Preliminary Assessment of Wind Actions in large span MSS

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Abstract Historically the use of Movable Scaffolding Systems (MSS) in bridge deck construction was restricted to the range of spans approximately between 30m and 60m. In the recent years, the use of MSS expanded to increasingly larger spans. These applications were made possible not only by the progress of structural analysis techniques and computational power but also the use of innovative structural solutions, such as an actively controlled prestressing system (Organic Prestressing System – OPS).However, as the span of the bridge deck increases, the span of the MSS increases as well. The MSS structure results much more slender and thus more vulnerable to Wind Action.As the design approach for wind actions in MSS is not included in the Wind Action Codes, it is necessary to create a specific set of rules. Even if basic specifications can be adapted from the rules for general metallic structures, some of the procedures have to be explicitly developed for this type of structure with very particular characteristics: changing support conditions, changing span distribution, changing in mass and mass distribution, changing location.Due to this variability, the design of MSS is divided in several operations and it is attributed a wind velocity for each of the operations.This paper gives an overview of the probability of occurrence of wind velocities czhosen for each operation.

Introduction

The assessment of Wind Actions and the reliability of structures subjected to them has received growing interest during the last few decades mainly due to the increasing boldness and complexity of the structures. The designers must, as always, assure that the Wind Action evaluation is accurate and adequate because boldness in structural design is often legitimated by a better evaluation of the loads. This increased knowledge on loads is clear even in the standards evolution. It has been observed that new standards are increasingly not only more detailed and complex but also more accurate and closer to reality.

Although some load types acting on structures are almost invariable considering the geographical location, there are a few actions that are highly dependent on environmental loads (wind loads and snow loads) and also seismic loads.

The construction of prestressed concrete bridge decks with Movable Scaffolding Systems (MSS) (Figure 1), a tridimensional lattice steel structure that supports the formwork used to construct one entire span of the bridge deck that additionally has the ability to self-launch between adjacent spans, is normally used for a 40-60 m span range. Until the last few years, bridges with 70-90 m were normally constructed with precast solutions, metallic solutions or cantilever method. However, over the last few years, experiences have been made and new solutions have been developed for the 70-90m span range (LMSS – Large Movable Scaffolding Systems) (Pacheco, 2011).

BERD is currently developing a 90m span LMSS (designated as M1-90-S). The M1-90-S is programmed for the partial construction of 4 viaducts in Turkey with a maximum span of 90m. The estimated time for execution is around 3 years including all assemblies and disassemblies. During this project the M1-90-S will operate at around 75m above the ground level.

Unlike a permanent structure, a LMSS has to undergo several operations with very different characteristics, namely:

- Static phase (usually called Concreting): suspension of the deck concrete weight while the deck is not self-supporting. The concrete weight is substantially bigger than the LMSS weight (in this case a ratio around 2.45). During this phase it is very important that the LMSS deformation is kept small in order to achieve a bridge deck with the desired geometry;
- Movable phase (usually called Launching): movement of the LMSS between adjacent spans facing an evolving structural system (the LMSS moves above supports that run through the entire main girder). During the movable phase the LMSS is more vulnerable to wind because fixation is limited especially in the transversal direction.

The disparity between operations that the LMSS is subjected usually leads to the consideration of different velocities for each stage (SEOPAN, 2007).

In this paper the Wind Action considered in the M1-90-S design is analyzed and is calculated the probability of occurrence of wind velocities based on statistical data available for Ankara, Turkey.

Figure 1 - MSS for the construction of a 70m span bridge in Slovakia

Extreme Value Distribution

The Extreme Value analysis of wind velocity and other geophysical variables, like floods or even seismic acceleration, is based on the application of at least one of the 3 Extreme Value Distributions identified by Fisher and Tippet. These 3 distributions are usually called Type I or Gumbel distribution, Type II or Frechet distribution and Type III or Weibull distribution (Bastos, 2008).

This study uses the cumulative distribution function for the Type I distribution of the largest values FI (also referred as the Type I Extreme Value distribution, or the Gumbel distribution) (Simiu & Scalan, 1996):

$$F_I(U) = \exp\left\{-\exp\left[-\frac{U-\mu}{\sigma}\right]\right\}\begin{cases}-\infty < U < +\infty \\ -\infty < \mu < +\infty \\ 0 < \sigma < +\infty\end{cases} \tag{1}$$

In Eq. 1, *U* is the extreme wind velocity for a specific period (in this paper it is considered 1 year or 1 day), μ and σ are referred to the location and the scale parameter, respectively. It can be shown that the mean value of *U*, *E(U)* and the standard deviation of *U*, *SD(U)* are:

$$E(U) = \mu + 0.57722\sigma \tag{2}$$

$$SD(U) = \frac{\pi}{\sqrt{6}}\sigma \tag{3}$$

Eq. 1 may be inverted to yield the percent point function, that is, the value *U* of the random variable wind velocity that corresponds to any given value of the cumulative distribution function. In the case of the Type I distribution:

$$U(F_I) = \mu - \sigma \cdot \ln[-\ln(F_I)] \tag{4}$$

A classical method approach to the problem of estimation is the *method of moments* (Simiu & Scalan, 1996). In this method it is assumed that the distribution parameters can be obtained by replacing the expectation and the mean square value of the random variable *U* by the corresponding statistics of the Sample, using Eq. 2 and Eq. 3. In this case:

$$\hat{\sigma} = \frac{\sqrt{6}}{\pi}s \tag{5}$$

$$\hat{\mu} = \overline{U} - 0.57722\hat{\sigma} \tag{6}$$

Where $\hat{\sigma}$ and $\hat{\mu}$ are estimations for σ and μ in the Eq. 1-4. The values $\overline{U}$ and *s* are the Sample mean and the Sample standard deviation of a Sample with dimension *n*. From the Sample data it is possible the calculate $\overline{U}$ and *s*:

$$\overline{U} = \frac{1}{n}\sum U_i \tag{7}$$

$$s = \left[\frac{1}{n}\sum\left(U_i - \overline{U}\right)^2\right]^{1/2} \tag{8}$$

Wind velocity in Turkey (Ankara)

Since there is very few information available about the wind in Turkey, it was necessary to conduct a specific study to characterize adequately the wind velocity for the region of Ankara, the place where the LMSS will be used.

This statistical study of wind velocities with very small probability of occurrence – extreme wind velocities – was based on the annual maximum wind velocity for Ankara found on (Firat, 2007) and collected by the Turkish Meteorological Department.

For the wind velocities with infrequent probability of occurrence – strong wind velocities – it is considered the daily maximum wind gust velocity for the year 2004 collected by the Turkish Meteorological Department and also available also on (Firat, 2007).

Fitting of Gumbel Distribution to the sample of annual maximum

Based on the Sample and using Eq. 5 and Eq. 6:

$$\begin{cases} \overline{U} = 20.13 m/s \\ s = 4.65 m/s \end{cases} \Rightarrow \begin{cases} \hat{\mu} = 18.04 m/s \\ \hat{\sigma} = 3.63 m/s \end{cases}$$

From the estimates above it is drawn in Figure 2 the Cumulative Distribution $F_I(U)$ based on Eq. 4. For comparison it is also included the Cumulative Distribution for the Sample.

Comparing the Cumulative Distributions from the Sample and from the Gumbel Distribution, apparently the Gumbel Distribution is well suited to represent the Sample.

Inherently from the definition of the method of moments the mean value and standard deviation from the Sample and the Gumbel Distribution are the same.

The Gumbel Distribution with the annual maximum wind velocity is used to characterize the probability of extreme wind velocities, typically from the magnitude of expected to be an annual maximum.

Fitting of Gumbel Distribution to the sample of Daily maximum

Based on the Sample of the daily maximum of wind velocity for the year 2004 found on (Firat, 2007) and using Eq. 5 and Eq. 6:

$$\begin{cases} \overline{U} = 8.50m/s \\ s = 2.83m/s \end{cases} \Rightarrow \begin{cases} \hat{\mu} = 7.22m/s \\ \hat{\sigma} = 2.21m/s \end{cases}$$

Repeating the procedure from the previous chapter, it is drawn in Figure 3 the Cumulative Distribution $F_I(U)$ based on Eq. 4 considering the estimates above. For comparison it is also included the Cumulative Distribution for the Sample.

Comparing the Cumulative Distributions from the Sample and from the Gumbel Distribution, it is clear that the Gumbel Distribution is adapted to the Sample.

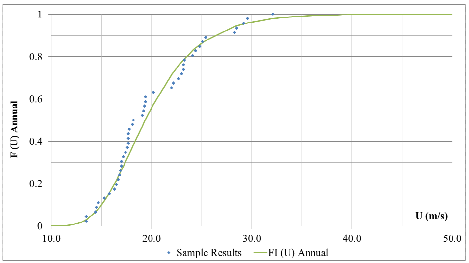

Figure 2 - Cumulative Distributions for the Sample of Annual Maximum and for the adjusted Gumbel Distribution

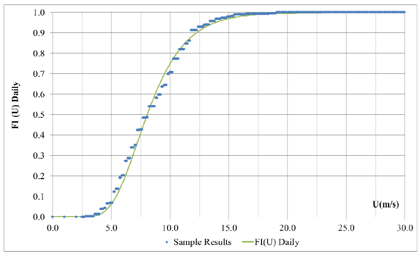

Figure 3 - Cumulative Distributions for the Sample of 2004 Daily Maximum and for the adjusted Gumbel Distribution

EN 1991-1-4 rules

The Standard EN 1991-1-4 (CEN, 2005) defines the velocity profile as a function of the fundamental value of the basic wind velocity, the height above the ground and the terrain roughness (considering 5 types of normalized terrain).

The fundamental value of the basic wind velocity, $v_{b,0}$, is the characteristic 10 minutes mean wind velocity, irrespective of wind direction and time of year, at 10m above ground level in open country terrain with low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights.

Since the LMSS will operate around 75m above the ground it is necessary to include the height effect when estimating the wind velocity acting on LMSS. The EN 1991-1-4 provides relations to estimate proportion between the peak wind velocities at 75m and 10m. Considering the terrain category II from EN1991-1-4 (CEN, 2005):

Terrain Category	z_0 [m]	I_v (75)	$v_p(75) / v_p(10)$
II	0.05	0.1367	1.2675

Table 1 - EN1991-1-4 relations between peak wind velocity for 75m and 10m.

Where z_0 is the terrain roughness length, I_v is the turbulence intensity and $v_p(z)$ is the peak wind velocity.

Being a structure with particular characteristics with narrow application worldwide, the LMSS are not directly covered by traditional standards and calculation rules are usually defined by the designer from its own experience. However, as it is clear from this chapter, there are some rules in the traditional standards that provide useful information and can be used. The use of traditional standards must be cautious and should be complemented with additional studies whenever it is possible.

Wind analysis for LMSS

As the LMSS is not attached to a specific place (it is intended to be used in the construction of several bridges possibly in different countries), it is difficult to establish a fundamental value for the basic wind velocity, because this value is specific to each place. For this reason, the wind velocity to be considered in the LMSS analysis is normally defined for the LMSS and not for an exact place.

Furthermore, as the LMSS is not a static structure, being subjected to several structural systems and very different loads, the wind velocity considered in each operation should be adjusted. For example, in the construction of these bridges in Turkey, 3 different wind velocities are considered (60km/h, 120km/h and 180km/h for 75m above the ground).

Using the Eq. 1 it is possible to estimate the probability for each wind velocity to be exceeded in the reference period, 1 day for the Gumbel Distribution adjusted to the values of daily maximum of wind velocity and 1 year for the Gumbel Distribution for the annual maximum. Additionally it is possible to establish also the MRI for each one of the 3 wind velocities using the Eq. 10.

The probability wind velocity of 60km/h is better estimated using the data from the daily maximum since it is almost certain that the wind velocity will be greater than 60km/h at least once each year. In this case it is important also to determine how many occurrences of wind velocities greater than 60km/h it is expected.

For the velocities of 120km/h and 180km/h, it is used the data from the annual maximum since the probability of one exceedance in one year is relatively small. If these wind velocities are surpassed it is very probable that it is only in one occasion.

For all wind velocities it is considered that each occurrence of exceedance has the duration of one day.

Considering the rules in the EN1991-1-4, it is possible to estimate the wind velocity for a height of 75m for a terrain category II by multiplying the peak wind velocity for 10m by 1.2675.

$v_p(75)$ [km/h]	$v_p(75)$ [m/s]	$v_p(10)$ [m/s]	*MRI*	3 YEARS *Number* occurrences	3 YEARS *Probability* [%]
60	16.7	13.1	15.1 days	72.3	6.61
120	33.3	26.3	10.2 years	0.293	0.027
180	50.0	39.4	364.4 years	0.0082	0.00075

Table 2 - Probability of exceedance at 75m of the velocities 60km/h, 120km/h and 180km/h for 3 years.

The strong wind velocity – 60km/h – is infrequent and is apparently a well suited for operational limit. The extreme wind velocities, 120km/h and 180km/h, have very low probability of occurrence.

In order to establish a probability of each position of the LMSS it is estimated the amount of time that LMSS will stay in each specific position in Table 3.

Operation	Description	Time [months]	Probability [%]
O.1	Assemblies and disassemblies	11.3	31.4
O.2	Without fixations – ready for launching	2.2	6.1
O.3	With fixations, without concrete	8.4	23.3
O.4	With fixations, concrete 1st stage, concrete fluid	2.1	5.8
O.5	With fixations, concrete 1st stage, concrete not fluid	5.2	14.4
O.6	With fixations, concrete 2nd stage, concrete fluid	2.1	5.8
O.7	With fixations, concrete 2nd stage, concrete not fluid	4.7	13.1

Table 3 - Time and probability of each MSS position.

The difference between operations O.4, O.6 and O.5, O.7 is that in the operations O.4 and O.6 it is considered that concrete is still fluid while in operations O.5 and O.7 it is considered that concrete is not fluid. The fact that concrete is not fluid allows assuming that the wind in the formwork is not transmitted to the metallic structure of the LMSS.

The analysis of operation O.1 is not included in the scope of this paper because it is an accessory operation (corresponds to the preparation of the equipment for bridge deck construction) and also because it comprises very different operations.

In some of the operations, the more sensible ones, a limitation is usually imposed to the wind velocity in the Technical Manual of the equipment in order to guarantee the adequate conditions to accomplish the operation. This limitation must be followed by the Responsible for the LMSS operation who must decide before initiating the operation if there are adequate conditions to complete the respective operation comprising the limitation imposed in the Technical Manual at all times.

In order to decide to start, the Responsible is also obliged to fill and sign a check list to engage his responsibility to start the operation. In this check list, the Responsible has to: 1) check the forecast for the period of the operation and some additional time (often 0.5-1.0 the duration of the operation to account for unpredictable situations) and 2) check the wind velocity in the anemometer of the LMSS. If any of these conditions is not verified, the Responsible must not start the sensible operation. Because these conditions are normally clear to the Responsible of the LMSS and other operators and also because the non-accomplishment of these conditions may imply major injuries or even death, the probability of non-accomplishment is normally very small.

About the wind velocity forecast, as the sensible operations are generally of short duration (maximum around 1 day), the probability that the wind velocity forecast matches the wind velocity verified is relatively high.

For these sensible operations it is assumed that the typical probability of forecast mismatch or Responsible bad decision to start the sensible operation without adequate conditions is in the interval [1%;5%]. Conservatively, in this paper it is adopted a value of 5% for all sensible operations where the wind velocity is limited in the Technical Manual.

Assuming that the events A (the MSS is in the operation O.n), B (the wind velocity surpasses U.n, being U.n the wind velocity considered in the calculation of the operation O.n) and C (forecast mismatch or operation responsible bad decision) are independent, the probability of all events are verified:

$$P(A \cap B \cap C) = P(A) \times P(B) \times P(C)$$

This probability value can be seen as the probability of wind velocity considered in the LMSS calculation being surpassed.

Event A		Event B		Event C		
Operation O.n	P(A) [%]	Wind velocity U [km/h]	P(B) [%]	Restriction in Technical Manual	P(C) [%]	$P(A)\times P(B)\times P(C)$
O.1	31.4	N/A	N/A	N/A	N/A	N/A
O.2	6.1	60	6.61	Yes	5	2.0E-4
O.3	23.3	180	0.00075	No	100	1.7E-6
O.4	5.8	120	0.027	Yes	5	7.8E-7
O.5	14.4	180	0.00075	No	100	1.1E-6

O.6	5.8	60	6.61	Yes	5	1.9E-4
O.7	13.1	180	0.00075	No	100	9.8E-7

Table 4 - Probability of wind velocity surpasses the wind velocity used in LMSS calculation.

As it can be seen in the Table 4, the total probability of a wind velocity not considered in the LMSS calculation is small for all operations, being relatively homogeneous for 2 groups of operations. The bigger probabilities are associated to sensible operations with wind velocity limitations in the LMSS Technical Manual.

Conclusions

It is important to consider the indications prescribed in the standards. However, in some particular cases like the LMSS, the applicability of the standards is often difficult or even inadvisable. An additional aspect to be taken into account is that the LMSS market is worldwide and sometimes it is not possible to verify simultaneously a wide variety of regulations. In both cases, the judgment of the LMSS designer is very important to define the particular set of rules to be used in LMSS calculation.

Through the analysis of the wind actions in the LMSS that is being developed for Ankara, one can verify that the probability of exceeding design wind velocities is small enough to consider that operation safety is assured and wind velocities are adequate.

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