MASTERS IN MECHANICAL ENGINEERING

MASTER THESIS

3D Modelling of Eiffel Tower using the Original Drawings

by

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A sincere gratitude to Prof. Stefano Tornincasa for the guidance and support.

Dedicated to my Parents and all my friends.

Special credits to my friends Chinthala Raviteja Reddy, Seelam Surendra Rajkumar and Chanti Koutil for all the support during the hard times.

Virtual credits to Tarun Kollarpati

Abstract

The Eiffel Tower was built in 1889 to celebrate the French Revolution's Centennial year during the Exposition Universelle at the Champe de Mars. The Eiffel Tower was completely built using Metal. Iron was the only material for a structure of this kind at those time as reinforced concrete did not yet exist.

Studying and understanding the Original Drawings of Eiffel Tower which is in French Language. Detail study of all the Crosslinks and Crossbars in the Tower. The studied drawings are replicated in Solidworks. Modelling of complete structure in simple way and simulating the whole structure or a part for wind effect.

Contents

1. THE EIFFEL TOWER

In 1900, on the eve of the opening of the fifth Universal Exposition in Paris, Mr. Gustave Eiffel was already a living myth. The 300 metre Tower that he had completed for the fourth Universal Exposition of 1889 had in fact borne his name even before that, namely since 1887, when the project conceived by his chief engineers, Maurice Koechlin and Emile Nouguier, was first accepted for the exhibition programme. Having compelled recognition as a monument to the glory of industry, the Eiffel Tower was by now also aa familiar sight to Parisians and tourists alike. It was still only a temporary structure, but it was anticipated that it would remain one of the attractions of the 1900 Universal Exposition, even if aesthetic tastes had since shifted towards more exuberant forms and the Tower was attracting only half of the visitors it had drawn in 1889.

Eiffel himself was rich, famous, and heaped with honours. Although retired from business, having been vilified and bruised by the Panama scandal in which he was amongst those implicated, he had thrown himself into a new carrier as a scientist. He now devoted his free time and ample fortune to advancing the study of meteorology and aerodynamics, all the time seeking a reason to prolong the life of the otherwise useless Eiffel Tower.

The two-volume compendium that he compiled so painstakingly for publication was at once a summing -up gift and an act of propaganda : this Tower, whose every detail is laid bare, must be preserved because it represents an extraordinary accomplishment of human genius and because it can offer a starting-point for various scientific experiments.

Eiffel was too aware of its importance not to claim paternity of the monument. By way of a frontispiece, opens with a portrait of Eiffel engraved by Mozzachi. It was undoubtedly Eiffel's talents as an engineer that propelled him into the pantheon of great inventors of structures. But his technical abilities would have been little without the skills he demonstrated as a businessman, capable of transforming his boldest ideas into built reality, gifted with determination and ambition that lead to take calculated risks in particularly favourable economic climate marked by the expansion of railways and the rise of metal construction.

The story of Eiffel is not simply that of a brilliant engineer, it is also that of the company he founded and to which he gave his name Beyond the epic tale of the individual, the progress of his business illustrates, in model fashion, how his success arose out of the conjunction of technical innovation, notably in construction process , the mastery of industrial manufacturing, the insistence upon quality, the mobilisation of talents and capital thanks to the charisma of the founder, the exemplary organisation of production and distribution, the skilful negotiations of contracts, good public relations and the constant application of pressure in the right places.

Eiffel built up his business just as he constructed his own myth- through his merits as an engineer and though his pronounced feel for commercial relations and his own publicity, which focused the success of his business on his person and on his name. From this point of view, the Tower represents a dual accolade: for the world's most famous engineer and for the inventor of a new world. But Eiffel was too far-sighted a businessman not to pay tribute to those who collaborated with him on the project. The three hundred and twenty-six engineers, foremen and labourers who designed, manufactured, and built the Tower are all acknowledged.

1.1. Mr. Eiffel's Tower

In 1884 Eiffel reached the age of 52 plans for a Universal Exposition to mark the centenary of the French Revolution of 1789.Not only would such an exhibition boost the economy with the major building works it would entail, but it would also restore France's "status" amongst the major powers. The centrepiece of the exhibition was to be a grand monument. The new possibilities opened by advances in technology and engineering had already encouraged inventors to dream of new way of defying gravity. In 1833, for example, the Englishman Richard Trevithick had proposed to build a cast-iron column a thousand feet high. The American engineers Clarke, Reeves & Co. Took up a similar idea with their proposal for a tower one thousand feet high for the Philadelphia Centennial Exhibition of 1876,and in 1881 the engineer Sebillot came back from America with a project for a 300 metre-high iron "sun tower “on which would be mounted an electric light capable of illuminating all Paris .He subsequently teamed up with Jules Bourdais, Architect of the Palais du Trocadero, to propose a highly ornamental masonry tower.

In June 1884 with the idea of a colossal structure already in the air, therefore - Eiffel's two chief engineers, Émile Nouguier and Maurice Koechlin came up their own design for a tower. Conceived as enormous metal pylon, comprised four exposed latticework legs made of iron, flared at the bottom and converging at the apex, which were tied together by further metal struts at regular intervals .Iron was the only material in question for a structure of this kind: reinforced concrete did not yet exist and even the tallest stone edifice ,the Washington monument still under construction (it would be completed in 1885),was only 555 feet (169 metres)high. Eiffel had by this time perfectly mastered the principle of building bridge piers, and the tower project was bold extension of the principle to height of 300 metres -equivalent to the symbolic figure of one thousand feet. The curve of the uprights was mathematically determined to offer the best possible resistance to the wind, which exert a horizontal force on the tower.

As Eiffel explained in his lecture to the society of civil Engineers on 30 March 1885, it was necessary to "do away with the large lattice bars on the vertical faces destined to withstand the action of the wind. To this end, the pillar is positioned in such a way that all the shearing force of the wind passes into the interior of the leading edge uprights lines drawn tangential to each upright, with the point of each tangent at the same height, will always intersect at a second point, which is exactly the point through which is passes the flow resultant from the action of the wind on that part of the tower support situated above the two point in question. Before coming together at the high pinnacle, the uprights appear to burst out of the ground, and in a way to be a shaped by the action of wind.

Nouguier and Koechlin's initial design were too technical for the Paris exhibition, which demanded more sophisticated works of architecture. Eiffel, meanwhile, had other matters on his mind and did not give the project his full attention, although he authorised his engineers to develop their idea in further depth. In order to make the project more acceptable to public opinion, the architect Stephen Silvester worked on the tower's appearance: his proposals included clad ding the feet in stonework pedestals, linking the four uprights and the first level by monumental arches which could serve as entrance gates to Exposition, and introducing large glass-walled rooms He also designed a bulb-shaped pinnacle and various ornamental features to embed top lish the whole. Presented with this modified version of a tower that could now be opened to completely changed his mind and visitors, Eiffel hastened to register a patent in the names of Eiffel, Nouguier and Koechlin "for a new configuration allowing the construction of piers and metal pylons capable of exceeding a height of 300 (three hundred) metres" (patent no. 164 364 dated 18 September 1884, National Institute of Industrial Property).

Eiffel subsequently purchased from his two colleague's exclusive ownership of the patent, including the international rights, in return for a premium of 1 percent of the total construction cost. The essential details of the project were finalised a few months later and rep resented a compromise between the initial design and its more decorative alternative. While Eiffel meanwhile attempted to discredit a rival project for a masonry tower put forward by the architect Jules Bourdais, on 1 May 1886 Edouard Lockroy, the new Minister of Commerce, announced a competition for ideas for the general layout of the 1889 Exposition.

The competition was open to French architects and engineers, and entrants were invited, amongst other things, to examine the possibility of erecting on the Champ de Mars an iron tower on a 1 square base, 125 metres wide at the base and 300 metres in height". It was an explicit reference to the project proposed by Eiffel, who had by now convinced the authorities of the merits of his plan. The competition attracted 107 entrants, the majority integrating the design of the tower proposed by Eiffel. The three first prizes were awarded to Ferdinand Dutert, Jean-Camille Formige, and Eiffel and Sauvestre, all of whom were commissioned to build an important structure for the Exposition - Eiffel and Sauvestre, of course, the 300-metre Tower.

Certain architectural details of the tower were now revised: the decoration was simplified, the scale of the arches limited, the size of the internal rooms reduced. The iron structure, on the other hand, affirmed itself as the dominant element of the composition. In January 1887 an agreement was signed between Eiffel, the French state and the city of Paris granting Eiffel a concession to operate the tower for twenty years in his own name, plus a subsidy amounting to 1,500,000 francs, which covered barely a quarter of the construction costs.

Anxious to protect his company, but also to reserve for himself full paternity of the project and any profits it generated, on 31 December 1888 Eiffel created a stock company with a capital of five million francs in order to provide the remaining financing for the project. Eiffel himself put up one half of this money from his own personal fortune, while the other half was provided by a consortium of three banks. The installation of the elevators would add another one and a half million francs to the budget, taking it up to a total of 7,800,000 francs. These costs would be recouped in just a few months, however, simply during the exhibition itself.

1.2. The Artist's Protest

Construction work had hardly begun when there appeared in the pages of Le Temps, in the issue of 14 February 1887, the famous "Artists protest against Mr Eiffel's Tower". Amongst the forty or so signatories were several leading names, including Charles Gounod, Guy de Maupassant, Alexandre Dumas the Younger and others less favoured by posterity. These defenders of the "beauty of Paris, until now intact". wished to protest "in the ignored name of French taste, in the threatened name of French art and history, against the erection in the very heart of our capital of the useless and monstrous Eiffel Tower, which popular ill-feeling, so often an arbiter of good sense and justice, has already christened the Tower of Babel. Is the city of Paris any longer to associate itself with the outlandish, mercenary fancies of a constructor of works of engineering, thereby making itself irreparably ugly and bringing dishonour? Because the Eiffel Tower, unwanted even by commercial America, is, no doubt about it, the dishonour of Paris." The protestors concluded by denouncing this ridiculously vertiginous tower, dominating Paris like an enormous black smokestack" and casting "the odious shadow of its odious column of bolted metal like an ink stain" across the whole city.

Other pamphleteers carried the violent diatribe even further, hurling insults like this truly tragic street lamp" (Léon Bloy), "this belfry skeleton" (Paul Verlaine), "this mast of iron gymnasium apparatus, incomplete, confused and deformed" (Coppée), "this high and skinny pyramid of iron ladders, this giant ungainly skeleton" (Maupassant again), "this hideous pylon of iron bars, this funnel-shaped grill" (Joris- Karl Huysmans).

Eiffel responded by emphasising the intrinsic beauty which, in his eyes, the tower possessed: "Because we are engineers, is one to believe that we give no thought to beauty in out designs or that we do not seek to create elegance as well as solidity and durability? Is it not true that the very conditions that give strength also conform to the hidden rules of harmony?" Eiffel considered his Tower above all to be a work of engineering. If he drew an implicit com parison between it and the great pyramids of Egypt (which were only artificial hillocks, after all"), it was to emphasise the trivial and at the same time exceptional character of his Tower, which fell outside the bounds of the artistic creations of the epoch.

His attitude towards these latter, on the other hand, was thoroughly convention his houses his furniture his pictures, in short the interior decor of his private life reveal him in effect as a bourgeois perfectly satisfied with the tasted of his day. For Eiffel, the tower's aesthetic was not avant-garde but simply outside the norm. It was purely rational, abstract, referenced to the laws of science, and moral, a "symbol of strength in and of difficulties overcome".

Without being the product of an avant-garde approach, the Tower was nevertheless the herald of a new aesthetic of transparency and lightness, applied to the very act of construction. This could not fail to strike the artistic establishment once the Tower was completed. The criticism burnt itself out in the presence of the completed masterpiece and in the light of the enormous popular success with which it was greeted.

1.3. The Construction of Tower

The Tower was constructed at record speed, more so considering that the number of workers on site never exceeded two hundred. It took only six months to build the foundations and 21 months to erect the metal structure. Eiffel's confidence in the laws of physics and his wealth of experience as a constructor meant that work proceeded calmly and dispassionately, in a similar fashion to the building of his metal viaducts.

When the ground was first broken on 26 January 1887, Eiffel already had access to a smoothly efficient manufacturing tool: his factory in Levallois-Perret, the company's headquarters, where a large proportion of the Tower's components would be made from iron supplied by the Dupont and Fold ironworks in Pompey (Meurthe-et-Moselle). All the individual parts were prefabricated in the workshops by "the lads on the ground": they were calculated, traced, cut out and punched with rivet holes to an accuracy of a tenth of a millimetre, pre-assembled into iron sections a few metres in length and then delivered to the Champ de Mars. Should they reveal defects of any kind, they were not reworked on site but immediately sent back to the factory. Some 40 engineers and draughtsmen prepared the 700 larger-scale views and 3,600 detailed drawings required for the fabrication of the 18,000 components that make up the Tower. Two-thirds of the 2,500,000 rivets needed to hold the elements together were inserted by a team of 150 workers at the Levallois-Perret factory.

For two and a half years, the construction site proved a veritable public spectacle, its perfection prefiguring the object to come. First to be put in place were the foundations - massive blocks of concrete installed a few metres below ground level on top of a layer of compacted gravel. These support the four iron pillars, whereby each corner edge rests on its own concrete block, which is connected by walls to the other blocks. The Tower's 7.341 tonnes exert a pressure of 3-4 kilograms per square centimetre. On the Seine side, the foundations descended lower than the riverbed and had to be excavated with the aid of water tight metal caissons, injected with compressed air so that the builders could work below the level of the water. (Eiffel had already had occasion to use pneumatic caissons in the construction of his Bordeaux bridge in 1857).

The girders were initially erected as overhanging and the four pillars then supported by twelve temporary wooden scaffolds 30 metres in height. Having reached the level of the first floor, more scaffolding 45 metres in height was used to install the four large horizontal girders. Above this first floor, the uprights supported themselves. The pieces were hoisted up by special steam cranes, which rose upwards at the same time as the Tower, using the runners destined for the elevators.

The most delicate part of the construction was the joining of the four large girders on the first floor. Thanks to the use of "sand boxes", Eiffel was able to assemble the metal structure to an accuracy of one millimetre, by progressively lowering the corners. Two of the pillars could also be height-adjusted by hydraulic jacks. A space was built into each of the shoes to be able to hold a jack capable of 9.5 cm of travel and a force of 800 tonnes, operated by a hand pump. This made it possible to adjust the alignment of the corners by very small degrees and to regulate very precisely the junction of the four pillars with the platform of the first floor. The jacks were only temporary: once the four pillars were joined, they were replaced by permanent steel wedges. Contrary to legend, therefore, the Tower is not built on jacks

The shorter girders were pre-punched with holes while still in the factory and connected on site by means of rivets. To join two such lengths of iron, conical pegs were first driven in with a sledgehammer to force them into their final position. Temporary bolts were then inserted, to be progressively replaced by thermally assembled rivets. As the heated rivets cooled down, they contracted, thus ensuring the pieces were held together very tightly. Putting in a rivet required a team of four men: one to heat it to red-hot in a small oven, another to insert it into the hole, holding it by the pre-shaped head, a third to shape the head at the other end and a fourth to flatten the river with a sledgehammer. Each pillar required six teams, reducing to two above the second floor.

Shepherded by a team of veterans headed by the engineers Compagnon and Milon, the 17 riveters and "steeple-jacks" recruited from amongst the workforce rapidly mastered any fear of heights, despite the acrobatic environment and severe cold of the winter of 1888/1889. They worked nine hours a day, and up to twelve in summer. Considering themselves to be underpaid, the workmen went on strike in September 1888, and again three months later. Eiffel negotiated with them and giving some thought to the comfort of his workers also built a canteen on the first floor. The construction site suffered only one fatality: an Italian labourer who fell from the Tower outside his working hours, and whose widow was discreetly offered compensation.

1.4. Public Success

The Tower did not simply have to be built. It also had to be able to receive the crowds of visitors that were expected to attend the Universal Exposition. To this end, it was equipped with several elevator systems, the first of this size and this height. The elevators serving the first floor were housed in the East and West pillars and were supplied by the French firm of Roux, Combaluzier and Lepape. The elevators in the north and south pillars, serving the second floor, were supplied by the American firm of Otis, and consisted of a double-decker cabin raised by a cable driven by a hydraulic piston. All four elevators were subsequently replaced between 1899 and 1912 by hydraulic lifts built by Fives-Lille, as explained in detail in La tour de trois centimetres. The third floor was served by a two-cabin lift system built by Edoux. A hydraulic piston with a stroke of 81 metres raised the upper cabin, with the lower cabin forming the counterweight. Visitors thus had to change cabins halfway up. All the original elevators have now been replaced, although part of their machinery has been preserved.

The assembly of the four pillars commenced in July 1887 and on 7 December the horizontal girders of the first floor were seated into place. The second floor was reached on 14 August 1888 and the Tower ad at completed in March 1889.

The Tower was not merely a triumph of technology but also a huge popular success, It was instantly acknowledged to be an extraordinary achievement, not the just a worthy entrance to the Universal Exposition but and an absolute masterpiece of engineering. It received two million visitors during the exhibition. Already the elected President of the Society of Civil Engineers of for 1889, Eiffel was also made an officer of the Legion of Honour. Now aged 57, he was a multi-millionaire and was able to purchase a luxurious private mansion in Paris, where he reigned in patriarchal fashion over a large household. He also owned a string of homes in Sèvres, Beaulieu on the Côte d'Azur and Vevey in Switzerland.

1.5. The Scientist

Eiffel set himself first of all to demonstrating the scientific usefulness of the Tower, in a bid to prevent its demolition, which was scheduled for 1910 after the expiry of the lease that he had signed for 20 years. The Tower had served as a meteorological observation station since 1889, and its height of 300 metres also allowed it to be used for various physics experiments: as a giant manometer for calibrating instruments for measuring pressure, for a Foucault pendulum, for spectroscopic measurements and the recording of wind speed and atmospheric temperature, for experiments on the curative properties of altitude etc. Eiffel retained an office on the third floor for the purposes of his astronomical and physiological observations.

All this increased interest in the Tower but was insufficient to demonstrate its practical value. The Universal Exposition of 1900 seemed an appropriate occasion to give it a new lease of life. After various suggestions for modifications, some put forward by Eiffel himself, it was finally integrated into the exhibition just as it was. Eiffel nevertheless carried out some significant renovations, as he relates in La tour de trois centimetres. Firstly, the Tower was completely repainted, in an orangey red that shaded off towards an electrical floodlighting system was installed. The layout of the platforms was improved and new restaurants, in chalet style and offering music and entertainment, installed on the first floor. Eiffel's office on the third floor was opened to the public. The most substantial work of all was carried out on the elevators, The system put in place by Roux and Combaluzier was replaced with hydraulic elevators built by Five Lille and all the Tower's other machinery given a thorough overhaul. All these modifications are described in scrupulous detail in La tour de trois centimetre Despite the million francs spent on upgrading the elevators alone, the Tower only attracted a "modest" one million visitors, half the number that had attended in 1889. The modernism and radicalism of the Tower were out of step with the decorative excesses of the architecture of the Belle Epoque. From 1901, its visitor numbers dropped back to very low levels.

Eiffel resumed his scientific activities, but now devoted his chief attention to aerodynamics. To measure the effects of air resistance, he ran a cable from the second platform to the ground, down the length of which he dropped specimens of different profiles, attached to a recording device that enabled him to measure the various speeds at which they fell. He embarked on a first series of such experiments in 1903. In 1909 he built a small wind tunnel at the foot of the Tower, followed in 1912 by a much larger one on Rue Boileau, which is still in service.

Alongside these important contributions to aeronautics, he was also interested in radio. In October 1898 Eugène Ducretet set up the first telegraphic transmission between the Tower and the Panthéon, four kilometres away. Five years later, Eiffel lent his support to a brilliant young officer, Captain Ferrié, who was attempting to promote the military applications of wireless telegraphy. The Tower proved itself able to support long-distance communications: a first link was established in 1903 with the military bases in the Paris region and one year later with the east of France. With the installation of a permanent radio station on the Tower in 1906, its longevity was assured. The lease granted to Eiffel was renewed on 1 January 1910 for another 66 years. He lived long enough to hear Europe's first public radio broadcast, transmitted from the antennae of his Tower in 1921. He died on 27 December 1923, just eleven years too early to watch the first tele vision broadcast, also transmitted from the top of the Tower immortalising his name.

2. DRAWING STUDY

To understand anything to design or model it is very important have a complete study of drawings. In this section the drawing study of the Tower is been explained.

2.1. Elevation Drawing

The complete Tower is described in following Elevation drawing. Entire Tower is been divided into Three stages followed by Terrace Floor.

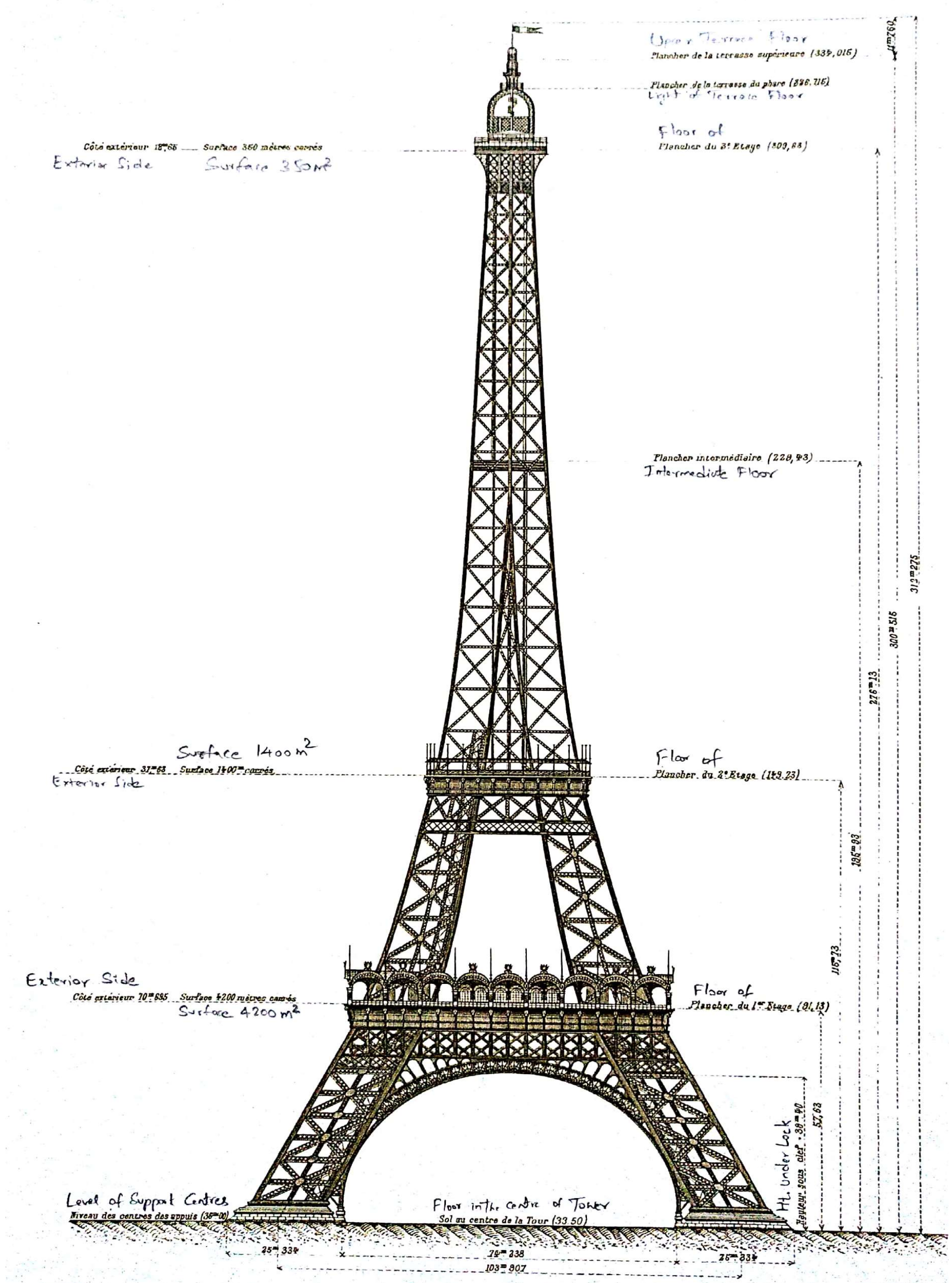


Fig.1 Elevation Drawing- Stages

The following Elevation Drawing is most important one which details about the individual heights. Entire Tower is divided into 30 Floors or Panels. This drawing also details about the distance within the Crossbows and distance between the Crossbows. These dimensions help in building the tower plane by plane up to 29 Towers.

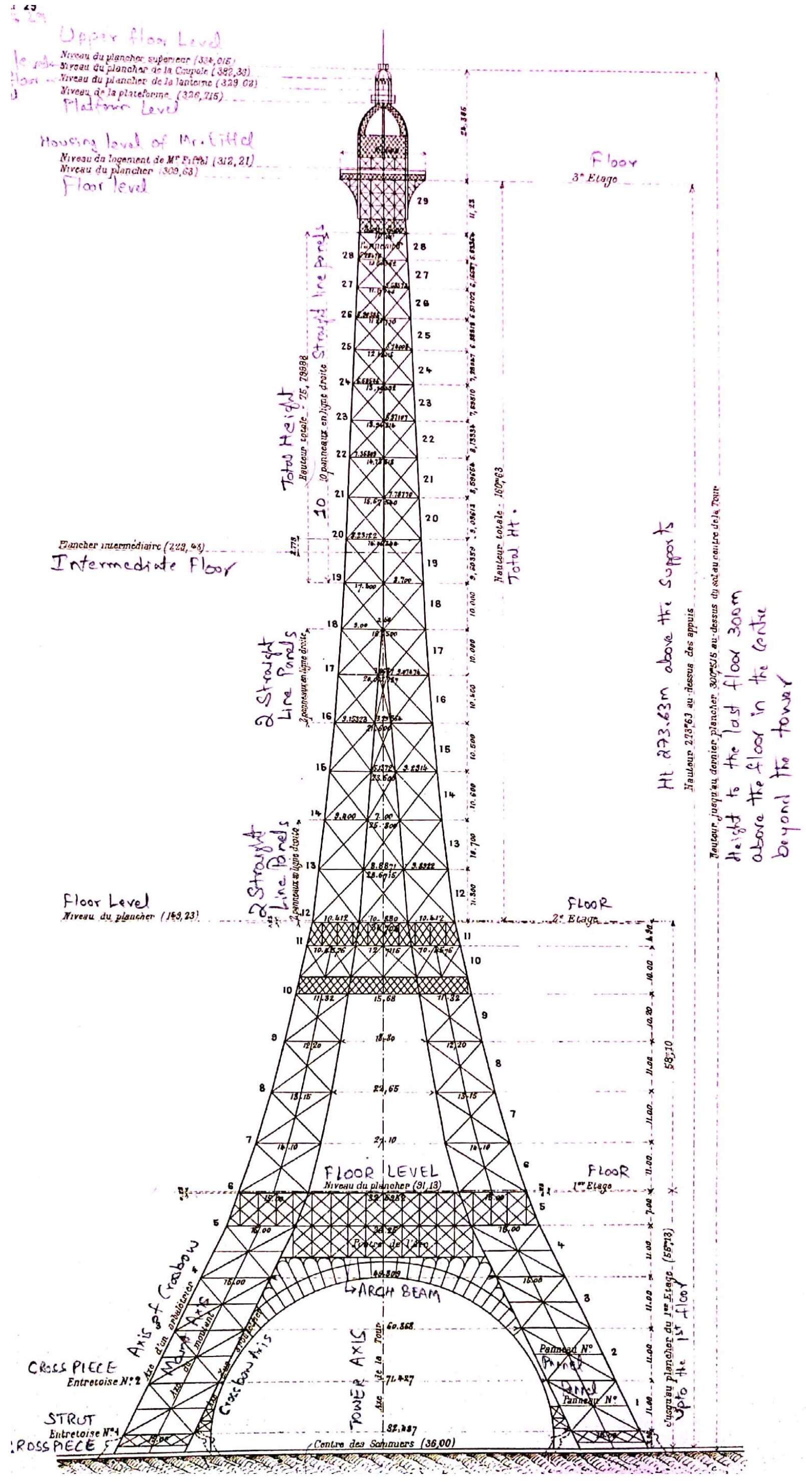


Fig.2 Elevation Drawing- Panels

2.2. Crossbows

The crossbows position changes as the elevation increases. From the following figures it can be noticed that the Crossbows reduces at different levels. It can be observed that in Lower stage there are four Crossbows at each corner making it to sixteen Crossbows. In the intermediate stage the Crossbows reduces to twelve Crossbows and at the upper part the Crossbow structure changes and reduces to just eight.

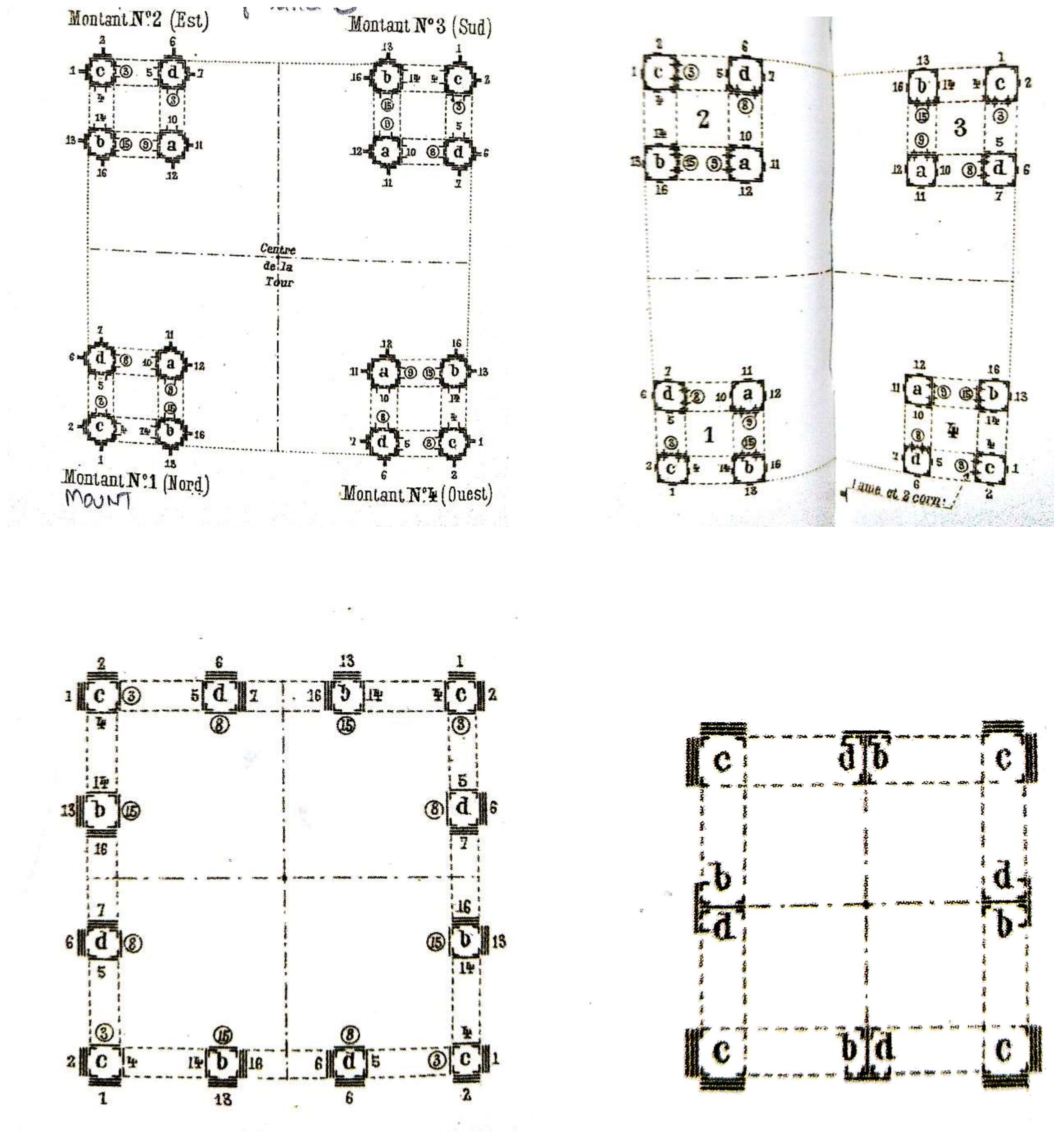


Fig.3 Crossbow Positions

2.3. Masonry

Following drawings of Masonry details about each Crossbow's foundation. It can be observed that the Base spring centre which is the Ground Level has been reached after 36 meters of deep Masonry. So, Tower is been given strong foundation of almost 10% of Elevation.

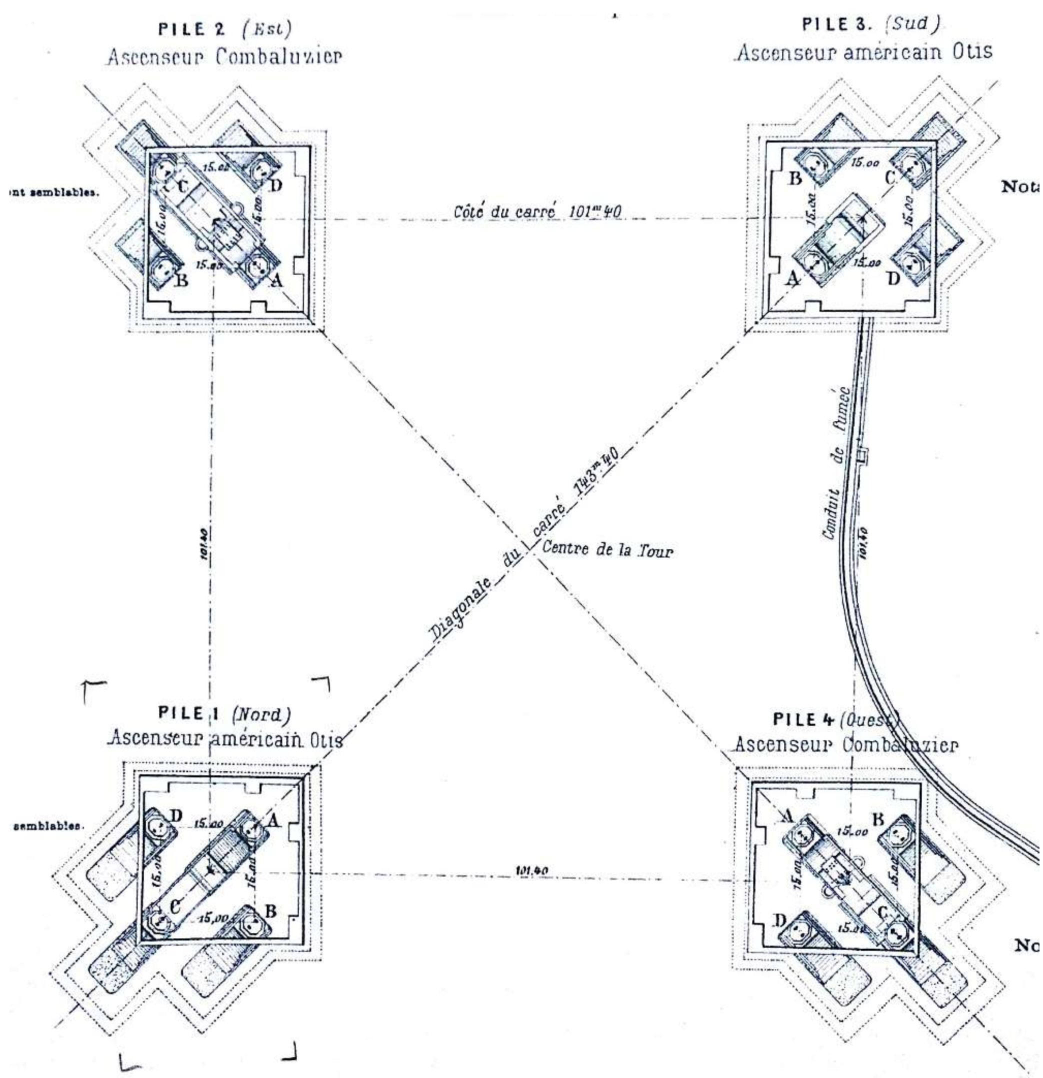


Fig 4 Masonry

As mentioned in the Elevation Drawing the distance between the Crossbows and within the Crossbows can be easily identified for the Lower part.

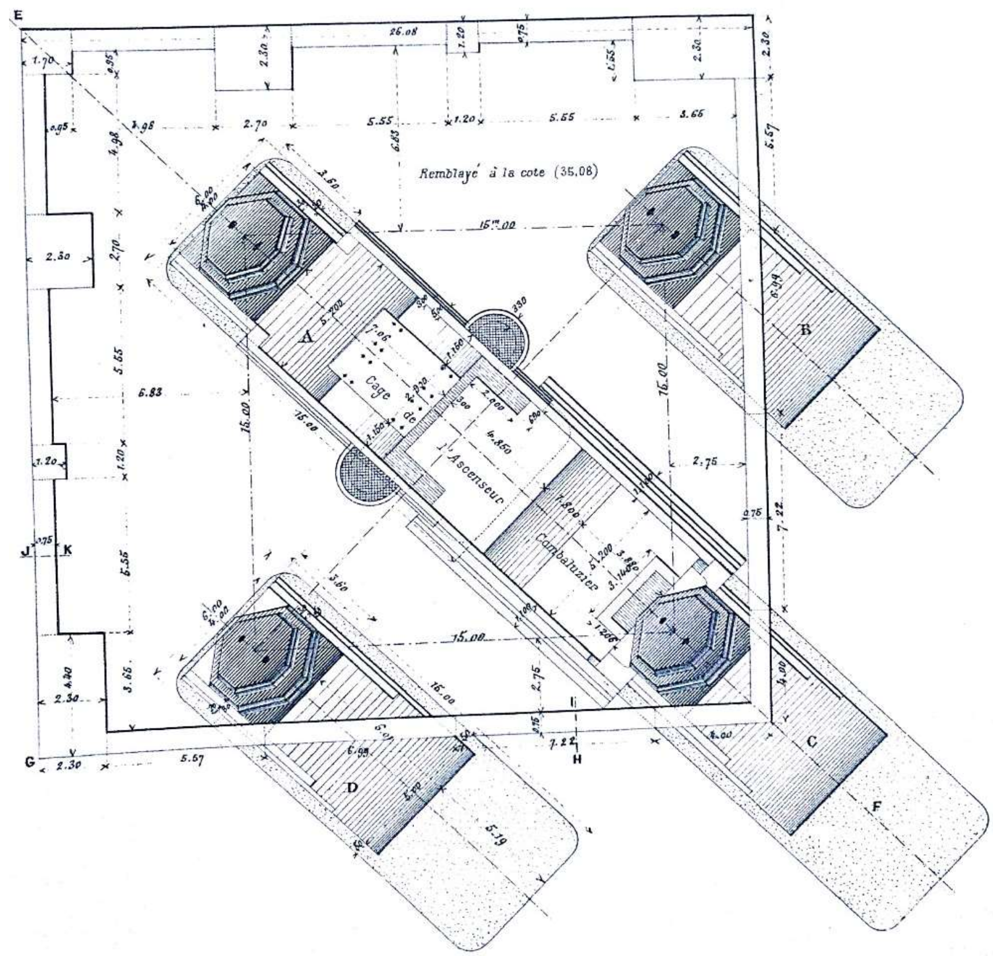


Fig. 5 Pile in the Masonry

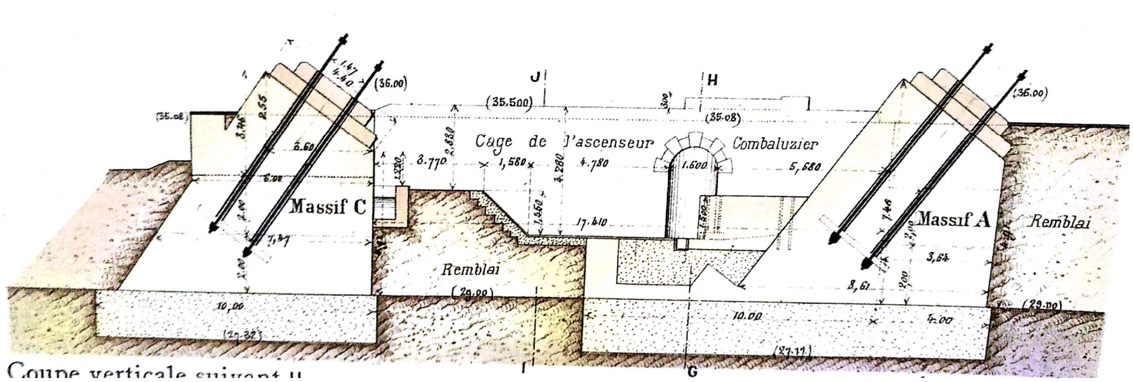


Fig.6 Pile in Cross Section

2.4. **Panels**

In the first stage there are 6 Panels. The first four panels are very similar with height of 11 meters and same inclination. The fifth panel is with different height of 7 meters in the same inclination. Later the inclination changes from Sixth Panel. There is an interconnected Beam Arc connecting Panels 4 and 5 of all the Piles.

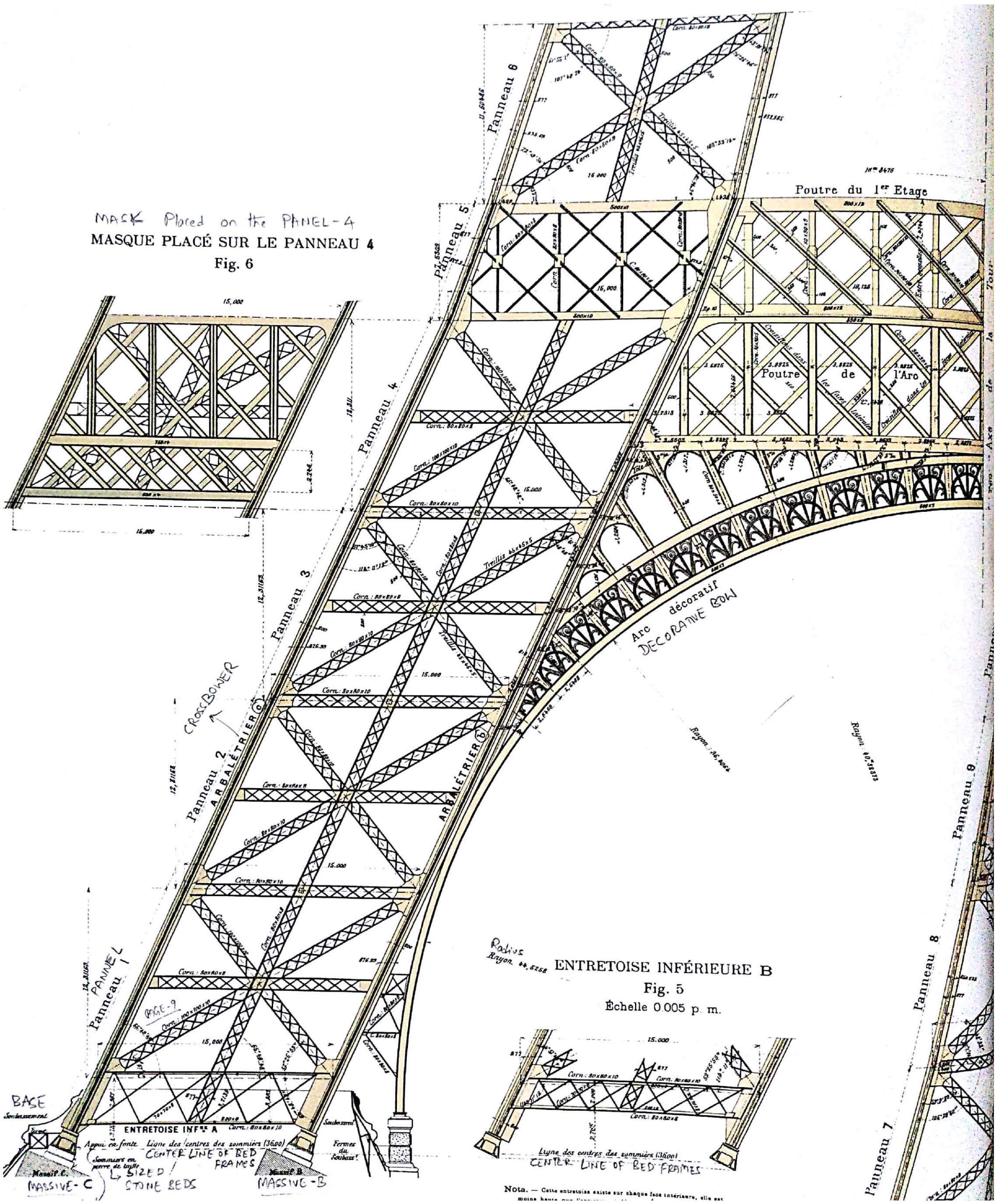


Fig.7 Details of Panels 1-6

The end of fifth Panel is the floor of first stage. After the sixth Panel it is no more of equal lengths, but the inclination is same. This inclination can be derived from the distances between Crossbows mentioned in Elevation Drawing.

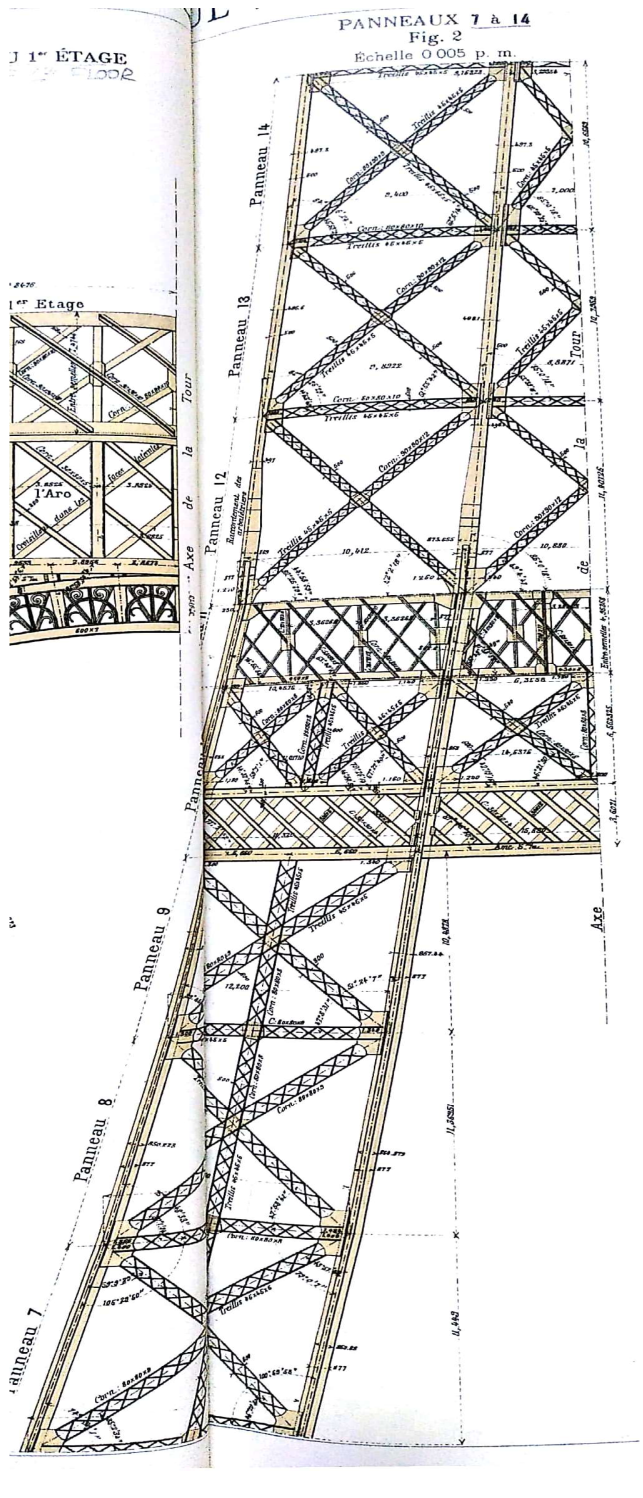


Fig. 8 Details of Panels 7-14

From Twelfth Panel the Crossbows are Converging. The inner Crossbows intersecting at twelfth floor is then elevating into single crossbow thus making sixteen crossbows into only Twelve Crossbows. Also, the inter-crossbars are connecting the Panels.

At the end of Seventeenth Panel again the Crossbows intersecting is converging to a single crossbow later making Twelve Crossbows into Eight Crossbows.

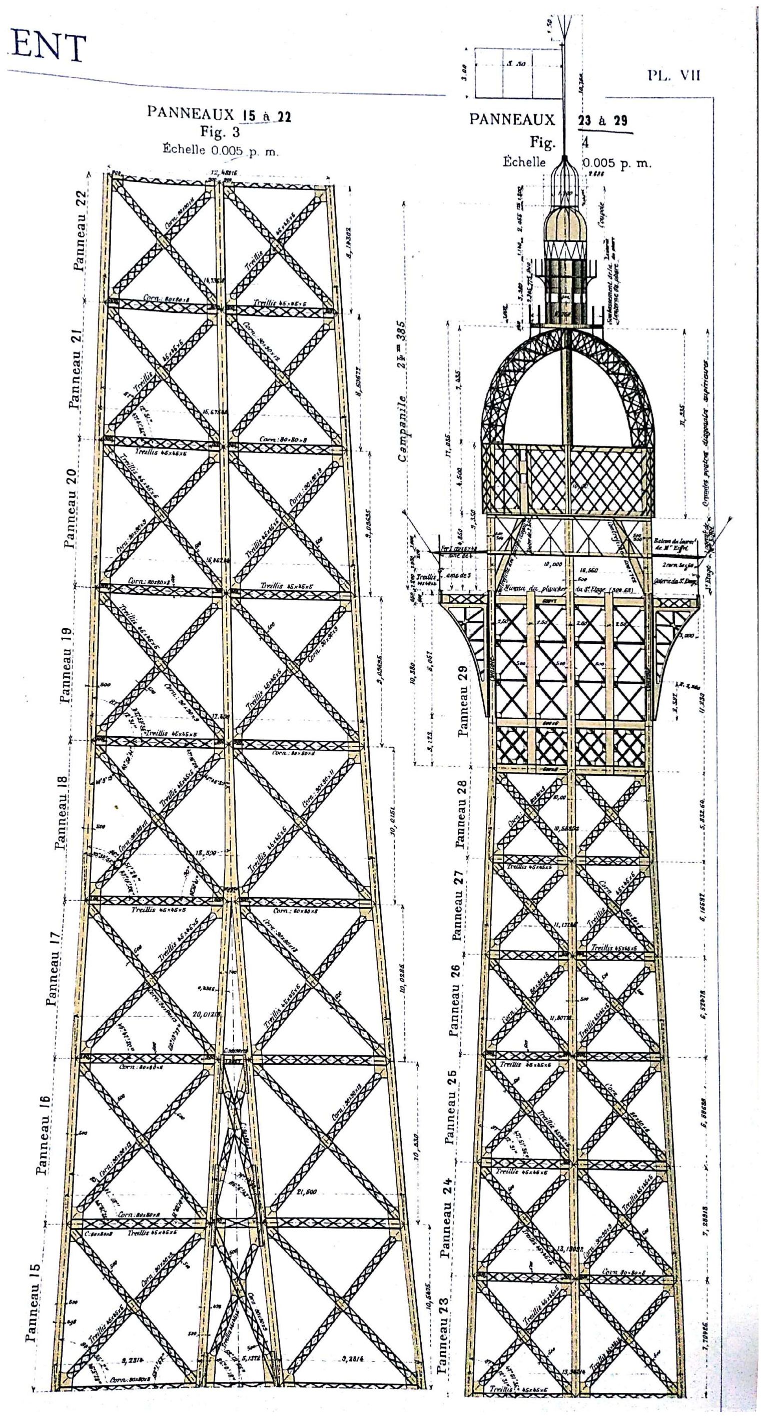


Fig. 9 Details of Panels 15 - 29

From Panels 18 to29 the elevation differs along with varying Crossbars.

Following figures gives the indications of Crosslinks and Crossbars connecting the Crossbows.

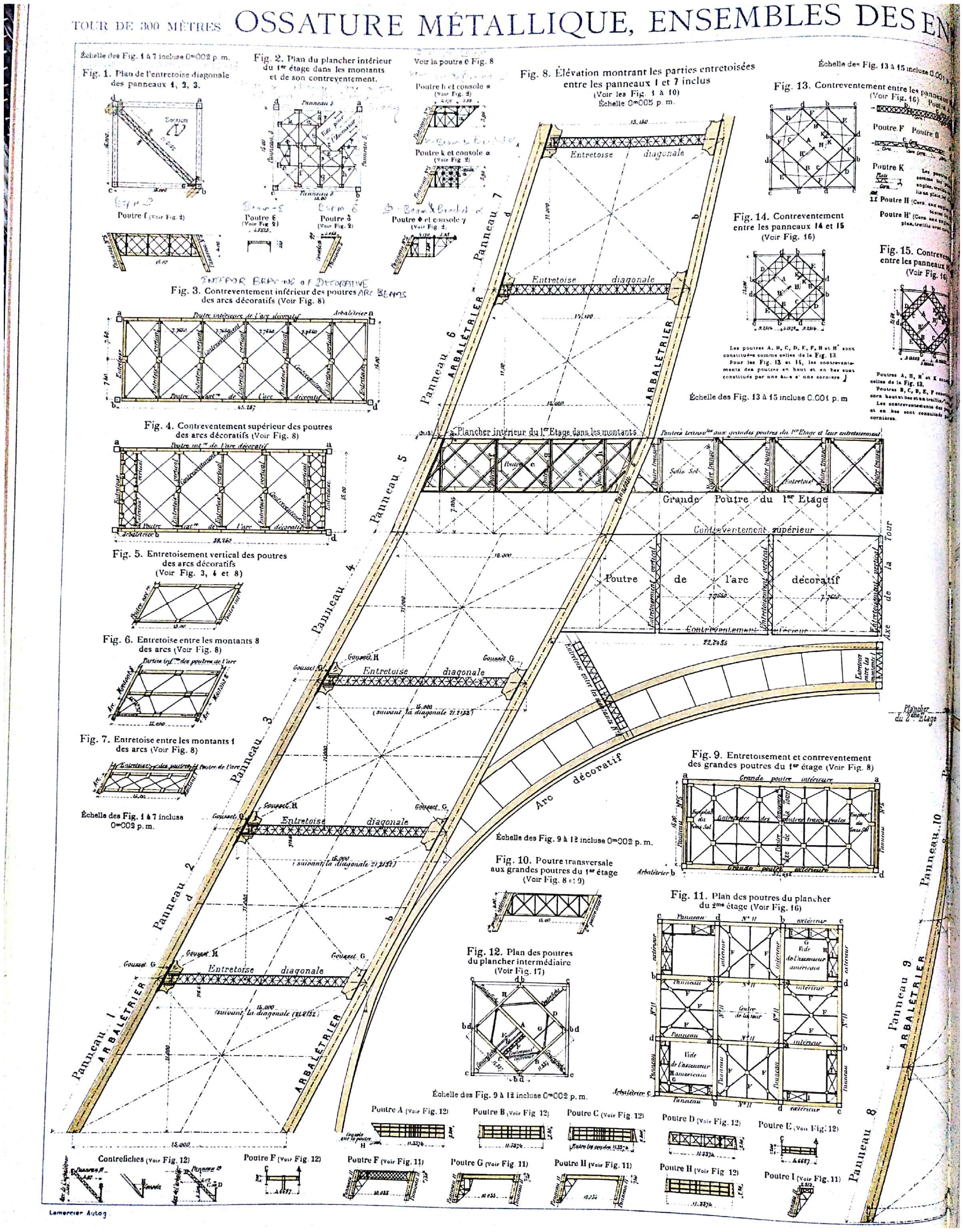


Fig. 10 Crosslinks in Panels 1-7

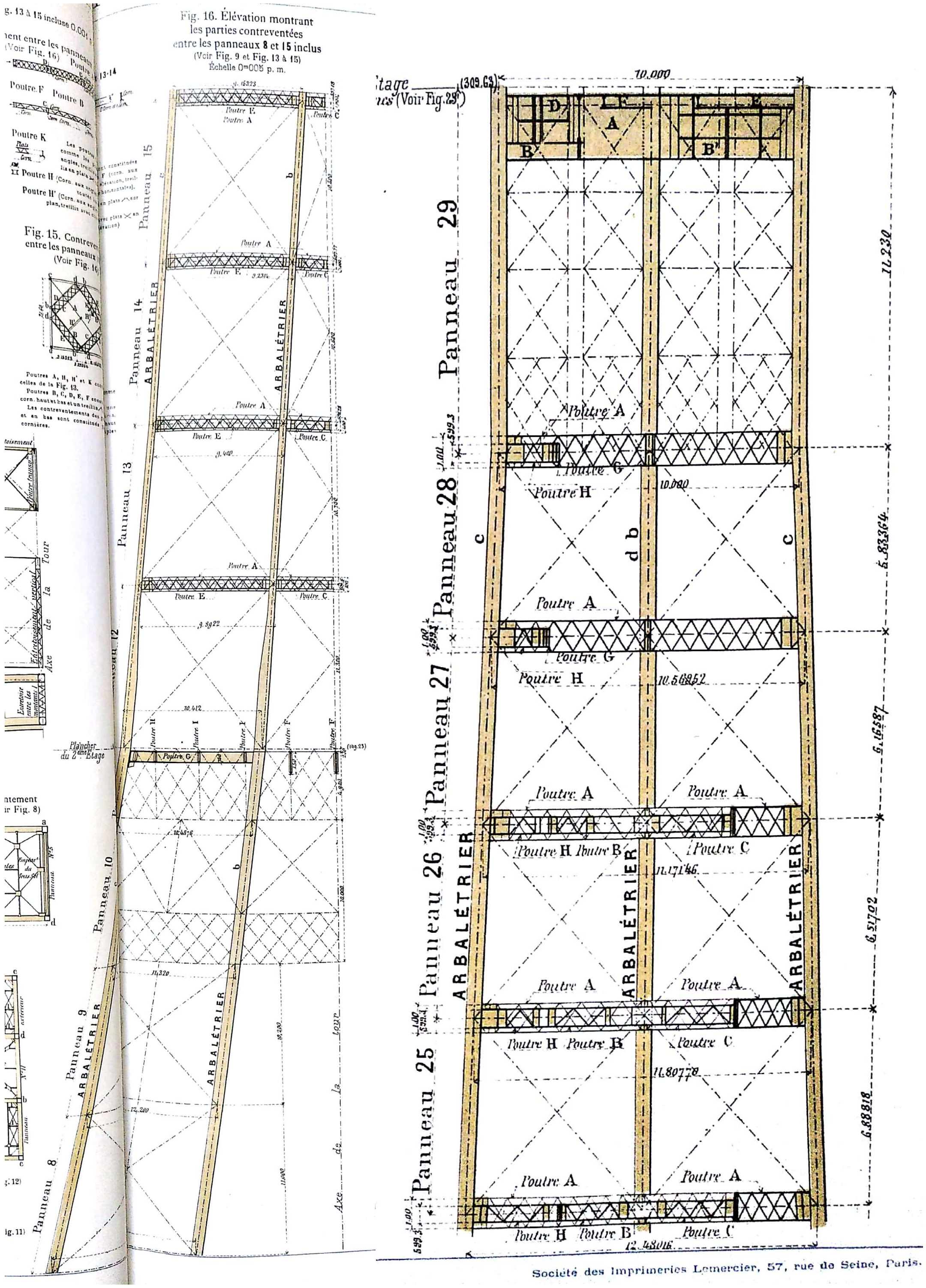


Fig. 11 Crosslinks in Panels 25-29

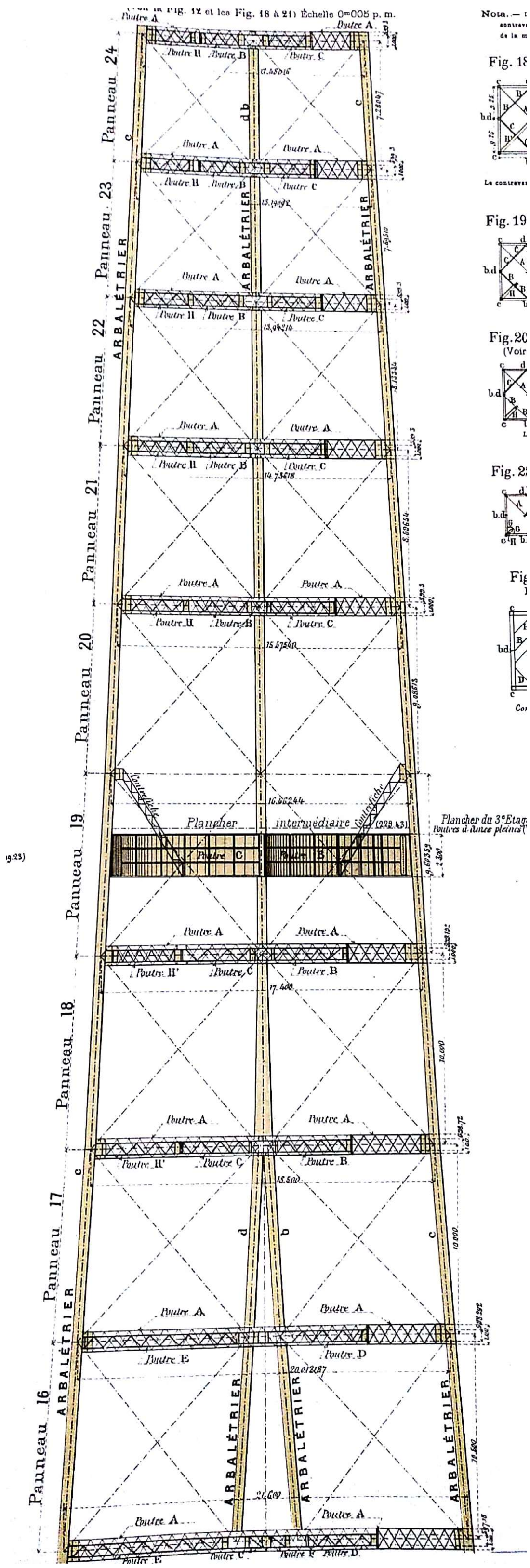


Fig. 12 Crosslinks in Panels 16-24

2.5. **Cross Bars**

Each Crossbow is connected by Crossbars which in turn are connected by Cross links.

Following figures represents Crossbars and Crosslinks of all the Panels.

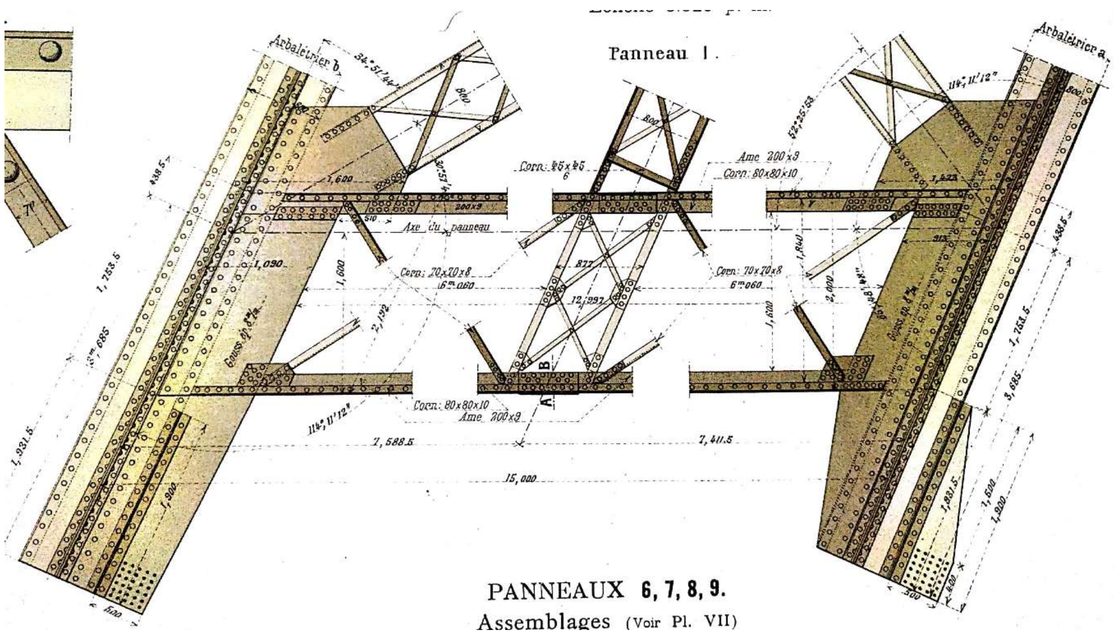


Fig. 13 Crossbars in Panels 6-9

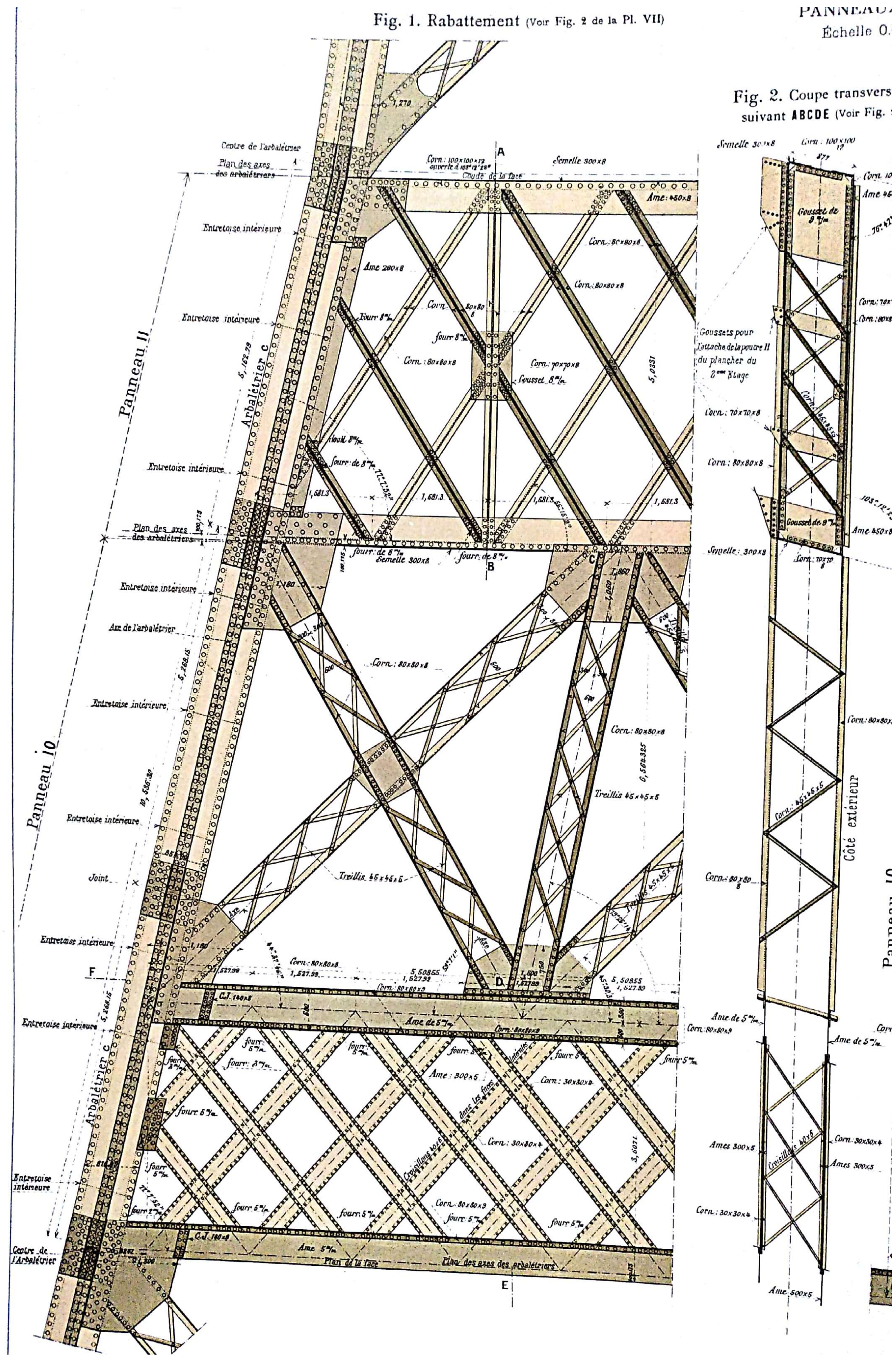


Fig. 14 Crossbars in Panels 10-11

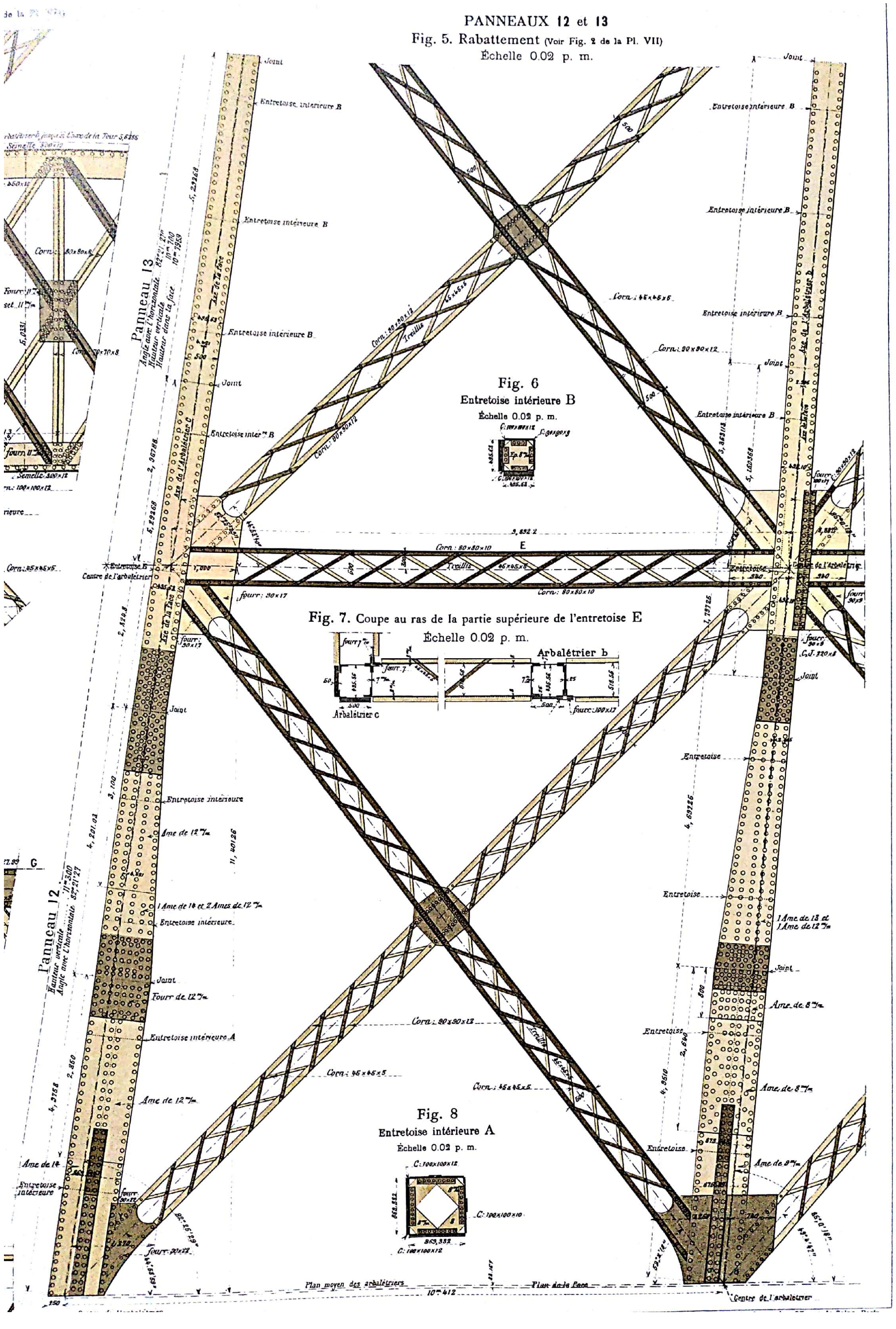


Fig. 15 Crossbars in Panels 12-13

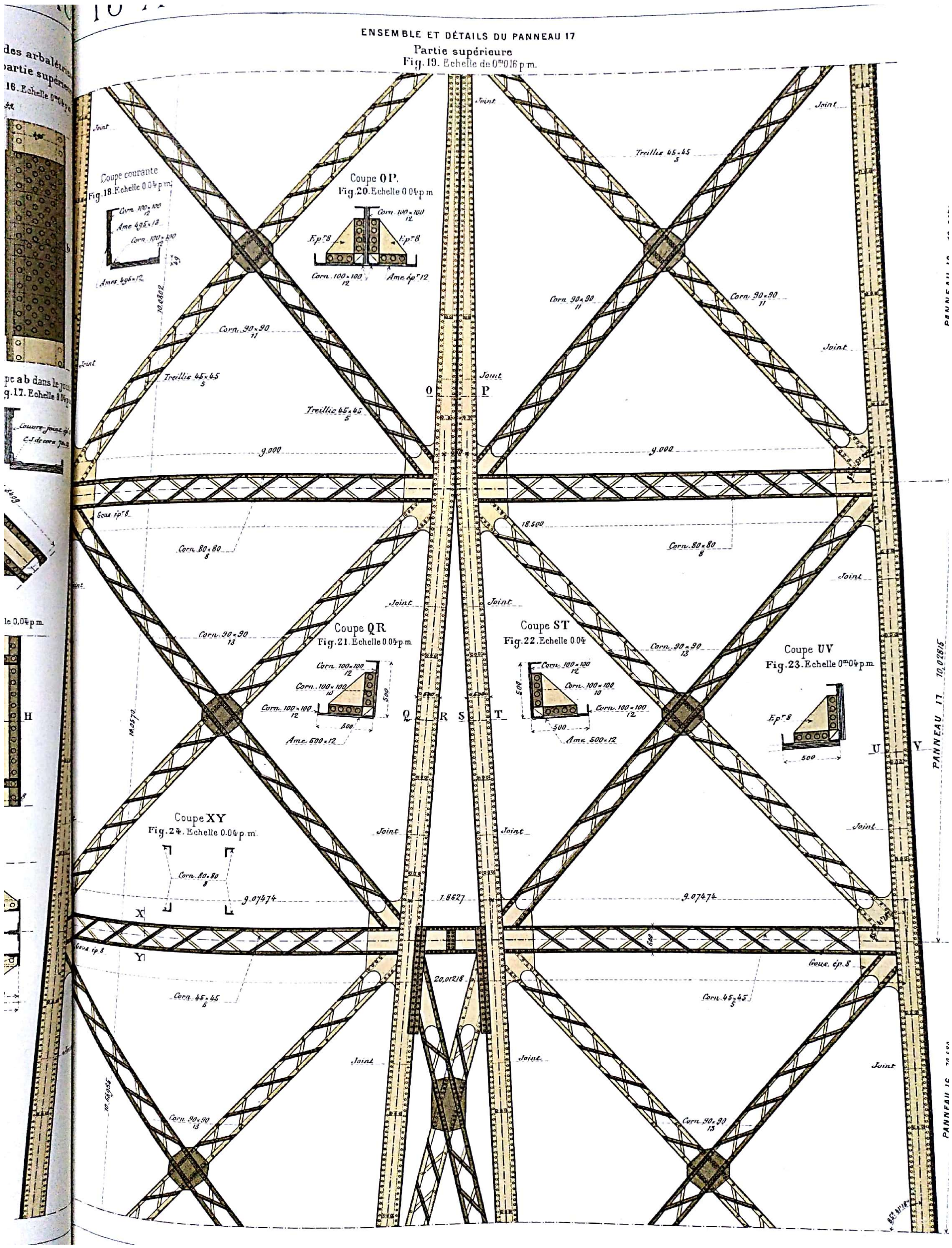


Fig. 16 Crossbars up to Panels 17

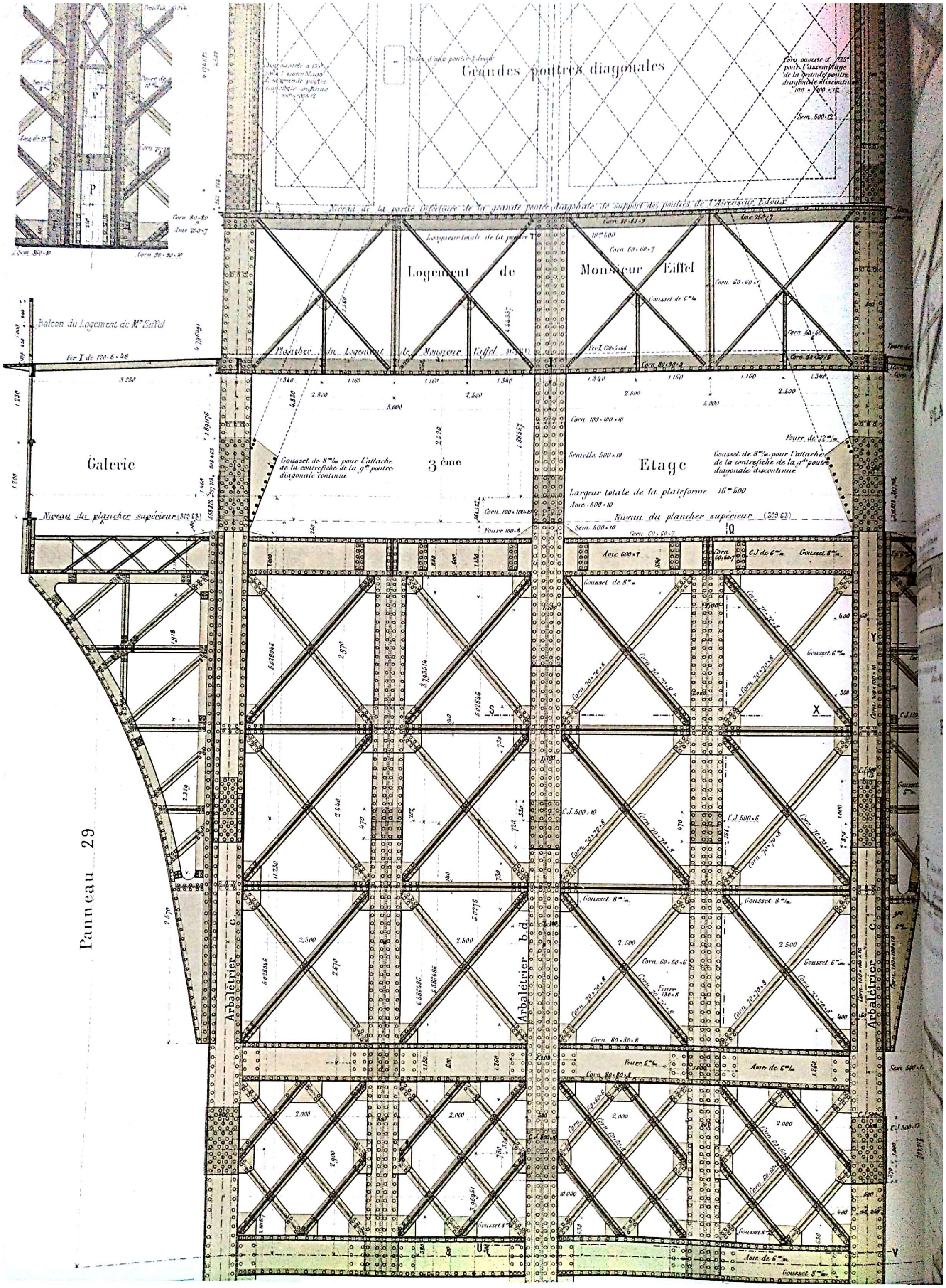


Fig. 17 Crossbars of Panels 29

2.6. **Upper Part**

The upper part is made into to Rectangular Platform with criss-cross bars connecting semi-circular. Finally, the top is covered by dome shaped sheet with a Pole Connecting at the centre.

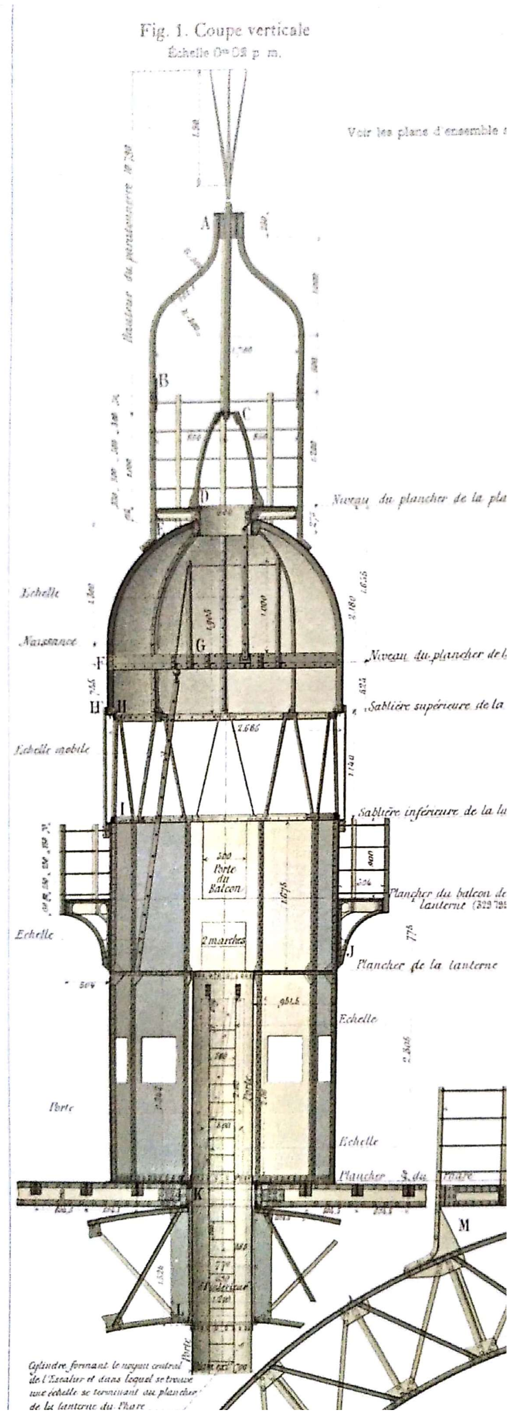


Fig. 18 Top Floor Dome Part

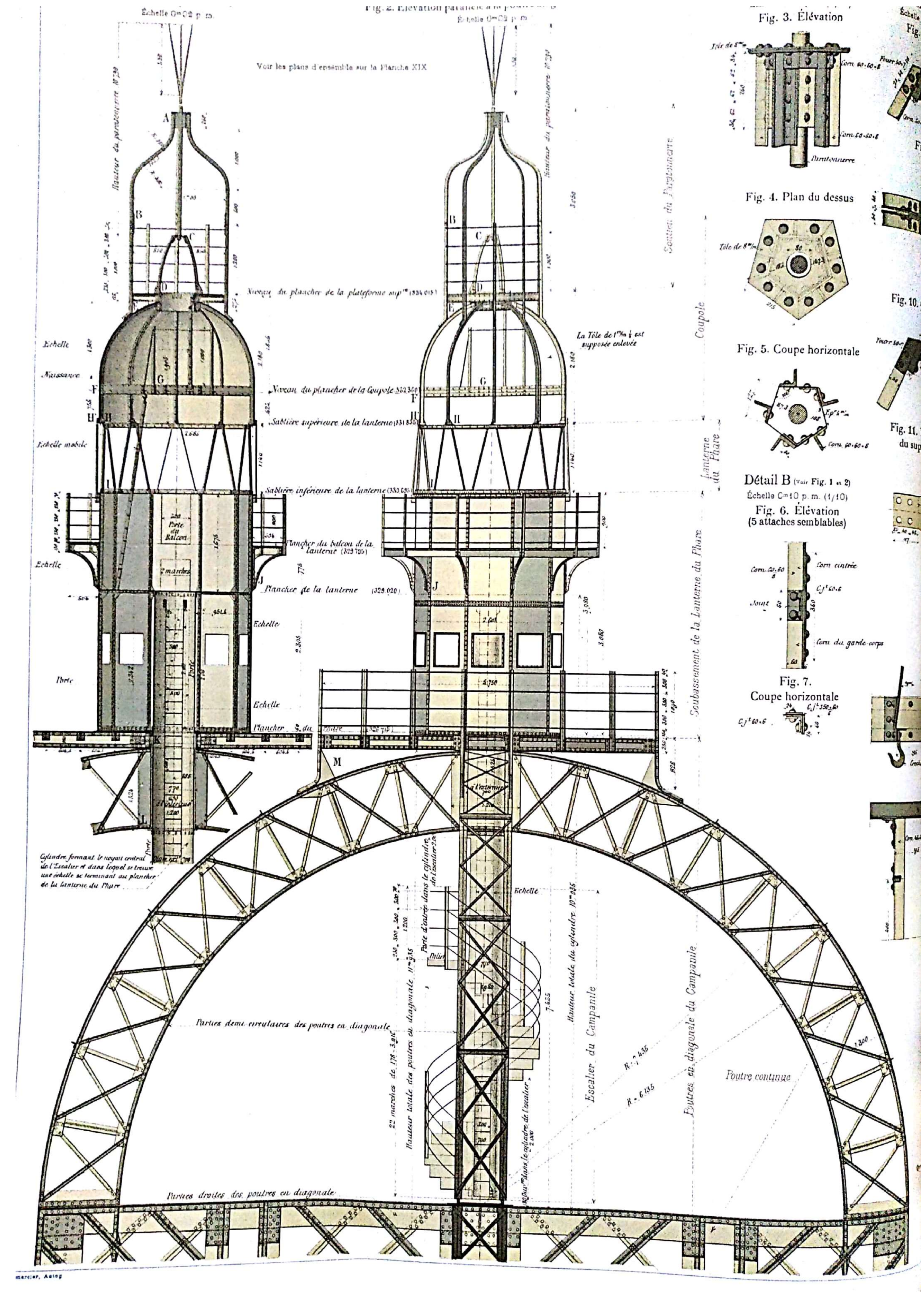


Fig. 19 Top Floor

3. MODELLING THE TOWER

The Crossbows of Tower is not leaned in a single direction or two direction. It is a Three-Dimensional inclination which cannot be modelled using simple Extrude command.

3.1. Crossbows:

Using the Elevation drawing the as defined in Elevation Drawing for the first Seven Panels the Planes are formed for each elevation as shown.

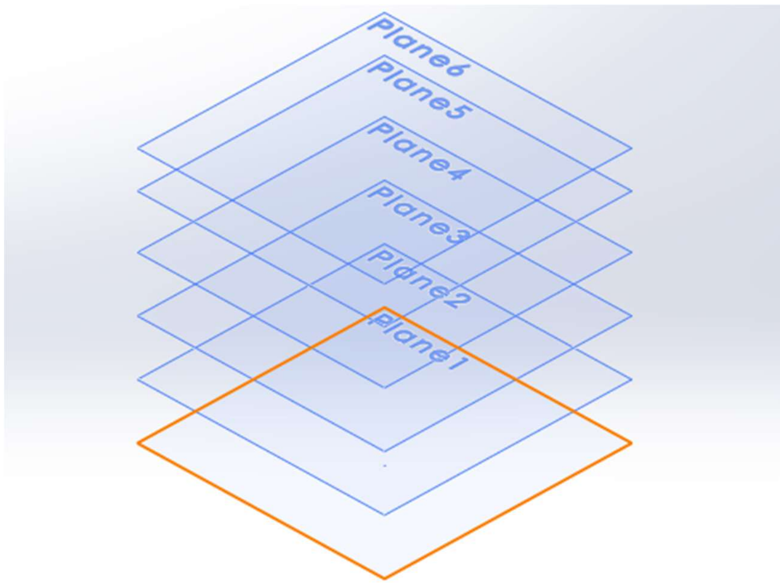


Fig. 20 Planes Creation

Once the planes are formed the cross section of Crossbows are drawn with distance been mentioned on Elevation Drawing.

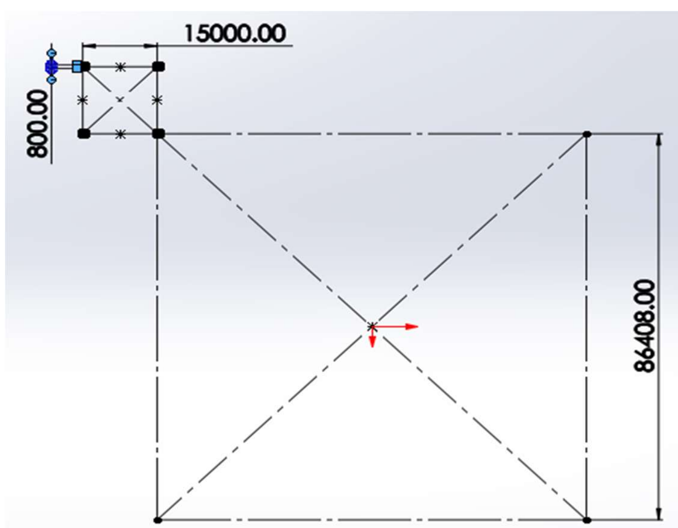


Fig. 21 Crossbow Section in individual Plane

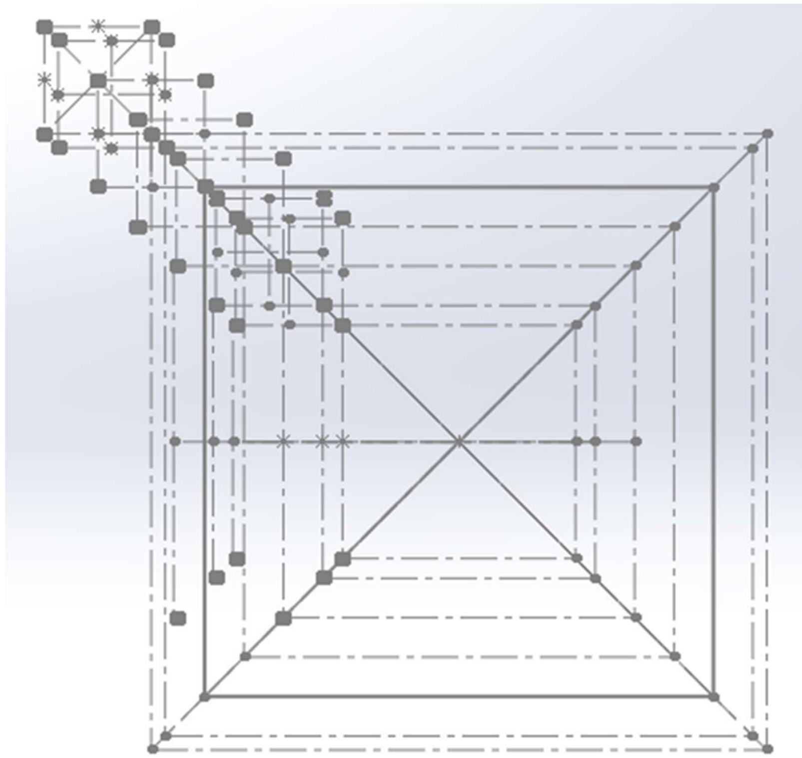


Fig. 22 Crossbow Sections of First Stage

Now the Loft command of modelling is used to Extrude these drawn cross sections into a Crossbow.

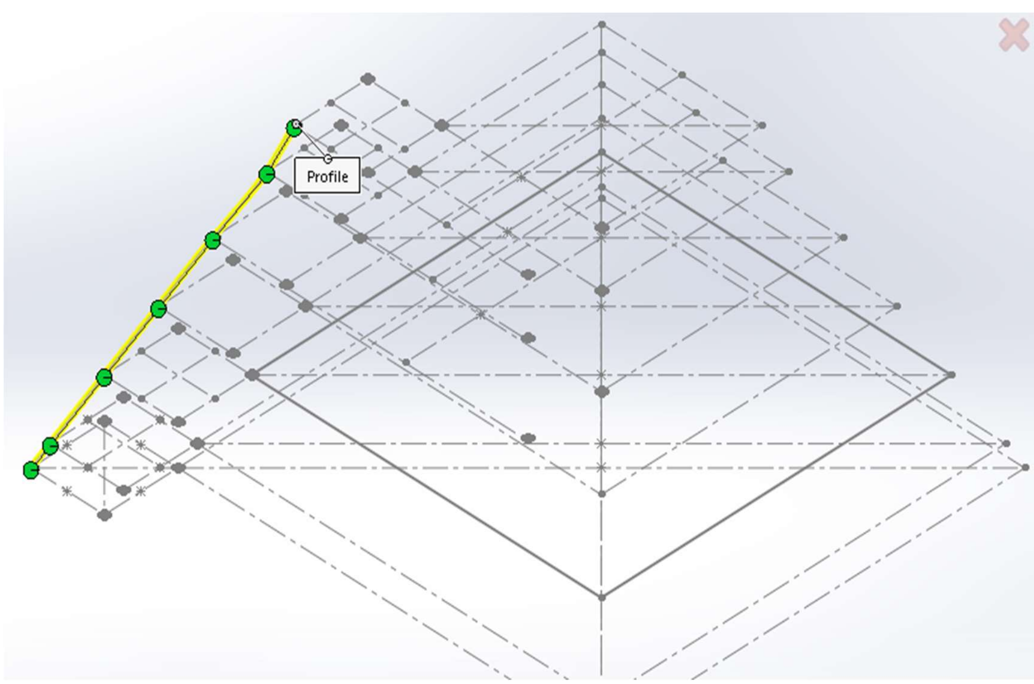


Fig. 23 Loft Tracing

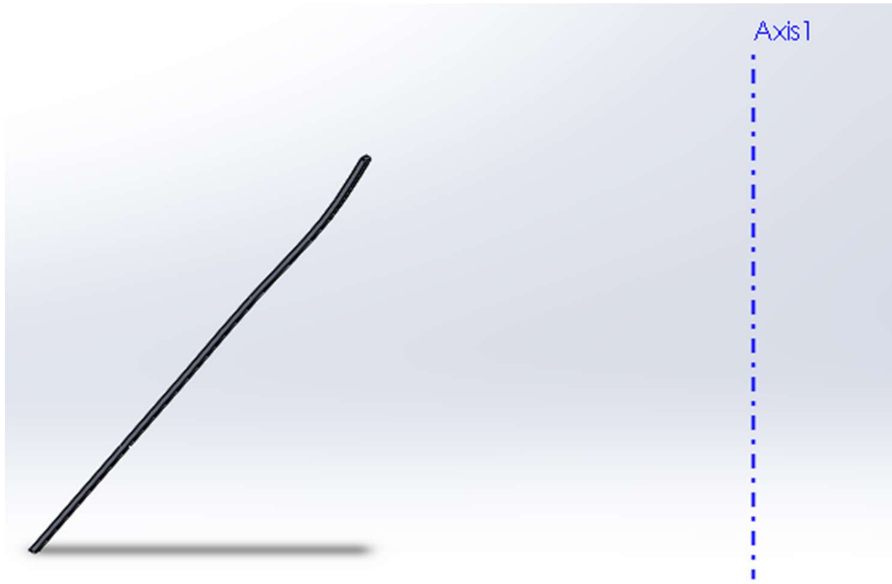


Fig. 24 Single Crossbow

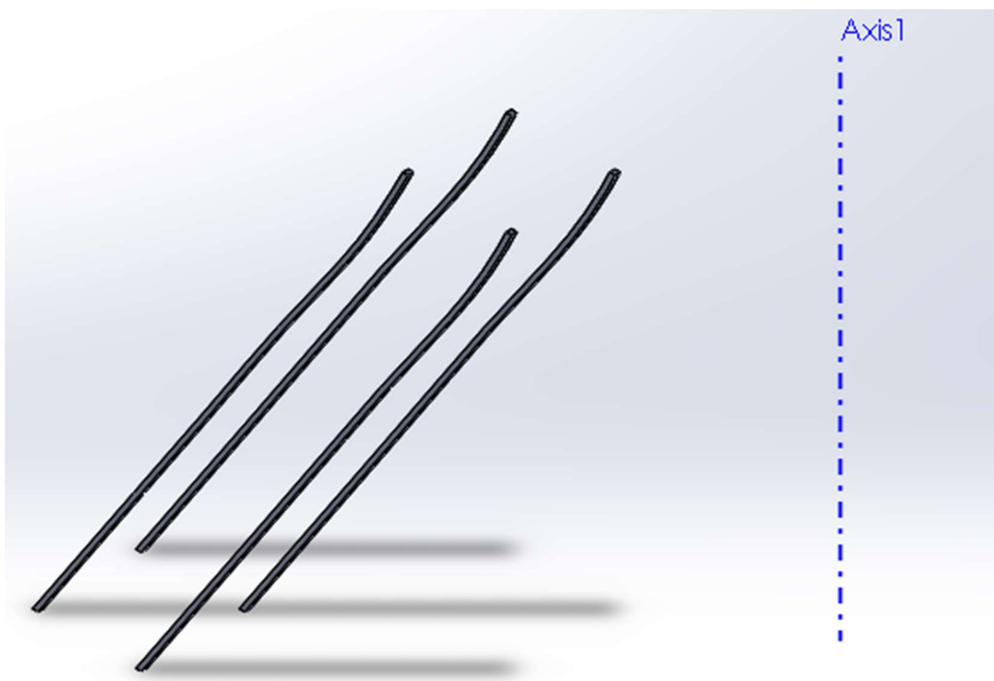


Fig. 25 Crossbow of a Pile

3.2. Crossbars

For each plane different Crossbars are to be created. For this another set of planes along the transverse direction must be created to mount. Now according to detail drawings of Crossbars each crossbar is modelled.

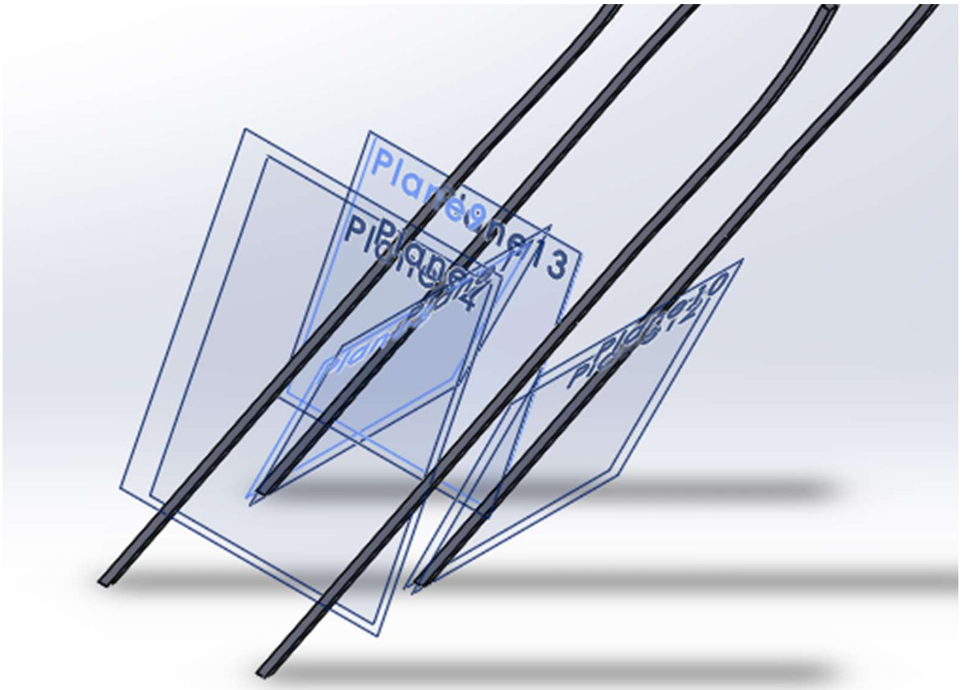
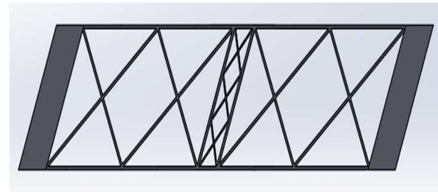


Fig. 26 Planes for Crossbars



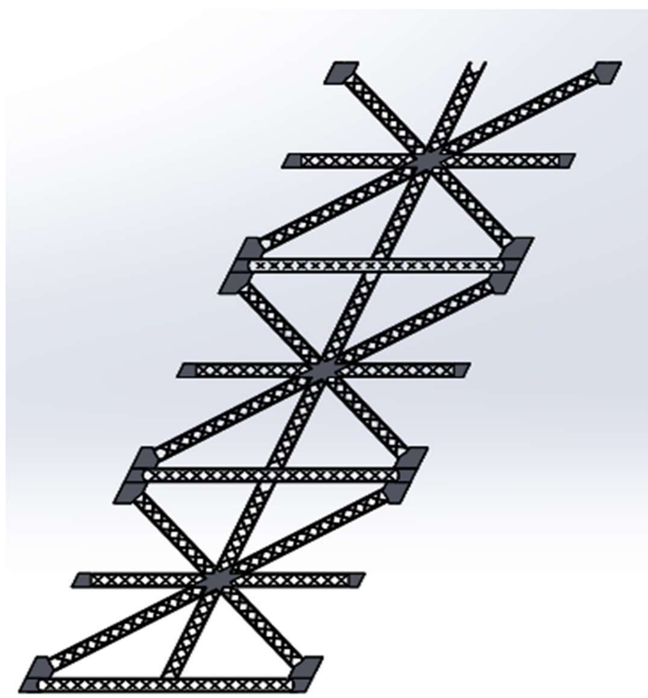


Fig. 27 Crossbars- First Stage

These modelled crossbars are assembled on to the Crossbow as shown.

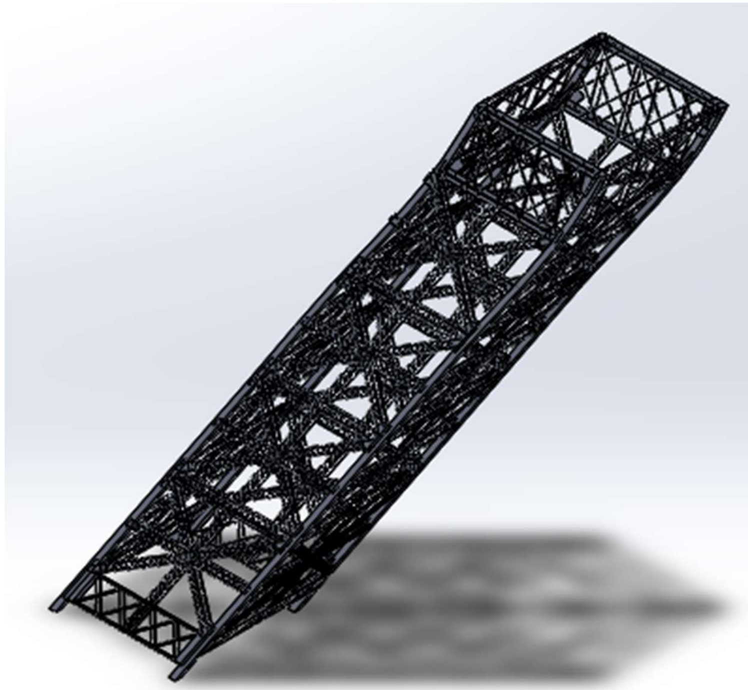


Fig. 28 Crossbars Assembled in First Stage

In the same way the Arc Beam is modelled as well.

Fig. 29 Arc Beam in First Stage

This similar procedure is used to build the Tower until Plane-29 with all the Cross bows, Cross Bars and Cross links.

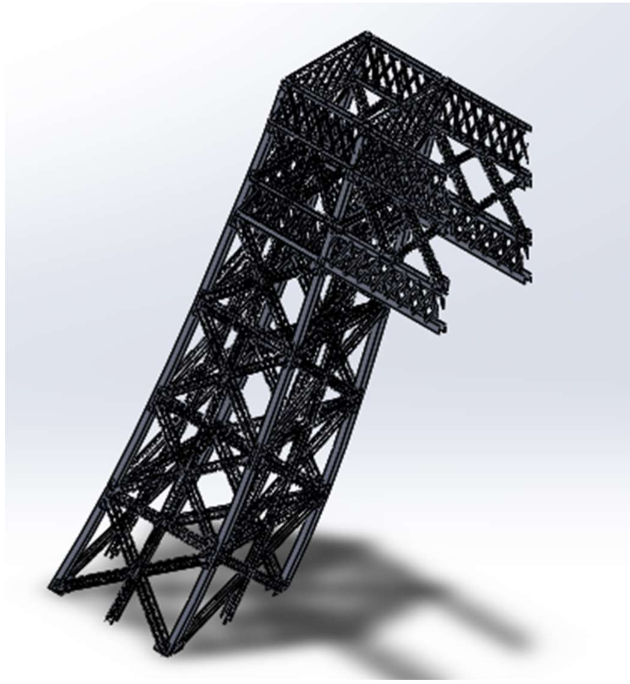


Fig. 30 Crossbars Assembled in Intermediate Stage

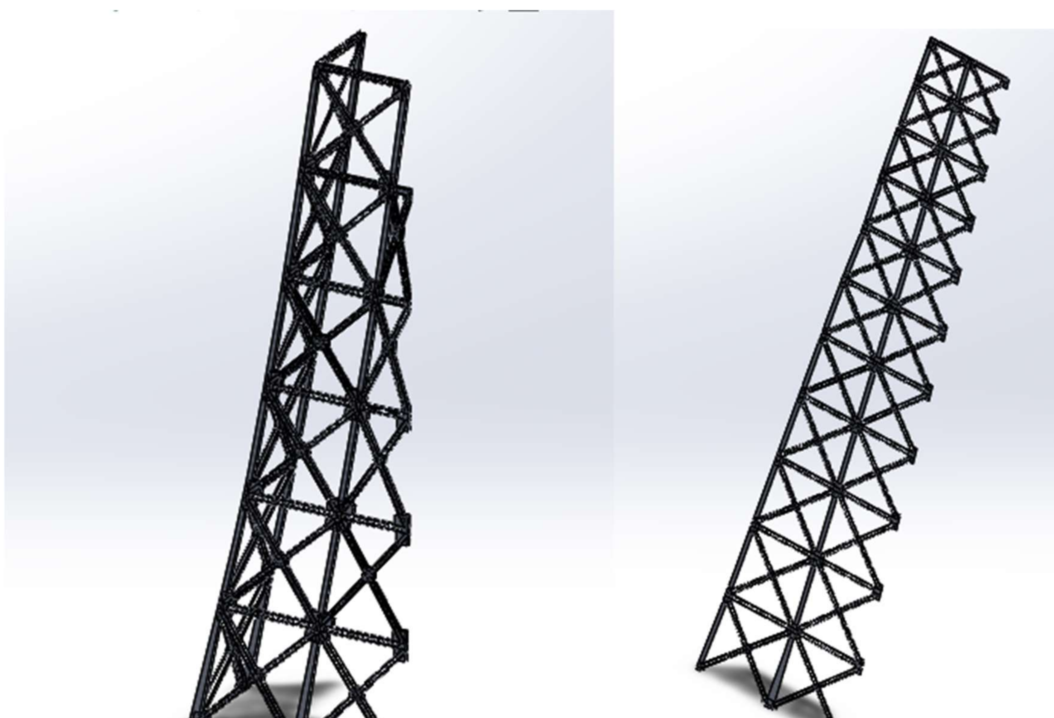


Fig. 31 Crossbars Assembled in Second and Third Stage

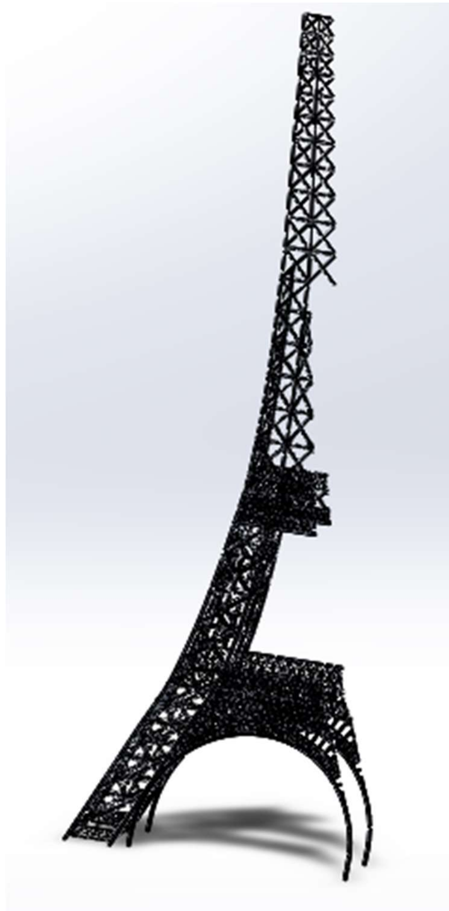


Fig. 32 Single Pile with all Stages

After a single Pile up to 29 Panels are formed then it is arrayed to the Tower form as shown.

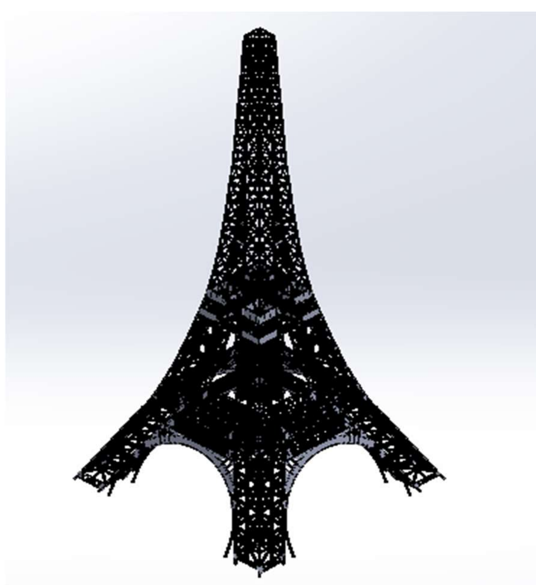


Fig. 33 Piles Arrayed

Now the Upper floor which is the 30th Panel is modelled as per the drawing and then placed on this arrayed model to Form the complete Tower.

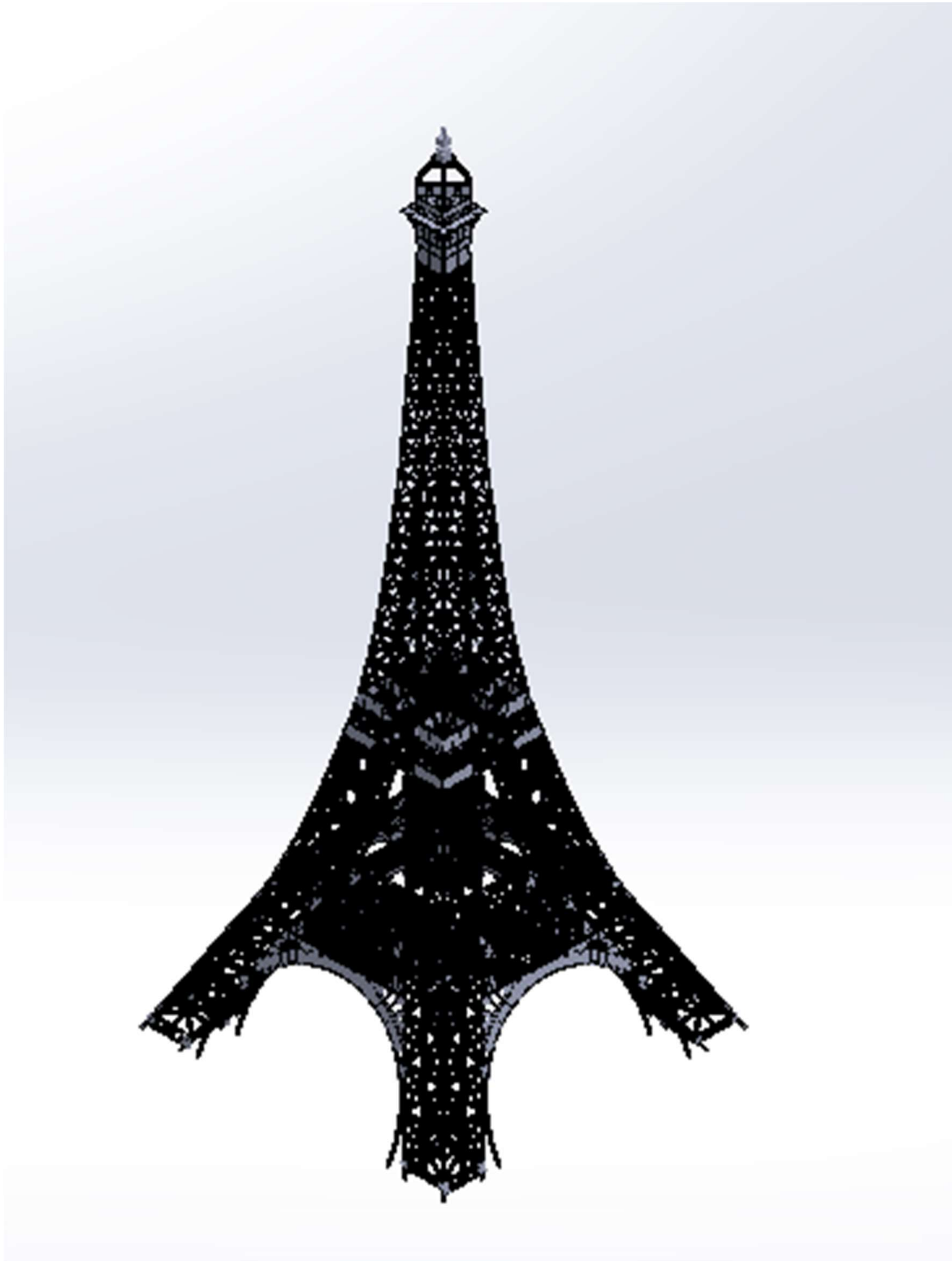


Fig. 34 Complete Tower

4. SIMULATION

Considering the complexity of the complete Model, Wind Flow Simulation is executed only for the Top Floor of the Tower.

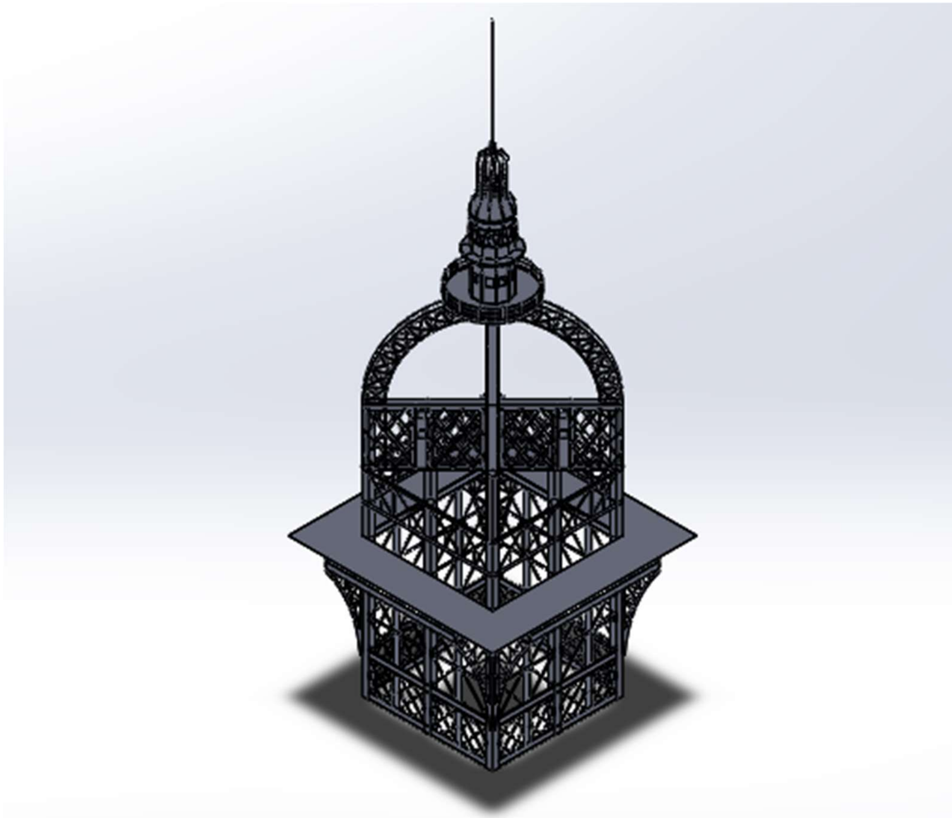


Fig. 35 Part for Simulation

4.1. Pre-Processing

- The model to be simulated is loaded first
- The problem is initiated by creating a new Wizard in the Simulation Package of Solidworks.
- A predefined or default configuration can be used.

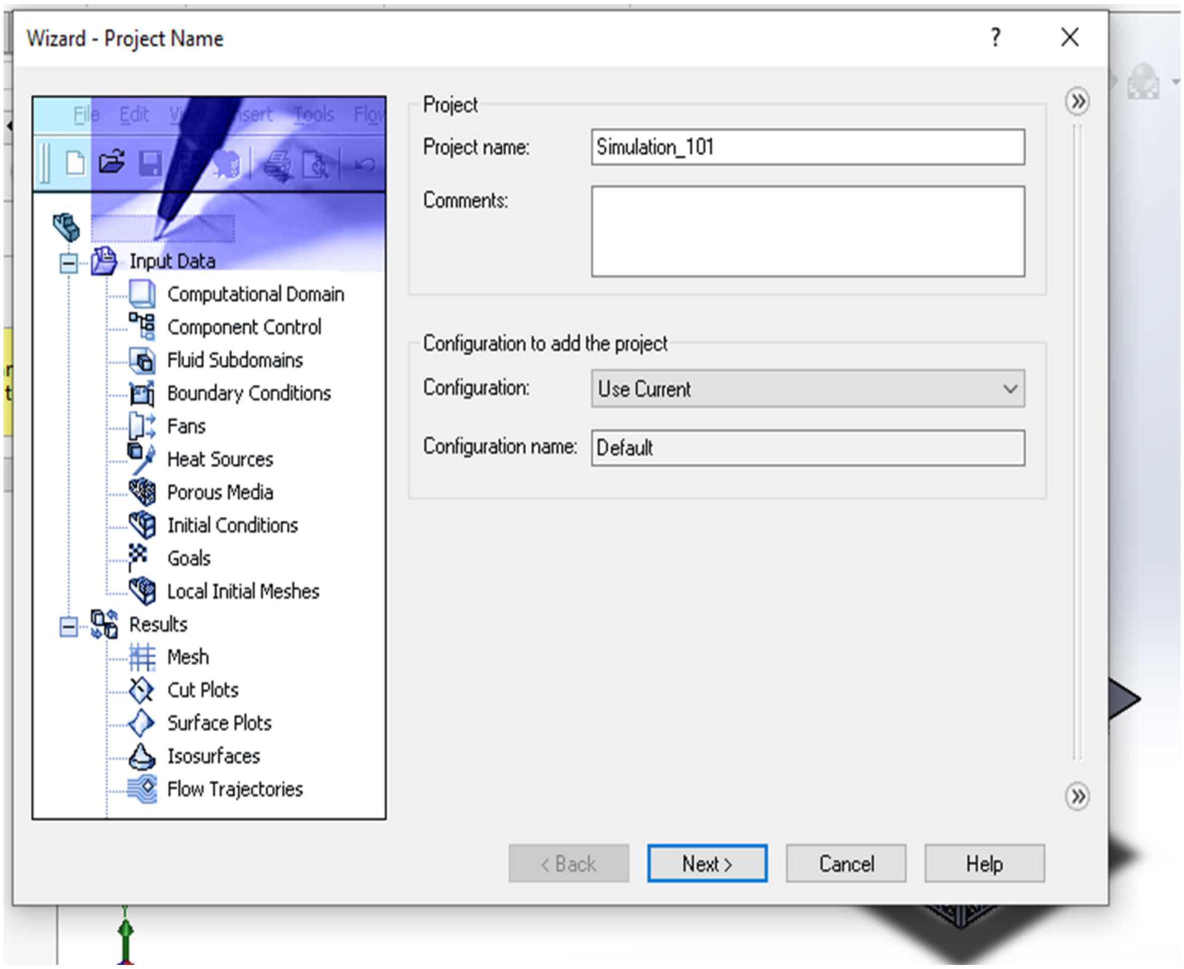


Fig. 36 Simulation Wizard

Unit System

The system of units to be considered is selected in this wizard.

Following are the choices of unit system available.

- Centimetre-Gram-Seconds or
- Foot-Pound-Seconds or
- S.I. Units are available.

A custom defined unit system can also be initiated if required. For this project S.I. Unit system is selected.

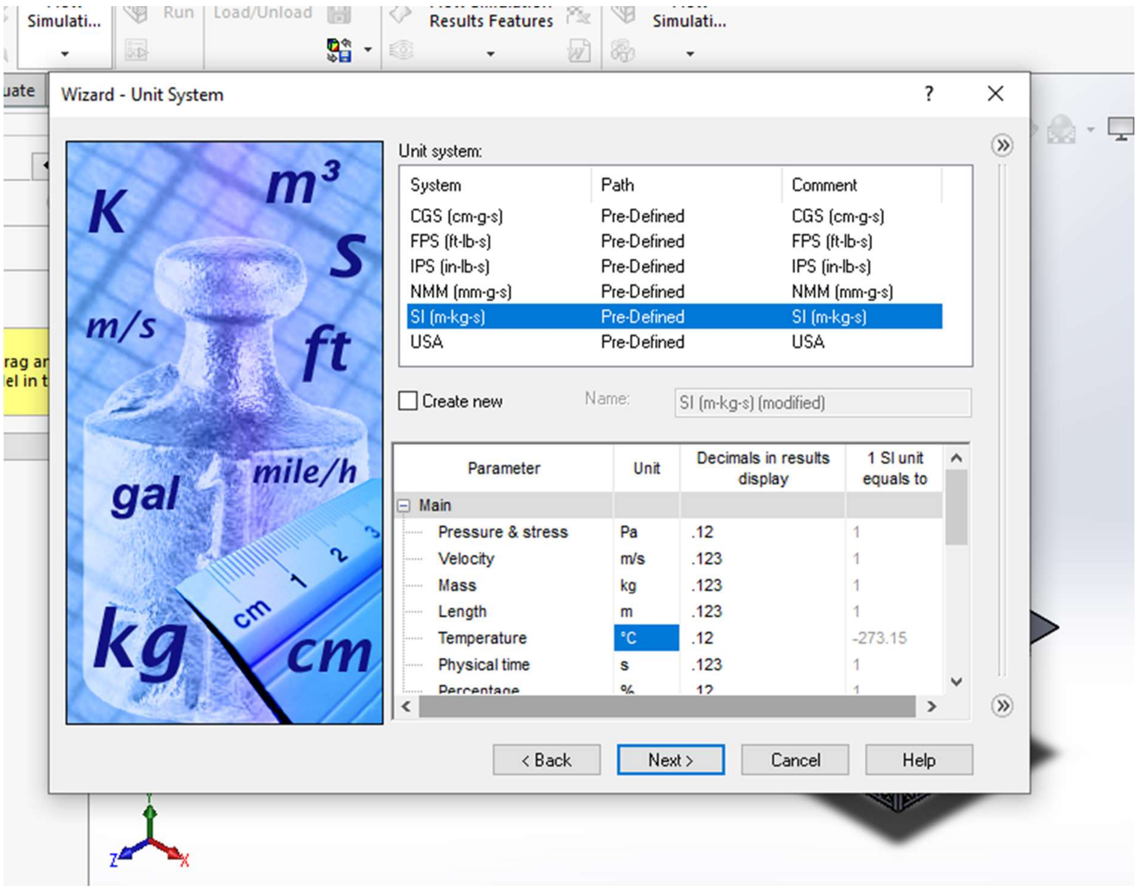


Fig. 37 Unit System Wizard

Analysis Type

The decision of Analysis type is made in this section.

There can be two types of flow for any problem

1. External- the flow over an object
2. Internal- the flow inside the domain

For this case, **External Flow** is selected neglecting Internal space and any cavities.

Following Physical Features can also be selected based on the requirement

- Heat Conduction in Solids
- Radiation – A choice of Solar Radiation can be defined based on Geographical location
- Time Dependent- Either Equilibrium which is for entire duration of time defined or Time Step where the considerations will be from initial to defined duration.
- Gravity- which can be defined in different co-ordinate axes
- Rotation- In case of Fan which makes the flow variations
- Free Surface

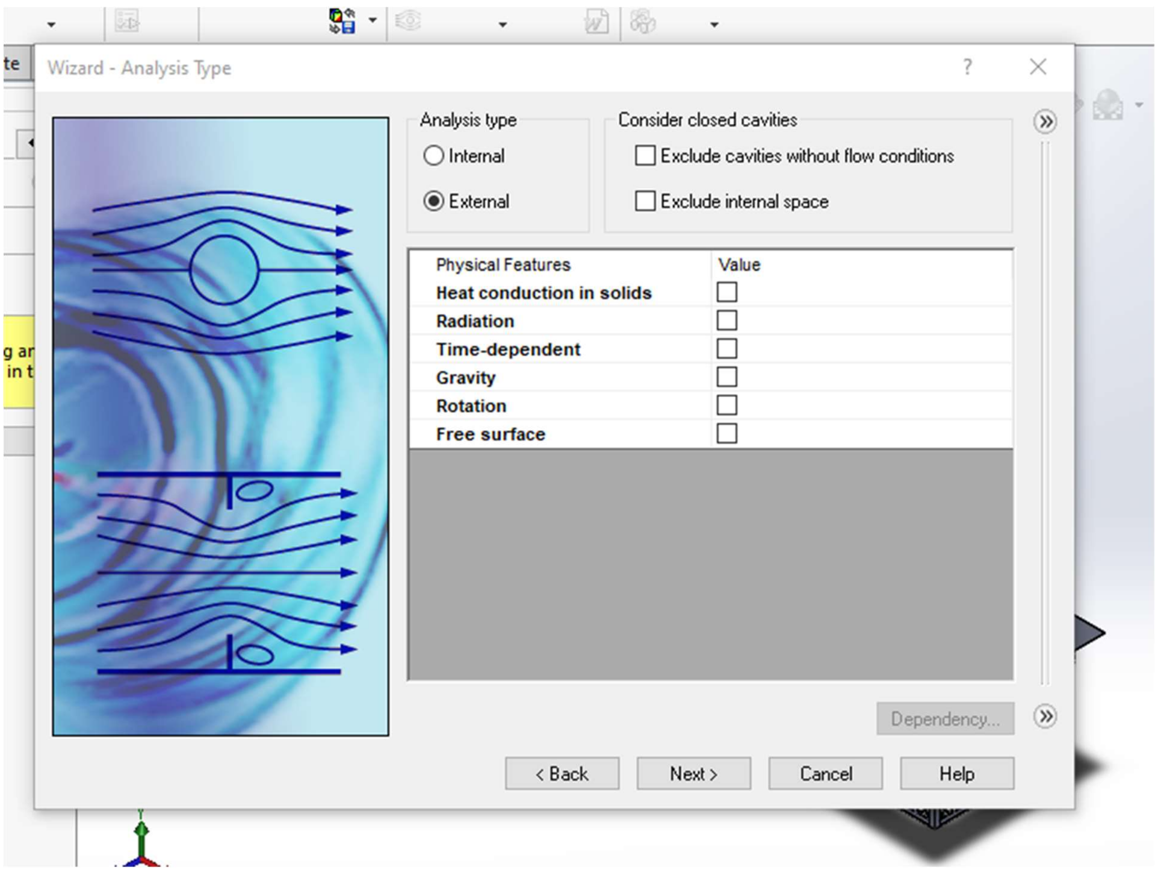


Fig. 38 Analysis Type Wizard

Fluid in Simulation

The choice of Air as fluid is defined followed by type of flow.

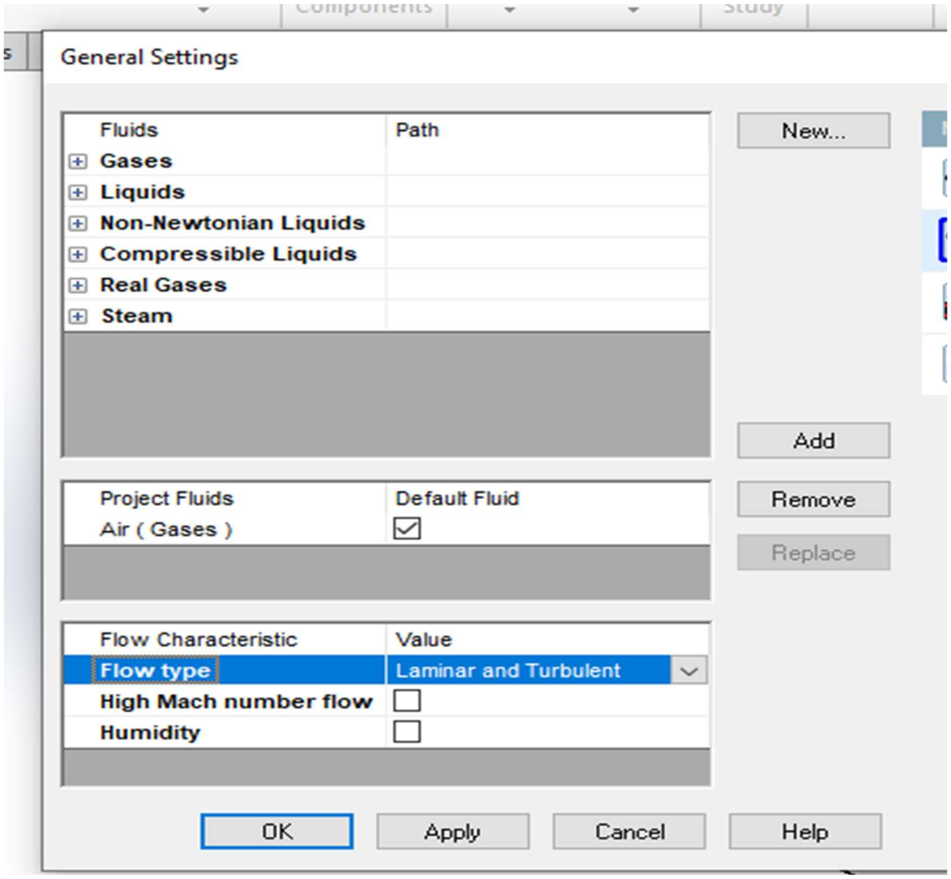


Fig. 39 Fluid Wizard

Wall Conditions

To decide is there any interaction with surroundings regarding the Heat Transfer. Following are the options that can be chosen

- Adiabatic
- Heat Flux
- Heat Transfer Rate
- Wall Temperature

For this problem since the tower is isolated, Adiabatic Wall Condition is selected. There is also option of Roughness to assign.

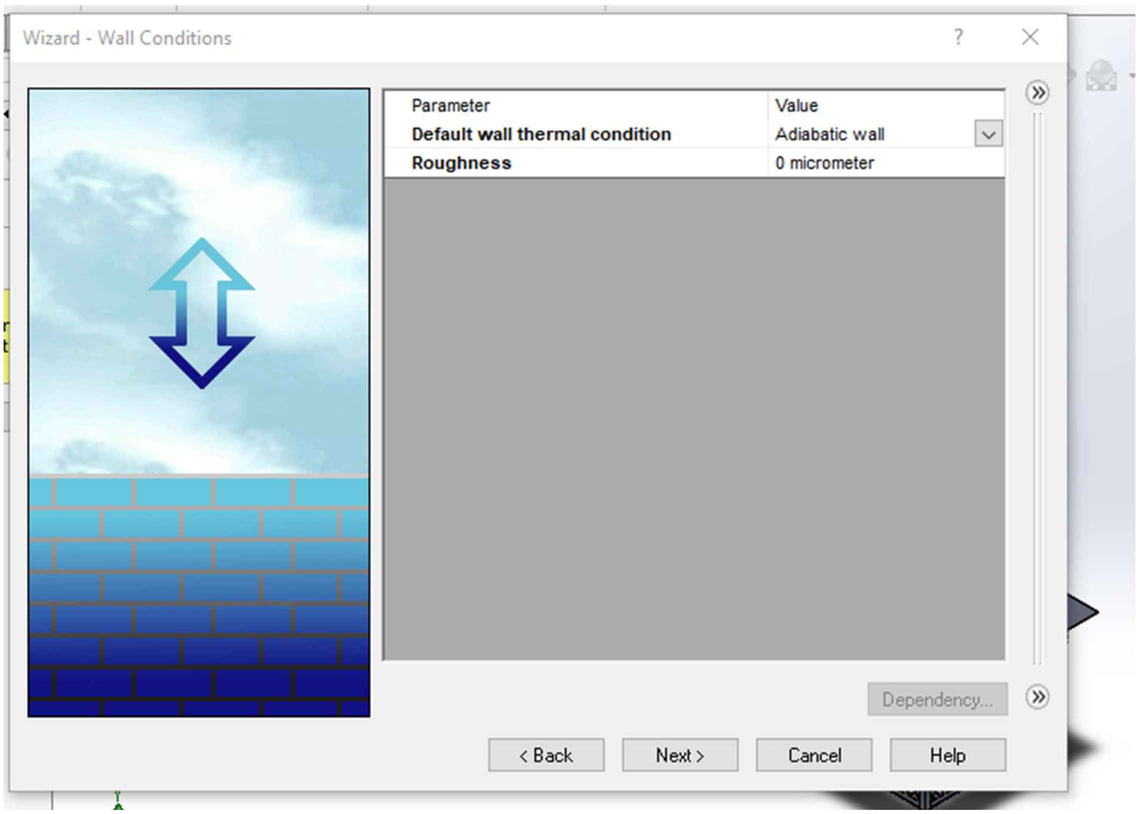


Fig. 40 Wall Conditions

Initial and Ambient Conditions

The Thermodynamic Properties are defined for Air.

- Pressure of 101.325 Pa and ambient temperature of 20 Degree Celsius.
- Wind parameters of Eiffel Tower is considered as **14m/s** as an average from the following plot and applied in one direction.

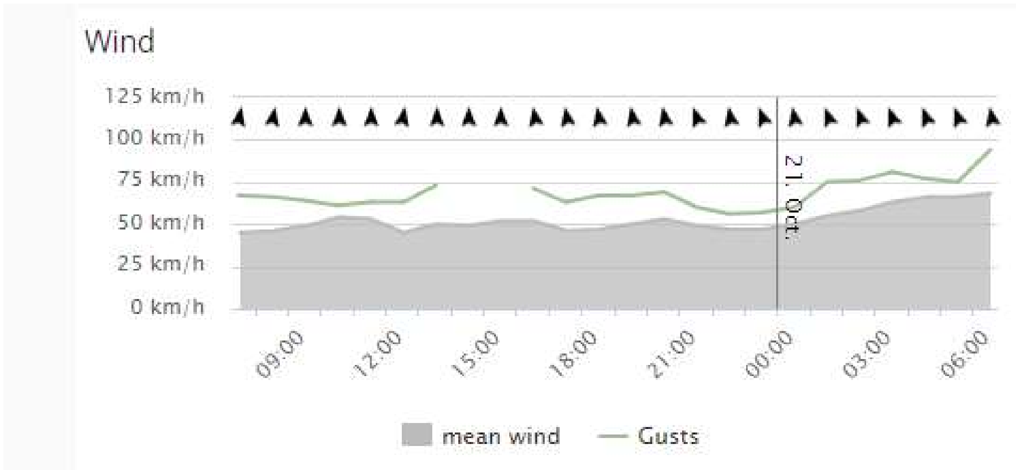


Fig. 41 Wind Speed

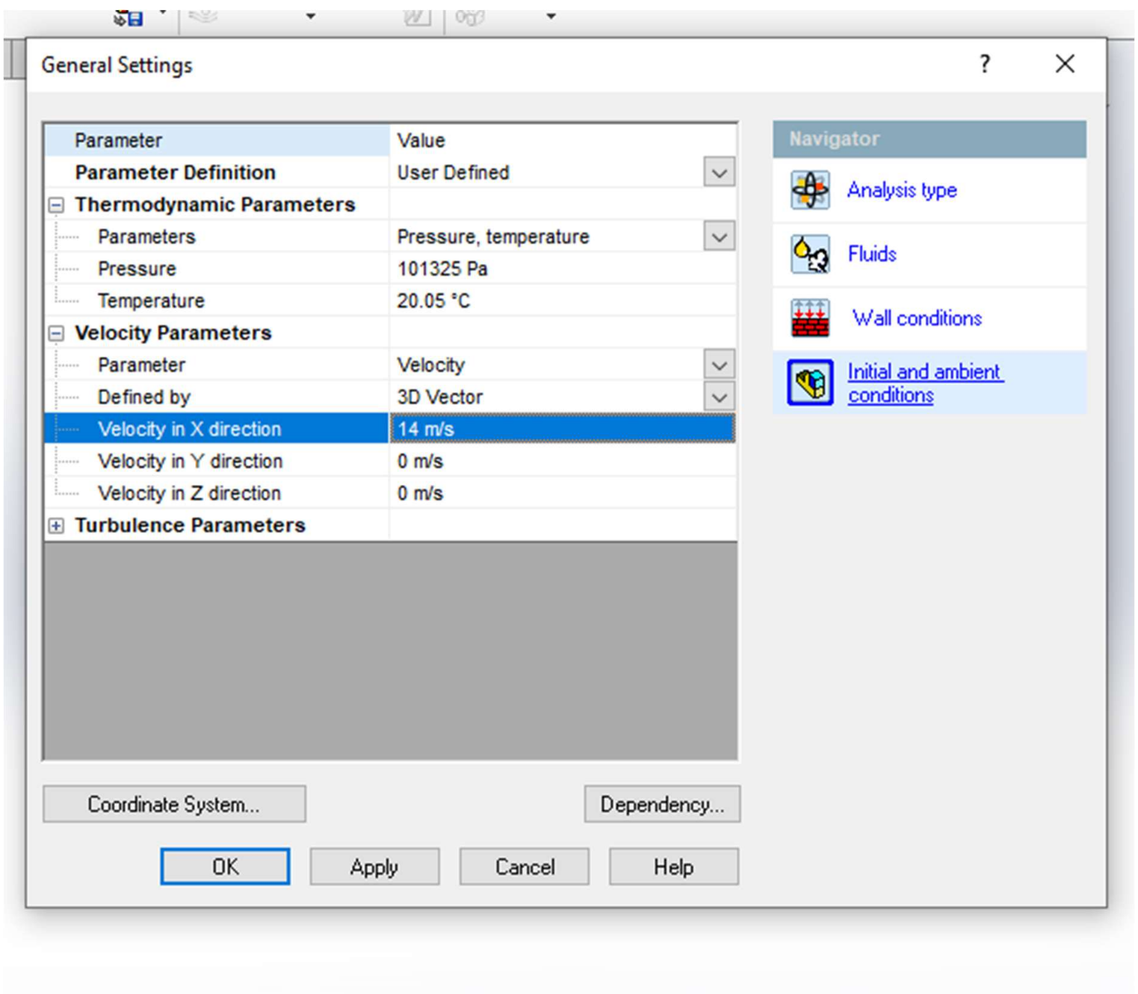


Fig.42 Initial and Ambient Conditions

4.2. Post Processing

The velocity applied is added in unit step values from initial value of 1 m/s to 14 m/s thus making 14 Design points.

	Pressure (Initial and Ambient Conditions) [Pa]	Temperature (Initial and Ambient Conditions) [°C]	Velocity in X direction (Initial and Ambient Conditions) [m/s]	Average Dynamic Pressure [Pa]	Maximum Dynamic Pressure [Pa]	Average Velocity (X) [m/s]	Maximum Velocity (X) [m/s]
Design Point 1	101325	20.05	1	0.5648	0.8379	0.9607	1.1774
Design Point 2	101325	20.05	2	2.2590	3.3630	1.9213	2.3590
Design Point 3	101325	20.05	3	5.0830	7.5628	2.8822	3.5374
Design Point 4	101325	20.05	4	9.0362	13.4488	3.8428	4.7173
Design Point 5	101325	20.05	5	14.1175	20.9933	4.8032	5.8935
Design Point 6	101325	20.05	6	20.3301	30.2405	5.7639	7.0735
Design Point 7	101325	20.05	7	27.6718	41.2264	6.7247	8.2590
Design Point 8	101325	20.05	8	36.1384	53.8420	7.6849	9.4383
Design Point 9	101325	20.05	9	45.7415	68.0471	8.6460	10.6102
Design Point 10	101325	20.05	10	56.4710	84.0834	9.6066	11.7948
Design Point 11	101325	20.05	11	68.3216	101.7971	10.5666	12.9775
Design Point 12	101325	20.05	12	81.3102	121.1337	11.5274	14.1564
Design Point 13	101325	20.05	13	95.4300	141.8925	12.4880	15.3183
Design Point 14	101325	20.05	14	110.6668	164.6749	13.4483	16.5047

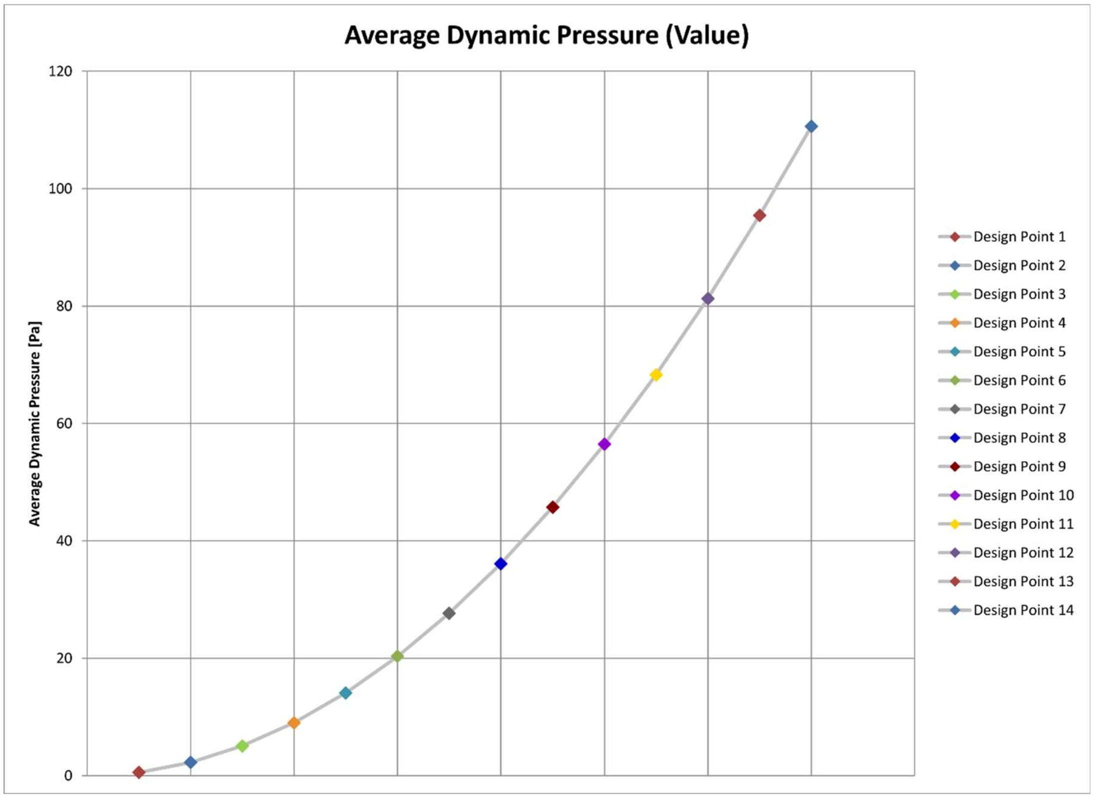
Table 1: Parametric Study

The Dynamic Pressure which is the Kinetic Energy for a unit volume of fluid is estimated. This dynamic pressure is due to different velocities of fluid.

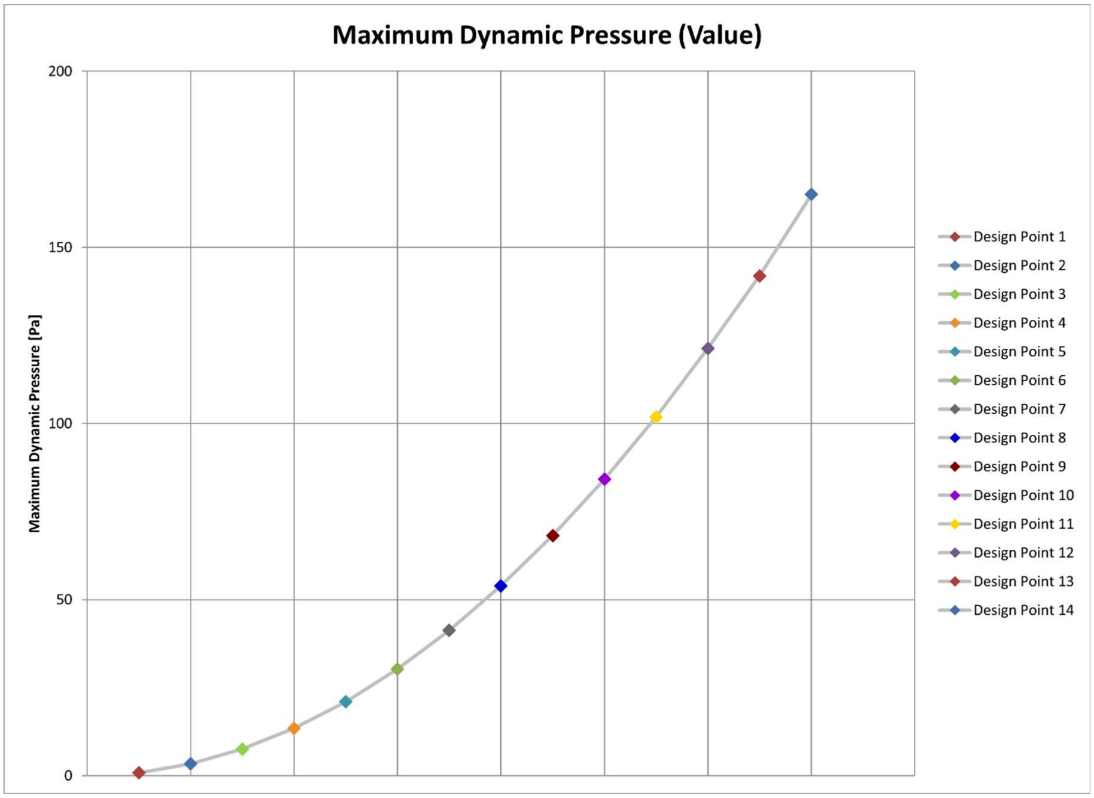
Dynamic Pressure, $q = \frac{\rho u^2}{2}$ in Pascals

Where, **ρ**- Density of Fluid in kg/m^3

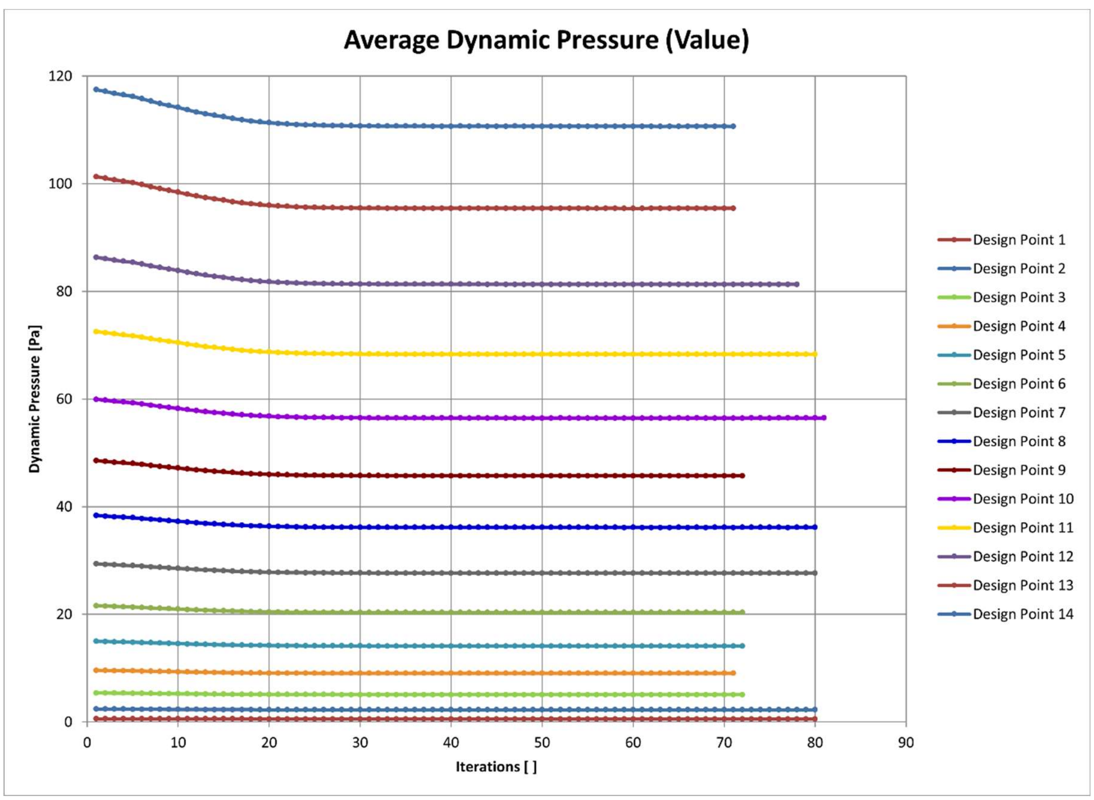
u- Fluid Speed in m/s



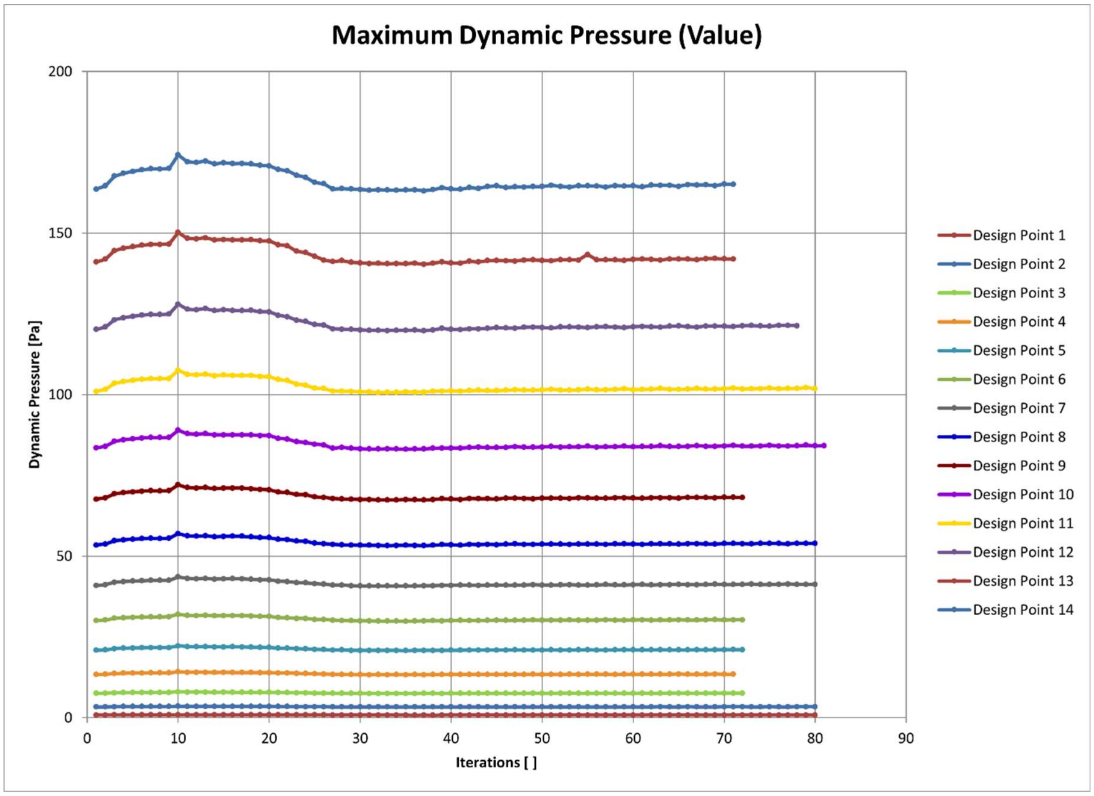
Plot-1: Average Dynamic Pressure for different Design Points



Plot-2: Maximum Dynamic Pressure for different Design Points



Plot-3: Average Dynamic Pressure in different Iterations



Plot-4: Maximum Dynamic Pressure in different Iterations

Bibliography

- The Eiffel Tower, Bertrand Limoine, Taschen Publications
- https://www.solidworks.com/sw/support/54117_ENU_HTML.htm?product=SOLIDWORKS%20CAD
- https://www.solidworks.com/media/fundamentals-3d-design-and-simulation