Wall formwork and climbing systems

Application of new wind load standards

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For the calculation of climbing protection panels and climbing formwork which are used for the construction of high buildings, wind and its subsequent effects is a decisive influencing factor. Compared to the predecessor standard, the considerably more comprehensive DIN 1055-4:2005 now allows the user to determine the wind loads for these systems. Up to now, this was only possible to a limited extent.

In the following article, a description is provided of the current standard on the basis of several examples whereby reference is made to the disadvantages as well as pointing out the limitations in the application. Furthermore, it is presented how PERI GmbH achieved more cost-effective calculation results through the application of wind-technological tests for its climbing systems which, in fact, go beyond the standard itself.

1. Introduction

In recent years, a completely new safety philosophy has generally become accepted in the construction industry. For the calculational handling of the problems of failure, there has been a change from a "global safety concept" to the so-called "partial safety concept" in nearly all standards.

The DIN 1055 "Lastannahmen für Bauten" (Design Loads for Buildings) series of standards, which originated in the 1970s and 1980s, have been replaced by the DIN 1055 "Einwirkungen auf Tragwerke" (Actions on Structures) series of standards. The new standard series is based on the European preliminary standards ENV 1991 (Eurocode 1): "Basis of Design and Actions on Structures" and thus on the partial safety concept. With the building law-related introduction of the current DIN 1055 on 1.1.2007, it has become relevant for structural planners.

For determining the wind loads on wall formwork and climbing systems, the previous standards (DIN 1055-4:1986-08 and DIN 1055-4/A1:1987-06) was applicable only to a limited degree as it was meant purely for estimating the wind pressure as a subordinated

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load on buildings or constructions: "For structures where – apart from the dead load – the wind load largely determines the calculation results, the specifications in the available standard are not regarded as a sufficient basis for recording the effects of wind load influences within the framework of safety verification“ (extract from [1] - Explanatory Notes (pages 23 - 29). With the current valid wind load standard, this restriction no longer applies.

The current standard features considerably more load cases and approaches for the calculations. This has had a positive effect as cases are now regulated formerly extensive wind tunnel testing would have become necessary. However, the differentiations within the standard are a disadvantage which leads to an increase in the work involved for the calculations.

2 Wind loads according to DIN 1055-4:2005 using examples

2.1 Wind loads on a free-standing wall

The basis for the current DIN 1055-4 is the EN 1991-1-4. As important new features, the current standard takes into consideration the geographical position of the building (wind zones) and different terrain categories for data collection regarding the surface roughness and topography. Furthermore, the height of the structure above the ground, period of application and the force coefficient of structures or structural elements of the construction have also been taken into account. Other factors, among other things, are seasonal factors, directional factors and neighbouring buildings.

The surface roughness of the surrounding area depends on the vegetation and buildings and significantly influences the wind velocity. The standard distinguishes between four terrain categories. Downstream from a change in surface roughness, the wind profile in a transitional zone gradually takes on the form which corresponds to the subsequent

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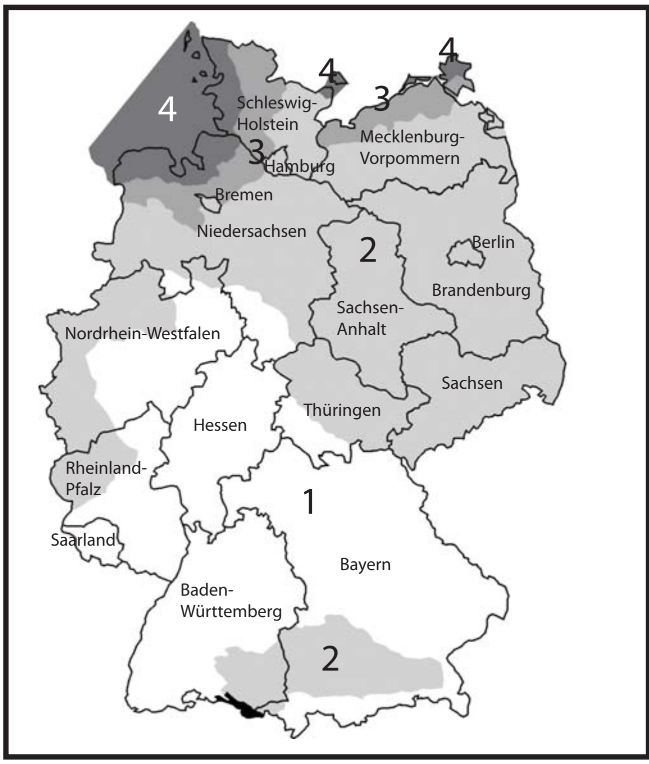
roughness. In this transitional zone, a mixture of profiles develops which depend on the distance from the change in surface roughness. As large areas of uniform surface roughness are rare in Germany, a mixture of profiles is usually the case. Accordingly, the standard recommends the application of the following three profiles: "inland mixture profile", "coastal mixture profile" and "islands of the North Sea".

The wind zones featured in wind zone maps (**Fig. 1**) are based on a European concept. Each wind zone corresponds to an average wind velocity v_{ref} over a period of 10 minutes. The values apply to a height of 10 m above ground level in the flat, open area which corresponds to Terrain Category II according to DIN 1055-4 Appendix B. With **equation (1)**, the velocity pressure q_{ref} can be calculated which, for its part, is included in [2] the given formulae for calculating the peak velocity pressure.



Windzone	V_{ref}
WZ 1	22,5 m/s
WZ 2	25,0 m/s
WZ 3	27,5 m/s
WZ 4	30,0 m/s

Fig. 1: Wind zone map for Germany. (Graphic: PERI GmbH)

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q_{ref} [kN/m²] = v_{ref}^2 [m/s] / 1600 **(1)**

Due to the numerous input variables which underlie wind load determination, the wind power is different with each case of application. Apart from the wind load standard, other more stringent provisions may have to be taken into consideration.

The wind pressure is calculated using the following formulae:

w [kN/m²] = $c_p * q(z) * \kappa$ or **(2)**

$c_f * q(z) * \kappa$ **(3)**

with

c_p und c_f = Aerodynamic coefficient and aerodynamic force coefficient: for many cases of application, the coefficients are regulated in the standard; alternatively, the values can also be determined by means of a wind assessment compiled by an expert.

q(z) = Peak velocity pressure: the value depends largely on the height z above the ground, surface roughness and topography

κ = Reduction factor according to DIN 1055-4 Table 1 (service life factor): the factor is dependent on the period of use of the construction; for a period of up to 2 years, this is 70 %.

For the peak velocity pressure inland in Wind Zones 1 and 2, a comparison of the DIN 1055-4 with its predecessor standard shows good conformity with the previous values (**Fig. 2**). In Germany, over 85 % of all construction projects take place in these two wind zones.

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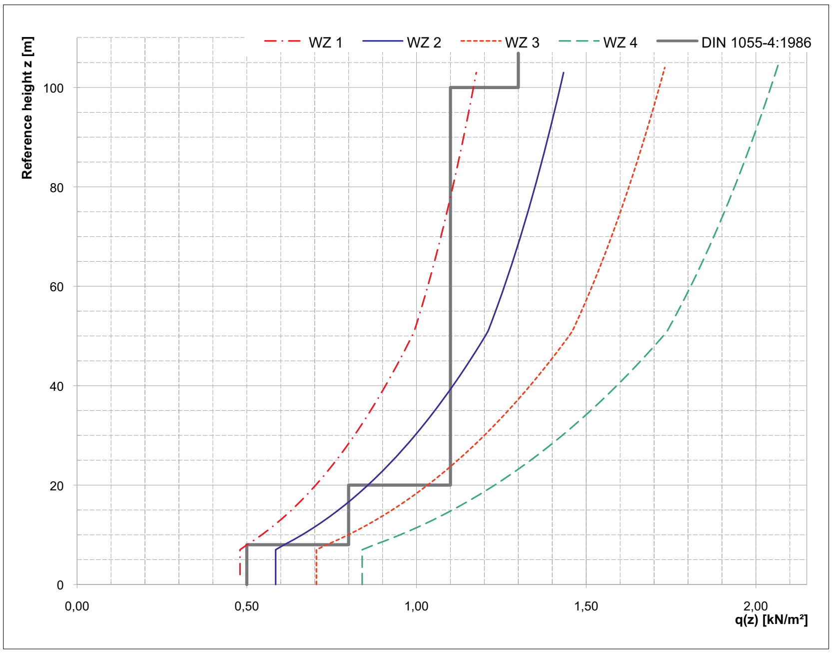

Fig. 2: Peak velocity pressure q(z) inland / comparison of the old and new standard. (Graphic: PERI GmbH)

If the aerodynamic coefficients are additionally taken into consideration and the wind loads which are to be used for the calculation are compared, the deviations between the standards can be substantial to some extent. The example of wall formwork positioned on a building (**Fig. 3**) makes this very clear.

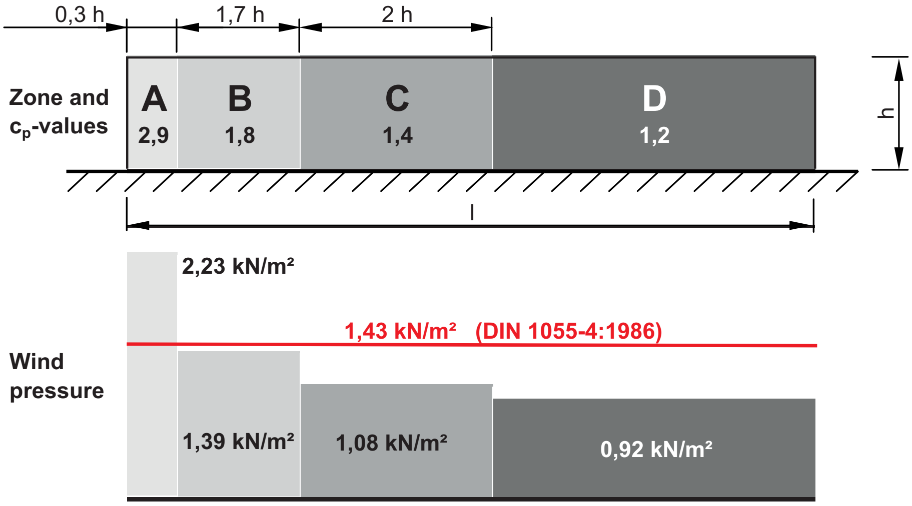

Fig. 3: Wind load on a straight, free-standing wall at a height of 40 m: l / h = 5, Solidity φ = 1.0, Wind Zone 2, Inland, Service Life Factor κ = 0.7. (Graphic: PERI GmbH)

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The standard divides free-standing walls into zones and provides aerodynamic coefficients ([2] Chapter 12.3) for each zone. The c_p-values of the example lie between 1.2 and 2.9. If a wall with a reference height of 40 m is erected for example in Berlin, the wind pressure is between 0.92 kN/m² and 2.23 kN/m² depending on the wall section under consideration. In order to ensure cost-effective construction, a differentiation with several dimensioning areas is therefore absolutely necessary.

2.2 Wind loads on climbing protection panels

For those cases which are not regulated in the standard, or if their application would provide uneconomical results, the user is free to carry out experimental aerodynamic wind simulations for determining the aerodynamic coefficients. A climbing protection panel is given here as an example which serves as an enclosure to be used on high structures during their construction.

Designed in the form of a high parapet, the climbing protection panel provides effective weather, privacy and safety protection for work carried out on floors that have already been finished as well as the levels still under construction above these. Starting from the upper mounting, the construction cantilevers over a maximum of two storey heights. It offers sufficient space for the formwork and concreting work in order to be able to safely construct up to two more floor slabs (**Fig. 4**).

According to construction progress, the climbing protection panel is moved upwards by crane or by means of an integrated hydraulic system.

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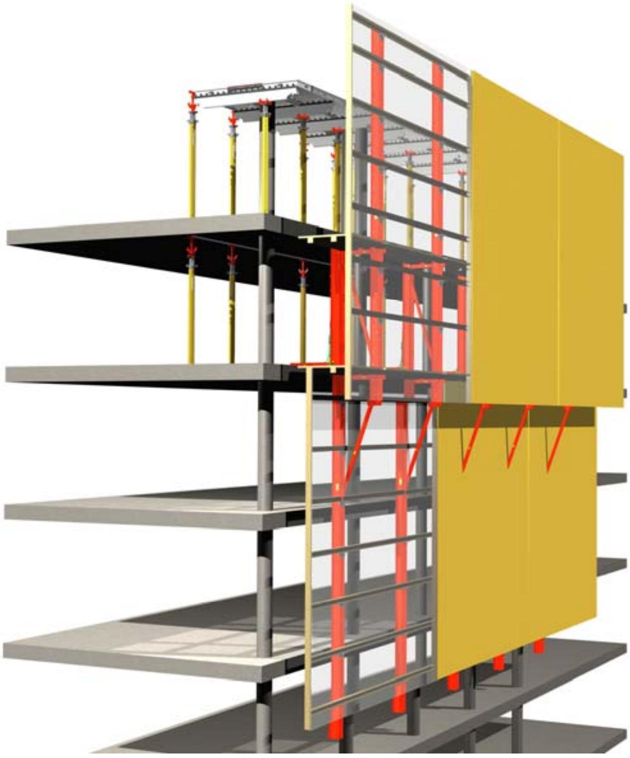

Fig. 4: Principle set-up of a climbing protection panel.

Discussion on the assumed design loads according to DIN 1055-4

As the operational spectrum of such a construction essentially concentrates on high buildings, the wind load becomes the decisive influencing factor of this construction. Chapter 12 of DIN 1055-4 offers a great number of possibilities of classifying the climbing protection panel regarding the determination of the wind pressure coefficients. Several questions arise as a result.

Can the protection panel be calculated as a "rectangular structure"?

The classification of a protection panel as a "structure" on basis of the explanatory notes in accordance with DIN 1055-4, Chapter 12.1.1 – 12.1.2, leads to incorrect results when determining the pressure coefficients.

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The reasons for this are that,

- no roof enclosure is available in the cantilevered area;
- the construction can be affected by an undercurrent during building progress as the building facade usually remains temporarily open below the protection panel;
- the protection panel is frequently climbed in an offset manner so that the enclosure is not continuously closed;
- non-rectangular building ground plans generate local incoming flow differences.

Can a protection panel be classified as an "attic"?

Evaluating the construction as an attic according to Chapter 12.1.3 Table 4, only takes into consideration the aspect of the missing roof enclosure but provides, however, no reference about the incoming flow conditions in the wind-facing and downwind areas of the protection panel.

Does a protection panel correspond to a "free-standing wall"?

Consideration as a free-standing wall with returned corners in accordance with Chapter 12.3 does not seem to be productive as the construction can be affected by an undercurrent and this approach, compared with wind flow aspects, is too unfavourable.

Is a protection panel a "separate structural component"?

Considering the panel as a separate structural component (e.g. as a billboard, see Chapter 12.3.3) is likewise not clearly regulated by the standard regarding the problem of "corner suction".

Other wind-relevant aspects are not mentioned in the standard. The ground plan geometry of the working level to be protected can have, for example, a significant influence on the wind stress of the protection panel construction and thus on its load-bearing capacity. **Fig. 5** shows the pressure distribution on a protection panel for different ground plans and wind directions. One can see that the pressure distribution greatly depends on the a/h and/or b/h ratio. Depending on whether the rear

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protection panel is subject to an overflow or not, the diagram shows clear differences in the pressure distribution.

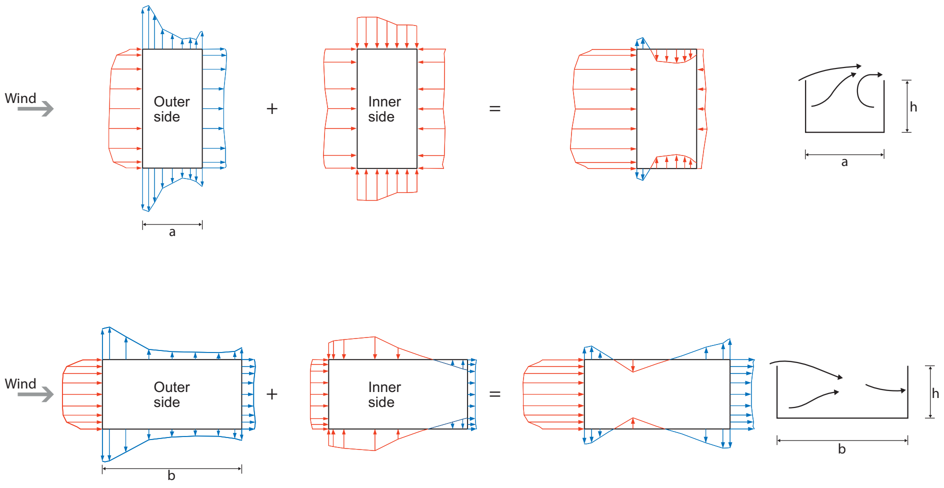

Fig. 5: Wind flow conditions on a protection panel subject to the ground plan geometry. (Graphic: PERI GmbH)

In case of an offset construction progress or an offset climbing protection panel, a similar effect is to be expected. Likewise, a building core climbed in advance can affect incoming flow conditions on the outer and inner sides of the protection panel. This effect means that the wind effect on the cantilevered open area as well as on the closed area of the construction due to the floor slabs must be regarded in differentiated terms. Distribution of the resulting equivalent load coefficients for wind pressure and wind suction over the entire course of the panel is shown in **Fig. 6**.

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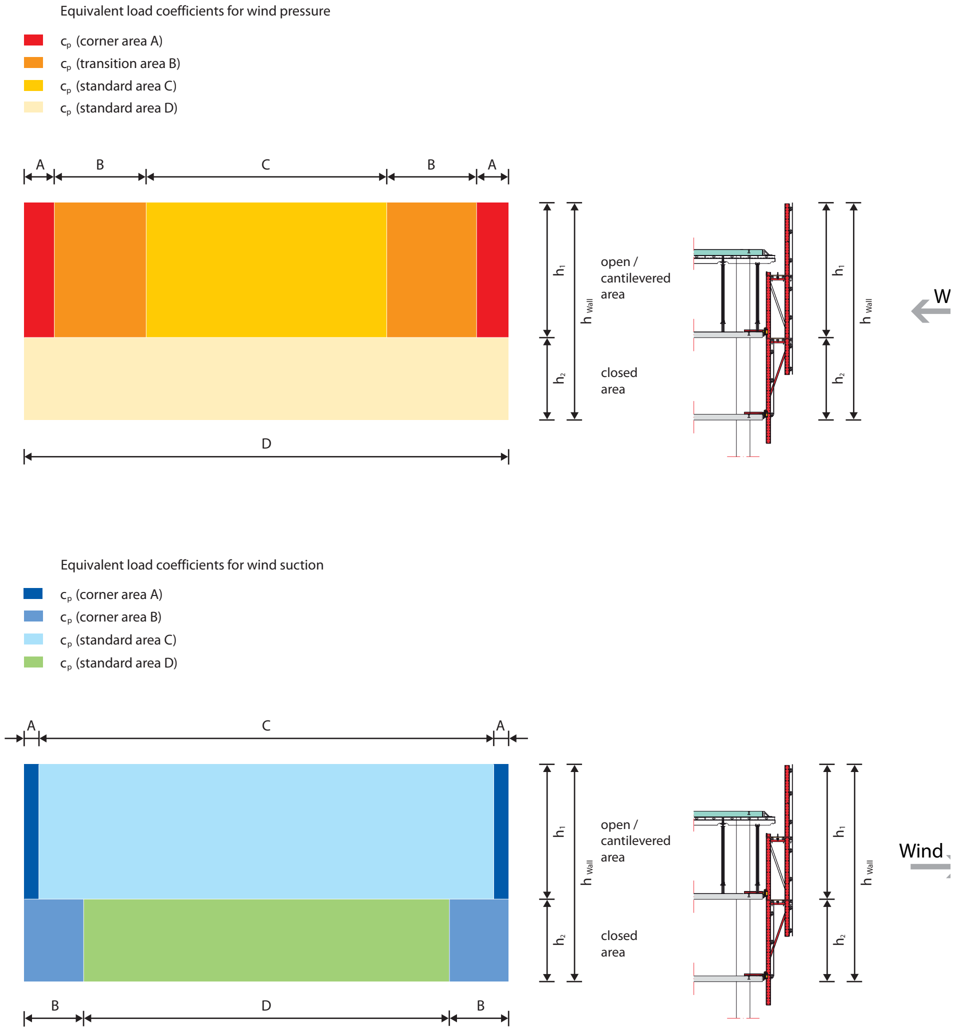

Fig. 6: Zones of different coefficients for wind pressure and wind suction on a climbing protection panel. (Graphic: PERI GmbH)

Reasons for a wind-technological investigation (WTI)

In order for the climbing protection panel to be able to provide a reliable statement regarding the aerodynamic pressure coefficients, the DIN 1055-4 has proved to be an inadequate resource. There are a number of other arguments which favour a WTI:

- Correct load assumptions as a basis for calculation

The previous discussion shows that without an available WTI, the wind load assumptions are insufficient as a basis for analysis of the protection

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panel and the awareness that the flow characteristic of the construction can only be assessed conservatively.

- Economical results

The most realistic simulation as possible gives more accurate results than a comparison carried out on the basis of the standardisation. Similar as with the free-standing wall (Chapter 2.1), the WTI provides areas with large differences for the c_p-values. For a cost-effective construction, therefore, the individual areas must be calculated separately.

- Classification of influencing parameters

With the help of the simulation, different building geometries as well as the sequenced construction progress and incoming flow occurrences can be depicted. The evaluation provides insights into important parameters and thus allows the separation and summarization of various influencing factors.

- International applicability

A wind-technological investigation experiences a wider acceptance internationally and saves, if necessary, on the implementation of the country-specific regulations which likewise offer no satisfying calculation method for these type of tasks.

- Sound calculation basis

Finally, a WTI offers a sound argumentation basis for the structural engineer in discussions with the test engineer.

2.3 Wind loads on climbing formwork

Even more complex and time-consuming than for the climbing protection panel is the ascertainment of wind effects on rail-climbed formwork systems with movable wall formwork and enclosed working platforms. The system looked at here is a bracket-type framework construction and has been designed as a load-bearing scaffold in the terms of DIN 4421

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and DIN EN 12812 for supporting a wall formwork. For the height of the three platforms, the vertical climbing rails are connected with the building in each case. The formwork can extend up to 5.70 m above the topmost attachment point.

Figure 7: Climbing formwork with enclosed working platforms. (Graphic: PERI GmbH)

Because of the enormous time and cost pressure on the jobsite, and in order to minimize risk of injuries and operating errors, the construction must be designed in a way that fast and smooth-running working operations are possible. For this purpose, the two top platforms are realised with widths of 2.40 m, whereby the side protection can have a closed design. Furthermore, the platforms have a lateral projection of approx. 1.00 m at the corners of a building.

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Discussion on the design loads according to DIN 1055-4

Those arguments that speak against the application of the DIN for the climbing protection panel can also be used here without any limitations. Compared to the protection panel, changes to the load effect from the natural wind can be expected here for the climbing formwork. Due to the closed side protection placed in advance, it is assumed on the one hand that the wind flow conditions on the formwork will be influenced. Thus wind loads could potentially be generated which significantly exceed the wind loads compiled for the upward cantilevered area of the climbing protection panel. On the other hand, the side protection is influenced by wind effects which are to be taken into consideration regarding the structural proof but the DIN, however, does not offer any suitable approach for this.

Reasons for a WTI

Climbing formwork is normally used for high structures and tower above these during the building phase. This means that the wind load is the most important influencing factor for the construction. In comparison to this there is the DIN which only provides conservative load assumptions and thus an uneconomical solution for the construction itself. Transferring the findings gained with the climbing protection panel was not so straightforward. Therefore, the climbing formwork was likewise evaluated in the context of a WTI.

One focal point of the WTI was the mutual influence of the formwork and side protection (**Fig. 8**). For wind pressure (wind perpendicular to the building) and wind suction (perpendicular on the formwork), the influence of two walls of different height and distances positioned one behind the other had to be determined and quantified in the form of load factors.

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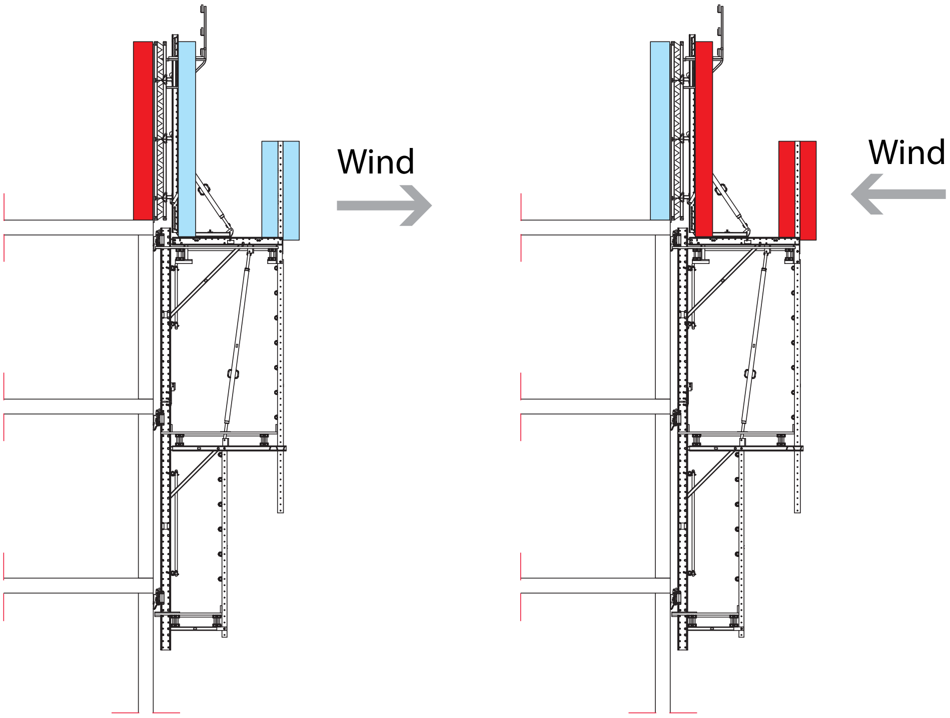

Fig. 8: Section through climbing formwork (red = wind pressure, blue = wind suction). (Graphic: PERI GmbH)

For each of the three wind directions, three areas (corner, transition, standard) were specified. The lengths of the individual areas depend on the structure and the system. The pressure coefficients of the areas differ substantially from each other (**Fig. 9**).

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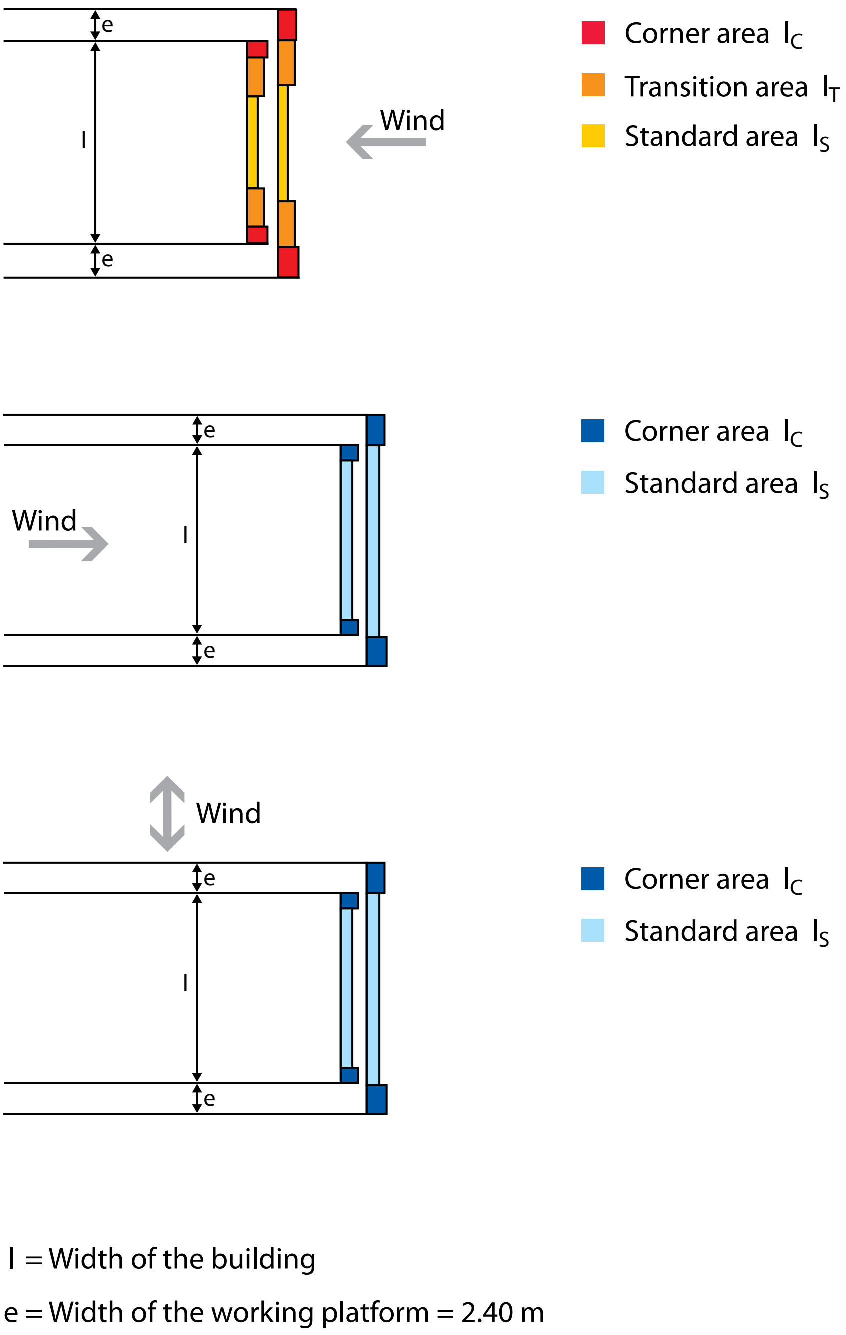

Fig. 9: Pressure coefficients for formwork and upper side protection. (Graphic: PERI GmbH)

Through this differentiation, the number of load cases to be examined for the calculations does actually increase but a standard-compliant and economic result is however achieved which, on the one hand, covers the

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load peaks in the corner areas and, on the other, takes into consideration the reduced wind load in the remaining areas.

The user of the system, who must differentiate whether he is in the corner, transition or standard area, has now more flexibility regarding the choice of connection points on the building as he can allow considerably larger spacings in the standard area.

3 Determining the wind loads according to EN 1991-1-4:2005

The individual Member States of the European Union have created wind zone maps for their respective territories which are based on a common calculation concept. The declared value of these maps is the basic wind velocity which is determined on a uniform basis (see Chapter 2.1).

If wind forces are determined according to EN 1991-1-4, the national appendices of each country are to be taken into consideration. The wind pressure is calculated with the commonly-used formula:

$$w\ [\mathrm{kN/m^2}] = c_p * q_p(z) * c_{prob}^2 \qquad \textbf{(4)}$$

with

c_p = aerodynamic coefficient according to EN 1991-1-4 Chapter 7.4; alternatively, values can be determined by means of wind assessments

$q_p(z)$ = peak velocity pressure according to EN 1991-1-4 Chapter 4.2 to 4.5; depending on wind zone, surface roughness, topography, utilisation height z

c_{prob}^2 = load-reducing factor according to EN 1991-1-4 Chapter 4.2; depending on service life and country

Determining the shape parameters conforms to DIN 1055-4 whereby a WTI may be used as an alternative. Ascertaining the velocity pressure and the service life factor are regulated through the national appendices whereby the given values clearly differ in part.

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For structures which are only temporarily erected, such as temporary structures or scaffolding, a load-reducing factor may be taken into consideration.

When determining the characteristic loads, the safety concept allows for an annual exceedance probability p of 2 % for a building with a reference service life of 50 years. This means that a structure must be able to resist a load once on average which is greater than the design load during this time. More detailed information on safety levels is available in the EN 1990 [3] and the Betonkalender 2006 Volume 1 VI, Chapter 2.4.3.

Determining the load-reducing factors is carried out using the [4] formula 4.2:

$$c_{prob} = \left(\frac{1 - K * \ln(-\ln(1-p))}{1 - K * (-\ln(0{,}98))} \right)^{n} \qquad (\mathbf{5})$$

The shape parameter K integrated in **Equation 5** along with exponents n can be regulated by the individual countries through their national appendices for the EN 1991-1-4 (see **Table 1**).

Service life factor ≤ 2 years	**K**	**n**	c_{prop}^{2}
Recommendation of the EN	0,2	0,5	0,64
Values for Germany	0,1	1,0	0,59
Values for France	0,2	0,5	0,70

Table 1: Examples of load-reducing factors. (Graphic: PERI GmbH)

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4 Summary

For state-of-the-art planning of a load-bearing construction which should be capable to stand up to static inspect, the indicated aspects are to be taken into consideration during the technical implementation.

In spite of the extensive analysis of cases, the DIN 1055-4 as well as the European wind load standard EN 1991-1-4 cannot provide satisfactory details regarding the aerodynamic coefficients for each application and assumptions on the safe side must be met which are uneconomical. It has been shown that for the climbing systems described in this article, these standards constitute an insufficient assessment basis.

For constructions whereby the wind load has a significant or even dominant influence on the entire calculation results, an aerodynamic flow test will provide the most reliable as well as often the most cost-effective result. In addition, a WTI serves as a sound argumentation basis for the structural engineer in discussions with the test engineer.

It has the further advantage that it is not based on any national standard and is internationally applicable. It provides only details regarding the aerodynamic coefficients of the individual components. Determination of the wind velocity and the resulting dynamic pressure takes place according to the national standards of each country.

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