KIMYO INTERNATIONAL UNIVERSITY IN

CENTRAL ASIAN JOURNAL OF STEM

ISSN 2181-2934 http://stem.kiut.uz/

CONSIDERING DIRECTIONALITY EFFECTS OF WIND ON EXISTING STRUCTURES USING METEOROLOGICAL OBSERVATIONS DATA.

A.J.Nurmamatov[1,a)], X.O.Mirzaxmedov[1,b)], O.O.Muxitdinov[1,c)], M.A.Musurmonov[1,d)]

[1] *Kimyo International University in Tashkent, Uzbekistan*

Author Emails
[a)] e-mail: jahongiir.nurmamatov@gmail.com
[b)] e-mail: Otabek.mirzakhmedov@gmail.com
[c)] e-mail: O.mukhitdinov@kiut.uz
[d)] e-mail: madumar94@mail.ru

Abstract. In many buildings, especially high rise ones, wind have been major problem by causing vibration as well as fatigue issues resulted from fluctuations of wind in random flowing. Wind flow randomness have been studied in many scientific researches and is convinced to follow some probabilistic models which helps researchers to predict the behavior in some way. If probabilistic models are fed with enough meteorological data obtained from weather observations, then reliable predictions or simulations would be possible to make.

Keywords: wind, directionality effect, meteorological data, probabilistic model, building.

1. INTRODUCTION

The main task of the thesis work is to analyze the directionality effects of wind climate and generate and apply some consistent models representing them.

The experienced load cycles inflicting fatigue damage to the façade of the buildings are influenced by local wind climate. The corresponding model for wind climate is also sub divided into two sub models according to intensity of the wind speed. The first model is model for storms and this applies the cases when speed of wind is above 14 m/s. The second model is a model for basic population and this applies for wind speeds below this threshold value of 14 m/s.

Analyzing of load cycles induced by wind in non-storm hours requires a probabilistic model for a basic population of wind speeds. Many statisticians apply Weibull distribution to model lower range of wind speeds because of its versatility and only two parameters have to be known to represent the distribution. Thus based on meteorological observations at Dusseldorf, shape and scale parameters of Weibull distribution have to be obtained for each year of observations starting from 1952 till 2017 and for each direction with 10^o stepsize, overall 36 directions. However, problem arises with the data from 1952 till 1975, since only 16 directions were used to observe wind speed of wind climate. These data should also be tackled carefully using trigonometric interpolation with Fourier series to obtain the Weibull parameters for 36 directions. Another random variable to be defined and modelled is frequency of sectors, calms and erroneous measurements for each calendar year. The first one can be modelled using Beta distribution not forgetting the limitation that the sum of frequencies of sectors and calms as well as erroneous measurements should always yield unity.

2. RESEARCH METHODS AND AVAILABLE DATA

2.1. Meteorological observations and data handling

Observation data is divided into two periods in which different methods was used to write the data. The first period encompasses years from 1952 till 1974. In this period of time the space is divided into 16 directions at which the wind speed is measured. Each direction encompasses quite larger gap of 22.5^o. The directions are written in numbers referring its angle and can be found using the following formula:

$$dir = idir \cdot \frac{360^o}{32} \tag{1}$$

dir – angle at which wind is directed, *idir* – the data referring to the direction.

The values of *idir* are only even numbers from 2 till 32, overall 16 sectors, that's why 360^o is divided by 32 and not 16.

The second period is from 1975 till 2017. In this period of time the observation format changed and the number of wind direction sectors are refined from 16 to 36 making each sector 10^o. And the directions can be calculated as follows:

$$dir = idir \cdot 10^o \tag{2}$$

Range of *idir* is from 1 till 36. The data after 1975 is favorable since in this format or in 36 directions all variables should be brought in, i.e. the data before this year is interpolated using Fourier series from 16 sector values to 36 sector values. The next chapter will discuss this issue broadly.

Furthermore, the meteorological observations encompass some erroneous measurements also. Their directions are marked with -9 or 99 and thus the wind speed data should be ignored when while reading the observations. However, they are not completely useless. In developing probabilistic model for frequency of sectors, the erroneous measurements are also taken into account as an observation and their counts are summed to total number of observations in a year. Since the total sum of all frequency of sectors and frequencies of erroneous measurements and calms should yield unity.

2.2. Probabilistic model for non-storm hours.

In modelling the wind speed, the probability distributions are really useful tool. It has been stated that the wind speed levels beyond 14 m/s are assumed to follow Weibull distribution. According to theory this distribution function fits a wide collection of recorded wind data. And the precision of the Weibull distribution is proven to be adequate. And only two parameters identify the Weibull distribution. The shape and scale parameters need to be found using the formulas explained in 2.1.4. subchapter. In the algorithm below, it has been explained how to find k and v0 taking into account their directions.

Algorithm 8. Calculating shape and scale parameter of Weibull distribution for each direction of wind using the meteorological observation data of wind speed.

Step 1. Calculate mean and standard deviation for each direction for each year.

$$mean(dir) = \frac{\sum_{\{i=1\}}^{N} x_i}{N(idir)}$$

$$\sigma(dir) = \sqrt{\frac{\sum_{\{i=1\}}^{N}(x_i - mean(dir)}{N(idir)}}$$

Here N is the total number of counts of observation in particular direction excluding erroneous measurements and the cases where speed is equal to zero. As stated above *idir*=2,32 before 75 th year and *idir*=1,36 after that.

Step 2. Calculate covariance:

$$\frac{m(idir)}{\sigma(idir)} = cov(idir)$$

Step 3. Calculate the value of k using following formula:

$$\frac{1}{k(dir)} = cov(idir) \cdot (1 + (1 - cov(idir))^2 \cdot \sum_{i=0}^{n} c_i \cdot cov(idir)^i$$

Step 4. Shape parameter has been found, via this parameter gamma function can be calculated:

$$\Gamma\left(1 + \frac{1}{k(idir)}\right)$$

Step 4. Using following equation below, it will be possible to find the value of scale parameter. In this formula ε=0:

$$v_0(idir) = \frac{mean(idir)}{\Gamma\left(1 + \frac{1}{k(idir)}\right)}$$

2.3. Re-distribution for refined sector width by Fourier series

We were able to create all the means and standard deviations for all directions after 75 th year. And taking steps in Algorithm 6, scale and shape parameters have been found. However, the directions before 75 th year differ from counterparts with being only 16 directions with 22.5^{o} gap interval each.

In order to find the k and v_0 for the whole refined period it is required to transform the 16 direction spanning 0^o- 360^o to 36 directions with 10^o interval. In other words, we need to find the intermediate values of function which goes through those 16 points with equally spaced 22.5^o. Those intermediate points are, to be more precise, at 10^o, 20^o, … 360^o.

To accomplish this task, we can use trigonometric interpolation or, another name, Fourier series interpolation. In mathematics it is an interpolation with trigonometric polynomials and used in finding a function that goes through some given data point that are equally spaced. This function should be trigonometric polynomial, that is it is the sum of sines and cosines of the given period. Thus it is better suited for interpolation of periodic functions. A trigonometric polynomial of order N has form:

$$p(x) = a_0 + \sum_{\{k=1\}}^{N} a_k \cdot \cos(kx) + \sum_{\{k=1\}}^{N} b_k \cdot \sin(kx) \quad (3)$$

The expression contains 2N+1 coefficients overall: $a_0, a_1, \dots a_N, b_1, \dots b_N$

The period is T and as indicated all x_i are equally spaced with period being divided into N parts:

$$x_k = \frac{k \cdot T}{N} \quad (4)$$

And x_k has following property:

$$x_0 < x_1 < x_2 < \cdots < x_N$$

$$p(x_n) = y_n, \quad n = 1, 2 \dots, N \quad (5)$$

$$p(x_0) = y_N \quad (6)$$

And interpolating coefficients could be found as follows:

$$a_0 = \frac{2}{N} \cdot \sum_{k=0}^{N-1} y_k \quad (7)$$

$$a_m = \frac{2}{N} \cdot \sum_{k=0}^{N-1} y_k \cos\left(\frac{2km\pi}{N}\right) \qquad m = 1, 2, \dots, N/2 \quad (8)$$

$$b_m = \frac{2}{N} \cdot \sum_{k=0}^{N-1} y_k \sin\left(\frac{2km\pi}{N}\right) \qquad m = 1, 2, \dots, N/2 \quad (9)$$

To have a better approximation this form of interpolation can be used. It is notable that the last element of summation is given with coefficient divided by 2:

$$s(x) = \frac{a_0}{2} + a_1 \cos\left(\frac{2\pi x}{T}\right) + a_2 \cos\left(2\frac{2\pi x}{T}\right) + \cdots + \frac{a_{\frac{N}{2}}}{2} \cos\left(\frac{N}{2} \cdot \frac{2\pi x}{T}\right) +$$

$$+ b_1 \sin\left(\frac{2\pi x}{T}\right) + b_2 \sin\left(2\frac{2\pi x}{T}\right) + \cdots + b_{n-1} \sin\left(\left(\frac{N}{2} - 1\right) \cdot \frac{2\pi x}{T}\right) + \frac{b_n}{2} \sin\left(\frac{N}{2} \cdot \frac{2\pi x}{T}\right) \quad (10)$$

We were able to formulate the Fourier series and now using this theory we can find the intermediate points' data before 1975. Below provided the algorithm to find those points given 16 directions data of mean and sdev.

Algorithm 9. Interpolation of means before 1975 to find the intermediate data with 10° interval. T=360° , N=16

Step 1. Define the 16 mean values to y_k

$$y_k = mean_{idir}, \quad k = 2{,}17, \qquad idir = 1{,}16$$

$$y_0 = mean_{17}$$

Step 2. Define x_k given T=360° , overall 36 values to be calculated.

$$x_k = idir \cdot \frac{T}{36} = idir \cdot 10$$

Step 3. Calculate a_0 using eq. (7)

$$a_0 = \frac{1}{8} \cdot \sum_{k=0}^{15} y_k$$

Step 4. Calculate a_m, b_m using equations (8) and (9), overall 16 coefficients need to be calculated:

$$a_m = \frac{1}{8} \cdot \sum_{k=0}^{15} y_k \cos\left(\frac{km\pi}{8}\right) \qquad m = 1, 2, \dots, 8$$

$$b_m = \frac{1}{8} \cdot \sum_{k=0}^{15} y_k \sin\left(\frac{km\pi}{8}\right) \qquad m = 1, 2, \dots, 8$$

Step 5. After all coefficients have been found, it possible to determine values of $s(x_n)$. Use formula (10) to find interpolated value at each x_n:

$$s(x_k) = \frac{a_0}{2} + a_1 \cos\left(\frac{2\pi x_k}{360}\right) + a_2 \cos\left(2\frac{2\pi x_k}{360}\right) + \cdots + \frac{a_8}{2} \cos\left(8 \cdot \frac{2\pi x_k}{360}\right) +$$

$$+ b_1 \sin\left(\frac{2\pi x_k}{360}\right) + b_2 \sin\left(2\frac{2\pi x_k}{360}\right) + \cdots + b_7 \sin\left(7 \cdot \frac{2\pi x_k}{T}\right) + \frac{b_8}{2} \sin\left(8 \cdot \frac{2\pi x_k}{T}\right)$$

k=1,36

Now it will be possible to find those sought intermediate points and use them in calculating the shape parameters of Weibull distribution. But we need to assess the formulation and correctness of our created model for interpolation. To do this, it will be required to show the continuous plot s(x) passing through the interpolating points of mean or sdev.

In Figure 1 and Figure 2 the interpolation of mean and standard deviation values found for the year 1960 have been accomplished. The graph of trigonometric function passes through all the given 16 points and thus it is considered best choice for the given data.

After ensuring that model for interpolation satisfies all necessary conditions it is possible to find those intermediate 36 points of mean and standard deviation with 10° interval for each year till

1974. Then again all shape and scale parameters of Weibull distribution for the years before 1975 have to be calculated.

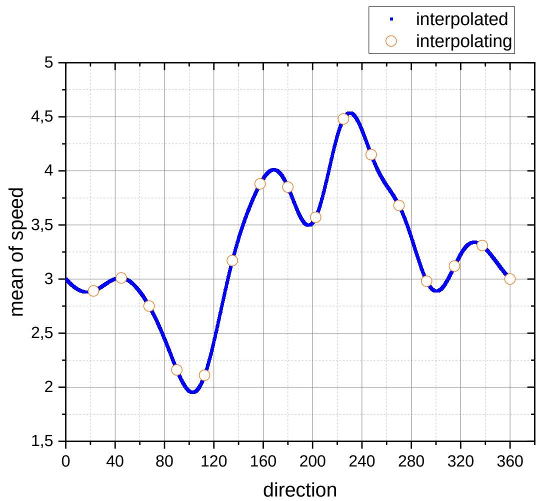


Figure 1. Interpolation of mean values from 1960th year using Fourier series

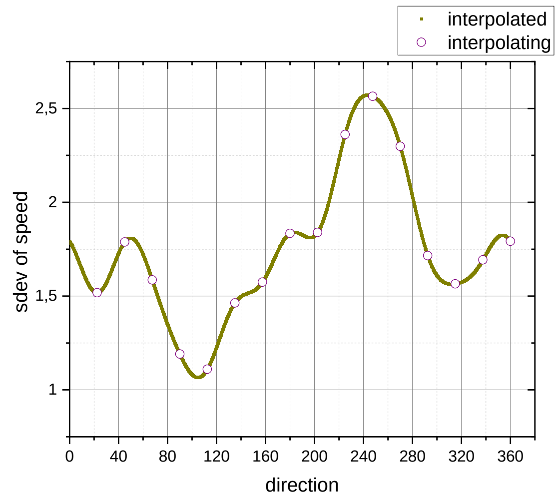


Figure 2. Interpolation of sdev values from 1960th year using Fourier series.

2.4. Normal probability plot.

Normal probability plot is most commonly used graphical technique to define the substantial deviations from normality, in other words, when it is necessary to identify whether a given random sample can be regarded as sample from Gaussian (normal) distribution this special plot technique is used. The observed trace of non-exceedance probability is plotted so called normal probability plot, in which the scales are changed so the target distribution can be represented by a straight line. The plot enables to classify the type of distribution according to its kurtosis, skewness and tail length. To plot the graph, the ordinate values of observations should be found. The cumulative distribution function can be found using the following formula when the number of observations is *N*:

$$p(x \le x_i) = \frac{i}{N+1} \tag{11}$$

To estimate the non-exceedance probability of x first x_{red} values should be found for the corresponding cdf values using inverse of error function:

$$x_{red} = inverf\,(2 \cdot p(x) - 1) \cdot \sqrt{2}$$

Inverse error functions is represented as follows:

$$\mathrm{erf}^{-1}\left(\frac{2x}{\sqrt{\pi}}\right) = x + \frac{1}{3}x^3 + \frac{7}{30}x^5 + \frac{127}{630}x^7 + \frac{4369}{28680}x^9 \tag{12}$$

To obtain better precision it is possible to use the following coefficient formulas for n-th order:

$$a_n = \frac{c_n}{2n+1}, \tag{13}$$

$$c_n = \sum_{k=0}^{n-1} \frac{c_n \cdot c_{n-1-k}}{(k+1)(2k+1)}\ , \ c_0 = 1 \tag{14}$$

After finding x_{red} the above inverse error function, finally the non-exceedance probability can be calculated to scale the observed cdf:

$$y = \frac{x_{red}+2.326}{2 \cdot 2.326} \tag{15}$$

After finding the non-exceedance probability the Weibull parameters, namely shape and scale variables, could be traced in normal probability paper. For that, the parameters of particular sectors should be sorted in ascending order and be plotted against the non-exceedance probability. Overall 66 years, from 1952 till 2017, are observed, thus N will be 66.

As it can be seen from both graphs there is no distinct departures from straight lines. Thus, we can assume that given data set of Weibull parameters follow Gauss (normal) distribution. The program Origin demonstrates also the linear fitting of data using Least-square method.

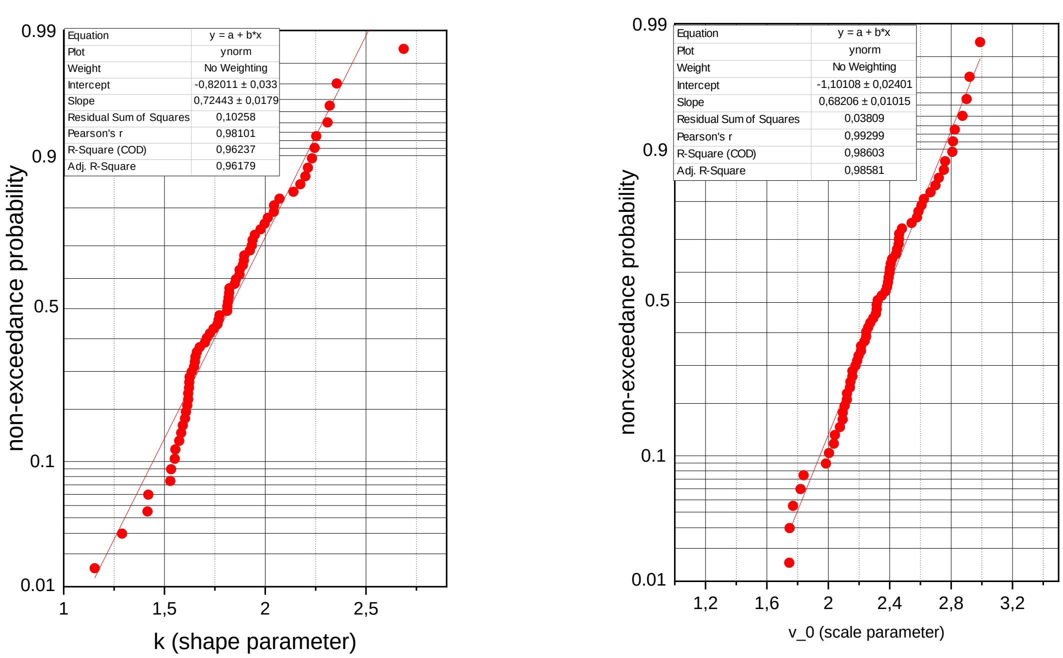


Figure 3. Normal probability plot of shape parameter and scale parameter values corresponding to sector 10.

2.5. Frequencies of directions after 1975.

We first deal with the frequencies after this year since they are already divided into sectors which we need for all of our calculations. As it is noted, it is vital to keep unity of sum of frequencies of directions and those of calms, and thus total number of counts for all directions should count these two type of measurements.

Algorithm 10. Calculate the frequencies of directions for each year

Step 1. Count each direction's measurements in array of 36 size.

$count_{dir} = count_{dir} + 1 \qquad dir = 1{,}36$

Step 2. Count erroneous measurements and calms in another two variables.

$count_{error} = count_{error} + 1$

$count_{calms} = count_{calms} + 1$

Step 3. Calculate each frequency by dividing each count to total sum.

$$freq_{dir} = \frac{count_{dir}}{\sum_{dir=1}^{36} count_{dir} + count_{error} + count_{calms}}\ ; \quad dir = 1{,}36$$

We would like to generate the random frequencies of each direction when we want to calculate damage, since it is influenced by the orientation of building as well as direction of wind. To do that however we need to know which type of probability distribution annual wind direction frequencies

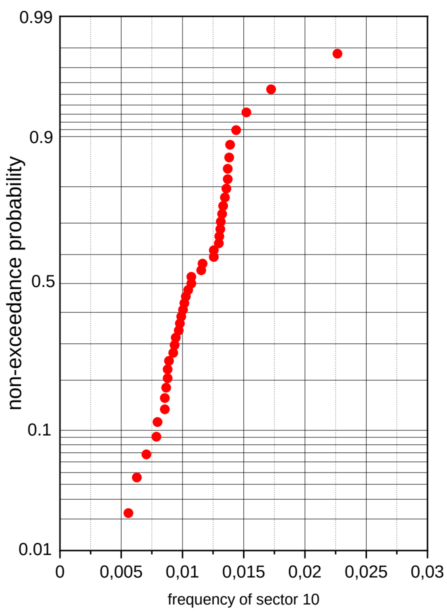


Figure 4. Normal probability plot of frequency data set distribution corresponding to sector 10.

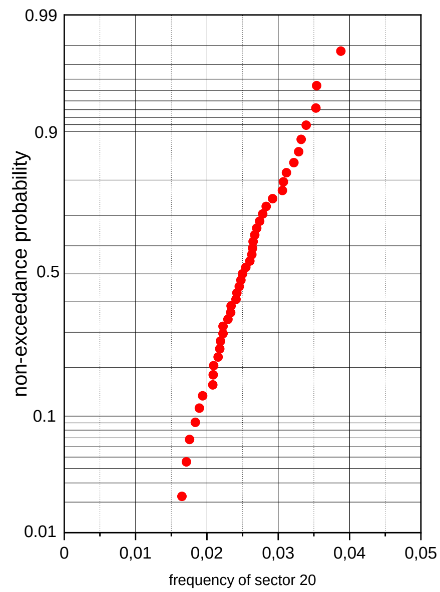


Figure 5. Normal probability plot of frequency data set distribution corresponding to sector 20.

follow. In order to identify this, it is required to sort one example of frequency values in ascending order and plot them in a normal paper and check, whether the trace obtained could be represented by a straight line. A normal probability plot allows one to verify whether a given data is distributed according to a normal distribution as described above. If the plot can be represented by a straight line, then one can assume that data set follows normal distribution. If it tends to be a curved than it is deducted that the trace should follow other distribution like Beta.

In the Figures 4-5, all 43 year frequencies of 10-th and 20-th sectors are plotted in normal probability paper. As it can be seen from the graphs that the trace of frequency data set cannot be represented by a straight line, meaning that the frequencies do not follow the normal distribution. 10

th sector shows higher deviations from straight line, while the latter sector. 20 th, demonstrates the tail being curved.

Thus one can come to conclusion that it is not best idea to model the frequencies with normal distributions. The another option for modelling is Beta distribution due to its versatility it can fit any set of data, including frequencies.

2.7. Frequencies of directions before 1975.

As indicated above the frequencies before 75 th year has a larger interval, thus intermediate points with interval 10^o should be found to be able to work with all available data. Here again it is possible to apply trigonometric interpolation with Fourier series and find the intermediate missing points of interest.

In the graph below it can be seen that that trigonometric interpolation has been applied for the frequency sectors in 1952 year and the graph line is fitting all 16 points. It is possible now to generate frequencies for 36 directions. To accomplish this task, the area under curve is divided into 36 parts and each part is divided by whole area to obtain the frequency for each direction. In this way we will be able to keep the unity of sum of the frequencies. The integration of area is done in very small steps and using the trapezoidal rule. Below short algorithm shows the way how it is done.

Algorithm 11. Finding frequency sectors for 36 directions keeping the unity.

Step 1. Apply Fourier series and get a_0, a(8), b(8) coefficients for the graph line.
Step 2. Define the step-size of integration (the smaller the step-size is the more precise the integration will be).

$$dt = \frac{360.d0}{10000}$$

Step 3. Start to calculate the integration of total area and integration area for frequency sectors using trapezoidal rule (midpoint rule).

$$sum_{total} = sum_{total} + \frac{(t+dt)+t}{2} \cdot dt, \qquad t = 0, dt, 2dt, \dots 360°$$

$$sum_{sector}(i) = sum_{sector}(i) + \frac{(t+dt)+t}{2} \cdot dt, \qquad t = 0, \dots 10°; 10°, \dots 20°; \dots; 350°, \dots 360°.$$

$i = 1,2, \dots ,36$

Step 4. Divide the array of sector arrays to total area to find frequency for each direction.

$$freq(i) = \frac{sum_{sector}(i)}{sum_{total}}, \quad i = 1,2, \dots ,36$$

This way we can keep the unity of the sum of frequencies of sectors plus frequencies of calms and erroneous measurements. Since in sum of after trigonometric interpolation the summation parts of cosine and sine will level itself to zero and only the $a_0/2$ coefficient will remain, which is simply the average of 16 frequencies and equal to 1.

We have now enough data to develop the probabilistic model which is Beta distribution. Probabilistic model should be created for each direction using ensemble of 66 years. Basic idea is to find the fitting curve *B(a,b,r,t)* of the frequencies of particular direction, considering their cdf as observed Fcum, ranging from 1/67 till 66/67. This fitting curve is achieved through iterating the lower and upper edges of ensemble data. These lower and upper edges are simply the smallest and biggest frequencies of data when they sorted in ascending order. The idea is application of Least square method to find the minimum of the sum of squared differences for the whole iteration process. The a and b should be iterated till optimum values of *a,b,r,t* tuple achieved. The Algorithm below explains broadly what steps should be taken in order to find such fitting curve of Beta distribution.

Algorithm 12. Fitting process of frequency of data for each direction to Beta distribution using ensemble 66 years' data.

Step 1. Get mean and standard deviation of 66 frequencies.

Step 2. Vary *a* and *b* in smaller steps. Step-sizes da, db could be taken as 1/1000. a_end=a-50da, b_end=b+50db. This search radius can be changed based on how well fitting looks.

do 100 a>=a_end
a=a-da
do 101 b<=b_end
b=b+db
end do
end do

Step 3. Get r and t for each a and b, using mean and standard deviation ignore the values when r and t are less 1.

$$h_1 = \frac{\mu - a}{b - \mu}; \quad h_2 = \frac{b - a}{\sigma}$$

$$r = \frac{h_1 \cdot h_2^2 - (1 + h_1)^2}{(1 + h_1)^3}; \quad t = r \cdot h_1$$

Step 4. Get the theoretical probability density and integrate the corresponding cumulative probability distribution in a sufficient fine grid between a and b for each frequency value.

$$Ftheor_i = \int_0^{freq_i} f(r, t, x)dx, \quad i = 1,2, \dots, 66.$$

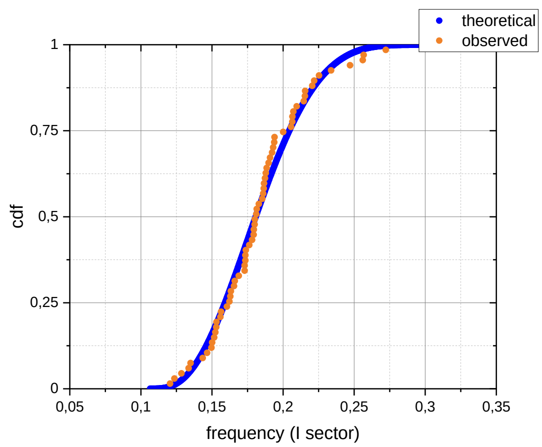
Step 5. Get observed Fcum using linear interpolation scheme.

$$Fcum_i = \frac{i}{N + 1}, \quad i = 1,2, \dots, 66, N = 66$$

Step 6. Get the difference between theoretical and observed cumulative distribution values and sum the squared differences.

$$sum = \sum_{i=1}^{66} (Ftheor_i - Fobs_i)^2$$

Step 7. Compare the summation for each iteration and find the minimum of them and for the minimum of summation $a_{opt}, b_{opt}, t_{opt}, r_{opt}$ values are found which builds best fitting line of Beta distribution.



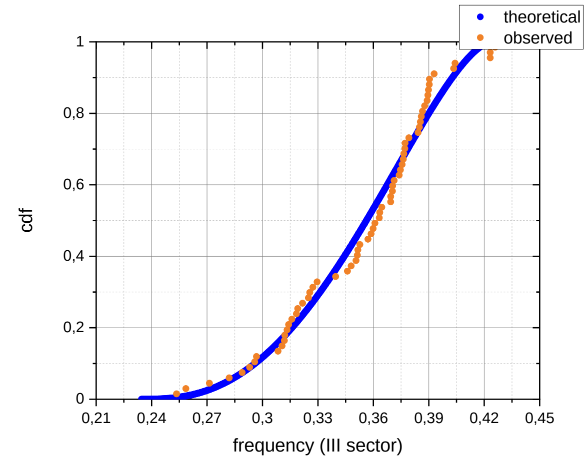


Figure 6. Fitting of observed frequency data set of first sector to Beta distribution

Figure 7. Fitting of observed frequency data set of third sector to Beta distribution.

For the simplification and show the procedure it is better to give an example of 4 sector case, in which the space of wind direction is divided into four 90^o sectors. Ensemble of 66 years' frequencies are fitted to Beta curve using above algorithm.

The curves show nice fitting of data and we are now able to produce frequencies from Beta distribution. However, the problem arises when frequencies of 3 sectors are summed. The summation yields sometimes values greater than unity and the fourth frequency becomes negative:

$$frel_1 + frel_2 + frel_3 > 1,\ freq_4 = 1 - freq_1 - freq_2 - freq_3 < 0 \quad (16)$$

Thus we need to come up with an alternative strategy to keep the unity of sum of frequencies. The basic idea is interpolating 16 frequency data for each year from 1952 till 1974 and using the integration only two 180^o sector frequencies $p_{180\text{-}1}$, $p_{180\text{-}2}$ should be found. Using them the relative frequencies should be found which are complementary.

$$prel_{180-1} = \frac{p_{180-1}}{p_{180-1}+p_{180-2}}, \quad prel_{180-2} = \frac{p_{180-2}}{p_{180-1}+p_{180-2}}, \qquad prel_{180-1} + prel_{180-2} = 1 \quad (17)$$

The next step is to iterate by varying *a* and *b* to find best Beta fit for $prel_{180-1}, prel_{180-2}$ as it is done for four sectors as an example above. And optimum *a, b, r, t* of Beta distributions will have following properties:

$$a_1 = 1 - b_2, \quad b_1 = 1 - a_2, \quad r_1 = t_2, \quad t_1 = r_2 \quad (18)$$

$$\mu_{p180-1} = 1 - \mu_{p180-2}, \quad \sigma_{p180-1} = \sigma_{p180-2} \quad (19)$$

In the next step, each 180^o sectors will be divided into two sectors resulting in four 90^o sectors.

$$p_{180-1} = p_{90-1} + p_{90-2}, \quad p_{180-2} = p_{90-3} + p_{90-4} \quad (20)$$

Again relative frequencies should be found for each couple:

$$prel_{90-1} = \frac{p_{90-1}}{p_{90-1}+p_{90-2}}, \qquad prel_{90-2} = \frac{p_{90-2}}{p_{90-1}+p_{90-2}} \tag{21}$$

$$prel_{90-3} = \frac{p_{90-3}}{p_{90-3}+p_{90-4}}, \qquad prel_{90-4} = \frac{p_{90-4}}{p_{90-4}+p_{90-3}} \tag{22}$$

Again these relative frequencies are complementary to their pairs and each of them should be iterated by varying their extremes to fit Beta distribution. The idea is to further divide each 90° sectors into two 45° sector, each 45° sectors into two 22.5° sectors and finally each 22.5° sectors into 11.25° sectors. We end up with 32 sector frequencies with 11.25° interval. Further thing to be noted is the sum of relative frequencies will not add up to unity if there calms and error measurements. Errors and calms each form a separate group, the sum of all observed relative frequencies has to be normalized to yield unity in the end, i.e. normalizing factor in years is

$$factor_{normalizing} = 1 - freq_{calms} - freq_{erronous} \tag{23}$$

In most years, erroneous measurements are rare, thus, final model can be extended to the probability distribution to get calms for a year.

After reaching 32 sector frequencies with 11.25° interval, it is possible to start generating random frequencies for 32 sectors and later interpolate them to obtain 36 frequencies for a year. A strategy is from very beginning to generate one independent relative frequency and one complementary to it so the unity is kept. And this should be continued till 32 frequencies are found

Algorithm 13. Strategy of generating 36 frequency values keeping unity of their sum.

Step 1. Generate random $prel_{180-1}$, and calculate $prel_{180-2}$
$prel_{180-2} = 1 - prel_{180-1}$
Step 2. Generate $prel_{90-1}, prel_{90-3}$ and find the remaining relative frequencies as above.
$prel_{90-2} = 1 - prel_{90-1}, \quad prel_{90-4} = 1 - prel_{90-3}$
Step 3. Generated all 45°, 22.5° and 11.25° interval frequencies in similar manner.
Step 4. Apply trigonometric interpolation with Fourier series to 32 generated frequencies for a year to obtain 36 frequency values.

In order to analyze generated random frequencies, it is a good strategy to plot time series of some sectors to know about the trends and any remarkable distinction between randomly generated and observed frequencies.

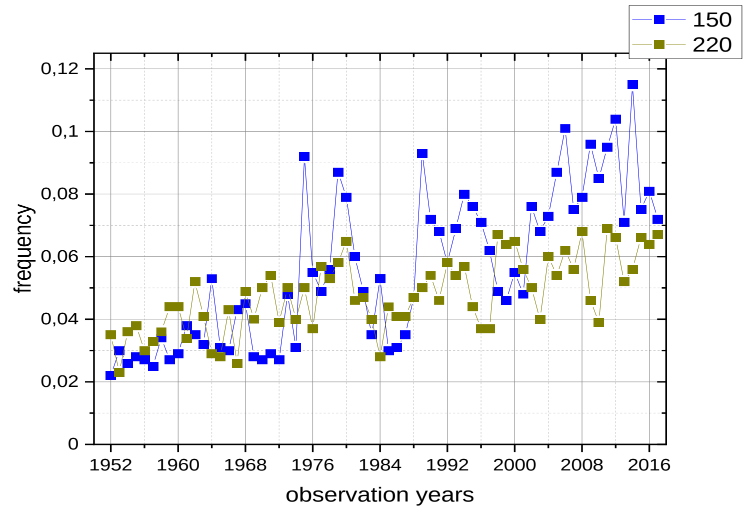


Figure 8. Time series of 150° and 220° sectors' frequencies

The plot shows that the direction 150° has a distinct jump in 1975. And it corresponds to a fairly sharp and isolated peak which is difficult to re-identify using re-distribution strategy based on Fourier-series for 22.5° values.

3. CONCLUSIONS

The main aim of the thesis was to consider the directionality effects of wind-induced fatigue damage for existing structures using the meteorological observations data in Dusseldorf from 1952 to 2017 as well as data from wind tunnel experiment implemented on box-shaped building.

In modelling the frequencies of sectors we end up with the shortcomings because of the rather large stepsize (22.5° gap between subsequent sectors) of frequency sectors' data written before 1975. Redistribution process with Fourier series and dividing the whole area under the curve into 2, 4, 8, etc. parts up to 32 and by keeping the unity of sum of sectors was strategy to model frequencies with Beta distribution. Fitting process of relative frequencies to Beta distributions have been done and in the end again the 32 values are interpolated to find the 36 sector values to match with data after 75th year. However, time series of generated frequencies from 52th till 74th years and the time series of the remaining 43 years showed significant inconsistencies in the trend. 150° and 220° wind flow directions values are plotted in this 66 year-time series and the values before 75th showed smaller radius of variation and rather smaller magnitude values compared to the values after this year. Thus it came to conclusion that using the data after 75th year to generate consistent model for frequencies would be better way. Or simply uniform frequency and average frequencies of sectors could be used.

REFERENCES

1. O. Garcia 1981. https://www.scionresearch.com/__data/assets/pdf_file/0010/36874/NZJFS1131981GARCIA304-306.pdf
2. Sheldon Ross, in Introduction to Probability Models (Eleventh Edition), 2014
3. H.J. Schäfer, Evaluation algorithm based on a modification of the Goniometric Model for the steady description of the S-N curve from the Low Cycle Fatigue up to the Ultra High Cycle Fatigue region
4. The role of fatigue damage on the reliability of existing building in regard to wind load. PD Dr.-Ing. habil. Michael Kasperski
5. Lecture notes. PD Dr.-Ing. habil. Michael Kasperski
6. The role of fatigue damage on the reliability of existing buildings in regard to wind loading. PD Dr.-Ing. habil. Michael Kasperski, Gou Rui