有限元理论基础及Abaqus内部实现方式研究系列2：S4壳单元质量矩阵研究

Theoretical Foundation of Finite Element Method and Research on the Internal Implementation of Abaqus Series 2: Study on the Mass Matrix of S4 Shell Element

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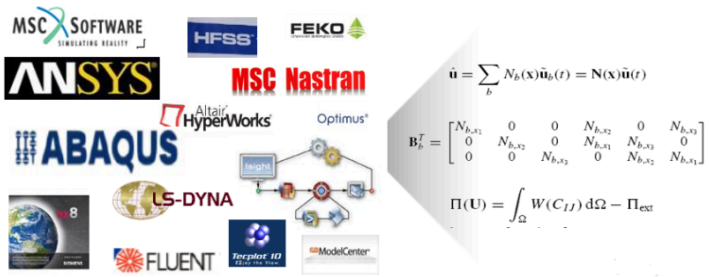
==概述== ==Overview==

在CAE领域，从学校、实验室的自研算法到实现真正的商业化软件是一条无比漫长的道路。我们不研究有限元的新方法、新理论，只是研究商用有限元软件的实现方式。有限元的理论发展了几十年已经相当成熟，商用有限元软件同样也是采用这些成熟的有限元理论，只是在实际应用过程中，商用软件在这些传统的理论基础上会做相应的修正以解决工程中遇到的不同问题，且各家软件的修正方法都不一样，每个主流商用软件手册中都会注明各个单元的理论采用了哪种理论公式，但都只是提一下用什么方法修正，很多没有具体的实现公式。

In the field of CAE, the path from the independently developed algorithms in schools and laboratories to the realization of real commercial software is an incredibly long journey. We do not study new methods or theories of finite elements, but rather the implementation methods of commercial finite element software. The theoretical development of finite elements has matured for decades and commercial finite element software also adopts these mature finite element theories. However, in the process of practical application, commercial software will make corresponding corrections on the basis of these traditional theories to solve different problems encountered in engineering, and the correction methods of each software are different. Each main commercial software manual will specify which theoretical formula each element uses, but only mention the method of correction, and many do not provide specific implementation formulas.



一方面我们查阅Abaqus软件手册得到修正方法的说明，另一方面我们自己编程实现简单的结构有限元求解器，通过自研求解器和Abaqus的结果比较结合理论手册如同管中窥豹一般来研究Abaqus的修正方法，从而猜测商用有限元软件的内部计算方法。在研究的同时，准备将自己的研究成果记录下来写成一个系列文章，希望对那些不仅仅满足使用软件，而想了解软件内部实现方法甚至是做自己的软件的朋友有些帮助。由于水平有限，里面可能有许多错误，

欢迎交流讨论。

On the one hand, we consult the Abaqus software manual for the description of the correction method, on the other hand, we program a simple structural finite element solver ourselves, and compare the results of our self-developed solver with Abaqus, combining theoretical manuals to study Abaqus' correction methods as if we were peering through a bamboo tube. This allows us to guess the internal calculation methods of commercial finite element software. While conducting research, I am preparing to record my research findings in a series of articles, hoping to help those who are not only satisfied with using the software but also want to understand the internal implementation methods of the software or even develop their own software. Due to my limited abilities, there may be many errors, and I welcome discussions and exchanges.

iSolver介绍视频： iSolver Introduction Video:

http://www.jishulink.com/college/video/c12884

==以往的系列文章== ==Previous Series Articles==

第一篇：S4壳单元刚度矩阵研究 http://www.jishulink.com/content/post/338859 研究基于Mindlin厚壳理论的S4壳单元的刚度矩阵在Abaqus中的实现方式

First article: Research on the Stiffness Matrix of S4 Shell Element http://www.jishulink.com/content/post/338859 This research explores the implementation of the stiffness matrix of the S4 shell element based on the Mindlin thick shell theory in Abaqus.

==第二篇：S4壳单元质量矩阵研究== ==Second Article: Study on the Mass Matrix of S4 Shell Element==

在模态分析或者动力学分析中，都必须计算质量矩阵。虽然Abaqus最近发展迅猛，但在模态分析时Nastran依然是行业标准，有些单位的模态分析只承认Nastran的结果，不能使用Abaqus等其它软件，所以，为了能更深入的了解Nastran的模态分析的优势，本章在研究Abaqus的S4壳单元的质量矩阵的同时也研究Nastran的Quad4壳单元质量矩阵的内部实现方式。研究方式是在自编程序iSolver根据成熟的理论实现质量矩阵，通过比较同一模型的Abaqus、Nastran的质量矩阵结果，结合帮助文档猜测这两个软件单元质量矩阵的内部实现方法。

In modal analysis or dynamic analysis, it is necessary to calculate the mass matrix. Although Abaqus has developed rapidly recently, Nastran remains the industry standard for modal analysis. Some units only recognize the results of Nastran for modal analysis and cannot use Abaqus or other software. Therefore, in order to gain a deeper understanding of the advantages of Nastran's modal analysis, this chapter studies the internal implementation of the S4 shell element mass matrix in Abaqus while also studying the internal implementation of the Quad4 shell element mass matrix in Nastran. The research method is to implement the mass matrix based on mature theory in the self-written program iSolver, and compare the mass matrix results of Abaqus and Nastran for the same model, combining the help documentation to guess the internal implementation methods of the mass matrices of these two software elements.

===S4壳单元质量矩阵研究总结=== ===Summary of the Research on the S4 Shell Element Mass Matrix===

Nastran的Quad4在计算质量矩阵时可选择一致或者集中，都使用完全积分。

The Quad4 in Nastran can choose consistent or concentrated mass matrix calculation, both use complete integration.

Abaqus一次壳单元在standard求解器默认使用一致质量，且质量矩阵的积分和壳单元的类型有关，S4是完全积分，S4R是选择积分。在explicit默认使用集中质量，但没找到输出质量矩阵的方法，所以没法研究。

In Abaqus, the shell element uses consistent mass by default in the standard solver, and the integration of the mass matrix is related to the type of the shell element, with S4 using complete integration and S4R using selective integration. In explicit, concentrated mass is used by default, but there is no method to output the mass matrix, so it cannot be studied.

针对一次壳单元，具体的质量矩阵在Nastran和Abaqus中的实现方式如下表：

The specific implementation of the mass matrix for the first-order shell element in Nastran and Abaqus is as follows in the table:

软件 Software	单元类型 Element Type	矩阵类型 Matrix Type	元素 Element	积分 Integration	修正情况 Correction
Nastran	Quad4	一致质量 Consistent mass	平动项 Translation term	三个都是完全积分 All are completely integrated	无
			转动项 Rotational term	取0 Take 0	无
		集中质量 Concentrated mass	平动项 Translation item	一致质量对应列相加 Sum of consistent mass corresponding columns	无
			转动项 Rotational item	取0 Take 0	无
Abaqus	S4	一致质量 Consistent mass	平动项 Translational term	三个都是完全积分 All three are fully integrated	无
			转动项 Rotational term	x、y完全积分、z取0 x, y fully integrated, z taken as 0	无

软件 Software	单元类型 Element Type	矩阵类型 Matrix Type	元素 Element	积分 Integration	修正情况 Correction
		集中质量 Concentrated mass	无法获取 Unavailable		
	S4R	一致质量 Consistent Mass	平动项 Translation Term	x、y都是减缩、z完全积分 Both x and y are reduced, z is fully integrated	xy修正，类似沙漏 XY correction, similar to a sandglass
			转动项 Rotational term	x、y完全积分、z取0 x, y fully integrated, z taken as 0	修正，没找到原因 Correction, unable to find the cause
		集中质量 Concentrated mass	无法获取 Unable to retrieve		

详细研究方法，见附件： Detailed research methods, see attachment:

有限元理论基础及Abaqus内部实现方式研究系列2：S4壳单元质量矩阵研究(SnowWave02 20170816).pdf

Finite Element Theory and Abaqus Internal Implementation: Series 2 - Study on the Mass Matrix of S4 Shell Element (SnowWave02 20170816).pdf

推荐阅读 Recommended Reading

Abaqus、iSolver与Nastran梁单元差异...

SnowWave02 免费 Free

转子旋转的周期性模型-水冷电机散热仿真 Periodic Model of Rotor...

技术邻小李 Technical Neighbor Xiao Li ¥100 100 Yuan

非局部均值滤波和MATLAB程序详解视频算法及其保留图形细节应用...

正一算法程序 Zhengyi Algorithm Program ¥220 220 Yuan

车身设计系列视频之车身钣金正向设计实例教程...

京迪轩 Jing Di Xuan ¥1