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SEISMIC ASSESSMENT OF CONCRETE TANKS CONSIDERING FLUID STRUCTURE INTERACTION AND NONLINEAR TIME HISTORY ANALYSIS

H.Friedl[1*], M. Kwapisz[1], A. Lechner[1], R. Flesch[1]

[1]AIT Austrian Institute of Technology
Österreichisches Forschungs- und Prüfzentrum Arsenal Ges.m.b.H.
Giefinggasse 2 | 1210 Vienna | Austria

herbert.friedl@ait.ac.at
maciej.kwapisz@ait.ac.at
rainer.flesch@ait.ac.at

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Abstract. *Seismic assessment of important existing structures what are designed according to prior seismic codes or even without considering any earthquake load is one of the most important issues for minimizing the seismic vulnerability. Within this work the seismic assessment of an existing building for radioactive waste management is presented. The investigated structure is designed as a water treatment plant consisting of six collecting tanks situated in a height of 4m and is supported by eight RC columns. The building is located in the area with the highest earthquake hazard in Austria. The main goal was to analyse the whole structure under dynamic excitation during an earthquake event and in case of overloading to give recommendations for possible retrofitting solutions. An improved method for the elaboration of precise structural models is presented, which combine dynamic in-situ measurements and FE-analysis. With dynamic in-situ tests under forced excitation by usage of a reaction mass exciter, the dynamic behaviour of the structures was determined. That followed a model updating procedure to increase the reliability of the numerical investigations. The main life loads of the building are the tanks filled with water. For consideration the fluid structure interaction (FSI) during dynamic excitation an approach with usage of adequate solid elements was implemented in the structural model. In order to assess the accuracy of the chosen approach and updated finite element model, linear spectrum analysis and time history analysis were carried out. In the parametric study, the influence of a number of parameters concerning earthquake and structural characteristics on the structural responses, especially the filling level of the collecting tanks, were investigated. For the nonlinear dynamic analysis a set of different artificial time-histories, which were generated fitting to the EC8 response, were used.*

1 INTRODUCTION

Seismic assessment of important existing structures what are designed according to prior seismic codes or even without considering any earthquake load is one of the most important issues for minimizing the seismic vulnerability. Further, there are several areas in Europe, where seismic zones were upgraded during the last decade according to recent research results. Hence, the seismic assessment of important existing structures like industrial facilities processing with toxic or nuclear materials are obviously to reduce the potential risk for the population and environment. Such structures with increased risk for the population are beyond the scope of the current design codes. Considering these aspects a more detailed approach as recommended in EC8 was carried out.

1.1 Seismic Assessment in combination with in-situ tests and FE calculations

The most accurate method to assess the seismic vulnerability of existing structures is to perform field investigations in combination with numerical calculations. The goal of the tests is to identify the modal parameters of the structure under consideration. A first model of the tested structure, which was elaborated on the basis of the design - documents can be fitted to measured results by an optimisation approach. This is done by minimizing the difference between measured and calculated modal parameters. This procedure is called “model updating”. In most cases for complex structures 3D – FE models will be used. The resulting model represents very well the status of the structure at the time of the investigation concerning mass, stiffness and boundary conditions. If no reliable information about strength can be found in the design documents, realistic assumptions must be used or adequate tests have to be carried out. The updated model means a realistic linear starting point even in the case of a strong earthquake. In the presented approach the investigations started with in-situ measurements of structural- and soil response using a reaction mass exciter VICTORIA of AIT.

1.2 Investigated structure

The investigated structure is situated in Austrians highest seismic region with a maximum horizontal peak ground acceleration of 2.15m/s². With consideration the effective value and soil amplification factor a design ground acceleration of a_g=1.8m/s² results. The building is designed as a water treatment plant with six collecting tanks supported by eight RC columns. Each tank has a capacity of 80m³, with a restriction of maximum filling of five tanks at the same time it leads to additional mass of 400 to (see Figure 2). The tanks are constructed as upside down pyramids with a cubical base. The total height of the building is 7.2m, the centre of the mass in a height of about 4m. The structure is surrounded by two adjacent buildings with a height of 14.2m and the building in the background with a height of 3.3m (see figure 1). Due to different foundation and mass distribution the buildings are connected only with elastic building joints.

The main goal was to ensure the structural safety during an earthquake event. The work was done in following steps:

- FE - modelling of the building including the water tanks
- Dynamic measurement to determine the modal parameters of the building.
- Model updating approach
- Detailed investigation of the structure under the seismic loads according EC8
- Recommendations for retrofitting

2 NUMERICAL MODEL

For analysis, a three dimensional model of the building was created in ANSYS (Figure 1). This model includes only a few simplifications and thus provides very accurate results and information on the utilization of individual structural elements. For considering the real mass distribution the lightweight roof construction was modelled in a simplified manner as equivalent mass at the last slab. It was assumed that it has minor impact on dynamic and static properties of the whole building.

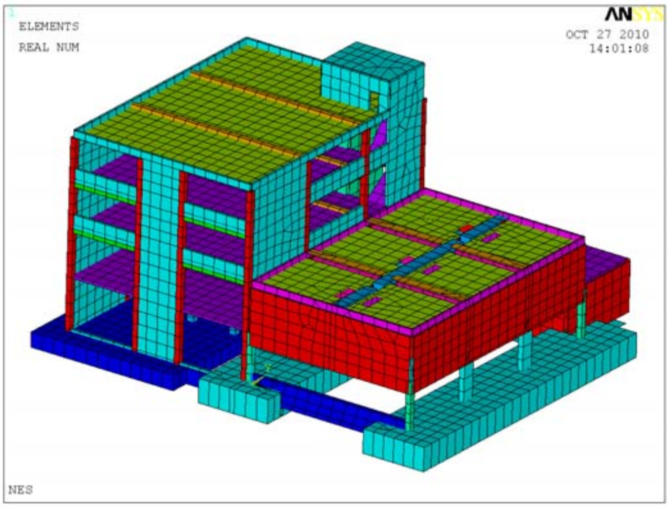

Figure 1: FE Model of entire building complex

Next to the structural system i.e. bearing walls, ceilings, beams and columns, also fluid elements (Fluid80) were implemented to model the realistic behaviour of water response in the tanks under dynamic excitation. The fluid elements are defined by eight nodes having three degrees of freedom at each node: translation in the nodal x, y, and z directions. The element input data includes eight nodes and the isotropic material properties. E_x, which is interpreted as the "fluid elastic modulus", should be the bulk modulus of the fluid (E_x=2.1E09 Pascal for water). The viscosity property is used to compute a damping matrix for dynamic analyses. A typical viscosity value for water is 1E-03 Pascal-sec. The connection between fluid and RC walls was conducted out with respect to the realistic behaviour of degree of freedom of fluid elements. At the boundary area the fluid elements have been coupled in perpendicular direction with the adjacent concrete surface elements. All other degrees of freedom are free and water can move in a realistic way under modal analysis (Figure 3) and transient analysis (Figure 8).

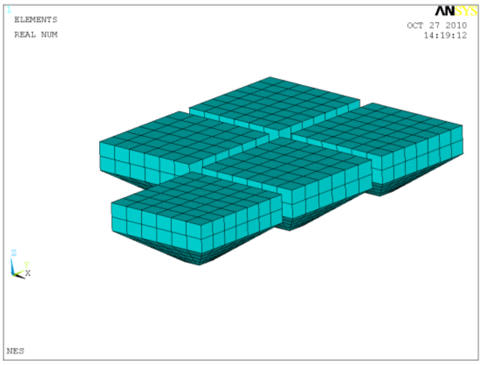

Figure 2: Fluid Elements

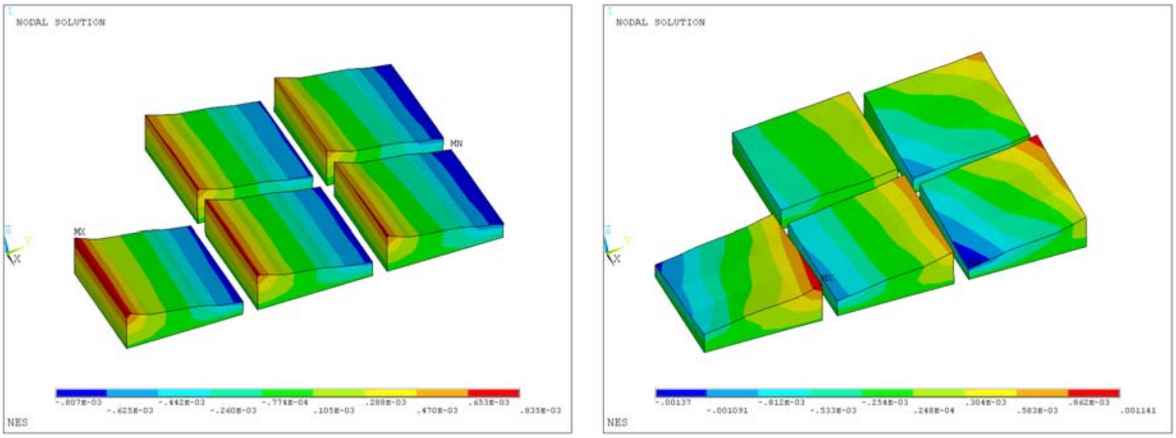

Figure 3: Movement of water – mode shapes

3 DYNAMIC MEASUREMENT

The reaction mass exciter "Victoria" was used as a vibration source to perform dynamic measurements of the building. To determine the vibration characteristics highly sensitive accelerometers were arranged at 34 points at four levels. The choice of the points was aligned to determine all representative natural frequencies and mode shapes.

Figure 4 left: connection with the building; right: position of the exciter mass

The excitation was carried out over an axial road chain between the structure and the exciter mass (Figure 4). The excitation angle of about 45° ensures to excite as many natural modes as possible.

4 MODEL UPDATING

Natural frequencies and modes shapes of the building were calculated and compared with the obtained parameters from dynamic measurement. The amount of water in the tanks during FE calculation was set to be the same as it actually was during the measurement. The calibration of the FE model was carried out with respect of the first three measured eigenmodes. In this case, the most important updating parameters were: E-modul of RC, E-modul of elastic connection between buildings and ground stiffness. Realistic maximum and minimum values of these parameters were assumed, and through series of analysis, whereas they were randomly changing, the most suitable solution was found. The natural frequencies, as well as the mode shapes of the FE model and measurement were in a good agreement (Table 1).

Mode	Natural frequency [Hz]		Deviation
	Measurement	FE model	
1	x	5.2	x
2	6,3	6,2	1,6%
3	8,7	7,6	12,6%
4	11,5	11,9	3.50%
		Average	5,9%

Table 1: Comparison of computed and measured natural frequencies

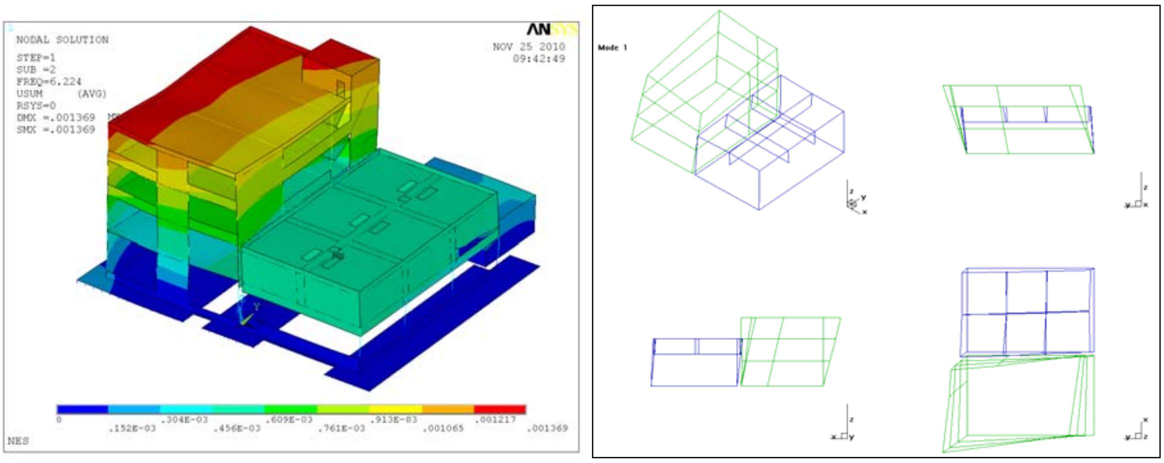

Figure 5: 2nd Mode: left: computed; right: measured

5 SEISMIC ASSESSMENT

First, a sensitivity study was carried out with the aim to identify the most unfavourable combination of filling levels. The positioning of the fulfilled tanks was varied with respect to maximum loading for each construction element and considering global torsion effects due to unsymmetrical set ups. The identification of the worst load case situations were obtained by linear spectrum analysis. Next to spectrum analysis, also transient time- history analysis was used. It was necessary to improve the behaviour of fluid elements and to allow material nonlinearities. For the nonlinear dynamic analysis a set of different artificial time-histories [1], which were generated fitting to the EC8 response, were used (Figure 6).

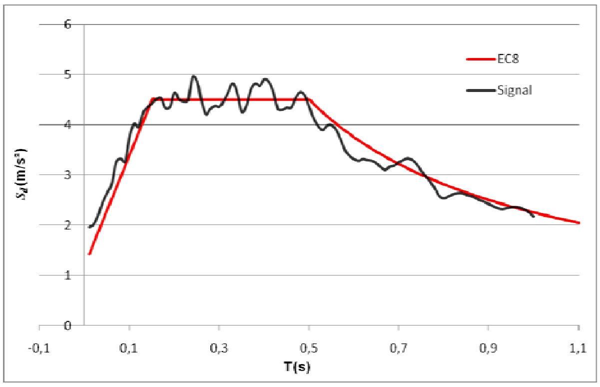

Figure 6: Response spectras

As mentioned in chapter 1.2 the building complex consists of three buildings, linked with a dilatation joint. Whereas the stiffness of this elastic material for small deformations was approximately identified by modal updating, it is difficult to assess its behaviour during the earthquake impact. Due to high deformations caused by seismic impact, connections to adjacent parts of the building may get lost during earthquake. The calculation was performed without connection to the adjacent buildings (Figure 7). Together with the high mass concentrated at the height of about 4 meters the building is extreme vulnerable to horizontal forces.

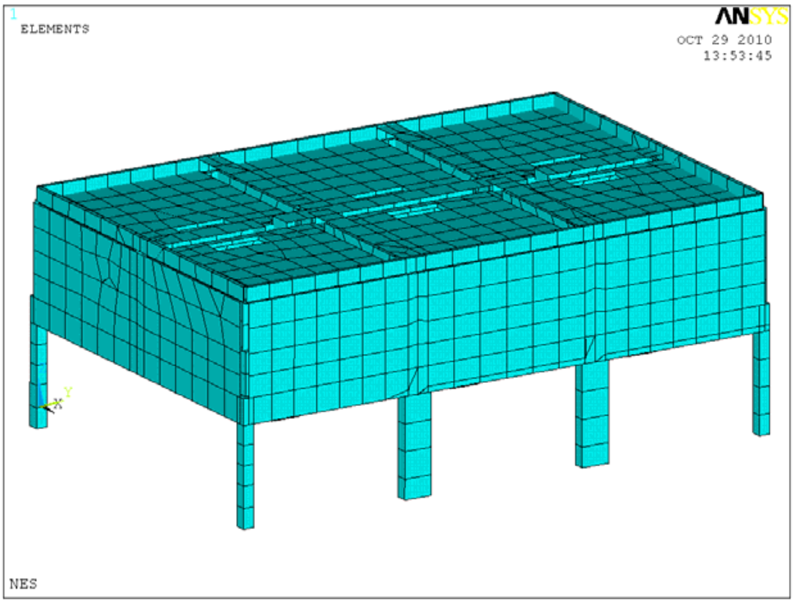

Figure 7: Water tank building treated as standing alone

The results from all transient analysis were averaged and the safety factors according the requirements of Eurocode 2 were calculated. The comparison between spectrum analysis and transient analysis types showed good agreement, with the differences about less than 20%. The deformation of the structure during time history analysis is plotted in Figure 8.

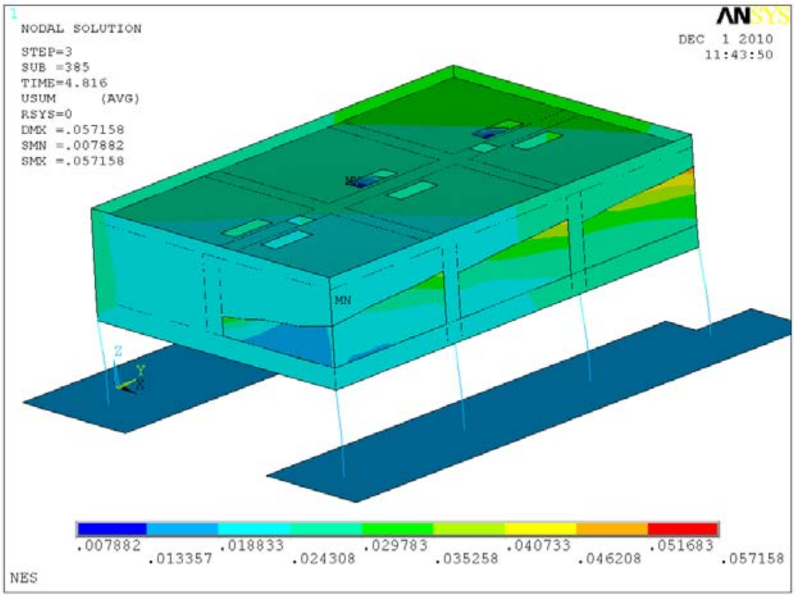

Figure 8: Deformation during time- history analysis

It is obviously that the most critical components of the structure in case of seismic impact are the eight columns in the ground floor. The structural design analyses were carried out according EC2 regarding possible shear and biaxial bending failure. An Important issue in post processing of transient analysis is the synchronism of the forces. Not only maximums are significant, but also the worst combination of all forces in time. For biaxial bending in every time step following simplified criterion (EC2) was used:

$$\left(\frac{M_{Edz}}{M_{Rdz}}\right)^{a} + \left(\frac{M_{Edy}}{M_{Rdy}}\right)^{a} \leq 1 \tag{1}$$

where:
$M_{Edz/y}$ is the design moment around the respective axis
$M_{Rdz/y}$ is the moment resistance in the respective direction
a is the exponent, which depends on the axial force

The example of time- depending bending moments (red and pink) and axial force (blue), as well as results from equation (1) are shown in Figure 9.

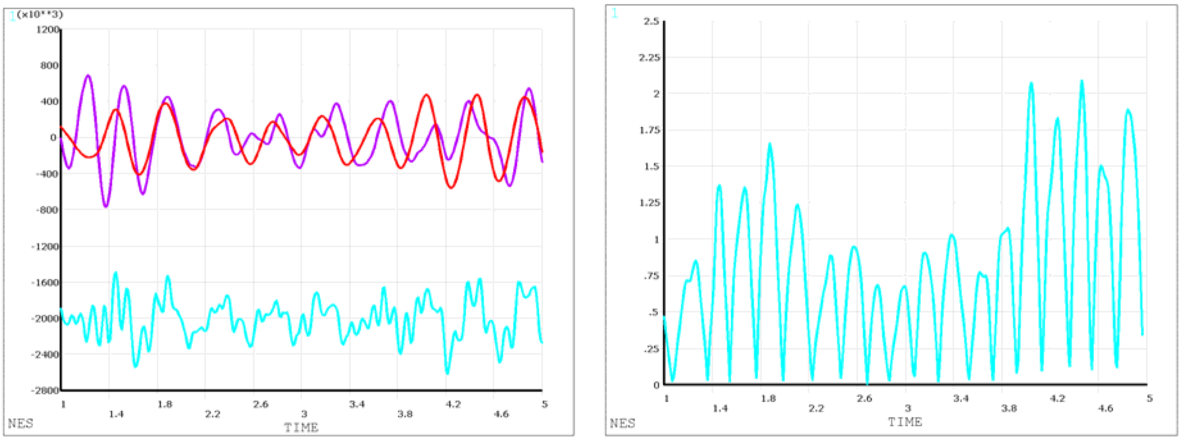

Figure 9 Left: bending moments and axial force; right: results of equation (1)

To assess the shear resistance, the equations (6.2), (6.8) and (6.9) from EC2 were used. Due to simultaneous dependency of shear and axial force, the calculation was carried out for every time step, and the worst case was taken for analysis. The structural design of the analysed columns doesn't fulfil the requirements according the standards. Furthermore the internal requirements regarding maximum deformation will exceed what will lead to damage of technical facilities and cause a potential risk for the environment.

6 STRENGTHENING RECOMMENDATIONS

Possible retrofitting designs were limited by requirement of the operator to minimize construction works inside the building due to interference with internal operation. The proposed strengthening solutions should take into account minimizing modifications for existing technical assets and facilities. Aware of these requirements also unorthodox seismic strengthening solutions, like asymmetric strengthening, were analysed. Due to asymmetric stiffening the dominant torsion mode increase the loading of the corner columns significantly. In fact of this, minor modifications of internal facilities were accepted by the operator and proper retrofitting solutions were investigated. All of the presented variants provide earthquake safety and fulfilled operator's requirements perfectly, so only simplicity of rebuilding will be the relevant criteria. Thank FE calculation a lot of various options could be investigated and optimised.

6.1 Variant 1: Additional walls

In Figure 10 the first variant is given. New walls to be built are marked in red. The torsion, caused by asymmetry, is reduced by the use of two outside walls, but could not be avoided. The big advantage is that the existing columns do not need to be replaced.

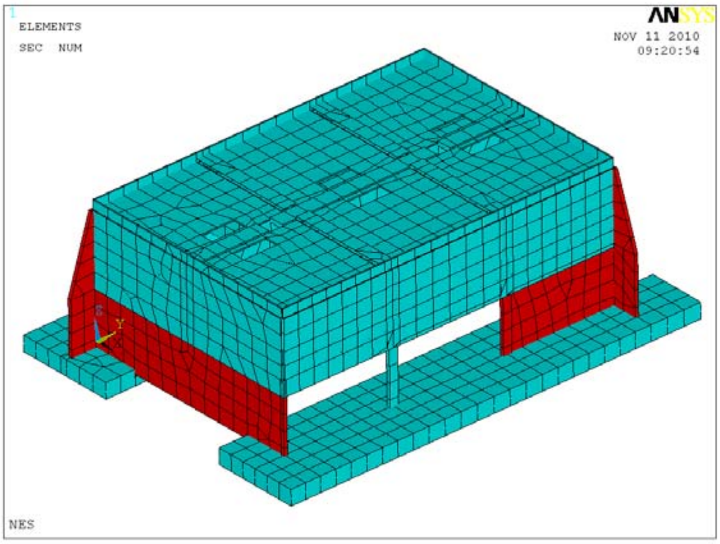

Figure 10: First retrofitting variant

6.2 Variant 2: Additional outside walls on the corners

This variant comprises adding strengthening short walls in each corner. The advantage is symmetry, disadvantage – demand to exchange of the existing columns (Figure 11).

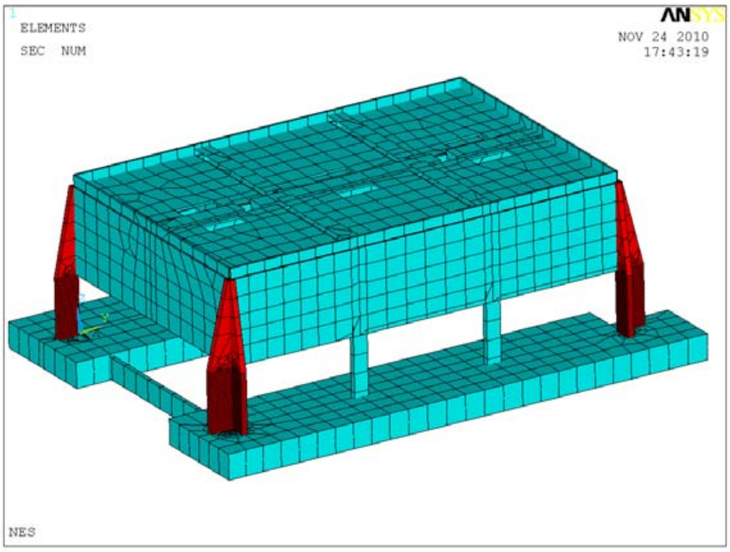

Figure 11: Second retrofitting variant

6.3 Variant 3: Connection with the other building through a damper

It occurred that coupling of both buildings would assure the earthquake safety of the water tanks. It could be achieved by implementing at least four dampers, two in each direction. Exact optimisation of dynamic parameters of dampers was not carried out in this stage.

7 CONCLUSIONS

By means of experimental modal analysis and finite element calculation a very realistic computer model for the entire building complex was created. Due to artificial excitation three mode shapes could be identified. The model adjustment was made on these three modes, whereby in addition to the Young's modulus of the materials, the elastic bearing joints to adjacent building parts and the boundary condition at the base were used as model updating parameters. The comparison of calculated with the measured mode shapes shows a very good agreement. With the improved FE model, earthquake analysis under consideration the local conditions and historical seismic events were carried out. Moreover following issues can be highlighted:

- Considering fluid structure interaction allows an adequate simulation of water behaviour under dynamic excitation and increase the reliability.
- Post- processing of transient analysis provides information about simultaneity of bending, shear and axial forces.
- Thank FE calculation a lot of various strengthening possibilities could be investigated and optimized

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