKNOWLEDGEMENTS

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8 REFERENCES

[1] IS: 875 (Part 1, 2 and 3) – 1987, *Indian Standard- code of practice for design loads (other than Earthquake) for buildings and structures,* Bureau of Indian Standards, New Delhi, 1989

[2] IS: 800 – 1984, *Indian Standard- code of practice for steel design,* Bureau of Indian Standards, New Delhi, 2002