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Building up a finite element model and calculating the wind load for large-span spatial hinged canopy of exhibition complex

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ABSTRACT

This article is aimed to provide information about calculation of the wind load onto complex geometric forms using modern computer program SOFiSTiK, which implements the finite element method (FEM). The calculation is made on the example of large-span spatial hinged canopy of exhibition complex "North canopy" in the Shushary village, Leningrad region. The problem of calculation of large-span spatial hinged form "North canopy" of exhibition complex for wind and snow loads has been faced while the company "Evgeny Gerasimov & partners LLC " developing the construction project of the Congress-exhibition complex in the Shushary village, Leningrad region. In this regard, there exists a need for research targeting to:

1. Examination of the construction’s strength and stability under its own weight, wind and snow load under different variants of the wind airflow direction.

2. Determination of the structure’s maximum deflections. The problem was solved taking into account the experience of spatial structures’ calculations and investigations.

Contents

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1. Introduction

This article is aimed to provide information about calculation of the wind load onto complex geometric forms using modern computer program SOFiSTiK (www.sofistik.ru), which implements the finite element method (FEM).

Calculation is made on the example of large-span spatial hinged design "North canopy" of exhibition complex in the village Shushary in Leningrad region.

2. Literature review

Over the past years, the use of steel in large-span spatial structures led to a growing quantity of constructions of unique architecture and forms. However, one of the biggest challenges in designing a proper finding and attaching wind loads to model. [24-26] Due to the fact that today in the codes there are no specific recommendations for the purpose of calculation of wind loads on the canopies of spatial structures with a complex configuration [3], increasingly chosen method of their determination by physical simulation models in wind tunnels.

Determination of wind loads on engineering structures of different purposes, such as high-rise buildings, bridges, TV towers, large-span coverage has become a necessary practice in their design and construction.

For example, a stadium in Dnepropetrovsk with wide-span console coating over the grandstand was one of such objects for which it was decided to perform complex experimental researching of the effect of wind impacts on the cover design and to determine the way of the aeration regime on the playing field in wind tunnels of the Kiev National aviation University in 2007. [18] The stadium of the sports club "Dnepr" is designed on the basis of international standards, with a capacity of stands on 30 thousand people and is designed for football competitions of the highest level. In accordance with the requirements of the FIFA spectator stands along the perimeter of the stadium are protected from atmospheric influences by canopies. Console sheds have been solved in the form of a three-dimensional system console trusses with a light coating on metal decking. (Figure1)

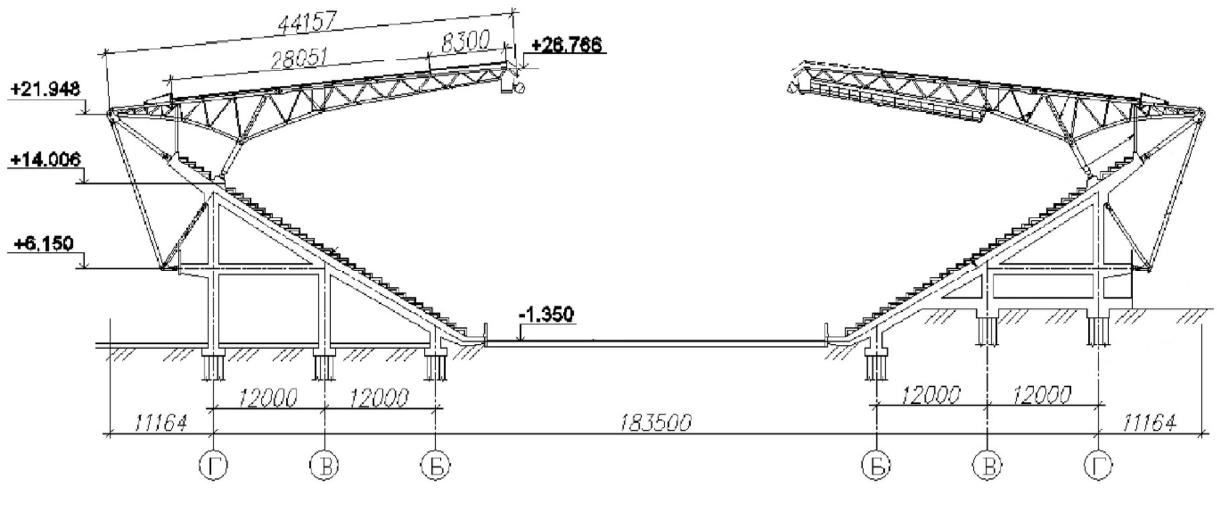

Figure1. Fundamental structural scheme of the cross-section of the stadium

Main bearing structures are made of tubular flat trusses, located on the perimeter of the stadium with a step 10.2 - 10.6m. On trusses in the transverse direction beams are directly carrying roofing system. Console trusses are spreading up to 30 meters inside. Rear ends of trusses, hanging down over the back edge of the spectator stands, are fixed by the system of struts to the reinforced concrete frame of the Seating bowl. Given the magnitude of the construction (the size of the canopy is about 18 thousand square meters) and a large console canopy over the stands, design of the cover can be applied to the category of unique objects.

For generating wind loads on the canopies of spatial structures with complex configuration was chosen the way of their definition by physical modeling of flow of the stadium models in wind tunnels of the National aviation University (NAU). Were made: model of standard cover direct site of the stadium with tribunes and tents (scale 1:300) and a full model of stadium (1:120) (figure 2). Both models had drains on the top and bottom surfaces of the roof to determine the value of air pressure in windy weather. Purging the full model of the stadium was carried out in the range of azimuth wind 0...360 degrees.

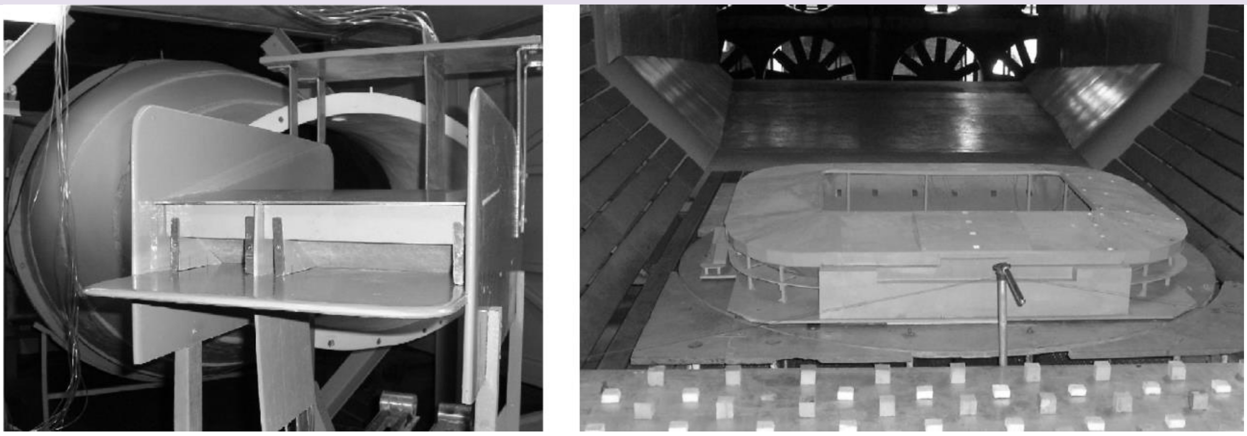

Figure 2. The model of a typical bay stadium (scale 1:300) and a full model of the stadium (1:120).

Research of wind loading on the original buildings and structures shows that there are significant differences between the real wind loads and code recommendations [24].

3. Problem definition

The problem of calculation of large-span spatial hinged form "North canopy" of exhibition complex (Fig.3) for wind and snow loads has been faced while the company "Evgeny Gerasimov & partners LLC " developing the construction project of the Congress-exhibition complex in the Shushary village, Leningrad region.

Figure 3. North canopy of exhibition complex

In this regard, there exists a need for research targeting to:

1. Examination of the construction’s strength and stability under its own weight, wind and snow load under different variants of the wind airflow direction.

2. Determination of the structure’s maximum deflections.

The problem was solved taking into account the experience of spatial structures’ calculations and investigations [1-26]

To perform the study the following source data have been obtained:

1. The canopy layout scheme, according to the architectural drawings.

The structure consists of the main framework, secondary trusses, diagonal trusses and the cladding-revetment system. Main trusses are located perpendicularly to the front of the main building, at that they represent console structures. Secondary trusses are transferring loads from the cladding substructure to the main trusses and, in addition, these secondary trusses make the base for console framework in the horizontal direction. Diagonal trusses create additional support for structure working as arches, transferring, through the steel support, most of the effort generated by external influences onto foundation (figure 4).

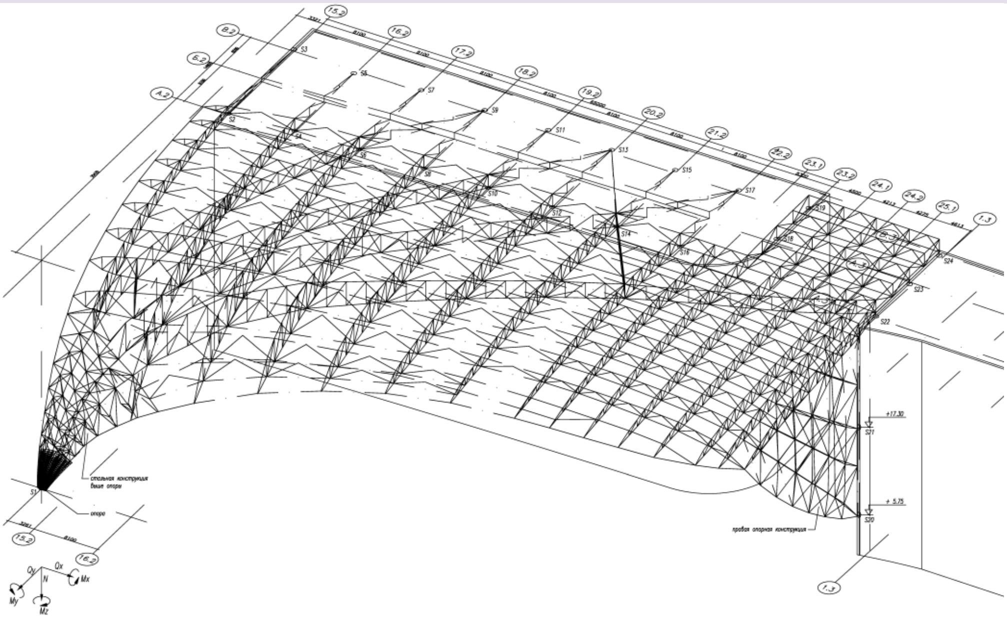

Figure 4. Construction of the northern canopy (main trusses, diagonal trusses and secondary trusses)

2. Materials and cross-sections.

All cross-sections represent the round tubes compliant to GOST 8732-78 diameter from 152 to 500 mm, wall thickness from 6 to 36 mm. All elements of the Northern canopy are manufactured of the steel grade C345 as by GOST 27772-88 (table1).

Table 1. Normative and design resistance to steel C345.

Steel	Thickness of steel, mm	Normative resistance, MPa (kg/mm2)				Rated resistance, MPa (kg/mm2)			
		plate, wideband universal		shaped		plate, wideband universal		shaped	
		R_{yn}	R_{un}	R_{yn}	R_{un}	R_y	R_u	R_y	R_u
C345	От 2 до 10	345 (35)	490 (50)	345 (35)	490 (50)	335 (3400)	480 (4900)	335 (3400)	480 (4900)
	Св. 10 до 20	325 (33)	470 (48)	325 (33)	470 (48)	315 (3200)	460 (4700)	315 (3200)	460 (4700)
	Св. 20 до 40	305 (31)	460 (47)	305 (31)	460 (47)	300 (3050)	450 (4600)	300 (3050)	450 (4600)
	Св. 40 до 60	285 (29)	450 (46)	–	–	280 (2850)	440 (4500)	–	–
	Св. 60 до 80	275 (28)	440 (45)	–	–	270 (2750)	430 (4400)	–	–
	Св. 80 до 160	265 (27)	430 (44)	–	–	260 (2650)	420 (4300)	–	–

3. Report of aerodynamic testing under wind loads (results of tests by Wacker Ingenieure of 10.10.2011)

4. Recommendation on the appointing the design snow and wind peak loads to exhibition complex, CNIISK named after Kucherenko, 2012 [22]

4. Building up a finite element model

The most effective way to build up a computational model refers to combining programs of structure geometry shaping and programs that define the physical properties built for geometric models. In the study of the Northern canopy there was used the following programs' pack:

AutoCAD->SofiPLUS->Sofistik.

The main principle of the finite-element model construction is to represent architectural form of the canopy with the primitives in a three-dimensional model of the AutoCAD environment. Further the module SOFiPLUS allows to convert primitives into sophistic structural elements, of "core" and "shell" types.

The three-dimensional polyline (3d polyline) component has been used as the primitive rod in the AutoCAD environment; it embodies an universal primitive allowing to simulate continuous segments in three-dimensional space. The "3dface", "Surface (network)", "Surface (nurbs)" were used as primitives of plate elements.

3d polylines turn into diagonal rods of trusses with relevant materials and cross-sections through the command "Structural line" of SofiPlus panel. All nodes, except base nodes, were modeled transferring efforts from element to element in all six degrees of freedom. Plates turn into shells of relevant rigidities through the command "Structural area" of panel "SofiPlus" (figure 5):

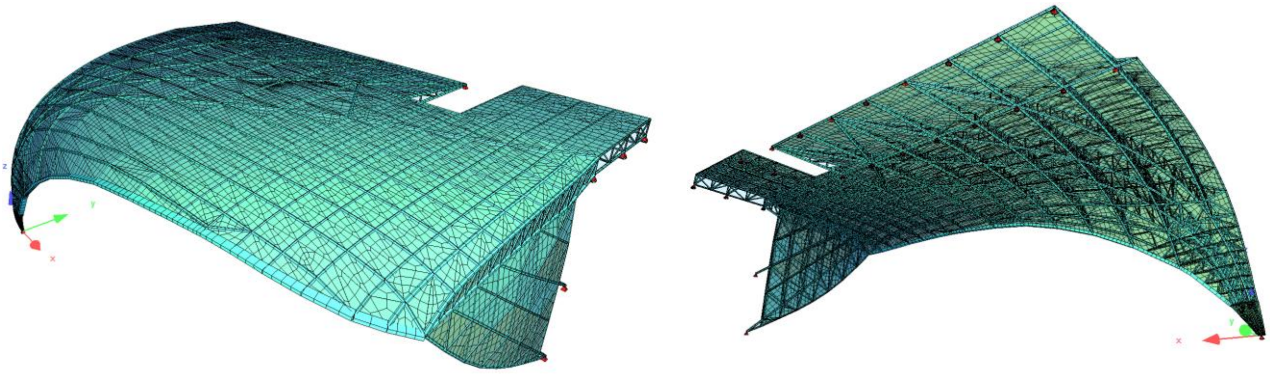

Figure 5. Rod and shell elements of the computational model

5. Loading finite element model

The structure embodies a quite complex space-planning and constructive solution that has no analogues. Neither SNiP 2.01.07-85* «Loading and impact» [3], nor other national and foreign regulatory documents do never contain data on distribution of snow and wind loads onto constructions of the given type. Aerodynamic coefficients are presented only for surfaces of different simple forms (flat solid structures, rectangular in plan buildings with a ridge coatings, rectangular in plan building with arched coatings, building with lanterns, canopies, etc) (figure 6).

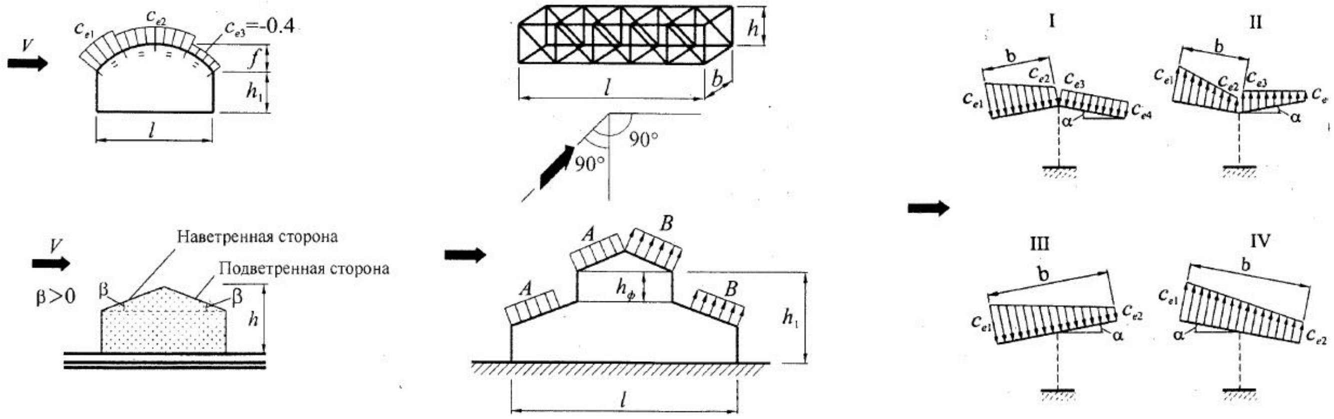

Figure 6. Loads to the surfaces of the simple forms in normative documents

The safe and economic design and construction of the canopy needs a realistic assessment of the wind loads (averaged by square) and local peak wind loads acting simultaneously on the design of the canopy. This requires an adequate wind tunnel testing (figure 7). To obtain the parameters describing the wind airflows the "Wacker Ingenieure», Germany, has effected comprehensive measurements using static sensors and constant temperature by thermoanemometers.

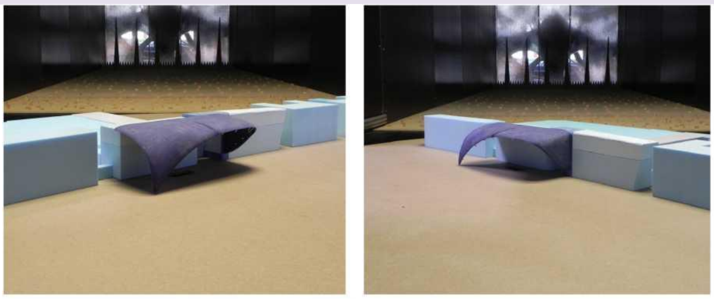

Figure 7. The test model of the canopy in a wind tunnel

In the result of blowing the distribution of quasi-static wind loads on the Canopy structure under different wind directions has been obtained. The distribution of snow load for the Northern canopy presented in the Recommendations for the appointment of the settlement snow and wind loads for the Congresses and exhibition complex in Saint-Petersburg, CNIISK named after V.A.Kucherenko [22] are based on materials of tests at the wind tunnel effected by "Wacker Ingenieure".

The wind and snow loads values are taken from the Recommendations on the appointed snow and wind loads for canopy of convention and exhibition complex (CNIISK named after Kucherenko). Before each isometric field-related load on snow and wind pressure, the coating elements at the scheme are painted with appropriate colours, so each loading value has been attributed the corresponding color (figure 8). Thus, the picture of the loading is transferred into a SofiPlus model.

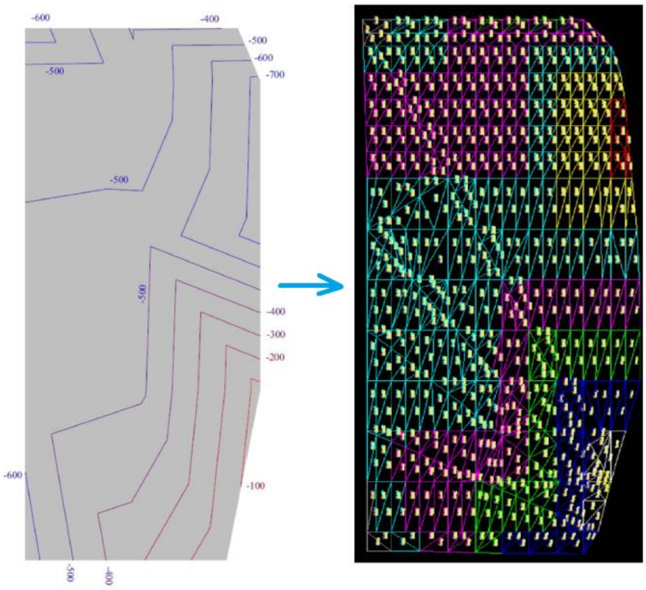

Figure 8. Loading the calculation scheme for isometric field snow and wind pressure

The Northern canopy calculations results obtained with the auxiliary of software complex SOFiSTiK serve to draw the following conclusions:

1. The stress at the whole structure rods at the most hostile loads combination do never exceed the tolerated ones (figure 9);

2. Maximum deflection of design at the worst combination of loads is below the limit one (figure 10). The most dangerous combination of loads is a combination from the influence of its own weight, snow and wind.

3. Value of stability factor for all loadings >1.

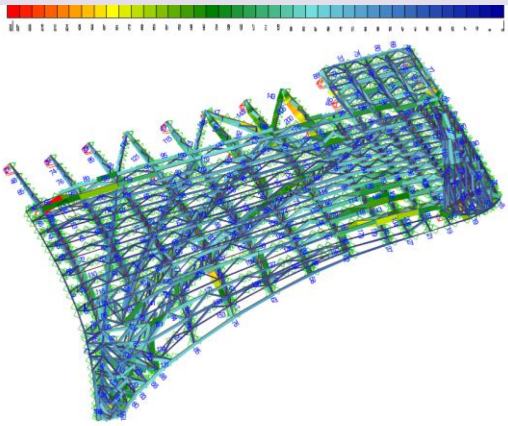

Figure 9. Equivalent stresses all sections, MPa (max.233 MPa)

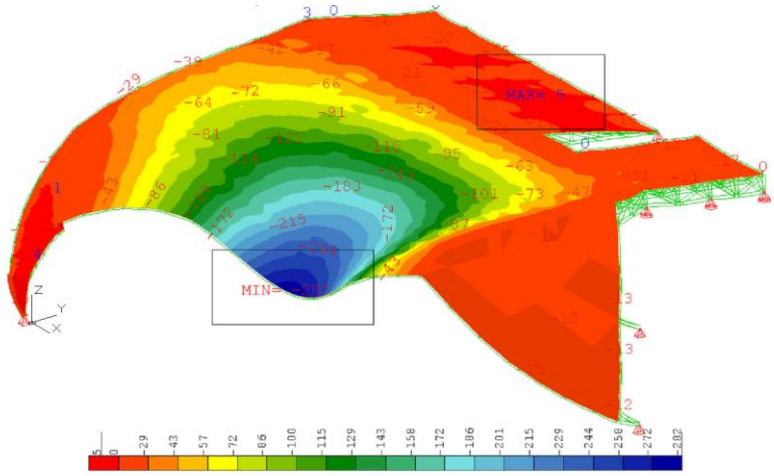

Figure 10. Sediment along the Z axis worst combined effects of the snow and wind, mm (max.282 mm)

6. Conclusions

1. The structure stress at any combination of loads is found safe being below the acceptable value. The canopy is characterized with stable total durability.

2. All deflections at any combination of loads are found safe being below the acceptable values. The structure is characterized with stable stiffness.

3. The overall system is safe and characterized with its structural stability in total.

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Конечно-элементная модель большепролетной пространственно-навесной конструкции выставочного комплекса

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ветровая нагрузка,
большепролетная навесная конструкция

АННОТАЦИЯ

Целью статьи является предоставление информации по расчёту на ветровую и снеговую нагрузку конструкции сложной геометрической формы с использованием современного программно-вычислительного комплекса SOFiSTiK, реализующего метод конечных элементов (МКЭ). Расчёт произведён на примере большепролётной пространственной навесной конструкции "Северный козырёк" выставочного комплекса в п.Шушары Ленинградской области Задача расчета большепролетной пространственной навесной конструкции "северный козырек" выставочного комплекса на ветровую и снеговую нагрузку возникла при разработке компанией ООО "Евгений Герасимов и партнёры" проекта строительства конгрессно-выставочного комплекса в поселке. Шушары, Ленинградской области. В связи с этим возникла необходимость следующего исследования:

1. Проверка прочности и устойчивости конструкции от воздействия собственного веса сооружения, ветровой и снеговой нагрузки при различных вариантах направления ветра.
2. Определение максимальных прогибов конструкции. Задача решалась с учетом опыта расчетов и исследований пространственных конструкций.

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