18th International Conference on the Application of Computer
Science and Mathematics in Architecture and Civil Engineering
K. Gürlebeck and C. Könke (eds.)
Weimar, Germany, 07–09 July 2009

COMPUTATIONAL STEERING FOR COLLAPSE SIMULATION OF LARGE SCALE COMPLEX STRUCTURES

T. Sikiwat*, M. Breidt and D. Hartmann

**Institute for Computational Engineering*
Ruhr-University Bochum, 44780 Bochum, Germany

E-mail: Tanongsak.Sikiwat@rub.de

Keywords: Computational steering, Demolition using controlled explosives, Structural collapse, Multibody dynamics, Multi-level simulation.

Abstract. *This contribution is concerned with advancements of a previous work that introduced a software system for computer aided destruction of structures using controlled explosives. There, first results of collapse simulations under consideration of uncertainty with regard to moderate complex and complex structures were obtained. This work presents improvements of the aforementioned software system, in particular by making use of computational steering concepts as well as enhancements of the simulation model for simulating large scale complex structures.*

1 INTRODUCTION

In order to model and simulate collapses of moderate complex and complex structures, a user-friendly and high performance software system is mandatory. Since a large number of simulation experiments have to be performed, therefore, next to an appropriate simulation model and high performance computing, efficient interactive control, visualization and steering capabilities of model parameters and simulation results are crucial.

A simulation of structural collapse has been investigated by many researchers, such as [1-5], and especially by a previous work in [6] that introduced a holistic software system for planning structural destruction using controlled explosives. As demonstrated, the computer simulation system dealing with demolition of moderately complex and complex structures using controlled explosive charges is a powerful tool to improve the collapse cascade of buildings. Nevertheless, in the cases of large scale complex real world structures, a holistic computer simulation is often associated with many uncertainties and high risks. As a consequence, the simulation models for these kinds of structures require improvements and advanced modeling concepts such that reliable simulation results can be obtained. Hence, this contribution will describe advancements of the previous work and presents improvements of the software system by making use of computational steering concepts [7] as well as enhancements of the simulation model for simulating large scale complex structures.

This contribution starts with the description of a multi-level simulation model for collapse cascades induced through blasts. Furthermore, an enhancement of the simulation model for large scale complex structures is suggested. The software system itself, serving as a computational steering tool, and improvements of the user interaction are discussed. Finally, an application example and its simulation result are shown to elucidate the capabilities of the software.

2 CONCEPT OF SIMULATION MODEL OF THE DEMOLITION OF A BUILDING

The simulation of large scale complex real world structures requires sophisticated concepts such that the simulation model used in the software system can cover the entire dynamic collapse process up to the final debris hill. As given in the aforementioned work, the simulation model applied is based on a multi-level approach. This multi-level model comprises three main levels as follows:

a) On a local level, the effects of the explosive charges are modeled such that the volitional damages can be captured and described.

b) On a near field level, the effects of the local damages on adjacent structure components are analyzed.

c) On a global level, the dynamic collapse of the entire structure is modeled based on the first and second level.

The physical core of the simulation model on the global level is based on a so-called "special multibody system" (special MBS) that is created adaptively during the simulation process. This concept makes it possible to obtain an efficient and realistic simulation of structural collapse, particularly with regard to the major collapse kinematics. Contrary to an extremely time consumed simulation using a finite element method, the optimization and the uncertainty analysis, which require a large number of simulations, become possible through the use of multibody system approach.

Within the global level, relevant effects of the local and the near field scale, such as fracture and failure processes of the reinforced concrete parts, are realistically approximated by means of tailor-made multibody subsystems. These subsystems employ force elements representing nonlinear material characteristics in terms of force/displacement relationships that, in advance, are determined by a Finite Element Analysis on the local and near field level. The computation of the resistance characteristic curve has to take into account a geometrical and physical nonlinearity to achieve a realistic approximation of the behavior of reinforced concrete. The knowledge of their distribution is also important because uncertainties of the parameters for material and geometry have affected the complete collapse simulation.

The calculation of the resistance characteristic curve is performed by the partner Institute of Reinforced and Pre-stressed Concrete Structure at Ruhr-University Bochum. This is based on the definition of a cut surface in the finite element model corresponding to that location where in the multibody system a force element will be considered. Using integration over the cross section and the stress values, the stress resultants are determined for moments and forces. With the displacement of the nodes of each element the corresponding rotation and displacement can be calculated [8].

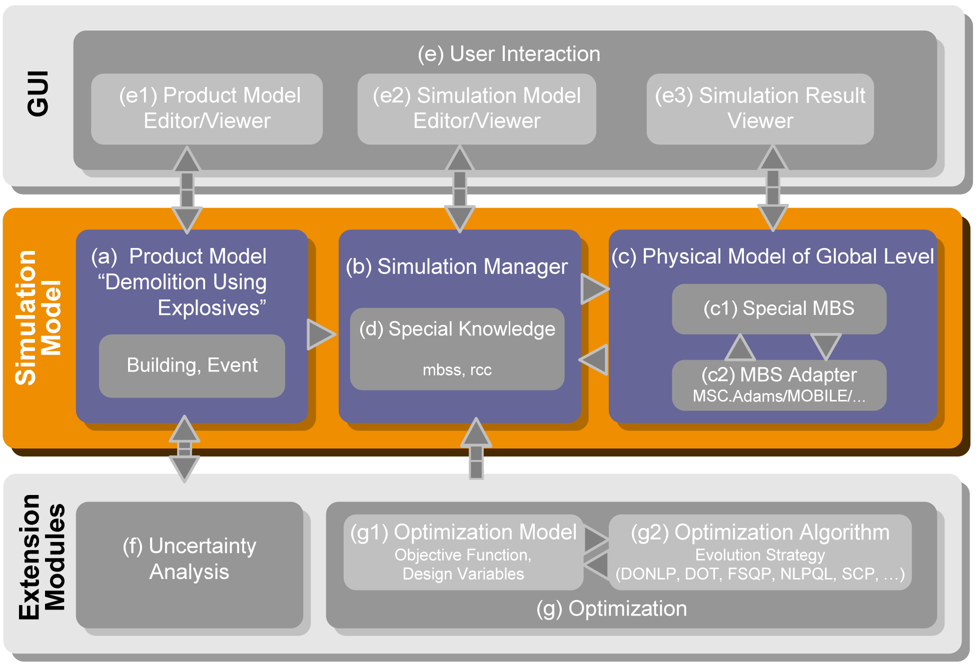


Figure 1: Schematic presentation of the simulation model for the global level of the multi-level-problem and coupling to optimization of demolition strategy and uncertainty analysis

Figure 1 shows the concept of the simulation model including all submodels which systemically describe the entire structure. As depicted, the extension modules such as the optimization and the uncertainty analysis are included. The figure 1 also illustrates the automated interactive modeling of the special MBS which uses different submodels. The submodel (a) represents the product model for the "demolition using controlled explosives". This submodel serves as a database and contains all relevant data needed for the global level simulation, such as the position, the geometry and material data of the parts of the building, the details of the preparatory work (i.e. modifications of the static structure of the building before ignition of the explosives) and the potential events (locations and ignition times of explosive charges). Using these data along with the results of the different submodels of the global level as well as the lower levels, the submodel "simulation manager" (b) creates a model description of the special MBS (c1). This modeling process is carried out by using special knowledge (d) that is implemented in the simulation manager submodel. The modeling process is executed by the simulation system – depending for example on upcoming events during the simulation – in every time step of the simulation process. The user interaction submodel (e) allows for an interactive control of the simulation model during the entire collapse process. Hereby, the creation and solution of the system equations is accomplished by multibody system software that is applied by the special MBS submodel via a specific MBS adapter (c2). Currently, the MBS software system MSC.ADAMS [9] is applied. The above mentioned submodels (a)-(c) of the simulation model and the user interaction (e) are implemented as distributed, object-oriented software components that are integrated into the simulation system to ensure a holistic multi-level simulation of the demolition process.

The uncertainty analysis (f) and the optimization submodel (g) are created and carried out in collaboration with the product model (a) as well as the simulation manager (b). For the solution of the optimization problem, a self-developed optimization software package [10] is utilized. This package contains numerous powerful optimization algorithms.

3 SOFTWARE SYSTEM

In this section, the software system serving in the sense of a "Computational Steering Environment" (CSE) for the multi-level simulation and optimization of demolition processes using controlled explosives is described. In brief, it is named CADCE, i.e. Computer Aided Destruction using Controlled Explosives. The architecture of CADCE is characterized by a modular component structure. Having implemented the software system as a multi-level architecture and bearing the computational steering concepts, different functions are encapsulated to allow for flexible interactions with the software user.

Figure 2 depicts the structure of the implemented software system, which uses Eclipse [11] as a basis and incorporates dependencies and connections between the individual components and application (e.g. pre- and postprocessing components, MBS and solver components, JMX, VTK, XML, etc.). For seamless integration into Eclipse, the core and UI components of CADCE are implemented as Eclipse plug-ins providing interactive control and visualization capabilities during the collapse simulation. In addition, the fuzzy analysis and the optimization in the extension module allow the extension of the capabilities in CADCE.

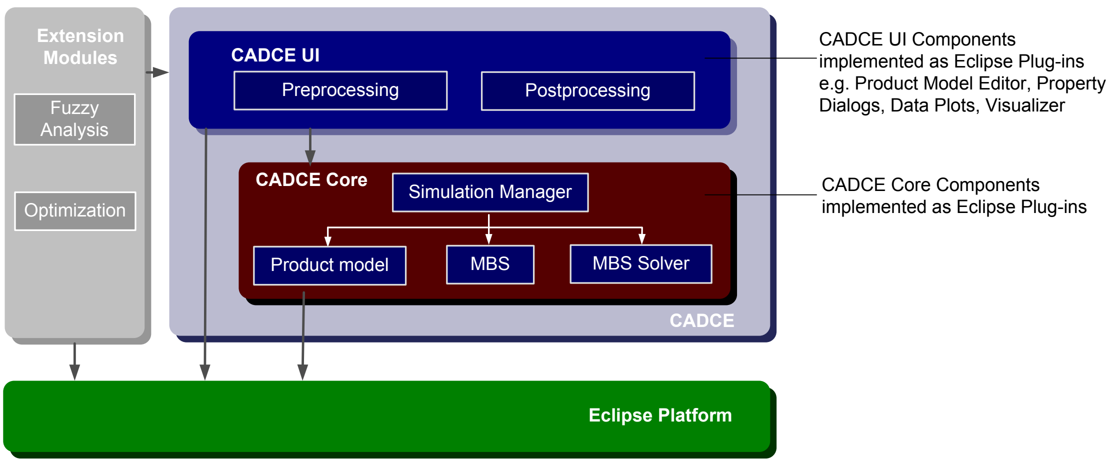
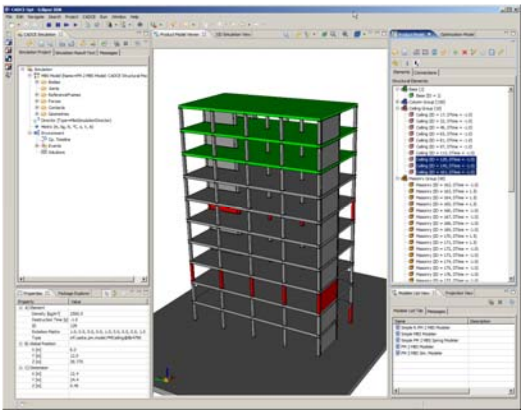
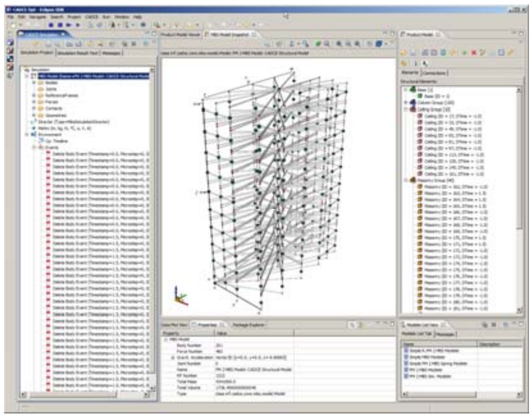


Figure 2: CADCE platform

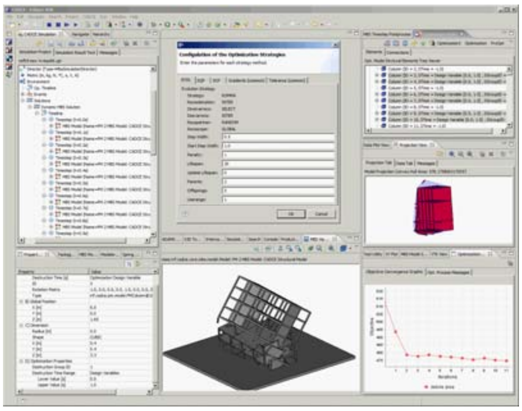
During the modeling process, a product model is generated via a product model component which composed of predefined structural and connection elements. The developed product model supports a generic property mechanism that enables users to store the meta data given in properties within the product model. The simulation manger component generates a MBS model based on the information of the product model. In the MBS mapping process, the modeler knows the semantics of the predefined properties, e.g. connecting types, use of springs and dampers, resistance characteristic curves, contact models, ignition times, discretization degrees etc., and can, therefore, establish appropriate MBS models and MBS simulations. After model generation, there is the ability to modify the provided MBS model interactively by using the property editors available in the CADCE workbenches.



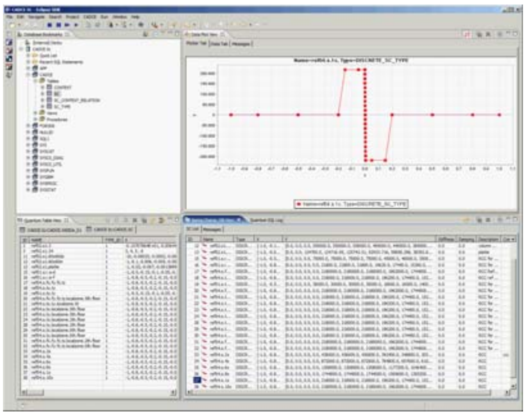
(a)



(b)



(c)



(d)

Figure 3: CADCE workbenches

Figure 3 exemplarily demonstrates several graphical workbenches of the CADCE software which is based on the Eclipse platform. These workbenches provide a uniform GUI for pre- and postprocessing; such as a generation of a product model, a creation of a MBS model and viewers to display simulation results, including various filters for import/export and exchange data in different formats such as DW, DXF, ASCII, and XML. Figure 3.a shows a snapshot of the developing of the product model, figure 3.b displays the mass representation in the MBS model. With the configuration dialog in the optimization workbench, as shown in figure 3.c, users can specify the design parameters and choose the strategies for the optimization process. The spring database in figure 3.d contains pre-calculated nonlinear force elements and can be accessed from the modeler during the MBS transformation process.

In the current CADCE version, besides the user interaction and various workbenches, many functions have been implemented and improved. In particular, a new MBS submodel has been developed using a generalized six-directional nonlinear force element. Furthermore, the simulation manager has been updated to incorporate the new element and to map data from the corresponding product model to the related MBS model correctly. As a further essential amendment, the rigid bodies in the MBS model can also be grouped and ungrouped adaptively during the simulation. Also a selection tool has been added to the product model component assisting users to choose the desired element in the model. In total, the mentioned capabilities added allow users to have a better control over the simulation model and therefore, to improve overall simulation results.

4 APPLICATION EXAMPLE

4.1 Reference model

A dilapidated ten-story building, located in a densely populated urban area and surrounded by several adjacent buildings, is chosen as a reference model. The structure is composed of a ten-story reinforced concrete frame stiffened by shear walls as shown in figure 4. The height, length and width of the building are 37.5, 24.4 and 12.4 m, respectively. Its total mass is about 4300 tons. The building was teared down by controlled explosives. However, due to the buildings density in the vicinity, the best blasting strategy needed to be selected carefully.

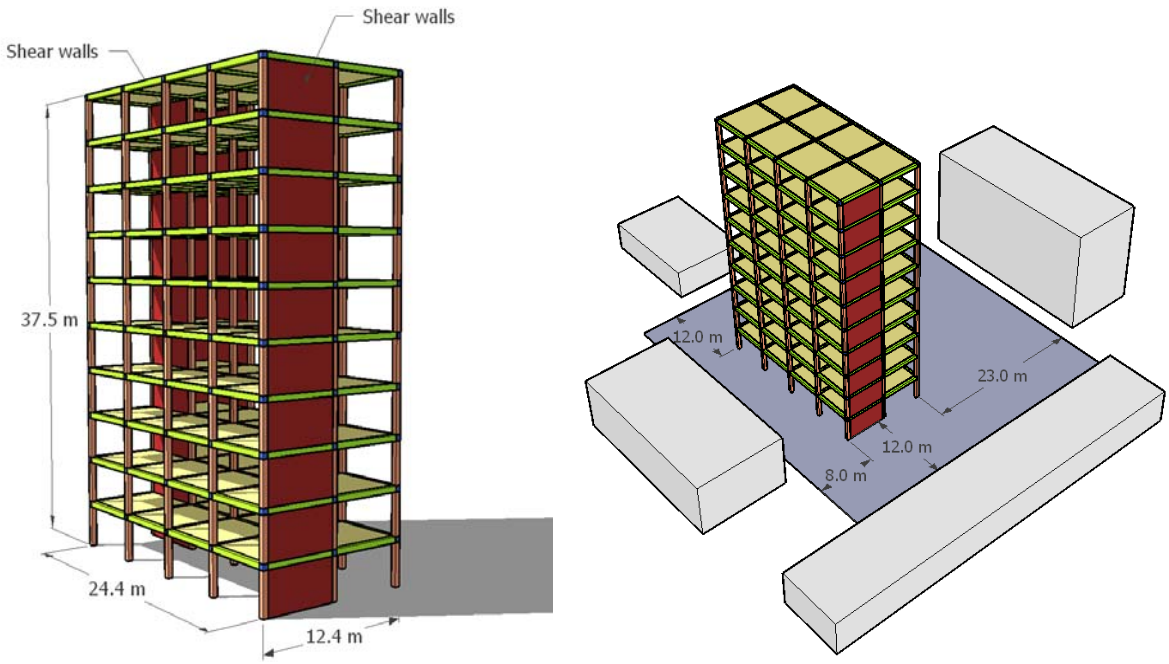


Figure 4: Reference model

4.2 Modeling of the structure

For defining the structural model, the CADCE product model component provides a user interface that is equipped with many useful standard tools, e.g. like Copy, Paste, Copy Array, Delete and Save. To establish the product model of the reference building, the structural elements on the ground floor are created by given positions and element types. Due to their similarity, the elements on the remaining floors are created effortlessly by the Copy Array tool.

The MBS model that is created by the simulation manger has 1320 degrees of freedom, with 480 general force connections. Figure 5 shows a snapshot of CADCE during the modeling process while Figure 6 opens the MBS view and reflects the simulation results in the CADCE workbench.

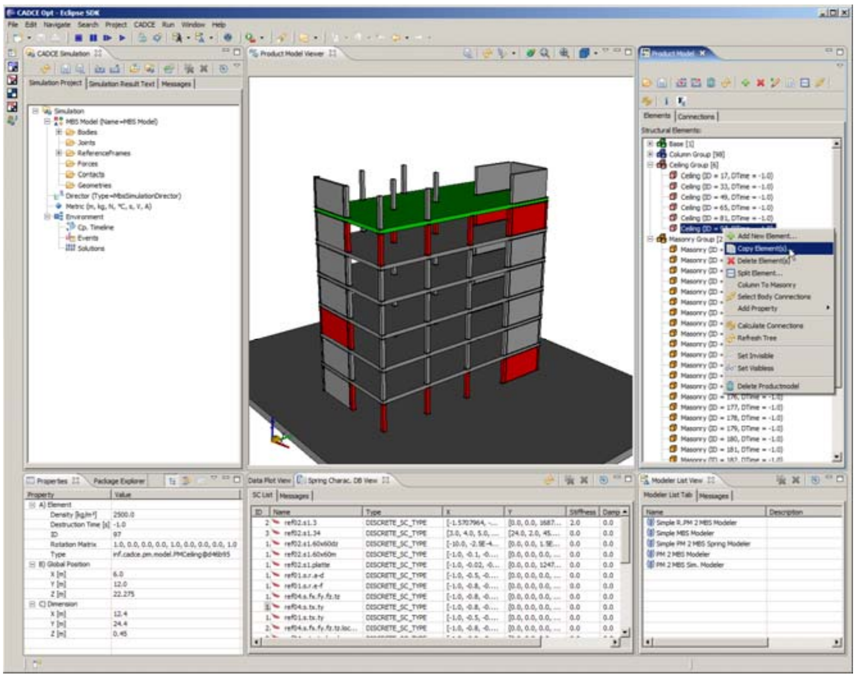


Figure 5: Construction of the product model

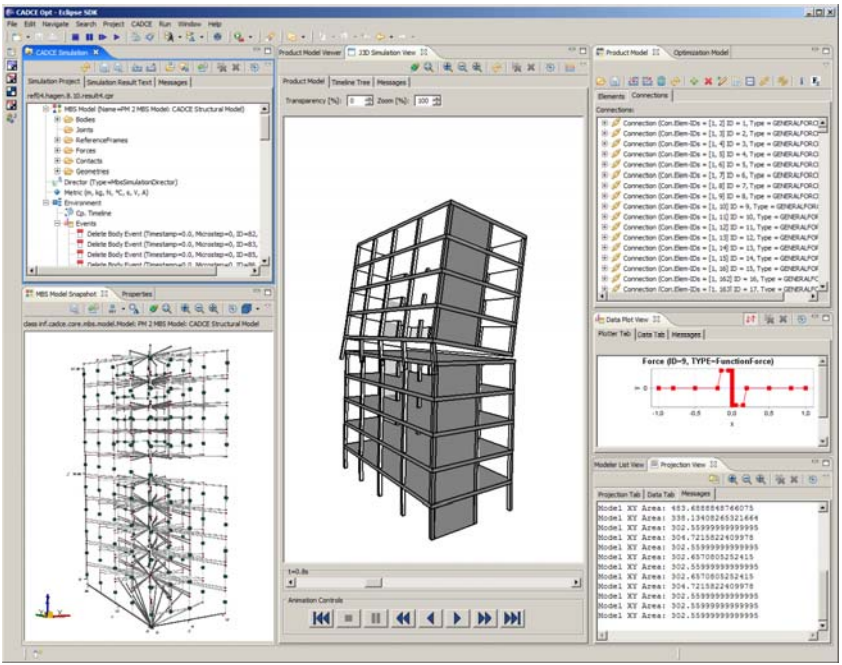


Figure 6: MBS model and the simulation view

4.3 Multibody analysis

The simulation of the multibody model described above is executed on a Intel Xeon CPU 5110@1.60GHz, 2GB RAM machine. It is to be mentioned that the simulation duration of 3 s requires approximately 2 h of calculation time. At the beginning, the supported structures on the 5th floor are removed from the simulation model. By that, the upper part of the building starts to bend down due to the dead load. As the remaining columns on the 5th floor fail to support the vertical dead load of the upper part because the compression stress is exceeded, the building collapses also in the vertical direction. Hence, a combined collapse is occurring. After 1.5 s, two rows of columns and a part of the shear walls on the 2nd and the ground floors have been removed in a zigzag shape. Accordingly, the simulation continues until the model reaches the full collapse at time 3 s after the explosion. The deformations of the building obtained from CADCE at different time sequences during the simulation are depicted in figure 7.

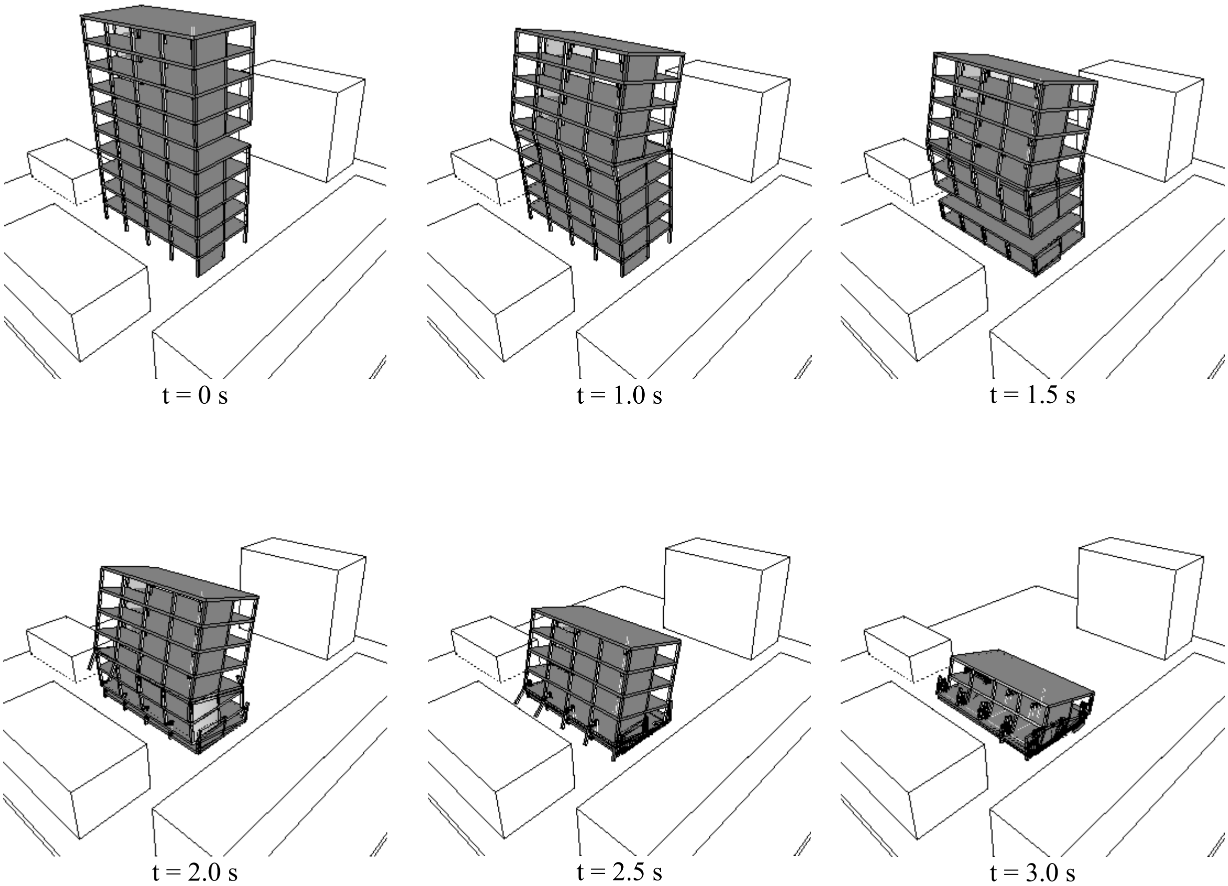


Figure 7: MBS result

5 CONCLUSION

This contribution has demonstrated the extension and advancements of the holistic software system CADCE used for the collapse simulation of the demolition of buildings by means of controlled explosives, in particular, with respect to large scale structures. By making use of computational steering concepts, the simulation models are highly flexible. It is possible to change the simulation parameters interactively during the simulation process and therefore the computational results that can be monitored continuously. The application demonstrates the capabilities of the software system in helping the design and planning of appropriate blasting strategies.

REFERENCES

[1] B. M. Luccioni, R. D. Ambrosini, R. F. Danesi, Analysis of building collapse under blast loads, Engineering Structures, 26, 1, 63-71, 2004.

[2] P. Kabele, T. Pokorny, R. Kostea, Finite element analysis of building collapse during demolition, Proceedings of the 16th International Conference on the Application of Computer Science and Civil Engineering, 2003.

[3] D. D. Bogosian, B. W. Dunn, J. D. Chrostowski, Blast analysis of complex structures using physics-based fast-running models, Computers and Structures, 72,1-3, 81-92, 1999.

[4] D. Isobe, M. Tsuda, Seismic collapse analysis of reinforced concrete framed structures using the finite element method, Earthquake Engineering & Structural Dynamics 32,13, 2027-2046, 2003.

[5] R. Seifried, W. Schiehlen, Computational analysis and experimental investigation of impacts in multibody systems, Multiscale Problems in Multibody System Contacts – International IUTAM Symposium, University of Stuttgart, 20-23, 2006.

[6] D. Hartmann, M. Breidt, V. v. Nguyen, F. Stangenberg, S. Höhler, K. Schweizerhof, S. Mattern, G. Blankenhorn, B. Möller, M. Liebscher, Structural collapse simulation under consideration of uncertainty – Fundamental concept and results, Computers and Structures, 86, 2064-2078, 2008.

[7] R. van Liere, J. D. Mulder, J. J. van Wijk, Computational steering, Future Generation Computer Systems, 12(5), p 441-450, 1997.

[8] S. Höhler, Zur Modellierung von Stahlbetonkonstruktionen mittels spezieller Mehrkörpersysteme unter statischen und kollapsdynamischen Aspekten, Dissertation, Ruhr-Universität Bochum, Fakultät für Bauingenieurwesen, Bochum 2008.

[9] MSC.ADAMS. Website http://www.adams.com

[10] M. Baitsch, Optimisation of imperfect structures using distributed components, in: Proceeding of the Seventh International Conference on Computational Structures Technology, B.H.V. Topping and C.A. Mota Soares (Editors), Civil-Comp Press, Stirling, Scotland, 2004.

[11] Eclipse. Website http://www.eclipse.org