

THE EFFECTS OF THE BASE MAT'S FLEXIBILITY ON THE STRUCTURE'S SEISMIC RESPONSE. PART II: PLATFORM SOLUTIONS

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ABSTRACT

The ultimate goal of the research is to provide recommendations for the SSI analysis in the time domain using detailed structural models and conventional FEM codes. In the first part of this report (also presented at SMiRT21) the “wave” solution for the sample structure was obtained by SASSI2000. In the second part of the report presented here this “wave” solution is used as a benchmark to check three variants of spring/dashpot “platform” models tailored for the time-domain dynamic analysis (ABAQUS was used by the author). The first variant is a simple “Winkler” model based on the uniform distribution of the translational springs and dashpots under the base mat. The second “optimal” model is more sophisticated; it accounts for the interaction forces concentration at the edges and in the corners of the mat. The third model is very special; it uses spring and dashpots with time lag between displacements/velocities and the response forces. In each case the initial seismic excitation is specially modified using the combined asymptotic method (CAM), providing the exact response for the rigid base mat in terms of the accelerations. Different formats of the seismic response (the response accelerations, the interaction forces and the internal forces in the structure) have proved to have different sensitivity to the platform model type. Horizontal response accelerations were almost similar in all models; vertical response accelerations in the centers of the room were not satisfactory reproduced by the first two models. In reproducing the interaction forces the “optimal” model was far better than the Winkler model. In reproducing the internal bending moments Winkler’s model has proved to be over-conservative, while the “optimal” model provided non-conservative results. For the third model the research is still in progress, but it promise to reproduce the forces and moment with high accuracy.

INTRODUCTION

The ultimate goal of the research is to give the recommendations for the SSI time-domain analysis to reproduce the frequency-domain “wave” solutions. The model structure and the soil foundation in the second part of the report are the same as the layered soil foundation no.2 and the structure no.2 with the internal walls previously described in Part I of this report [1].

Three spring-dashpot platform models of the same soil-structure system were tested against the “wave” solution described in Part I. These were the Winkler model, the “optimal” model and the “time gap” model. The difference between the models was in the “soil” springs and dashpots. For each model the special modified platform excitation was developed to reproduce the integral interaction forces and the whole structural motion in case of the rigid base mat.

“Platform” solutions were obtained using ABAQUS code. Like in Part I, three formats of the seismic response were studied: the acceleration spectra in the different nodes of structure; maximal nodal soil-structure interaction vertical forces in the different base mat nodes; maximal bending moments in the different elements of base mat. The goal was to estimate the scale and the type of errors occurring in the CAM platform solutions as compared to the “wave” solutions.

NUMERICAL RESULTS

The first “platform” model tested in this research against the wave solution was the so-called “Winkler” model. The integral translational complex dynamic stiffness in three directions was taken from the SASSI impedance curves at the frequency 6 Hz and then distributed uniformly over the bottom of the mat. As a result, nodal stiffness at the edge is two times less than that in the internal node and two times greater than in the corner.

As expected, the results in terms of the acceleration spectra are similar and precise in the rigid base mat case. The more flexible is the mat, the more different are the response spectra. The most sensitive is the vertical response to the vertical excitation in the middle of the room floor (i.e. $\frac{1}{4}$ of diagonal from the corner). The

comparison of 2% spectra obtained by SASSI (the “wave” solution) and ABAQUS (the “Winkler” solution) is shown in Fig.1 for the middle of the room floor and in Fig.2 for the rigid roof.

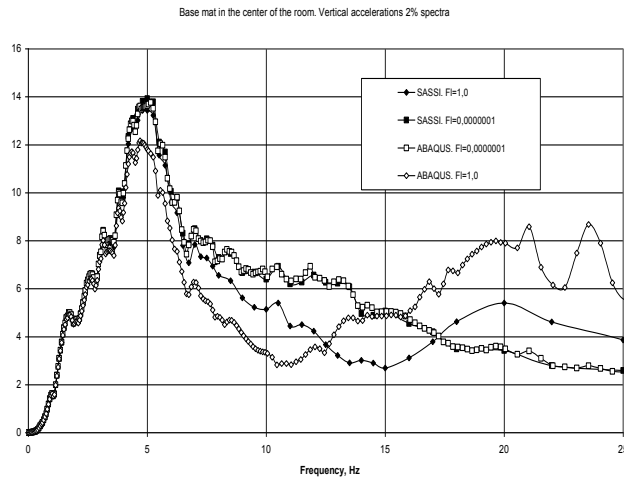


Fig.1: Vertical base mat accelerations in the middle of the room floor as response to the vertical excitation

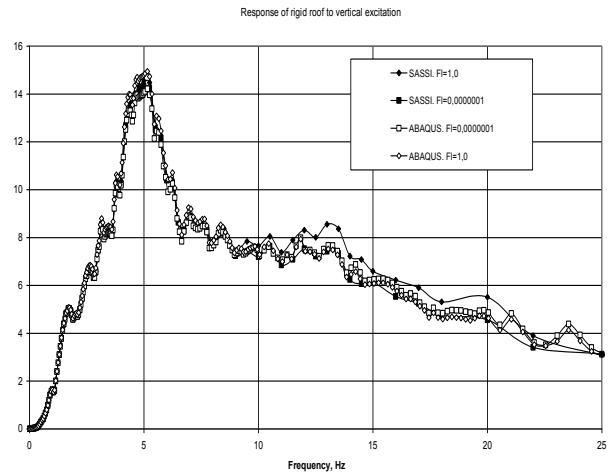


Fig.2: Vertical accelerations in the middle of the rigid roof as response to the vertical excitation

For the corners and the centers of the edges the Winkler model seems to be satisfactory. The comparison with the wave solution is shown in Fig.3 and Fig.4.

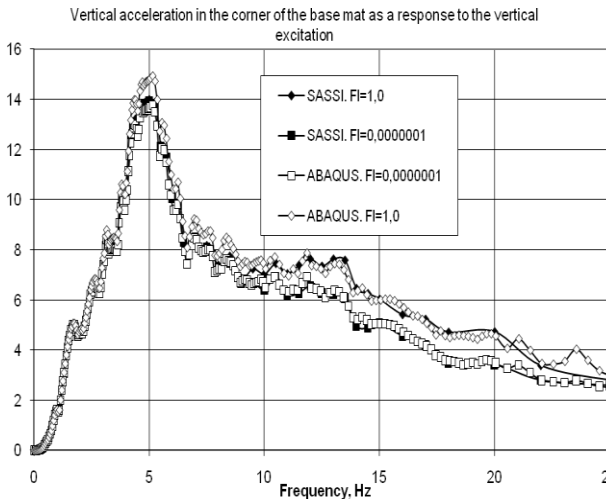


Fig.3: Vertical accelerations in the corner of the base mat as response to the vertical excitation

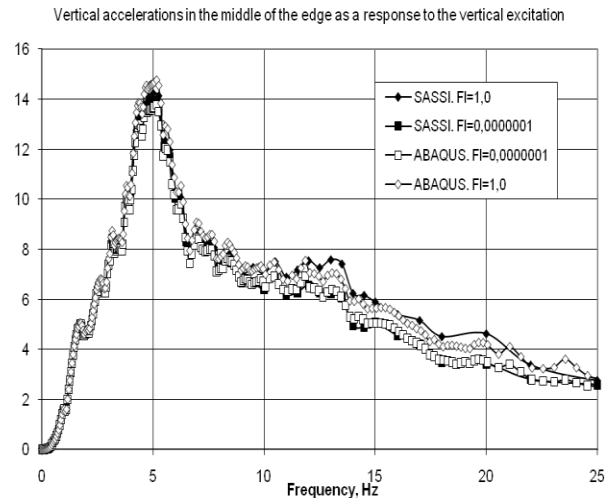


Fig.4: Vertical accelerations in the center of the edge as response to the vertical excitation

The “optimal” model was more sophisticated. The idea was to find out the limitations provided by the very structure of the spring/dashpot model studying the best possible choice of springs and dashpots. First, the full (i.e. nodal) impedance matrix provided by SASSI in the frequency domain was convoluted to the diagonal translational form using the rigid translational displacements of the mat. Thus, the node-soil-node interaction was accounted for in the rigid case. Then node by node the optimization procedure was carried out to find the “best-fit” nodal spring and dashpot parameters providing minimal difference in the nodal interaction force with wave solution (relative displacements/velocities Fourier spectra were used as weights). The results of such optimization for two nodes are shown in Fig.5, 6. They are more or less average of the wave impedances around 3.5 Hz.

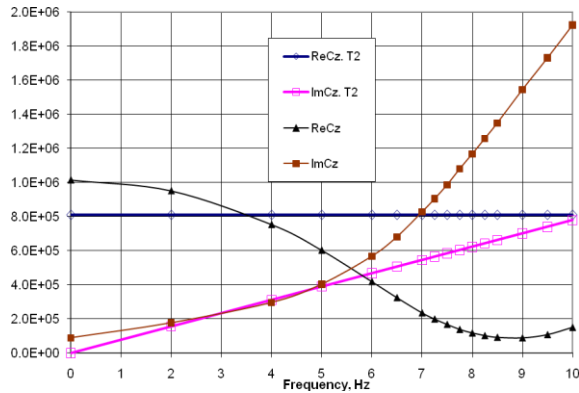


Fig.5: "Optimal" vertical nodal stiffness in the center of the edge

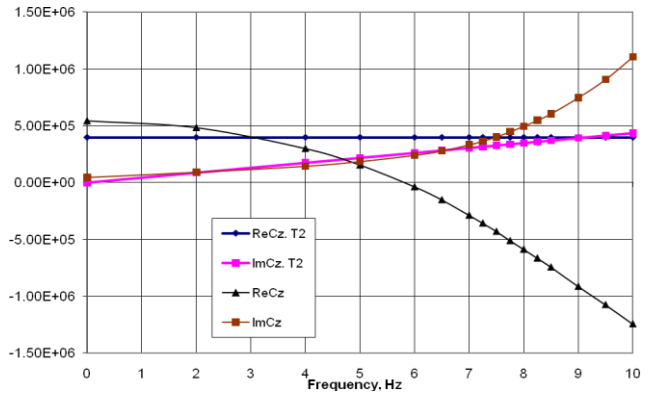


Fig.6: "Optimal" vertical nodal stiffness in the center of the mat

After each of 81 base mat nodes was treated in this way, the distribution of the nodal spring and dashpot parameters was obtained, as shown in Fig.7, 8 in comparison with SASSI "wave" solution taken at 5 Hz. Nodal row 1 is along the edge, nodal row 5 comes through the center of the base mat.

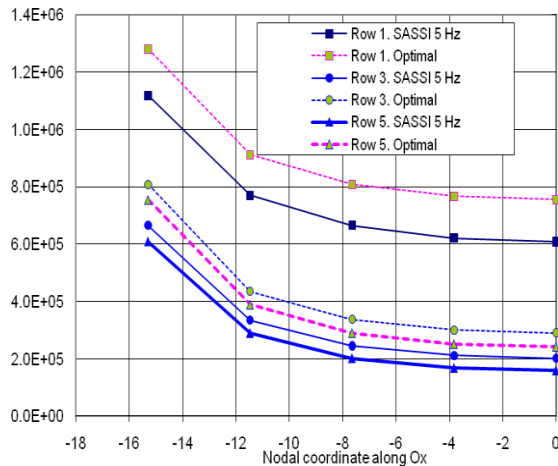


Fig.7: Distribution of the spring parameter

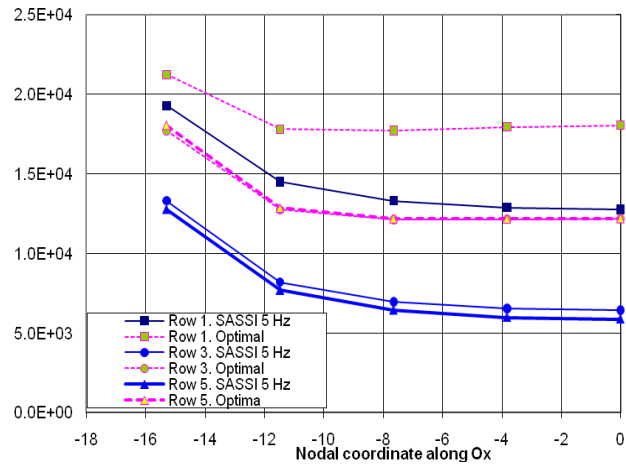


Fig.8: Distribution of the dashpot parameter

Fig.7 and Fig.8 show the well-known concentration at the edges and in the corners.

Like for the Winkler model, the platform excitation was modified for the "optimal" model from the initial one to account for the difference in the integral stiffness shown above.

In terms of the response accelerations the "optimal" model has proved to be somewhat better than the Winkler model. However, the results for the center of the flexible base mat (see Fig.1 for the Winkler model results) are still considerably different from the wave solution. This is surely due to the node-soil-node interaction which is not present in both platform models (only the "rigid part" of it is present in the "optimal" model, as mentioned above).

As to the other nodes in the structure, the response accelerations are satisfactory reproduced by the "optimal" model (like by the Winkler model, see Fig.2, 3, 4).

In terms of the maximal interaction forces the "optimal" model seems to be far better than the Winkler model. The comparison is shown in Fig.9. The order of the nodes is similar to [1]; it is shown in Fig.10. It should be noted, however, that in the central region of the mat the error of the "optimal" model is considerable, and the "optimal" solution is non-conservative.

In terms of the maximal internal bending moments in the base mat the "optimal" results have proved to be considerably non-conservative. The comparison with the "wave" solution (including Winkler model as well) is shown in Fig.11. The order of the elements is shown in Fig.12. It is similar to [1].

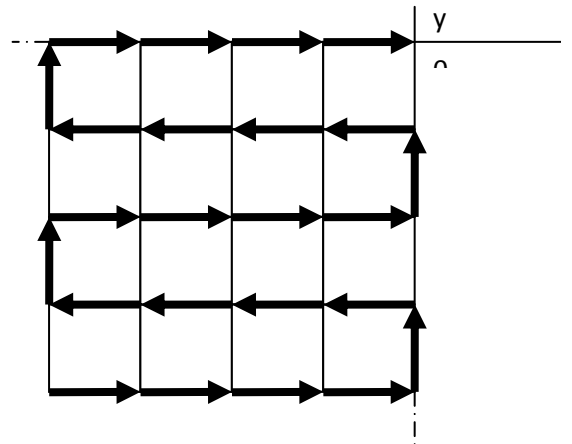
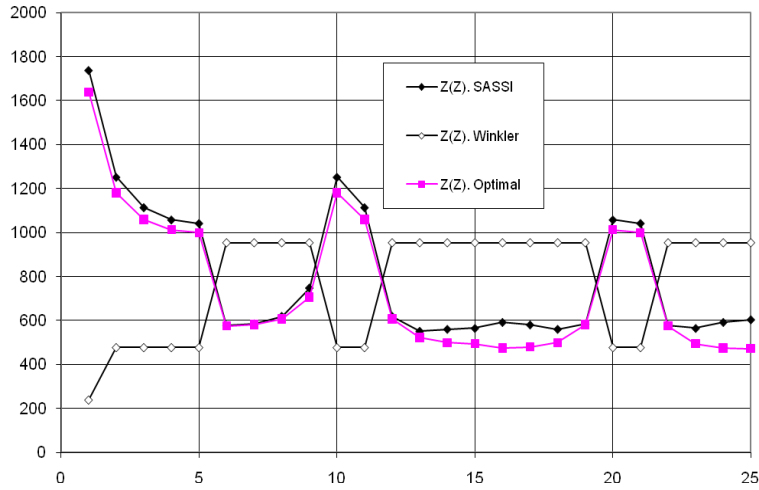


Fig.9. Maximal vertical nodal interaction forces as response to the vertical excitation. The order of the nodes is explained on Fig.10

Fig.10. The order of the nodes in Fig.9

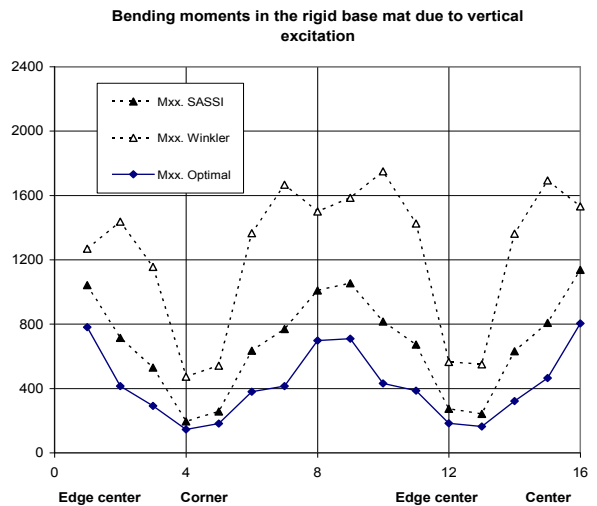
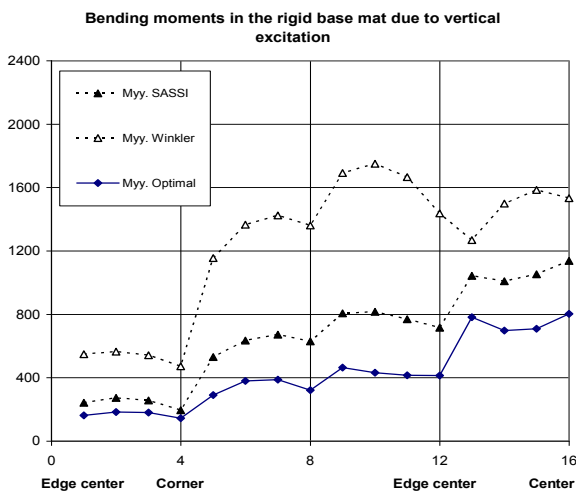


Fig.11. Comparison of the internal bending moments in the rigid base mat due to the vertical excitation

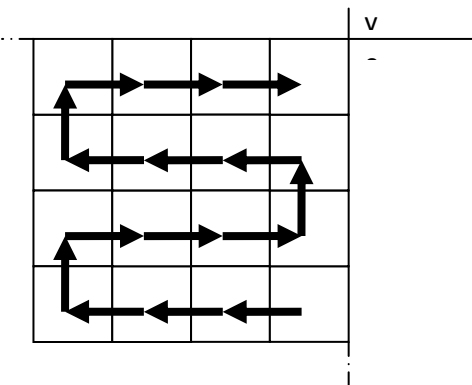


Fig.12. The order of the elements in Fig.11

The shape of the “wave” curves for the bending moments obtained by SASSI in Fig.12 is better reproduced by the “optimal” model, than by the Winkler model. However, the level of the maximal moments is underestimated.

The third model (the so-called “time gap model”) was like the “optimal” one, but in each node two spring/dashpot pairs with certain time gaps were added to the conventional pair. In the frequency domain each pair of special spring and dashpot with time gap adds some new frequency-dependent function to the impedance, enabling to approximate the “true” frequency dependence of the stiffness (previously obtained from the “wave” solution) far better than just the ordinary spring and dashpot. The comparison of the nodal stiffness in the center of the base mat is shown in Fig.13 (0.004 and 0.135 are the time lags in seconds).

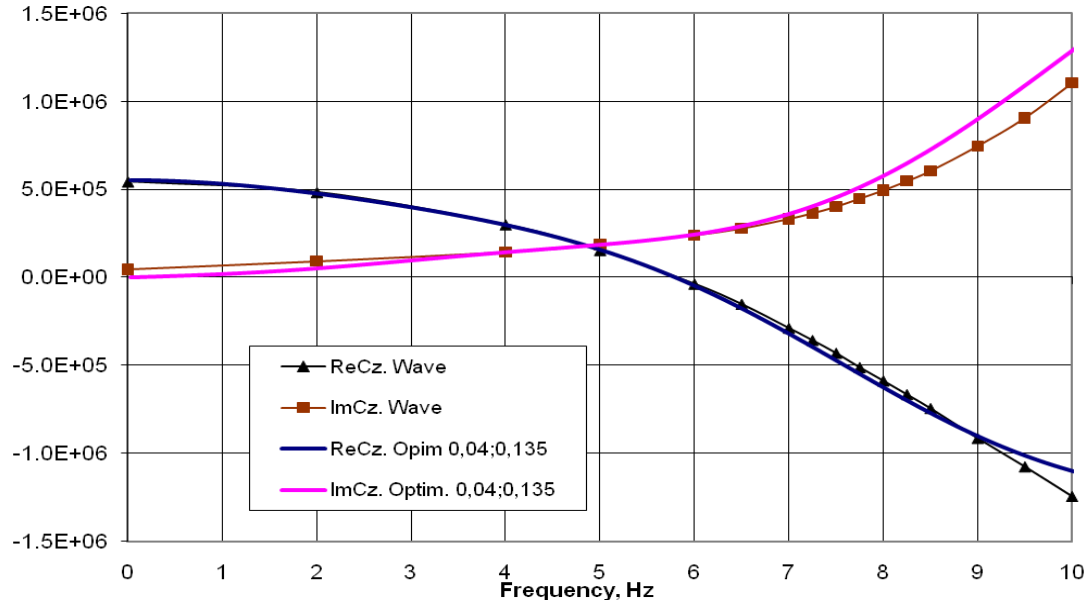


Fig.13: Comparison of the complex vertical nodal stiffness in the center of the base mat

The picture in Fig.13 is far better than in Fig. 6. As a consequence, the comparison of the nodal force time histories is far better than in the previous cases. For the center of the rigid base mat it is shown in Fig.14.

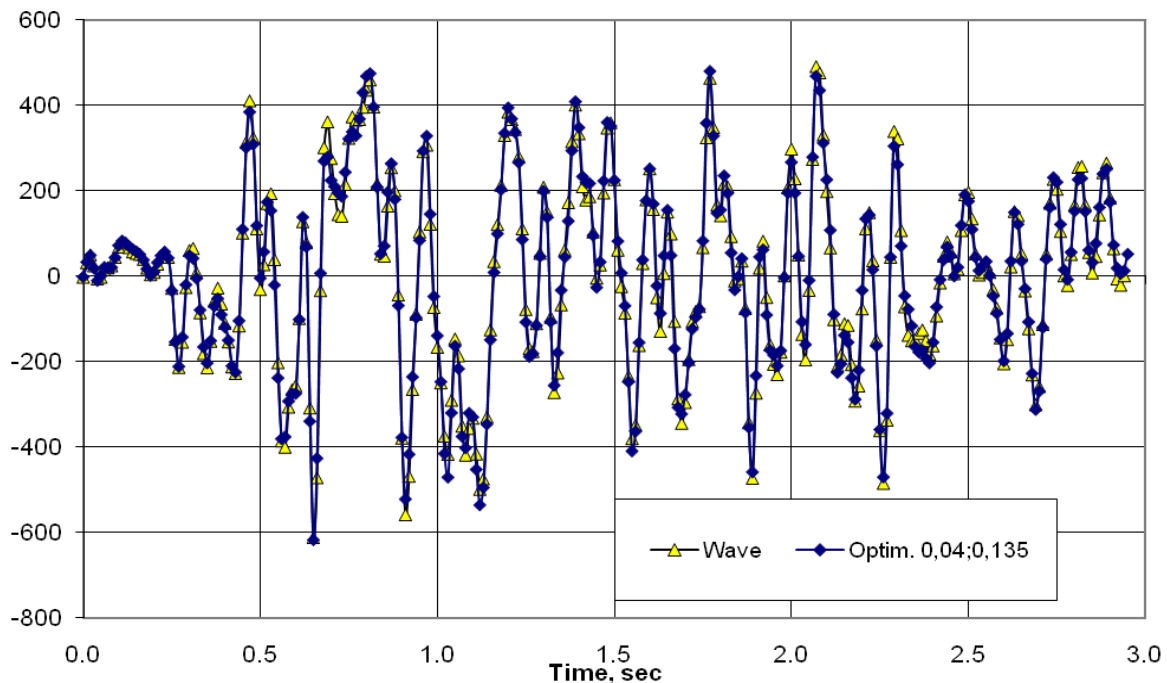


Fig.14: Time histories of the vertical nodal interaction force in the center of the base mat

In this case no modification of the “platform” excitation was performed.

As the ultimate goal is to provide a tool for the time domain analysis, one must have a tool to implement such special springs and dashpots. In ABAQUS such tool is the user subroutine. At the moment the work is in progress. The next goal is to obtain the dynamic solution in ABAQUS and compare the maximal nodal forces and internal bending moments in the same format as for the other two platform models described above.

CONCLUSIONS

1. For the case of the rigid basement the platform results in terms of structural accelerations in both cases (Winkler model and “optimal” model) proved to be similar to the “wave” ones. Hence, the horizontal response accelerations (with minor dependence on the base mat flexibility) are satisfactory reproduced in all platform models even for a flexible base mat.

2. Vertical response accelerations generally are better reproduced by the “optimal” model. For the lowest floor with dense walls the influence of the base mat flexibility on the structural accelerations is not very significant, except in the centers of the rooms at the mat itself. There none of the two platform models (Winkler or “optimal”) could reproduce the additional spectral peak occurring due to the base mat’s flexibility (see [1]).

3. Maximal soil-structure interaction forces for the vertical excitation are far better reproduced in the “optimal” platform model, because this model explicitly reproduces the concentration at the edges and in the corners.

4. Maximal bending moments in the rigid base mat generally are also far better reproduced in the “optimal” model. The excessive conservatism of the Winkler model has gone. Moreover, the shapes of the distribution curves in response to the vertical excitation for the structure with the internal walls in the “optimal” model (unlike Winkler model) reproduce the “wave” solution. However, the maximal internal bending moments in the rigid mat are considerably underestimated by the “optimal” model.

5. The implementation of special springs and dashpots with time gaps in addition to the “ordinary” ones enables to improve the approximation of the frequency-dependent stiffness. That may allow the accurate time-domain solution of the SSI problems. The additional research is in progress to prove the advantages of the new approach.

REFERENCES

- [1] Tyapin, A., “The effects of the base mat’s flexibility on the structure’s seismic response. Part I: wave solution”, *SMiRT21*, New Delhi, India. 6-11 November 2011. Rep. #85.