Optimum design of Geodesic dome’s jointing system

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Abstract. This study attempts to create a new design for joint connector of Geodesic dome. A new type of joint connector design is proposed for flexible rotating connection; comparing it to another, this design is cheaper and workable. After calculating the bearing capacity of the sample according to EC3 and Vietnam standard TCVN 5575-2012, FE model of the design sample is carried out in many specific situation to consider the stress distribution, the deformation, the local destruction... in the connector. The analytical results and the FE data are consistent. The FE analysis also points out the behavior of some details that simple calculation cannot show. Hence, we can choose the optimum design of joint connector.

1. Introduction
Nowadays, the development of space frame is growing due to its great structural potential and visual, buildings that require large space such as sports arenas, exhibition pavilions, assembly halls, transportation terminals, airplane hangars ... frequently use Geodesic dome [1]. This dome has a huge bearing capacity, its “omnitriangulated” surface provides an extremely stable structure under the form of a large spherical volume with minimal surface area [1,2]. Though, Building up a Geodesic dome is very complicated due to its multiple types of members that are located in a three-dimensional space with different angle of rotation, and hence the force transfer mechanism is more complex. Jointing system is very important because more members are connected to a single joint; in the past decades, the effort expended on research and development of jointing systems has been enormous, and many different types of connectors have been proposed but they have not proved to be very successful mainly because of the complexity of the connecting method [3]. Our research aims to create a new optimized design of joint connector for the Geodesic dome to make it cheaper and easier to build up.

There are over 250 different types of jointing system suggested or used in practice like: Mero system (Disc node, Bowl node, Cylinder node, Block node, Space deck ...), Triodetic system, Unistrut system, Nodus system, Unibat system.... [2,3] These systems all have good bearing capacity but their drawback is they are only designed to connect fixed-numbers of bars with certain angle rotation; there are hundred to thousand bars in a Geodesic dome, so that the cost of the production of joints and the construction time are very large [2,3]. To resolve those problems, we propose a new optimized joint connector that ensures:

- Good bearing capacity
- Connected bars can rotate flexibly
- Easy and quick assembly
- Capability of mass production for all nodes at different positions

Base on different types of joint connector and its inconvenient, we propose a new joint connector that can solve these conditions. Numerical analysis methods have been used to analyse the behavior of the new connector. A 3D finite element model, which accounts for material behavior of the connector,
is built in ABAQUS. The finite element model is verified by corresponding hand calculation results compare to Vietnam standard TCVN and EC3 specification.

2. Method

2.1. Proposed joint connector for Geodesic dome

New connector (as shown in Figure 1) consists:

- Ring: carries directly load
- Bolts
- Hook as shown in Figure 2: Links the ring and bars

![Figure 1. Design template of joint connector of Geodesic dome.](image)

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![Figure 2. Details of the hook.](image)

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• Supporting box as shown in Figure 3: receives and disperses stress on the top of the bar

![Supporting box diagram](image)

**Figure 3.** Details of the box.

2.2. *Computing strength using design code*

2.2.1 *Vietnam standard (TCVN 5575 – 2012)*

Assuming that the connection between elements of the template is perfect, the design connector is considered to be able to carry loads when the bearing capacity and the deformation of all elements and all contact points meet the demand of loading condition [4]. The followings need to be checked:

- The ring: shear and bearing strength.
- The hook: stress and deformation at its immediately reduced section; stress and deformation at contact point dangerous positions that contact the hook with the ring or bolts.
- The bolts: shear and bearing strength.
- The supporting box: stress and deformation at contact point; welded connection.

2.2.2 *Component method of EC3 – 1993*

In component method, the connections between elements are represented by deformation areas that are considered like springs. Those springs, based on the connection structure, are linked into a system, loads are transferred to the system through the springs and the system can show the capacity of the template. The component method assumes each element (component) in the joint is capable to carry the design load, thus we don’t need to check element but the assembly of them when they work together [6].

![Component method diagrams](image)
Figure 4. Components used in the sample: [6]
a- Plate in tension (compression)  
b- Bolt in shear  
c- Bolt in bearing.

There are 5 components in the design sample as shown in Figure 5:
Component 1: ring  
Component 2: hook  
Component 3: bolt  
Component 4: supporting box  
Component 5: top of the box

![Figure 5. Assembled components checked of the sample.](image)

In a serial system: \( F_{td} = \min(F_i); \quad S_{td} = \left( \sum \frac{1}{S_i} \right)^{-1} \)
In a parallel system: \( F_{td} = \sum f_i; \quad S_{td} = \sum S_i \)

In a sample tension, the system has 2 parallel branches 2-3-4 in series with component 1. The equivalent resistance of the sample: \( F_{Rd} = \min(F_{Rd1}; 2F_{Rd2-3-4}) \)
In a sample compression, the system has component 1 in series with component 5. The equivalent resistance of the sample: \( F_{Rd} = \min(F_{Rd1}; F_{Rd5}) \)

2.3. FEM model

FEM model is built in ABAQUS to observe the behavior of the design joint connector in specific situation in reality; observing the stress distribution, the yield point, the local destruction … we verify the theoretical results and also study the behavior of details of elements that theoretical calculation can’t response.

| Table 1. Mechanical properties of the simulate sample. |
|------------------------------------------------------|
| Steel | Bolt |
| Young modulus E (Pa) | \( 2.1 \times 10^{11} \) | \( 2.1 \times 10^{11} \) |
| Poisson ration v | 0.3 | 0.3 |
| Yield stress (Pa) | \( 3.8 \times 10^8 \) | \( 8.3 \times 10^8 \) |
| Ultimate strain | 0.25 | 0.25 |

2.3.1 The hook in tension

Figure 6 shows the model of the hook in tension in ABAQUS.

Boundary condition: encastre at the section in touch with the ring.
Loads: Distributed load increases from $1 \times 10^5$ N/m$^2$ to $1 \times 10^8$ N/m$^2$

![Figure 6. The hook in tension.]

2.3.2 The box in compression
Boundary condition: encastre at the top.
Loads: Distributed load increases from $1 \times 10^5$ N/m$^2$ to $3.3 \times 10^8$ N/m$^2$

![Figure 7. The box in compression.]

2.3.3 The ring
The ring under pressure of 5 clusters of hook is modelled in with the boundary condition as shown in Figure 8.
Loads: Distributed load increases from $1 \times 10^5$ N/m$^2$ to $1 \times 10^6$ N/m$^2$
2.3.4 The group of two hooks, two bolts and box in compression

We model the group with the boundary condition and loads as shown in Figure 9. Type of contact between elements is surface to surface.

3. Results and discussion

3.1. The hook in tension

By analytical method, tension resistance of the hook is calculated: \[ F_{\text{hook}} = 92.4 \text{kN}. \]

In the FEM model, the hook is damaged first at its points of reduced section and the damage force is about 97.1 kN, which is 5.08% different from theoretical calculation. The maximum deformation is also at this section as shown in Figure 10.

It approves that the examined point in analytical method is compatible with the behavior of the hook in tension.
3.2. The box in compression
Observing FEM model, the box in compression is damaged when the force reaches 248 kN, which is 5.25% different from theoretical calculation (235.62 kN).

3.3. The ring
Bearing resistance of the ring is calculated: \[ F_{\text{ring}} = 651 \text{kN} \]. Observing the ring under pressure of 5 clusters of hook in FEM model, the ring’s bearing capacity is much higher than the hook’s. Absolutely, the hooks are damaged first at the contact points with the ring.
3.4. The group of two hooks, two bolts and box in compression

Observing the group two hooks – box – two bolts working together in compression, the box is damaged first at its contact point with the bolts. At that time, the hook still works in yield region and the bolts work elastically (Figure 14). It is consistent to the partial damaged method used in theoretical calculation. We obtain the allowable compression force on the box is 48.9 kN. Comparing to the theoretical result (46.75 kN), 4.6% of deviation can be accepted.
4. Conclusion
A new joint connector for Geodesic dome is designed with 4 main elements (ring, hook, box, and bolt). The strength of each element is computed and examined by Vietnam Standard TCVN and EC3. The sample is modelled in ABAQUS with some specific situation. Theoretical calculations and FE analysis have an accepted deviation, the design sample may works efficaciously in reality. Compare to existing connectors, this new connector is very flexible assembly, easy to produce and can be used for almost all types of nodes on the dome. Expansive researches are proposed like: observe the behavior of the connector in more situations, verify the working of the connector in experiments, observe connector between dome and column ….

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