Advanced Investigations of Grid Spatial Structures Considering Various Connection Systems

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PREFACE

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Chapter 1

INTRODUCTION

1.1 General description

In the past decades, spatial structures have been significantly developing in the architectural field. Most of all, the single layer spatial structure has become very popular, having not only with the aesthetic advantages, such as lightness and transparency of the roof, but also the economic benefit of saving material. Recently, the free-form spatial structures or the complex-shaped surfaces have been spotlighted in the field of architecture, for example the DZ-Bank in Berlin (Frank O. Gehry), the British Museum in London (Norman Foster), the New Fair in Milan (Massimiliano Fuksas), Westfield in London (Buchan Group International / Benoy) and My Zeil in Frankfurt (Massimiliano Fuksas) and so on.

There are several important factors in such single layer lattice dome and complex-shaped spatial structures, for instance, optimal form-finding and high material strength. However, the optimal design and analysis of the connection nodes are significant points in free-form spatial structures, because such extraordinary geometries and their continuously changing curvature can be defined by the angles of the connections' geometries. At the same time the stiffness in the connection plays an important roll for the stability of the whole free-form structure [Stephan et al 2004] [Knippers et al 2008]. Therefore, it is very important to recognize that the appropriate analysis and connection design have to be performed, in order to design the reasonable global single layer spatial structure and free-form spatial structures.

Of course, there are already many node connection types, which have been applied to single layer structures and free-form spatial structures. Companies and researchers have developed more than 250 different types of connection systems used for real global grid shell structures in order to provide proper connection systems [Lan 1999]. It is not enough to understand mechanical behavior of connecting systems, however, merely by taking into consideration the real geometrical characteristics of the connection systems. An important task that remains to be undertaken is an in-depth analysis of single layer grid shell or free-form spatial structure based on the integration of the various types of connection systems.

1.2 Research problems and aims

The node connection systems that were adopted to realize the completion of the structures in question have very varied forms making it difficult to compare them. In other words, because they have specific connector geometries, the characteristics of each connector should be considered in terms of appropriate analysis but also optimal design of global structures.

Several experimental and analytical works have already been reported for spatial frame structures. Fathelab, for instance, discovered that connection stiffness has a considerable effect on the load-displacement behavior of a structure, and the amount of material used could be significantly reduced and safer structures could be achieved if the effects of the actual joint properties are taken into consideration during the design process[Fathelbab 1987]. El-Sheikh determined that the overall behavior and failure mode of a structure were influenced by the bending stiffness of a connection [El-Naschie 1990]. The influence of the rigidity of a joint on the critical load of a single-layer dome has been studied and the equilibration of different critical loads with differing joint rigidity has been obtained [López 2003]. With one of the widely used connecting system ORTZ in Spain [Makowski 1984], the numerical and experimental tests for single-layer latticed dome indicated the influences such as dome geometry, slenderness of members, joint rigidity and load hypothesis on the behavior of the single-layer spherical domes [López et al 2007]. Using relative nodal stiffness obtained by controlling the moment of inertia at the end part of the beam element, the influence of nodal stiffness on the global single-layer grid shell could be examined [Bulenda et al 2005].

However, it is not sufficient to simply present the specific characteristics of various connection systems based on their different geometries and forms. The analysis of the whole global structure should of course be considered using more exact specifications of different connector shapes and forms. Particularly, since free-form spatial structures have appeared in the field of architecture, even more types of connection systems have been developed for use in practice. Thus it is quite natural that the node connecting systems, which exhibit a wide variety of structural and geometrical characteristics, should be analyzed in a more advanced way.

Concerning the above mentioned research problem of various connecting systems, in terms of the design of single-layer grid shells, so far most analysis of connection behaviors have been based on the use of either of a perfect pinned or rigid joint in practice, even though many researchers and engineers have already reported that most real node connecting systems employed in spatial structures are neither a perfect pinned nor a perfect rigid joint, but a semi-rigid connection which shows nonlinear stiffness behavior. Many reasons can be introduced for this problem, but one of the problems is the functional limitation of commercial finite element programs that have been being used in practice. Therefore, it would be valuable for the influence of various node connectors on the buckling load in the whole spatial structure to be investigated using a commercial program package so that common architects and engineers can understand and apply these findings to real situations.

This semi-rigid connection is able to reduce the amount of structural material used but it is difficult to determine the exact stiffness of the connectors when they show strong nonlinear behavior. Moreover, deviation of the bolt-holes may bring more severe nonlinear characteristics, so that the load bearing capacity of connection systems may be weakened.

As for the deviation of the bolt-holes, namely bolt clearances, in a steel structure, the European standard prEN 1090-2 very simply mentions the available application of bolt-holes. This, however, is not sufficient to estimate exact structural integration between deviations of bolt holes in the node connector and the whole spatial structure [Hoelbling et al 2009]. Thus, it is clearly necessary to investigate the influence of node connection system, taking bolt clearances in the node connector on the grid shell structure and free-form grid spatial structures into consideration.

Based on the above research problems, the following aims and hypotheses have been formulated for this research;

1. To study node connector systems that have been adopted and reported on for grid shells or free-form spatial structure.
2. To investigate the influence of the connectors' nodal stiffness on the buckling behavior in global structures with various curvatures, taking initial geometrical imperfection into consideration.
3. To investigate the influence of bolt clearances in the node connector which can have a crucial influence on the buckling load of grid shells with different rise-span ratios and initial geometrical imperfections.

1.3 Synopsis

The connection systems which have been adopted in grid shell and free-form spatial structures are briefly mentioned in chapter 2. From traditional spatial structures to the latest free-form spatial structures, a lot of connection systems have been developed. Of course, they have their own various geometrical characteristics which should be investigated.

In chapter 3, the results of two experimental bending tests and numerical analysis are compared. Before numerical analysis of four different node connections which consist of various geometrical characteristics is performed in chapter 4, all the numerical methods, such as applying all the functions of ANSYS, are checked for reliability by comparing the experimental results and numerical analysis.

Based on the process of numerical analysis in chapter 3, numerical bending tests and an axial test performed on four node connectors are presented in chapter 4. Three splice connectors and one end-plate connector have been selected from those discussed in chapter 2, so that the main characteristics of the systems examined are comparable those used in practice. Particularly, different bolt clearances are modelled to determine their influence on connection stiffness.

Chapter 5 presents the buckling behaviors of global grid shells using the results gained in chapter 4. Due to the specific functions of ANSYS, two sizes of span with three different rise-span ratios are modelled. All aspects of the nodal stiffness, including the effect of bolt clearances, have been integrated into the whole models which were included initial geometrical imperfection. As a result, the influence of differing stiffness of various connection systems using three different rise-span ratios have been examined.

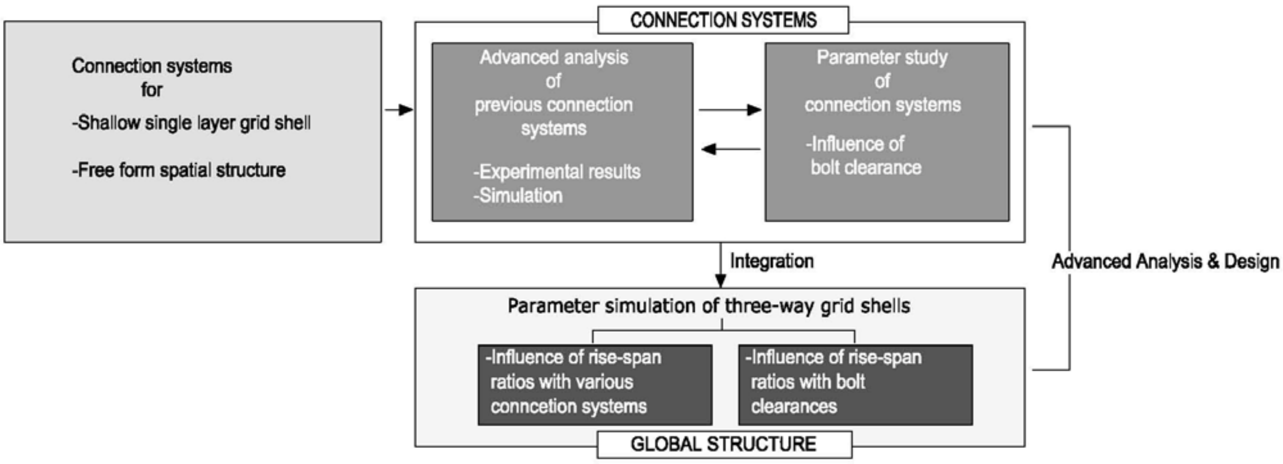

Figure 1.1: Diagram of research synopsis