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MODELING OF LOADS FROM TSUNAMI WAVES ON THE STRUCTURE

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Abstract. Currently, the improvement of methods for calculating building structures is continuing, including, among other things, methods for determining the magnitude of the load. Despite the fact that for most impacts, the principles of determining loads and methods from the application have been formed for a long time, a number of special tasks are sometimes encountered in design practice, for example, the impact of tsunami waves on a structure. This article is devoted to modeling the wave roll on a structure in the "Fluid Flow (Fluent)" module of the ANSYS 2021 software package and comparing the results obtained with the methodology presented in SP 292.1325800.2017 "Buildings and structures in tsunami-prone areas. Design rules". The studies presented in this article have shown that the nature of the propagation of hydrodynamic pressure when modeling wave rolling in ANSYS is similar to that presented in SP 292.1325800.2017: according to a triangular plot with maximum pressure at the bottom. But at the same time, the value of the maximum pressure on the joint venture is about 1.5 times greater than according to the calculation in ANSYS, which is explained by many different factors. But, despite this, modeling of the tsunami waves rolling on the construction site can be performed at the pre-project stage in order to assess the nature of the pressure distribution over the surface of the object, which will allow choosing the most suitable structural and space-planning solutions.

Keywords: calculation of building structures, stress-strain state, tsunami, loads, building structures

МОДЕЛИРОВАНИЕ НАГРУЗОК ОТ ВОЛН ЦУНАМИ НА СООРУЖЕНИЕ

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Аннотация. В настоящее время продолжаются усовершенствование методов расчета строительных конструкций, включающих в себя, в том числе, и способы определения величины нагрузки. Несмотря на то, что для большинства воздействий уже достаточно давно сформировались принципы определения нагрузок и способы из приложения, в проектной практике иногда встречается ряд особых задач, например, воздействие волн цунами на сооружение. Данная статья посвящена моделированию наката волны на сооружение в модуле «Fluid Flow (Fluent)» программного комплекса ANSYS 2021 и сравнению полученных результатов с методикой, представленной в СП 292.1325800.2017 «Здания и сооружения в цунамиопасных районах. Правила проектирования». Исследования, представленные в данной статье, показали, что характер распространения гидродинамического давления при моделировании наката волн в ANSYS аналогичен представленному в СП 292.1325800.2017: по треугольной эпюре с максимальным давлением внизу. Но при этом величина максимального давления по СП примерно в 1,5 раза больше, чем по расчету в ANSYS, что объясняется множеством различных факторов. Но, несмотря на это, моделирование наката волн цунами на объект строительства может выполняться на стадии предпроекта, чтобы оценить характер распределения давления по поверхности объекта, что позволит выбрать наиболее подходящие конструктивные и объемно-планировочные решения.

Ключевые слова: расчет строительных конструкций, напряженно-деформированное состояние, цунами, нагрузки, строительные конструкции

INTRODUCTION

Tsunami is the Japanese name for a system of gravitational waves arising in the sea due to large–scale disturbances of the free surface. Despite all the possible danger of tsunami-prone territories, people have long settled in such territories. Most often these were fishing settlements that were supposed to be organized on the coasts. But with the development of science, humanity manages to reduce the risk of staying in tsunami-prone areas. The evolution of methods for calculating building structures for the impact of tsunami waves plays an important role in this, which leads to the possibility of designing tsunami-resistant buildings. [1, 2]
The purpose of the calculation of building structures is to assess their bearing capacity. For these purposes, software complexes based on the finite element method are currently most often used. This method has high accuracy, but implies solving a large number of equations, so this method has become popular with the spread of computer technology. Thus, at present, designers have a fairly effective way to determine the stress-strain state of structures. But it is important to understand that in order to obtain adequate results, it is necessary to enter adequate initial data, including geometric and stiffness parameters of the structure under study, boundary conditions of the design scheme and, of course, loads (both the way they are applied in the design scheme and their numerical value).
In the global design community, conventions for setting power loads (both permanent and temporary) in the design scheme have been formed for a long time. Such loads are applied to the structural elements, as a rule, in the form of static loads. Also, methods for applying instantaneous dynamic loads (such as wind pulsation or earthquake) have been formed for a long time. Thus, for most loads, it is unambiguously clear how to set them in various computer computing programs. But, in design practice, sometimes there are special tasks, for example, the impact of tsunami waves on a structure.
Strictly speaking, on the territory of the USSR (and further on the territory of the Russian Federation), according to the resolution of the Council of Ministers of the RSFSR No. 19 of January 8, 1964, construction in tsunami-prone areas is prohibited. This led to the fact that in Russia for a long time there were no building codes for the development of sea coasts exposed to the danger of a tsunami. [3, 4]
Only since 2018, the code of rules of SP 292.1325800.2017 "Buildings and structures in tsunami-prone areas" approved by the order of the Ministry of Construction of the Russian Federation No. 915/pr dated June 23, 2017 is put into effect. Design Rules", developed by the working group of the ANO "Regional Alliance for Disaster Analysis and Reduction". [5, 6]
SP 292.1325800.2017 allows you to find the value of the load from the expected tsunami wave, which in the future should be set as a static load in the direction of the expected action of the tsunami wave. However, currently there are a large number of software systems capable of simulating the roll of a wave on a structure, which will allow us to estimate the distribution of pressure from the wave over time. Such programs include Autodesk CFD, XFlow, ANSYS and others.
This article is devoted to modeling the wave roll on the structure in the "Fluid Flow (Fluent)" module of the ANSYS 2021 software package and comparing the results obtained with the methodology presented in SP 292.1325800.2017.

MATERIALS AND METHODS

According to SP 292.1325800.2017, the loads from the tsunami are special and are taken into account in a special combination of loads (clause 5.5.1 of SP 292.1325800.2017). Setting loads of a special combination that takes into account the impact of a tsunami on a structure depends on the purpose and location of this structure (clause 5.1.2 of SP 292.1325800.2017), which makes the methodology presented in this document universal and applicable for most design cases in tsunami-prone areas.

For example, the specific load on the frontal face of the structure from the impact of boron according to SP 292.1325800.2017 is determined by the formula (1):

$$P = 0{,}33 \cdot \rho \cdot C_1^3 \cdot \exp(1{,}4\mu) \cdot \mu \cdot (3-\mu) \left(1-\frac{t}{t_*}\right) \cdot t \cdot K_{\text{пр}} \cdot \sin^3 \varepsilon + 0{,}5 \cdot \rho \cdot g \cdot C_1^2 \cdot t^2 \cdot \mu \cdot K_{\text{пр}}, \quad (1)$$

where C_1 – the speed of the boron front when rolling ashore; μ – dimensionless parameter; t_* – duration of the impact of the boron front on the coastal object; t – wave propagation time; ε – the angle between the direction of propagation of the boron front rolling onto the shore and the frontal face of the structure; $K_{\text{пр}}$ – the permeability coefficient of the face of the structure, equal to the ratio of the material-filled part of the face of the structure to its total part. [6]

As can be seen from formula (1), this document takes into account various factors affecting the magnitude of the load from the tsunami wave on the structure. But, in fact, in this approach, we bring an almost instantaneous shock load to a static one (albeit with a fraction of the duration equal to 0).

The "Fluid Flow (Fluent)" module of the ANSYS 2021 software package allows you to simulate the movement of liquids and gases, including taking into account the interaction with obstacles (in our case, these are buildings and structures). The process of performing calculations is similar to those in most calculation programs (such as Lira or SCAD), but each stage has its own peculiarities.

At the first stage, a calculation scheme is created. It consists of a three-dimensional structure (that is, taking into account the actual dimensions of all building structures that will be exposed to interaction with water). And also the calculated area is modeled – the area of space in which a liquid (or gas) will be generated and interact with obstacles. Figure 1 shows a computational model of a fragment of a bridge structure with a computational domain.

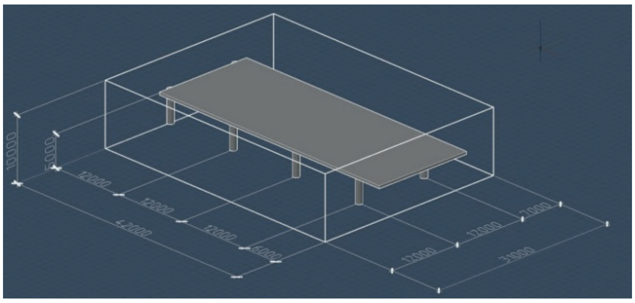

Figure 1. Calculation model

At the next stage, this calculated area is divided into finite elements. ANSYS tools allow you to thicken the grid of finite elements near the boundaries of bodies (bridge structures), which will increase the accuracy of calculations, reducing the calculation time. A fragment of the generated finite element grid is shown in Figure 2.

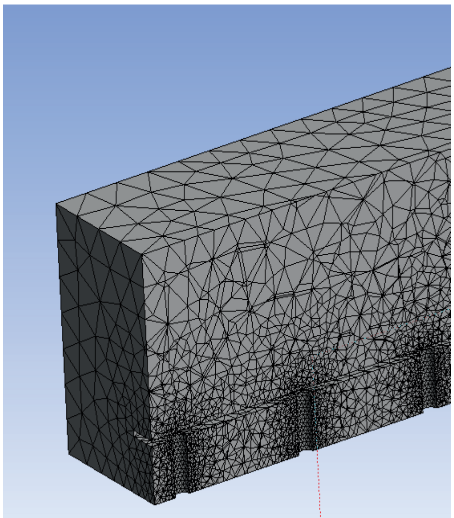

Figure 2. Fragment of finite element grid generation

At the next stage, the initial data is set, of which there is a huge amount in this software package. Initially, the parameters of the input face of the computational domain are set – on which waves will be generated (the blue face in Figure 3). A wave propagation model is chosen for this facet: in this study, the "Short Gravity Waves" model is adopted according to the theory of a cnoidal/solitary wave. This choice is justified by the fact that all other wave generation mechanisms, which are presented in the "Fluid Flow (Fluent)" module, are designed for medium and large depths, and this study examines the roll of waves on shore structures. Also, the height of the waves (8 m for this calculation) and the speed of their propagation are set here (the speed is taken as in the calculations for SP 292.1325800.2017). Secondly, the output faces (red faces in Figure 3) – from which water can come out either calmly or taking into account resistance to different pressures (atmospheric pressure was established in this study). Thirdly, other faces (gray faces in Figure 3) on which waves will not be generated, but which limit the movement of the wave: these are the faces along the movement of water, the structure itself and the lower face (denoting the ground). If the "No Slip" parameter must be unambiguously set for the faces along the wave motion in order to exclude the loss of wave energy when interacting with them, then it is possible to set roughness for the remaining faces. So, in this scheme, the roughness height (0.2 m) and the constant roughness (0.5) were set, simulating the interaction of the wave with the earth's surface, similar to the parameter n required to determine the dimensionless parameter μ from the formula (1). [6, 7]

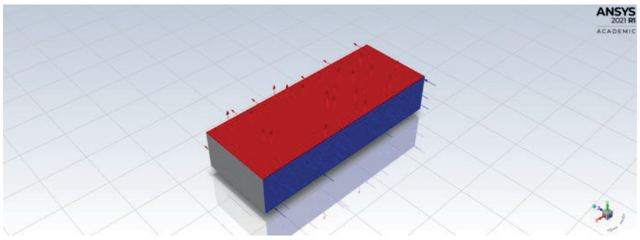

Figure 3. Boundary parameters of the computational domain

In addition to the boundary conditions discussed above, the parameters of the volume of the computational domain itself were also set. The main of these parameters are the presence of gravity (9.81 m/s2) and the multiphase of the model. Monophasicity implies that several different substances (in this case air and liquid) occur in the computational domain. Standard density and viscosity parameters are set for each substance, taken from the default ANSYS program library.

After the calculations, we get a picture of the water distribution in the calculated area at the required time (Figure 4).

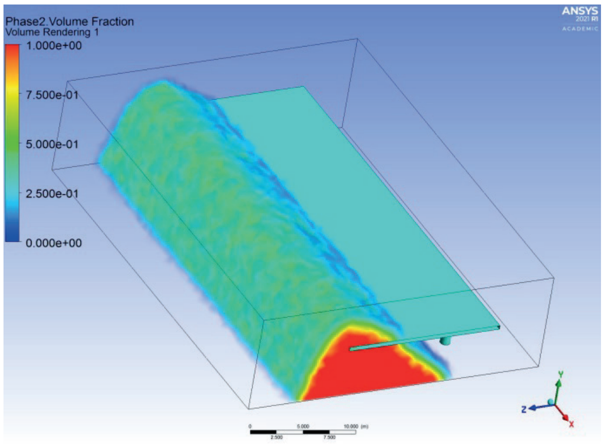

Figure 4. Wave rolling on a bridge fragment

And you can also look at the pressure isofields, at the areas of interest to us, for example, on the surface of the structure under study (Figure 5).

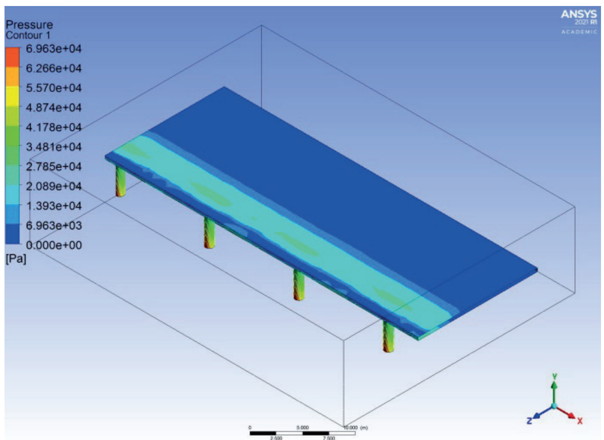

Figure 5. Pressure from the wave on the structure

As can be seen from Figure 5, the nature of pressure propagation is similar to that presented in SP 292.1325800.2017: according to a triangular plot with maximum pressure at the bottom. The maximum pressure value in this calculation is 69630 Pa. At the same time, the maximum pressure value according to the formula (1) for the same wave is 103590 Pa, which is about 1.5 times more than according to the calculation in ANSYS.

RESULTS

It should be understood that this distribution is characteristic only for this particular case (accepted geometric characteristics of a construction object, accepted wave height, etc.). Another important point is that formula (1) is valid for boron – the most dangerous variant of a tsunami wave is a vertical wall of water, while ANSYS simulates ordinary waves of the desired we need heights. Therefore, it is possible that a special wave propagation model for collecting water will appear in future versions of ANSYS, and then the difference in the results of the joint venture and roll modeling in ANSYS will be even smaller. But at the moment, ANSYS can be considered as an alternative to testing models in the pool – to assess the nature of the interaction of waves with structures of various shapes and sizes, as well as to see the nature of the pressure distribution over the surface of this structure.

CONCLUSION

The magnitude of the load from the tsunami bar when calculated according to the methodology presented in the joint venture is about 1.5 times greater than when modeling the roll in ANSYS, which is explained by many different factors.

Modeling of the tsunami waves rolling on the construction site can be performed at the pre-project stage in order to assess the nature of the pressure distribution over the surface of the object, which will allow choosing the most suitable structural and space-planning solutions.

It is necessary to further develop both methods for calculating loads from tsunami waves and software systems capable of simulating the roll of tsunami waves on various objects. The ultimate goal of this development should be software systems capable of simulating the roll of tsunami waves on building structures with sufficient accuracy, as well as obtaining pictures of the stress-strain state of these structures, which should lead to the design of safe buildings and structures in tsunami-prone areas.

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