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SEISMIC ANALYSIS OF PRESTRESSED STADIUM ROOF

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Abstract. *The paper deals with seismic analysis of Austria largest stadium roof. Detailed finite element model is updated on the base of experimental modal analysis. The model enables to analyze the seismic behavior of the roof. The real stress in the natural prestressed structure plays an important role and has influence on the dynamic behavior. Natural frequencies and modes of numerical models with and without prestress are compared. The paper presents the time history analysis results using earthquake records from strong motion database.*

1 INTRODUCTION

Stadiums are civil engineering structures which reflect the mastership and building art of particular place and time they are built in. Structures of stadiums surround large spaces with a free view of the field. That results in large spans of the roof structures. The structural design uses not only the advanced material technologies but also geometry, which allows the load transmission into reduced number of supports in the inner space. Places where many people gather demand the fulfillment of rigorous safety requirements. This is the reason why stadium structures are very interesting from civil engineering point of view. Ernst Happel Stadium in Vienna is the largest stadium in Austria. The comprehensive analysis of the stadium was done after 25 year lifetime since last rebuilding. The paper presents some interesting results obtained in dynamic analyses of the stadium roof.

Figure 1: Ernst Happel Stadium.

2 STRUCTURE

The geometry of the roof structure is defined by outer and inner elliptical ring in the plan view. The stadium roof is supported on the outer ring only. The inner ring withstanding tension stabilizes the roof. The shape of the stadium roof meets the minimum of the potential energy. For that reason is the height of the roof variable.

The structure consists of steel beams and steel-concrete composite joints.

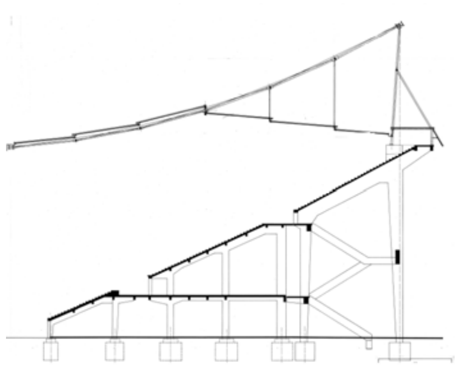


Figure 2: Radial cross-section of the structure.

Figure 3: Steel structure.

3 FINITE ELEMENT MODEL IDENTIFICATION

The finite element model of the stadium roof bearing structure was prepared in ANSYS environment.

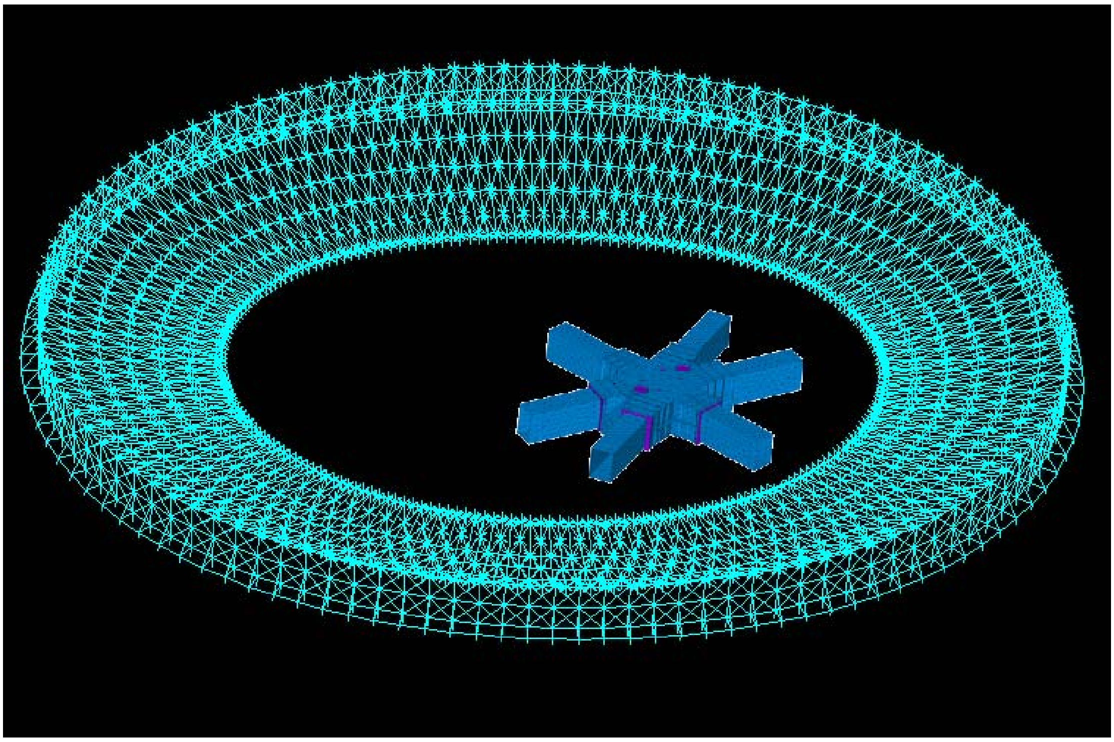


Figure 4: Finite element model of the whole roof bearing structure and join in detail.

The initial state (geometry, stress) of the structure - model without external loading was compared with results of experimental testing. In the modeling the identification process of the model required to follow the process of the real structure erection: in the first phase the roof structure was supported over whole area and in the second phase the preliminary supports were removed. The removal of the preliminary supports resulted in the new roof shape formation and prestress generation.

The simplified join model fulfilled the error minimization criteria of identification procedure.

3.1 Modal analysis

The modal analysis is still the most frequently used method within the frame of structural model identification methods. The numerical modal analysis was carried out by block Lanczos method.

The basic problem of the identification was to define the prestress in the model. The solution of this problem is explained above. Table 1 shows the natural frequencies considering the prestress caused during building and the case without prestress. Figures 5-7 compare the first 10 modes of prestressed roof structure and 10 modes of roof structure without prestress.

Frequency	1	2	3	4	5	6	7	8	9	10
Prestress	0.392	0.392	0.479	0.480	0.645	0.647	0.766	0.789	0.826	0.833
No prestress	0.224	0.225	0.258	0.263	0.338	0.339	0.472	0.474	0.630	0.631

Table 1: Natural frequencies [Hz] for prestressed model and model without prestress.

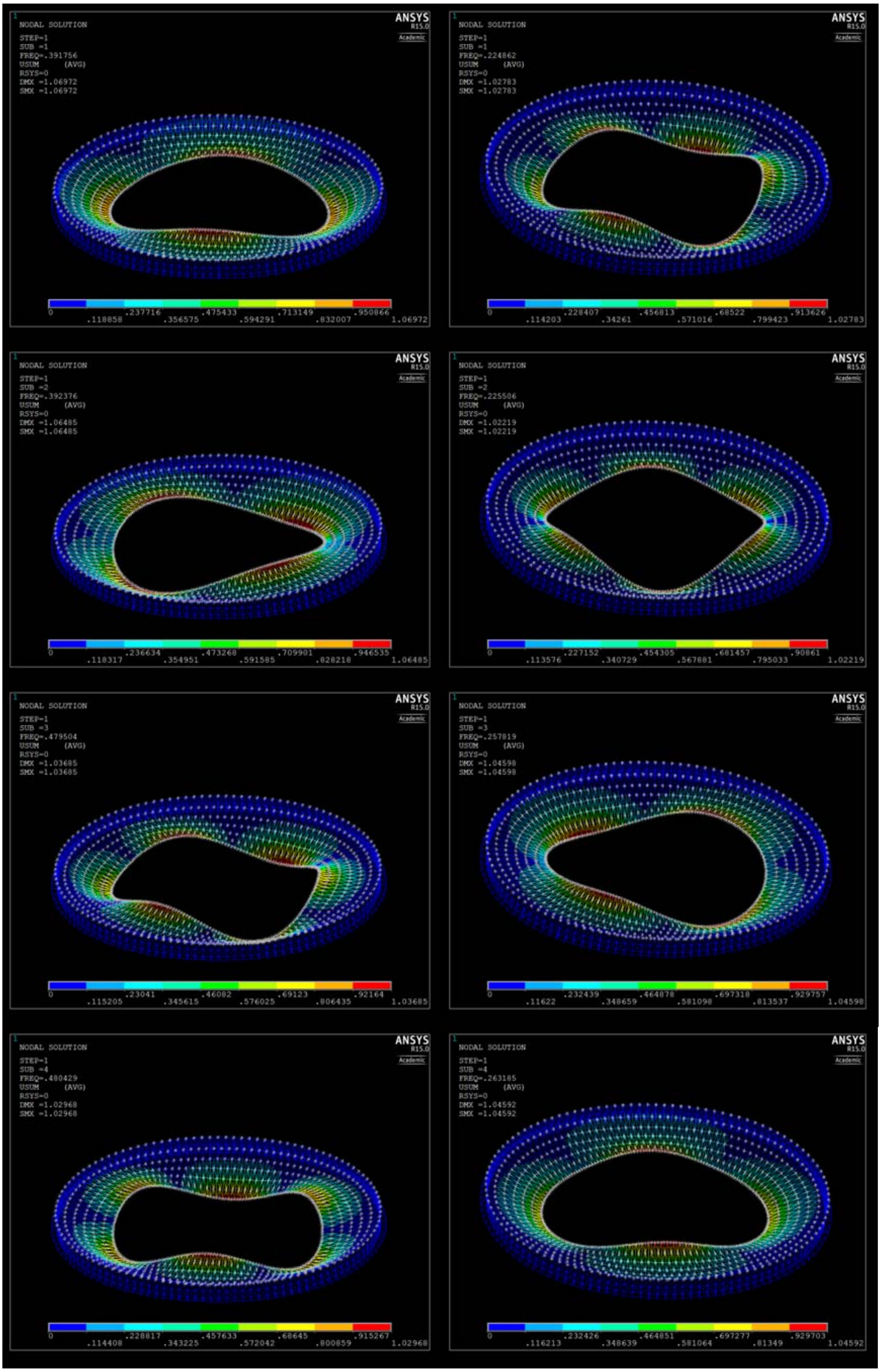


Figure 5: First 4 modes, left: prestressed, right: not prestressed.

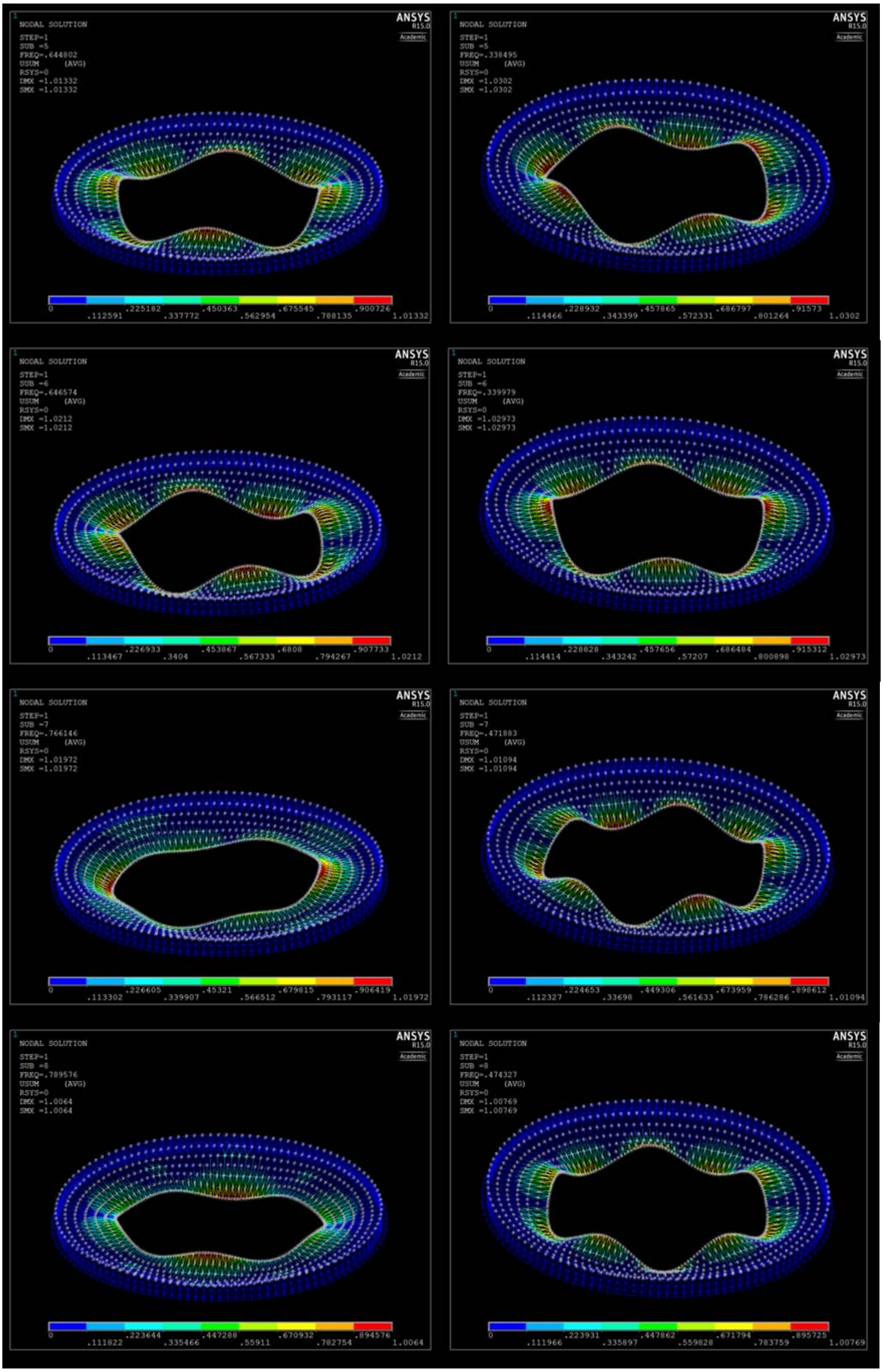


Figure 5: First 4 modes, left: prestressed, right: not prestressed.

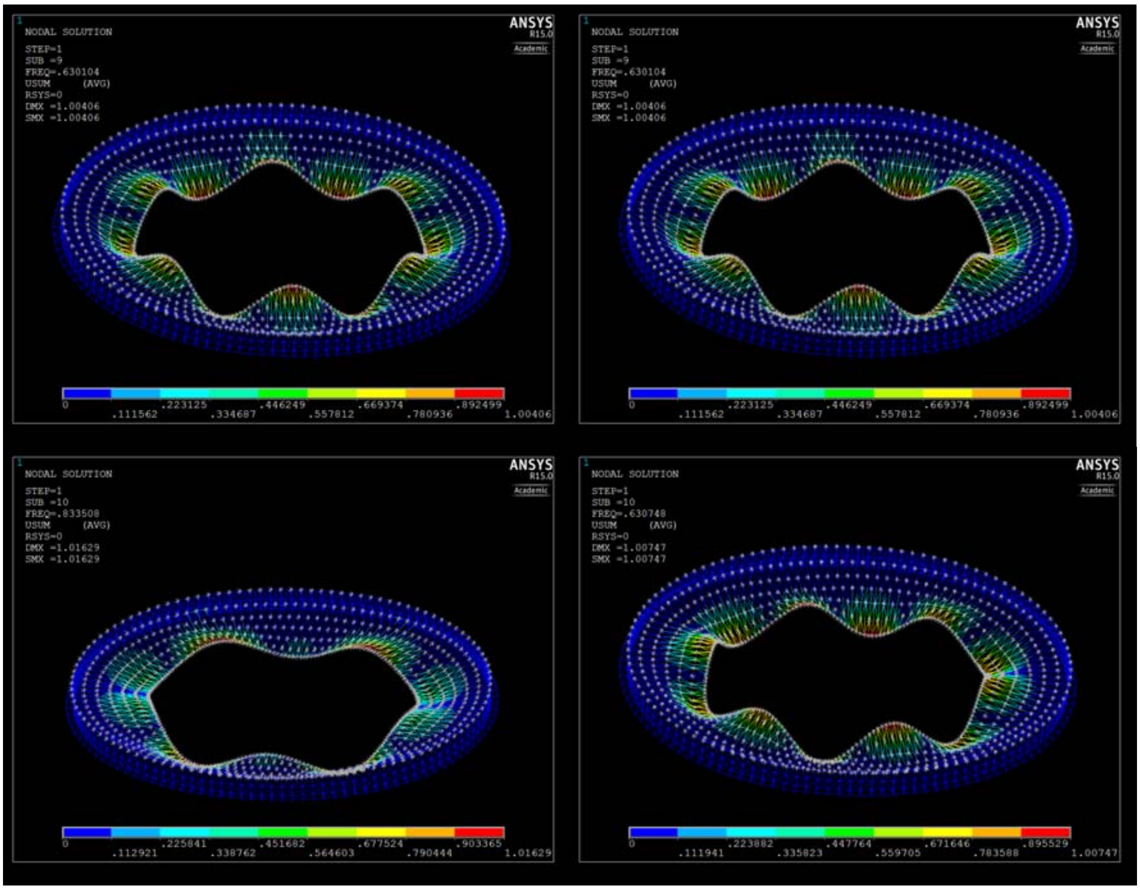
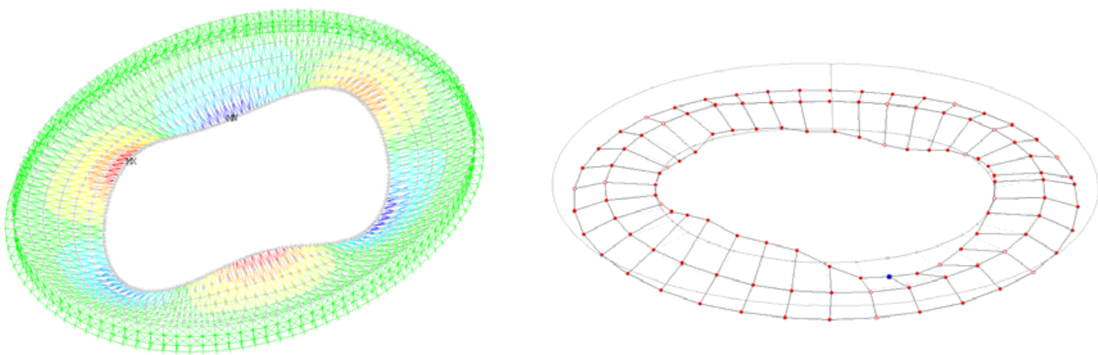


Figure 7: Modes 9-10, left: prestressed right: not prestressed.

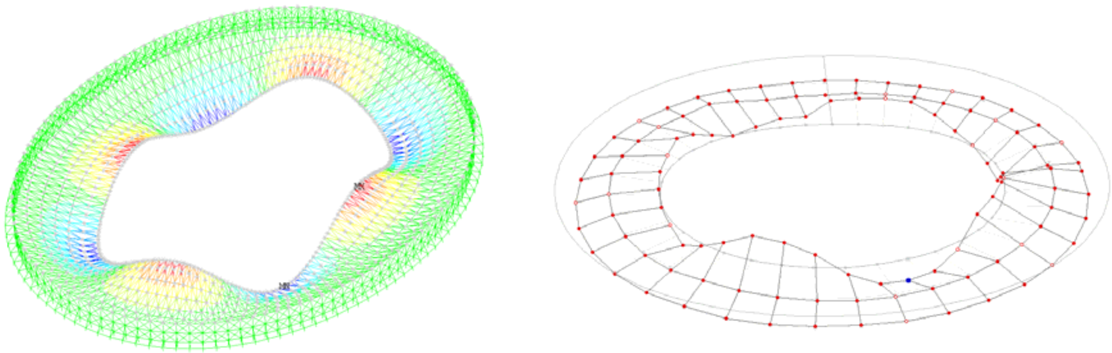
3.2 Model update

The experimental testing of the stadium roof structure was realized by Vienna Consulting Engineers with BRIMOS System. Ambient vibration was analyzed. The Ibrahim random decrement technique enables the modal identification of the structure. Natural frequencies and modes obtained from testing and numerical model were compared. The finite element model update was proceeded until the error of the natural frequencies was < 2%. The Figure 8 shows identified modes.

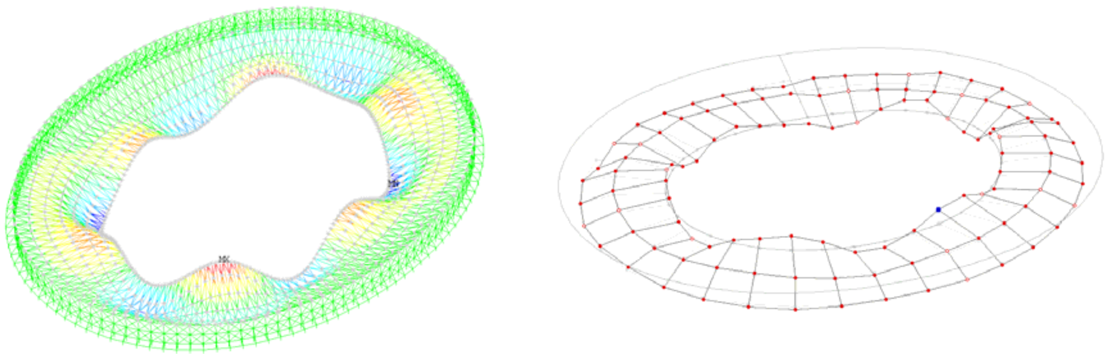


f_{1i} = 0,48Hz

Figure 8: Comparison of numerical and experimental obtained modes. (continue)



f_{2i} = 0,65Hz



f_{3i} = 1,0Hz

Figure 8: Comparison of numerical and experimental obtained modes.

3.3 Time history analysis

Comprehensive analysis of the Ernst Happel Stadium structure according Eurocodes [2] was carried out by Vienna Consulting Engineers. Load cases including static and dynamic forces caused by dead load, wind, snow and earthquake in prescribed combinations were analyzed in the report [1].

The presented paper focuses analysis of the response of the structure excited by strong motion signal in time domain. Appropriate accelerogram from earthquake strong motion database is used in time history analyses. Because of the roof geometry not only horizontal components of the seismic acceleration were required, but also the vertical component of the seismic acceleration was needed. Generally, the appropriate accelerogram must have the same frequency content as it is prescribed in EC8 for the soil and for the location of the structure. Inertia forces were calculated from seismic excitation (mass x seismic acceleration) in three directions (x, y, z). Results show that the geometry of the stadium roof had a decisive influence on the dynamics and the vertical displacements (uz) were dominant.

The accelerograms from COSMOS database were applied.

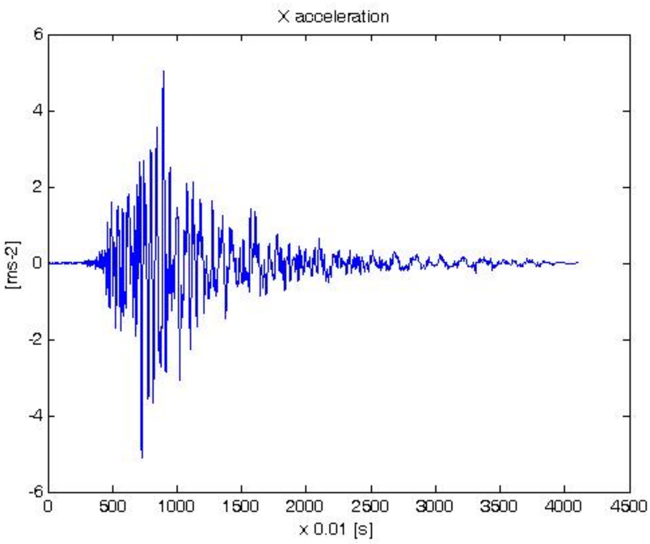


Figure 9: Seismic excitation: X acceleration.

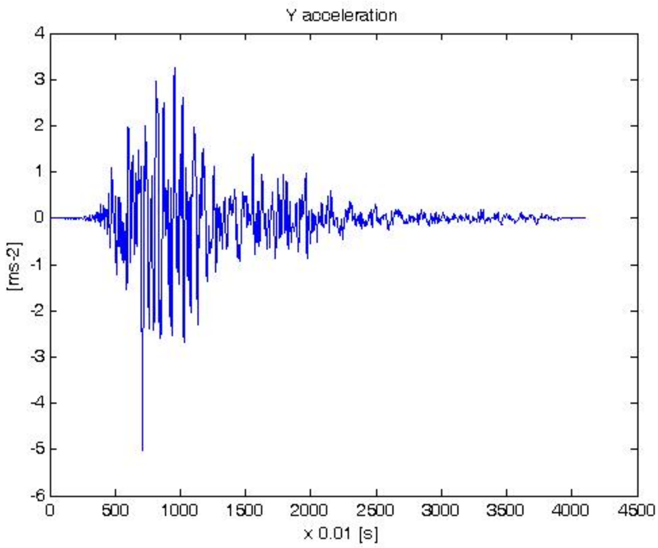


Figure 10: Seismic excitation: Y acceleration.

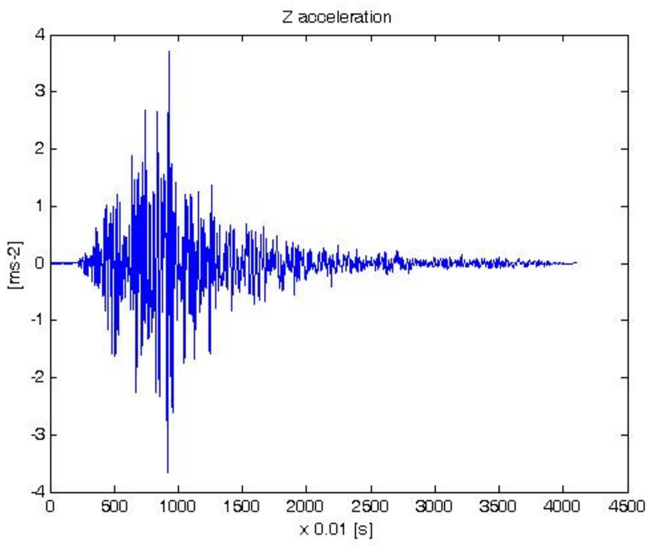


Figure 11: Seismic excitation: Z acceleration.

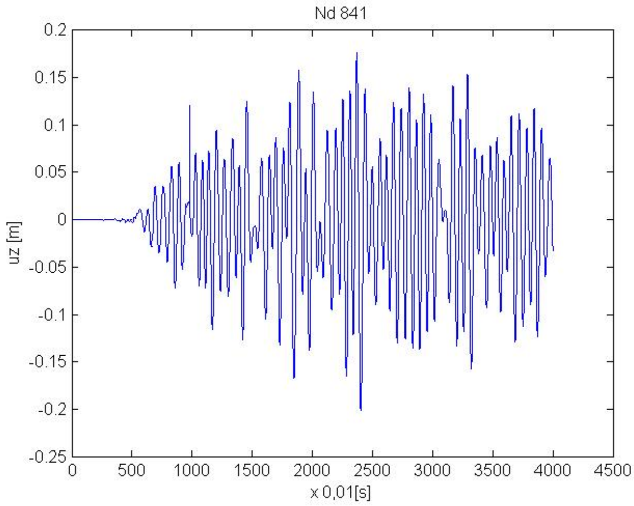


Figure 12: Vertical displacement Nd 841 - major axis.

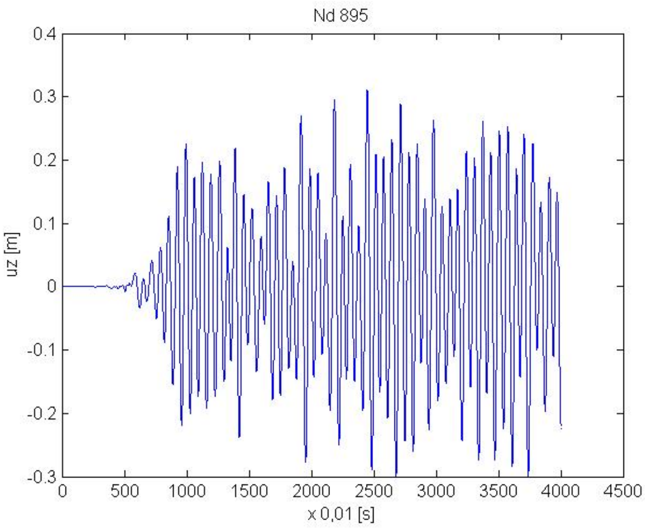


Figure 13: Vertical displacement Nd 895 - minor axis.

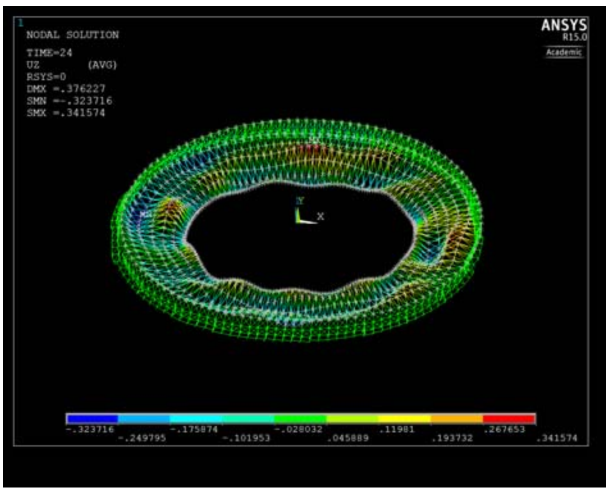


Figure 14: Vertical displacement t = 24s.

4 SUMMARY

Detailed finite element model of Austria largest stadium roof was created. The model was updated on the base of experimental testing. The model was verified using comparison of natural frequencies and modes obtained from numerical analysis and experimental testing. It was shown that the real prestressing in the structure plays an important role. The real prestress in the model was achieved by simulation of the building process. The obtained model was used for seismic analysis in time domain. The 3D excitation was chosen from strong motion database. The results showed the dominancy of vertical displacement according the geometry of the stadium roof.

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