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Consistent Mapping of CAD-Models to FEM-Models

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Abstract. *Engineers think in terms of macroscopic structural models. The Finite Element Method employes microscopic structural models. Efficient structural analysis depends on effective transformation between these two models. Special requirements for delayed notification and delayed reanalysis arise in distributed environments.*

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1 The Scenario

An engineer thinks of a structure in a macroscopic way: his structural system is a set of plates, beams, columns and foundations, subjected to external influences such as loads and changes in temperature and supported at selected locations in different fashions such as simple or fixed supports.

The engineer also thinks of structural behaviour in a macroscopic way. He does not consider a beam to be a 3D-solid for which a 3D-stress distribution is determined. For him, a beam is a 1D-behavioural element with normal force, moments and shear forces varying along the axis of the beam. The beam is usually dimensioned on the basis of these behavioural variables, not on the basis of the stresses determined in a plane stress analysis. Similar observations apply to columns and floor plates.

The Finite Element Analysis looks at structures in a microscopic way. The structure is decomposed into meshes of finite elements, whose shape and size is determined by the accuracy requirements of the method of analysis and of the behaviour of the specific structure which is being analysed. Mesh adaption is used to achive the required level of accuracy. In addition to the geometry, the external influences and the support conditions are also decomposed to suit the finite element mesh. The result of a finite element analysis are the values of the behavioural variables at the macroscopic level of the mesh. Frequently , different elements have different local coordinate systems, for which the coefficients of non-scalar behavioural variables are specified. The types of finite elements that are used (beams, plates, folded plates, 3D-solids, ...) determine wheather the microscopic behavioural variables are identical in nature to the macroscopic variables or not. If, for instance, a macroscopic beam was analysed with a 3D-finite element mesh, the macroscopic behavioural variables are force and moment, where the microscopic behavioural variable is stress.

The convenient application of the finite element method to structural engineering problems depends on efficient transformation between the macroscopic and the microscopic view of a structure. The need to transform macroscopic structural elements into microscopic finite elements is obvious. The need to transform microscopic behavioural variables into macroscopic behavioural variables is less obvious and more difficult to implement efficiently.

The level of difficulty of the symmetric transformation between macroscopic and microscopic models of structures depends strongly on the type of finite element that is used. The effort is least for bars of constant cross-section. Since the displacement functions which are used to derive the stiffness matrix of a bar solve the governing differtial equation of the bar exactly, the entire bar can be considered as one finite element without loss of accuracy. Thus the transformation from structure to mesh is straightforward; the macroscopic and the microscopic behavioural variables are identical. In contrast with bars, finite floor plate elements require considerable effort for mesh adaptation and for transformation of microscopic behavioural variables to the macroscopic model. In some cases such as T-beams whose flayes are floor plates, special problems arise.

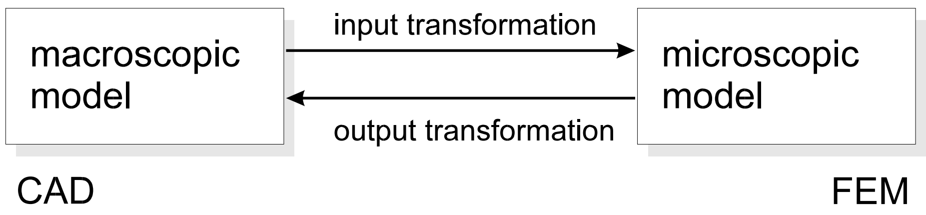

Figure 1: Transformation between macroscopic and microscopic models

2 Available Tools

Two major types of software are currently being used to model and to analyse structural systems: Computer Aided Design systems (CAD) and finite element systems (FEM). Software houses provide different types of links between their CAD and FEM products, which vary from simple mesh generators to systems which can transform behavioural variables.

The term Computer Aided Design (CAD) is misused in software products. The word "Design" implies a tool for the support of engineering design as a whole. In reality, CAD-software mainly serves to map geometry and does not contain components for other significant aspects of engineering design such as the analysis of mechanical behaviour or the dimensioning of structural components.

The term Finite Element Method (FEM) is used to denote a specific method for the analysis of the behaviour of bodies. The mathematical description of the laws which govern the behaviour is assumed to be known, e.g. certain laws of physics or of chemistry. It is also assumed that the behavioural constants for theses laws are known, e.g. the elastic constants of the material of the body. For a body of specific shape, which is subjected to known external influences, the mathematical equations are solved with the FEM to yield a prediction of the behaviour.

A comparison of the CAD-model and the the FEM-model of a structural system shows that the CAD-model contains only part of the information that is required for the FEM-model. The geometric information describing the macroelements (such as the polygon which bounds a floor slab) in the CAD-model must therefore be augmented as follows for the FEM-model: generation of finite element meshes with specified properties such as node density, nodal variables and element type; generation of finite element properties from geometric properties, for instance moments of inertia of bar elements; generation of external loads from geometric properties and load intensities; specification of support conditions at the nodes of meshes; specification of material properties of finite elements.

The generation of the properties of the FEM-model is controlled with parameters such as type of structural element, mesh density, load intensity and boundary condition, which are not part of the data structure of a traditional CAD-system. Typical structural subsystems such as floors, frames or stabilizing cores must be identified by the engineer in the macrosystem. Traditional CAD-systems are not suited for this purpose. All of the preceeding information should be stored persistently so that it remains available for subsequant modification of the micromodel.

The transformation of behaviour from the micromodel to the macromodel depends on information which is not available in tradition FEM-systems. This information concerns aggregation of microelements to macroelements and aggregation of stresses to stress-resultants subject to restrictions, for instance the effective width of the flaye of a T-beam in a floor.

This analysis of the available CAD- and FEM-tools shows that they are not adequate of convenient transition between microscopic and macroscopic models of structural systems. In their traditional form, both tools lack the information and methods required for convenient transformations of input and behavioural variables in both directions. Significant design decisions, such as analysing with or without sidesway, are difficult to implement with existing systems.

3 Modification of Structural Systems

During the design of constructural facilities, structural systems are subject to change. It is not uncommon for modification to be frequent and small in volume. An automatic complete reanalysis of the complete structure after each modification is not always desirable. The interaction between the microscopic and the macroscopic model must account for delayed updating of the models.

Design modifications are introduced in the macroscopic model by changing geometric macroelements, macroloadings or macrosupports. If macroproperties are changed, the microproperties, the behavioural microvariables and the behavioural macrovariables become invalid. Thus the macromodel must be updated by transformation of the macromodel, the micromodel must be reanalysed and the computed behavioural variables must be transformed into the macromodel.

If the CAD-model and the FEM-model are small in size and are stored in a local computer environment, the properties of the FEM-model can be updated by repeating the generation process. If the models are large in size or stored in a distributed network environment, it becomes attractive to restrict the updating to the affected subsystems of the structure. For efficiency reasons, it is not possible to update the FEM-model automatically after each modification of the CAD-model or the control parameters. Restoration of consistency between the CAD-model and the FEM-model is therefore delayed. It may be triggered explicitly by the engineer or implicitly when behavioural data of the FEM-model are accessed after the CAD-model has been modified.

Methods for restricted delayed updating of a FEM-model to restore its consistency with a part of or with the entire CAD-model depend strongly on suitable registration of the modifications in the CAD-model. It is not advisable to register the modifications for each individual object, since this leads to an excessive amount of administrative data and a large number of search operations. On the other hand, it is not adequate to restrict the registration of modifications to a class of objects as a whole. Different objects of this class may be components of different substructures, some of which are changed and others not. The usual data structures of object-oriented FEM-modelling are therefore not adequate for restricted delayed updating.

Efficient methods of updating are developed from set theory. Objects of the structural system, which belong to different classes, are combined to form sets, such as the set of all objects belonging to a particular floor of a building. If one of the objects of the set is modified, the set as a whole is considered to be modified. Some of the objects of the CAD-model may belong to more than one set, for instance to a floor substructure and to a frame substructure. Each set may be regarded as an object.

The sets in the CAD-model are mapped to corresponding sets in the FEM-model. Thus the objects representing the finite elements, the loads and the support conditions for a floor substructure form a set of objects in the FEM-model. If only the floor set in the CAD-model is modified, then only the input data of that floor set of the FEM-model need to be updated.

Restriction of updating to a set of objects of the FEM-model does not imply that the reanalysis can be restricted to the same set, since the behaviour of different sets of objects of the structure may be dependent. Frequently, however, the engineer may be satisfied with a reanalysis of a single set, such as a floor substructure. The extent of the analysis which has led to the results for a particular set of the FEM-model is registered for the set as a whole and need not be registered for each individual object of the set.

4 Concepts of Future Systems

It is expected that furure systems for structural analysis will be characterised by convenient transformations between macro- and micromodel and by operative support for delayed modification in distributed environments. In order to achive this aim, further research and development are required in several areas:

- Effective interactive methods for the specification and identification of geometric elements, loading patterns and support conditions in the application surface of the macromodel.
- Functionality for interactive specification of element type and node density in the application surface of macromodel.
- Classes and sets of objects for the information in macromodel and for the parameters controlling the transformation from the macro to the micromodel.
- Zoning and version control of the macromodel to facilitate delayed modification of the micromodel in distributed environments.

- Notification mechanisms for changes in the structural system; selection of suitable subsystems for reanalysis.
- Effective algorithms for initial meshing in given polyeders and polygons and for adaptation of these meshes to the mechanical behaviour, including multilevel meshes for iterative solutions.
- Functionality for the interactive specification of the aggregation of microscopic behavioural variables in the application surface of the micromodel.
- Classes and sets of objects for the micromodel to facilitate delayed reanalysis of the micromodel and notification of the macromodel in delayed environments.

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