UDC 692.445 **doi:10.31650/2707-3068-2021-25-21-26**

TEST OF A NET DOME FRAGMENT

[1]**Hilodo O.Y.,** PhD in Engineering Science, associate professor,
gil@soborka.net, ORCID: 0000-0001-5387-5538
[1]**Arsiriy A.M.,** PhD in Engineering Science, associate professor,
arsiriy@ukr.net, ORCID: 0000-0003-3262-1488
[1]**Korshak O.M.,** PhD in Engineering Science, associate professor,
bagiraolga@ukr.net, ORCID: 0000-0001-7346-252X
[1]**Kovtun V.P.,** engineer,
paka@ukr.net, ORCID: 0000-0002-7454-9296
[1]*Odessa State Academy of Civil Engineering and Architecture*
Kitaiev A.A., director
info@dvutavr.com, Ltd. *«ECODVUTAVR»*

Abstract. A geodesic or net dome, also known as a Fuller's dome, is a spherical structure. Geodesic domes are well receptive to asymmetric loads, especially snow and wind, have high aerodynamics, increased rigidity and stability. It should be noted that the larger the diameter of the sphere, the greater its bearing capacity, and the strength of such dome slightly depends on the building materials used. With significant advantages, the design and construction of wooden net domes has not become widespread. The fact is that net domes are spatial structures with a large number of elements, which accordingly entails a large number of nodes. The elements of the dome are connected with dowels, wet film gauge, bolts, wood screws, staples, screws, nails. Adhesive connections on washers are used, also steel clamps, straps, overlays are applied. However, they all have disadvantages, the scope of each connector is different, and their cost is often comparable to the cost of the dome elements. We offer a universal connector for connecting dome parts at any angle. As a result of introduction of such technical decision of knot, we receive essential simplification of a design, reduction of quantity of components, at the same time with increase of its manufacturability. To study the operation of the joint of wooden glue-board elements of the dome with the use of a universal connector, its experimental studies were carried out.

The purpose of the study: to study the actual operation of the connection of wooden parts of the dome with a universal connector in the form of rotating fasteners that rotate freely on the draw bolt, to assess its strength and deformability, to assess the possibility of using such a connection in the design of spatial structures. To solve the tasks, a full-scale fragment of the dome was tested, which includes characteristic nodes with rigid adjacency of elements to each other.

Keywords: wooden geodesic dome, universal connector, dome fragment test, dome node test results.

Introduction. Recently, the world's production of wooden houses with new architectural and design solutions and mobile buildings is growing rapidly. One of the effective directions in the industrialization of construction is the use of wooden glued structures that can significantly increase the durability of buildings, reduce the weight of buildings, reduce the harmful effects on the environment. Dome structures, known since ancient times, are now entering a new stage of development. They began to be more widely used as exhibition pavilions, warehouses, sports facilities and, of course, as residential buildings. Steel and reinforced concrete are commonly used in the construction of domes, but wood materials allow them to be built no less resilient. Glulam retains all the advantages of conventional - significant strength and elasticity at low weight and free of natural defects: cracks, damage caused by fungi, diseases, growths. Combining the advantages of a spatial dome shape with the advantages of glued wood makes it possible to obtain an effective design of a low-rise mobile home.

Specific difficult in the design and manufacture of spatial structures are the joints of the rods, which can be rigid or hinged. Preferably, the nodes are rigid, which provides the spatial operation of the structure and reduces its deformability. The design of a rigid node is determined by the size and number of connecting elements and the forces acting in them. Knots of wooden structures are made, as a rule, with the presence of steel strips that connect the wooden rods with bolts or nails. Net domes are three-dimensional structures with a large number of elements, which accordingly entails a large number of nodes. The elements of the dome are connected with dowels, wet film gauge, bolts, wood screws, staples, screws, nails. Adhesive connections on washers are used, also steel clamps, straps, overlays are applied. Such units have limited load-bearing capacity and require a significant number of parts, the cost of which is often comparable to the cost of the elements of the dome. We offer a universal connector for connecting the details of the dome at any angle [10]. As a result of introduction of such technical decision of knot, we receive essential simplification of a design, reduction of quantity of components, at the same time with increase of its manufacturability. To study the operation of the joint of wooden glue-board elements of the dome with the use of a universal connector, its experimental studies were carried out. The purpose of the study: to study the actual operation of the connection of wooden parts of the dome with a universal connector in the form of rotating fasteners that rotate freely on the draw bolt, to assess its strength and deformability, to assess the possibility of using such a connection in the design of spatial structures. To determine the degree of rigidity of the node. To solve the tasks, a full-scale fragment of the dome was tested, which includes characteristic nodes with rigid adjacency of elements to each other.

Analysis of recent achievements and publications. To connect the elements that work on compression, skew notches or crutches are used, the ends of the elements are cut at certain angles. Overlays connected by bolts or nails to ensure stable operation of the connection are additionally installed on the crutches. When connecting the elements in the joints at an angle, there is a need to use mechanical connections. Development and introduction of new types of connections of wooden designs basically follows a way of application of various treenails. Noteworthy are the nails used in the United States and Germany, with a cut of hardened steel, which causes their high load-bearing capacity when working on shear and pull-out. Strengthening the treenail connection with additional elements reduces the likelihood of chipping and crumpling of wood [1]. Interesting results of tests of treenail joints of large-span wooden structures reinforced with steel plates inserted into pre-cut grooves are presented in the work [2]. When using nail joints, as well as when using treenails inserted into pre-drilled holes, there is a simultaneous inclusion in the work of all connections. The pliability of the joints in the elements with such compounds is due to the crumpling of the wood in the nests, as well as the bending deformations of the treenails themselves. The designs of rigid assemblies are given in works [3, 4], but they have a low load-bearing capacity with a large number of connecting elements. In works [5, 6] it is proposed to connect wooden structures on bolts that transmit forces through inserted steel gasket that works together with wood, which contributes to the redistribution of local stresses of crushing and chipping in an area comparable to the size of the gasket and helps to increase the bearing capacity of the connection. It is interesting to study the connections with claw gaskets [7], but they have a limited scope when there is access to the working surface from above or below the element during its reinforcement. The results of systematic experimental studies of the joints of glued wooden structures are published quite rarely and to a limited extent. Among such works it is necessary to note article by Ishmaeva D.D. and Vdovina V.M. [8], which shows the method of testing and construction of a rigid assembly of glued wooden elements. Known types of connections can not be referred to the universal, especially when it is necessary to combine wooden elements of the spatial structure at free angles. Therefore, the development of new types of connections is an urgent and timely task.

The purpose of the work is to perform an experimental-computational study of the stress-strain state of a fragment of a net dome made of glued wood with a universal connector, to determine its bearing capacity under the influence of static load. Analyze the operation and degree of rigidity of the dome assembly with a universal connector.

Research methodology. Due to the complexity of the experiment on the full-scale construction of the dome, it was decided to evaluate the tasks set by the experiment on a separate fragment of the dome, which includes characteristic nodes with rigid connections of elements with each other. In addition, the work of such nodes mainly determines the reliability of the entire dome, so the results can be taken into account when developing recommendations for the design and calculation of the dome. The test fragment is made of five unified glue-board elements of I-beam cross section. The choice of shape and dimensions of the experimental sample is based on the dome net structure, the cross-sections of the elements of which are obtained taking into account the requirements of the technology of manufacturing nodes and thermal insulation of the dome shell conduit, which performs both load-bearing and enclosing functions. I-beam elements of wooden bars 600 mm long, the sizes of cross section are accepted: shelves made of wooden bars 50x60 mm, a wall made of a USB plate, 10 mm thick. Material for samples - glued pine wood of the II grade.

Fig. 1. A fragment of the dome under load

The test rig is a steel frame mounted in the power floor. To ensure the stability of the fragment, hinged, steel supports were made under the inclined elements of the dome, i.e. four supports of the dome fragment, located along the perimeter, fixed from possible movements. Based on this, in conditions close to real, there are only nodes with connectors. The concentrated load was created by a hydraulic jack mounted on the axis of symmetry of the fragment. During the test, the deformations of the nodes were measured using time-type indicators with a division price of 0.01 mm. Stresses in the elements of the fragment were found by deformation using resistive strain gages. Tensor resistors made of constantan wire on a film backing with a base of 30 mm were used to study the stress-strain state. To record data, a resistive strain gage was used, which is designed to measure the output voltage of resistive strain gages with the transfer of information to an external control computer. The layout of strain gages with the place of application of the load is shown in Fig. 2.

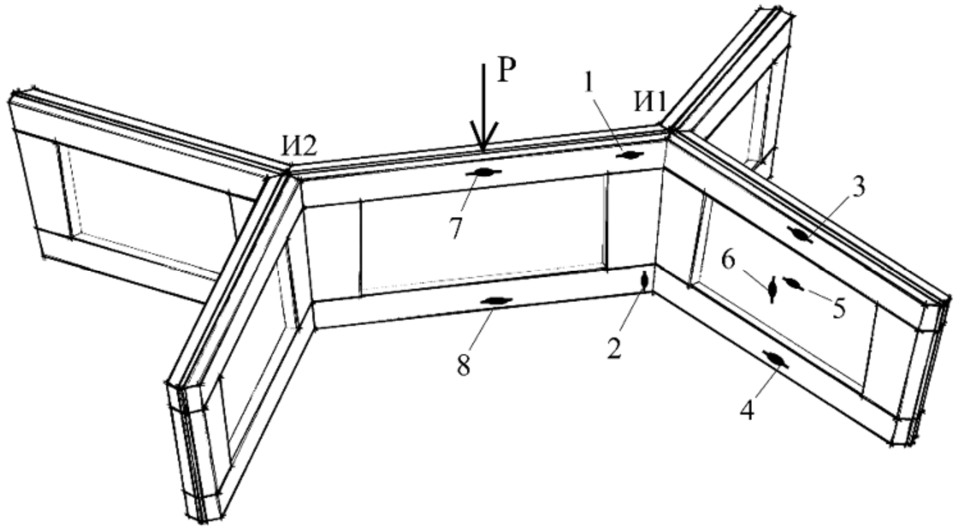

Fig.2. Scheme of installation of resistive strain gages and clock-type indicators

Before testing, the structure of the fragment was carefully inspected visually. Actual wood defects were compared with those allowed by the norms. In addition, the quality of the node structure was checked, the nuts were tightened, and the load was centrifuged. During the tests, the temperature and humidity were regularly monitored. The ambient temperature was 14-15 ^{0}C, relative humidity was in the range of 55-65%. The load of the dome fragment was carried out in steps with a step P=9 kN. The loading rate was assumed to be continuous and uniform with the fixation of the finite time. The load time at each stage was equal to 1 minute, the holding time under load - 15 minutes. Measurement of deformations was performed after loading and immediately before the new load stage. During the tests, the condition of the investigated structure was continuously monitored in order to fix possible damage.

Research results. The dome fragment was tested in full compliance with the above procedure. During the tests, the vertical deformations of the nodes of the fragment increased in proportion to the increase in load. The obtained test results showed that the proposed design of the node with a universal connector meets the operating conditions of the rigid connection of the dome elements. The fragment was loaded to 99 kN and no signs of failure were detected.

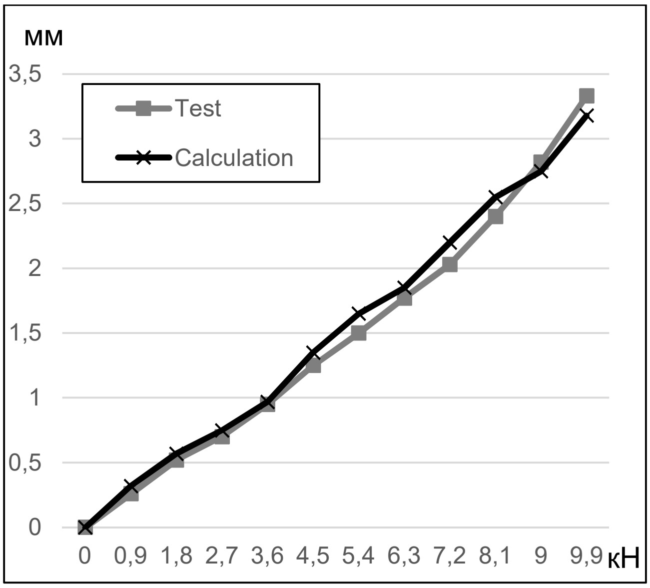

Fig. 3. Dependence of node deflections on the load

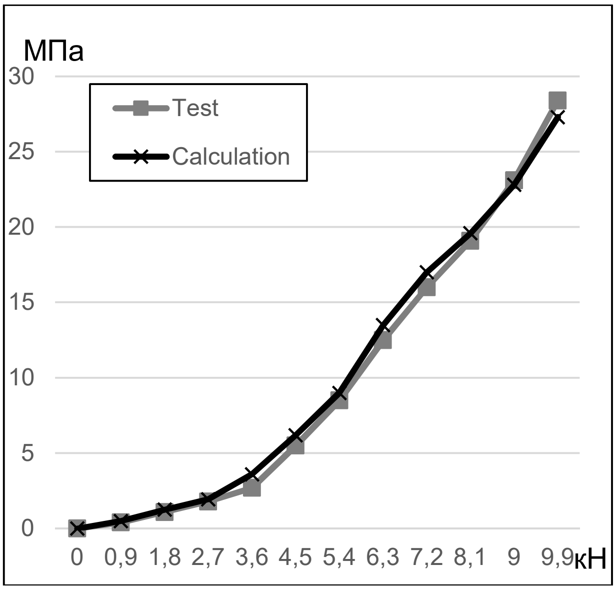

Fig. 4. load stresses on resistive strain gage area No.1

The nature of the deformation of wooden elements showed mainly their elastic work. The maximum deformation of the node is 3.29 mm. Fig. 3 shows a graph of deformations growth. The operation of the connection is elastically plastic in nature with pronounced elastic deformations to a load of 72 kN and the growth of plastic deformations in the last stages. As a result of the experiment, the stress-strain state of the wooden elements of the fragment was established - they work on compression, except for the area of the horizontal element near the applied load. The most characteristic results were obtained from the resistive strain gage No. 1 (Fig. 4), located close to the upper node with the connector. The calculation of the digital model of the fragment of the dome is performed in the "Lira" software package.

Conclusions and prospects for further research.

1. A study of the stress-strain state of a fragment of a net dome made of glued wood with a universal connector was conducted.
2. The test showed the possibility of using such a connection as a rigid node of the spatial structure.
3. The proposed design of the node with a universal connector allows you to consider it as sufficiently rigid, which ensures the interoperability of all connecting elements.
4. The elements in the node operate together, supporting each other.
5. The stress state close to the node is characterized by local transmission of force through plastic washers, the strength of which is much less than the strength of the steel elements of the connector.
6. n further research it is planned:
   - To study the fragment of the net dome with steel washers of the universal connector.
   - To study the fragments of the net dome with different sections and structural solutions of wooden elements.
   - To study the fragment of the net dome with upgraded versions of the universal connector.
   - To study the model of a whole net dome for different types of loads.
   - Develop a computer model of a net dome.
   - Perform the calculation of the load-bearing elements of the dome under the action of static loads, taking into account the elastic-plastic operation of the nodal joints.

References

[1] N.J. Blass, P. Schädle, "Ductility aspects of reinforced and non-reinforced timber joints", *Engineering Structures*, vol. 33, pp. 3018–3026, 2011.

[2] Milan Šmak, Bohumil Straka, "Development of new types of timber structures based on theoretical analysis and their real behaviour", *Wood research*, 59 (3), pp. 459−470, 2014.

[3] Гётс, К.Г. Атлас деревянных конструкций/К.Г. Гётс, Д.Хоор.пер. с нем. Н.И. Александровой; под. Ред. В.В. Ермолова. – М.: Стройиздат, 1985-272с.

[4] Шмидт А.Б. Атлас строительных конструкций из клееной древесины и водостойкой фанеры/А.Б.Шмидт, П.А.Дмитриев.-Москва: Издательство Ассоциации сторительных вузов, 2002г.

[5] Вдовин В.М. Конструкции из дерева и пластмасс/В.М.Вдовин. – Ростов н/Д: Феникс, 2007. -250с.

[6] Вдовин В.М. Вклеенные металлические шайбы в соединениях деревянных конструкций: моногр./В.М. Вдовин, М.В. Арискин. – Пенза: ПГУАС, 2012. -184с.

[7] Глухих В.Н. Деревянные конструкции с применением когтевых шайб и учётом начальных напряжений древесины.: моногр./ В.Н.Глухих, А.Г.Черных. – С- Петербург: СПГАСУ, 2018. -284с.

[8] Ишмаева Д.Д. Жёсткие узлы клеёных деревянных балочных элементов на вклеенных стальных шайбах/ Ишмаева Д.Д., Вдовин В.М. // Вестник ОГУ. – 2014.- №1(162) - С. 189-195.
[9] Patent na vinakhíd №117276. Uníversal'niy z´êdnuvach dlya z´êdnannya detaley budível'nikh konstruktsíy píd doviĺ'nim kutom nikh konstruktsíy za dopomogoyu uníversal'nogo z´êdnuvacha. Kovtun V.P. opubl. 10.07.2018.
[10] Gilodo A.Y. Effective structure of a wooden residential building in the form of a geodesic dome with a universal connector/ Kovtun V.P., Arsirii A.N., Angel A.A. // Bulletin of Odessa State Academy of Civil Engineering and Architecture, 2021, no. 82, page 19-26

ВИПРОБУВАННЯ ФРАГМЕНТА СІТЧАСТОГО КУПОЛА

[1]**Гілодо О.Ю**., к.т.н., доцент,
gil@soborka.net, ORCID: 0000-0001-5387-5538
[1]**Арсірій А.М**., к.т.н., доцент,
arsiriy@ukr.net, ORCID: 0000-0003-3262-1488
[1]**Коршак О.М..** к.т.н., доцент,
bagiraolga@ukr.net, ORCID: 0000-0001-7346-252X
[1]**Ковтун В.П.,** інженер,
paka@ukr.net, ORCID: 0000-0002-7454-9296
[1]*Одеська державна академія будівництва та архітектиури*
Кітаєв А.А., директор
info@dvutavr.com, *ООО «ЭКОДВУТАВР»*

Анотація. Геодезичний або сітчастий купол, також відомий, як купол Фуллера, є сферичною конструкцією. Геодезичні куполи добре сприймають несиметричні навантаження, особливо снігові і вітрові, мають високу аеродинаміку, підвищену жорсткість і стійкість. Варто відзначити, що чим більше діаметр сфери, тим більше його несуча здатність, а міцність такого купола мало залежить від використовуваних будівельних матеріалів. Маючи серйозні переваги, проектування і будівництво дерев'яних сітчастих куполів не набуло широкого розповсюдження. Справа в тому, що сітчасті купола являють собою просторові конструкції з великою кількістю елементів, що відповідно тягне за собою велику кількість вузлів. Між собою елементи купола з'єднують за допомогою шпонок, гребінок, болтів, шурупів, скоб, гвинтів, цвяхів. Використовуються клейові з'єднання на шайбах, також застосовують сталеві хомути, тяжі, накладки. Однак всі вони мають недоліки, область застосування у кожної сполучної деталі своя, а їх вартість часто порівнянна з вартістю елементів купола. Нами пропонується універсальний конектор для з'єднання деталей купола під довільним кутом. В результаті впровадження такого технічного рішення вузла, отримуємо істотне спрощення конструкції, зменшення кількості складових, одночасно з підвищенням її технологічності. Для вивчення роботи стику дерев'яних клеедощатих елементів купола із застосуванням універсального конектора проведені його експериментальні дослідження. Мета дослідження: вивчити дійсну роботу з'єднання дерев'яних деталей купола з універсальним коннектором у вигляді поворотних кріпильних елементів, що вільно обертаються на стяжному болті, дати оцінку його міцності і деформативності, оцінити можливість використання такого з'єднання при проектуванні вузлів просторових конструкцій. Для вирішення поставлених завдань проведено випробування натурного фрагмента купола, що включає характерні вузли з жорстким примиканням елементів один до одного.

Ключові слова: дерев'яний геодезичний купол, універсальний конектор, випробування фрагмента купола, результати випробування вузла купола.