MODEL AND SENSOR DATA MANAGEMENT FOR GEOTECHNICAL ENGINEERING APPLICATION

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ABSTRACT: Monitoring is an actual problem in almost all disciplines of civil engineering. Especially in geotechnical engineering monitoring is very frequently applied, mainly during the construction phase. The recorded sensor data must be evaluated against the designed values. Also the models used for the forecasting of the behaviour of the investigated engineering structure have to be updated in consideration of the actual situation, i.e. the recorded sensor data. As in geotechnical engineering the actual situation itself and also the information about the soil properties will change several times during the construction phase, a high number of data, models and model versions will be investigated. All these data, models and model versions have to be managed. Therefore we propose an object-oriented framework to holistically model the building system, the engineering system, the sensor system, the workflow and the monitoring data in order to have a proper documentation of data, information and knowledge and to retrieve, combine and alternate any aspect of the overall system in a fast and controlled way. The different monitoring processes to be supported are identified and requirements for the development of an information system for monitoring are specified. A short application scenario should show the high complexity of the problem and emphasise the need of automation of the information management for monitoring.

KEYWORDS: structural monitoring, model management, data and process modelling.

1 INTRODUCTION

The main goal of monitoring is (1) to check if the behaviour of the system is between the predefined target borders and (2) if the model assumptions from the design phase were right and if they are still up to date. Figure 1 shows a generalised method for the observation of engineering systems, deduced from the observational method, firstly proposed by Peck [5] for geotechnical engineering and meanwhile introduced in Eurocode 7. The observational method is a well known example for monitoring in geotechnical engineering where a number of models and model versions as well as various measurands have to be managed. Figure 1 also shows that the tasks usually assigned to monitoring, namely measuring and interpretation of measured data, are embedded in the lifecycle of the civil engineering structure. Hence in scope of the whole lifecycle monitoring comprises also forecasting of the system behaviour and application of preventive and corrective maintenance measures in case of latent or actual malfunction. Furthermore even if the actual observation of the engineering system will begin at the earliest with the construction process, the preparation for monitoring has to be arranged already in the design phase. Already there the system behaviour will be forecasted based on the engineering model which will be chosen according to the given boundary conditions and first versions of the model and alternative models may be developed. The importance of considering the whole life-cycle for monitoring was also discussed in [1],[2].

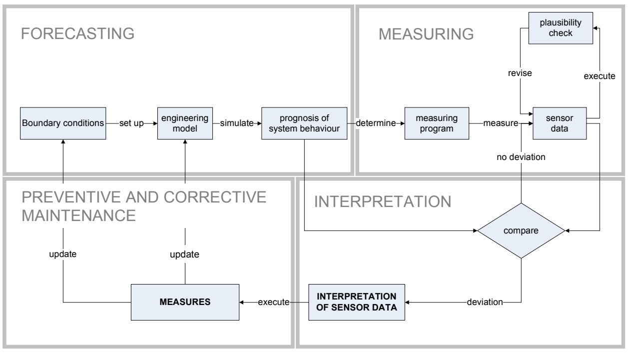

Figure 1. Information flow in structural monitoring [10].

The holistic model can be sub-structured in four parts according to Figure 1:

Forecasting of the system behaviour is a well known task, done by engineers every day in order to find the best design for engineering structures. In scope of monitoring it is also the basis for the determination of the measuring program, i.e. the selection and placement of the sensors.

Measuring is from the technical point of view meanwhile on an advanced state. Using visual inspections and non-destructive investigation procedures, applying radar, ultrasonic echo and impact echo techniques the condition of important buildings can be analysed based on engineering methods [6] in defined time intervals and necessary maintenance measures can be drawn. Also systems for automatic measuring do exist [12]. Continuous monitoring with sensors is today technically almost possible. While previous sensor systems were associated with high effort for installation and maintenance costs [4], wireless sensors with integrated computation units for data analysis – especially Micro-Electro-Mechanical Systems (MEMS) [1] enable a flexible and cost-effective application [3]. It is to be assumed that both sensor nets and their frequency of application will grow in near future. Therewith also the amount of data, which will be recorded and hence needed to be transferred, interpreted and displayed will grow of course.

The *interpretation* of measured data is the important step, which converts the sensor data to information, suitable for decision making. For this interpretation the measured data have to be evaluated against the forecasted system behaviour. This means that the engineering model has to be adjusted to the measured data. Therefore possibly the variation of parameters or the complete change of the engineering model will be needed. If the system status is beyond predefined borders, correction measures are required, which also demand the modification or exchange of the engineering model and possibly the modification or extension of the sensor net.

Preventive and corrective maintenance measures improve the condition of the engineering structure, but they also cause new boundary conditions and hence the engineering model must be updated again. These changes of models or actualisations of parameters have to be managed and documented in any way. A continuous actualisation of the engineering models both by modification of parameters and by selection of new suitable models is necessary for the prediction of the future system behaviour as specified in chapter 2. Especially for the reaction on undesirable system behaviour the last version of the model as well as the history of the model development – which represents the development of the system status – may be helpful for the determination of measures. Therefore it is also necessary to know the circumstances, boundary conditions and pre-decisions which leaded to the selection of the engineering model – information that are usually known by the designer of the model, maybe also written in any way, but usually not represented in structured, formal, machine-readable form that will enable automatic subsequent processing. The quintessence is that the real problem and hence the focus of this research is not the measuring of physical facts itself, but the interpretation and management of the data and the updating and management of the engineering models. To handle these problems an information system for model- and data management requires (1) the storage of the engineering models independent from the application program to enable the availability and reuse of models over the whole lifetime independent from file formats of the used software, (2) the possibility of import and modification of the models by software applications and restore as model version to the model management, (3) retrieval and reuse of already investigated variants and (4) modelling of assumptions and boundary conditions which are the basis of an engineering model – the last one is required for automatic search for better model in case of modifications in the engineering structure or if the model does not represent the sensor data appropriately. The exchangeability on demand and the systematic choice of the models under consideration of complexity, accuracy and reliability are hardly supported by state-of-the-art monitoring systems, despite of the significant influence of the selection of the engineering model on the results [11]. The actual insufficient formalisation of the domain 'monitoring' and the low interoperability of the different software products support these requirements only in a very restricted range [10]. In the following we will introduce a concept which considers these aspects and which enables the (semi)automatic modification and management of measured data, models and model versions.

2 APPLICATION SCENARIO

The main task of the proposed approach is to provide an information system to support the management of the recorded sensor data and the modification of the engineering models. The engineering model of the structure must be evaluated and adjusted to any new situation in order to get a clear understanding of the condition of the engineering structure and to enable new and better forecasting of the future behaviour. For example Figure 2 shows an application scenario of model modification in geotechnical engineering.

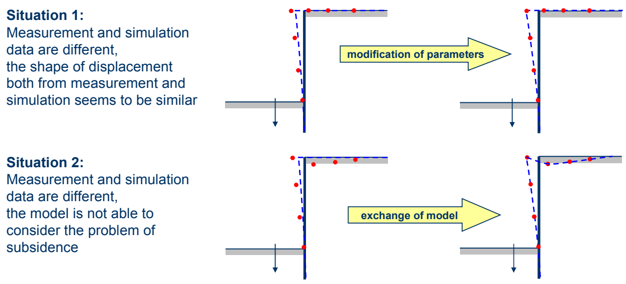

Figure 2. Application scenario of model modification and exchange.

The figure shows the sheeting of an excavation. The dashed line represents the forecasted deformation. The points represent the deformation recorded by sensors. Forecasted and recorded horizontal deformations in Situation 1 are close to each other. Therefore the model can be adjusted to the recorded data by modification of the model parameters. Depending on the number of investigated parameters the result will be a variety of model versions. Situation 2 shows additionally to the horizontal deformation also vertical subsidence which has not been forecasted by the chosen model, i.e. the model can not be simply adjusted to the measured data by parameter variation. A new engineering model is needed which is able to represent additionally the vertical subsidence. Hence, there arise various models which may again have various model versions. Given that the excavation will be done in several steps and given that in each step new information about the real soil conditions will emerge, we see that the number of investigated models may be very high. The complexity of the problem will also increase with the number of project partners, i.e. principal, consulting engi-

1 combination of mechanical elements, sensors, actors and electronic circuits on a chip

neers, expert planners, executives and site supervision, who have different demand on detailedness and type of information. This simple example shows the high complexity and the high number of models which have to be managed. It is a multidimensional problem that consists of management of engineering models, their history of development, their boundary conditions as well as component based modelling and management of the processes.

3 APPROACH

The proposed information system for monitoring of engineering structures consists of the four main components illustrated in Figure 3: (1) the sensors which deliver data about the actual behaviour of the system, (2) the engineering systems itself, (3) the analysis tools for interpretation of sensor data and (4) the processes which define the workflows of the monitoring procedure. The whole system is represented by a system model.

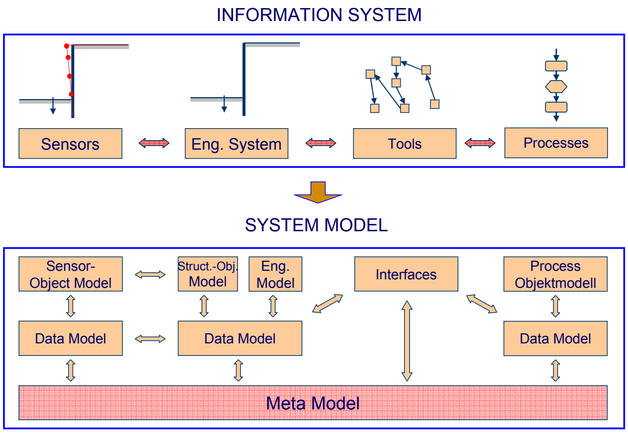

Figure 3. Monitoring System and System Model.

Each engineering system is an object with object-specific properties. If we consider engineering systems in geotechnical engineering, e.g. an excavation sheeting, the properties can be of different type. On the one hand there are geometrical and topological properties, which can be represented by the structural object model. On the other hand there are the physical properties of the material. They can be represented mathematically by material laws, i.e. by engineering models. The engineering model describes the system behaviour of the building. In order to be identifiable and reusable, both the structural object model and the engineering model need as a basis for their instantiation a well defined and structured data model. Also the second part of the system, the sensors, have properties which must be described by a sensor object model and a data model. The measured values have to be set in context with the engineering model. This would be possible by object oriented modelling both of the engineering system, e.g. by an IFC[2] building model, and also of the sensors. Complementary to the object oriented modelling of civil engineering structures the object oriented modelling of sensors is a straight forward idea which will enable to define the characteristics of the sensors, especially the kind of data provided and hence provide the basis for the management of sensor data. Furthermore it will enable the definition of the topology between the sensors and special parts of the building. This is an important point because therewith the sensor will be linked directly to the engineering structure and hence this provides the definition of the relationship between forecasted and measured values. It is also the basic step to enable the updating of the engineering models according to the measured values. The analysis tools for interpretation of sensor data interact with the whole system through input and output interfaces. These interfaces must also be well defined in order to combine all the parts to one operating information system. The reuse of models and tools demands also that even such models and tools must be able to be included whose data structure and interfaces are heterogeneous as a result of their different origin. This integration task should be realized through a comprehensive meta model. Management and reuse of models is so far used in mechanical engineering and chemical engineering [1]. The adoption of these methods for civil engineering problems, especially their application for structural monitoring seems to be a promising approach. As reusability demands highest possible generality, generic but domain-specific models have to be established. Reusability and management of models demand also independence of the analysis tools. Most available software products do not separate models and analysis tools, and hence reduce their flexibility for the application to special cases or hinder reuse of models or parts of them. Therefore the clear partition of models and applications is proposed. Models should be classified as much as possible and separated from other models and application tools, as shown in Figure 4.

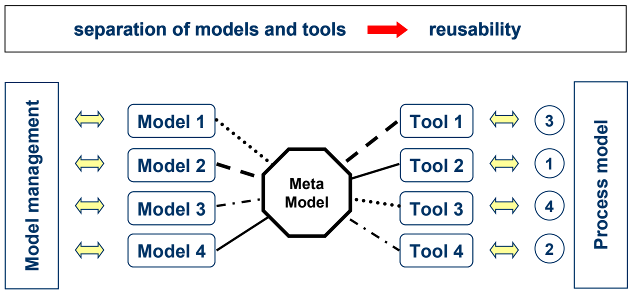

Figure 4. Component based approach for reuse of models.

The problem arising from this approach is that everything which has been partitioned has to be recomposed to a complete system on demand. Clearly defined interfaces both for tools and models are required for the integration of these components and to configure one information system. A meta model enables the interpretation of the descriptions of interfaces, models and tools. It provides the information about the model purpose and which tool can work with this model. In order to define also the sequence of application of models and tools a process model has to be setup accordingly. Of course partitioning all the models in small generic parts produces a very large number of models. In order to manage and store these models, a model management system is needed to enable

2 Industry Foundation Classes: object oriented data model for building information modelling, developed by the International Alliance for Interoperability (IAI)

access and management of models and model versions. Finally, the information logistic, i.e. the procedure of data evaluation and hence the sequence of the system tool usage, must be described by process models. They describe the sequence of actions and conditions for their application. One of the most common methods of process modelling is the graphical EPC-Method[3], which was developed for the ARIS-Framework[4] by Scheer et al. [7]. It has been developed for modelling of business processes. The elements of an EPC are events, functions (actions) and logical connectors. Based on these elements process chains can be built, whereas an event is the precondition for a function and the result of the function is again an event. Because these elements are very generic the transfer of the business application to monitoring applications should be possible.

4 CONCLUSIONS

The primary goal of the presented approach is the modelling of sensors and their topological connection to the engineering structure as well as the management of models and model versions. This research is still at its beginning. As already mentioned topological connection of the sensors to the engineering structure can be realised by object-oriented modelling of both the sensors and the structure. Because this is one of the crucial pre-conditions for the linkage of sensor data to engineering models the next step of the work will be to develop data models for sensors and complement the existing building data models, e.g. the IFC data model, by a geotechnical engineering extension. These models should consider besides the geometrical and topological properties also the structural behaviour, i.e. material laws. Additionally to these data models a meta model will be developed, which represents the required domain knowledge to enable the flexible (semi)automated combination of models and tools. The system will be complemented by the development of a model management system which should be able to manage the storage, exchange and documentation of models and model versions and hence makes the whole workflow and the different steps of monitoring and model modification more transparent and traceable. Finally, the identification of all the monitoring processes, their modelling and implementation using the well known methods of business process modelling should bring more support for the engineer to handle the partially very complex monitoring workflows

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3 EPC = event driven process chain

4 ARIS = architecture of integrated information systems