THE EFFECTS OF THE BASE MAT'S FLEXIBILITY ON THE STRUCTURE'S SEISMIC RESPONSE. PART I: WAVE SOLUTION

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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. Some time ago the solution of this sort has been achieved in the format of the combined asymptotic method (CAM). However, there remains an important limitation: CAM is accurate for the rigid base mat only. So, the additional research is needed to find out a) what is the impact of the base mat flexibility to the seismic response; b) how can one account for this impact using the conventional tools. In the first part of the paper the first question is partly answered. "Wave" solutions are obtained in the frequency domain using SASSI2000 code, without CAM at all. Different formats of the seismic response (e.g., the response accelerations, the soil-structure interaction forces, the internal forces in the structure) have proved to have different sensitivity to the base mat flexibility. This wave solution is further (in Part II, also presented at SMiRT21) used as a benchmark for the different "platform" models.

INTRODUCTION

Some time ago the author has proposed the combined asymptotic method (CAM) to perform the SSI analysis [1, 2]. It is called "combined" because it combines the frequency-domain and the time-domain calculations. It is called "asymptotic" because it is precise only for the rigid contact surface between structure and soil.

The final format for the time-domain calculations in CAM is a platform model (i.e., detailed model of a structure placed on distributed "soil" springs and dashpots resting on a rigid platform) with some kinematical excitation put on the platform. This model looks like a conventional one. The difference is in the kinematical excitation applied to the platform: it is modified from the conventional seismic excitation. The modification matrix takes into account the dynamic inertia of the structure and the difference between the actual "wave" impedances and the "platform" impedances. The modified excitation generally has six components (three translational and three rotational ones), even if the initial excitation had only three translational components.

CAM has proved to be a powerful tool for the SSI analysis. Still, the rigidity of the contact surface remains the main limitation of CAM. Another limitation is in the format of the results: even for the rigid contact surface CAM does not provide correct interaction forces over the base mat and internal forces in the basement (they depend on the distribution of the soil springs and dashpots in the platform model). All other internal forces and floor response spectra provided by CAM in this "rigid" case are accurate.

The next step of the research is to investigate the effects caused by real flexibility of the basement (i.e., of the contact surface). Obviously, this research should consist of the two parts. In the first part the "exact" solution (without CAM) should be studied. In the second part different platform models with modified excitation should be studied with a comparison of the response parameters to those of the "exact" solution. The goal is to estimate the scale and type of errors occurring in the CAM solutions for the flexible basements or even for the rigid basement in the response interaction forces and internal forces in the basement.

This report contains the first part. The second part is presented in the separate report.

SAMPLE STRUCTURES AND SOIL FOUNDATIONS

The sample structure resting on the surface of the soil foundation was subjected to the seismic excitation.

Two variants of the soil foundation were considered in the test analyses. Variant no.1 was a homogeneous half space. Density of the soil was ρ=2.0 t/m^3; shear wave velocity V_s=400 m/s; primary wave velocity V_p=1100 m/s, material damping 5%. Variant no.2 was a layer 26 m thick of the same soil as in variant no.1. This layer was resting on a homogeneous half space with different wave velocities and damping: shear wave velocity V_s=800 m/s; primary wave velocity V_p=2100 m/s; damping 2%.

Single variant of the seismic excitation time history was considered. According to the SASSI methodology, each of three excitation components was treated separately. Vertical component had maximal acceleration 0.21g; both horizontal components had maximal acceleration 0.4g.

Two variants of the structure were considered: a box-like structure no.1 without the internal walls and the same structure no.2 with the internal walls parting the interior into four equal rooms. Horizontal dimensions of the base mat were 30.6 x 30.6 m; thickness was 2 m. Walls were 1 m thick, 7 m high and flexible. The whole mass of the building (25570 tones) was uniformly distributed over the roof; walls and base mat were assumed weightless.

Base mat was assumed flexible; elasticity module was $E=E_0/fl$, where the concrete elasticity module was E_0=0.3*10^8 kN/m^2; *fl* is a flexibility coefficient. This coefficient was varied in the range from zero (rigid base mat) to 1.0 (real concrete base mat). The internal damping (the material one; this is the requirement of SASSI) was taken 4%.

SASSI2000 code [3] was used to obtain the "wave" solution. In the SASSI model all structural elements (base mat, walls and roof) were modeled by rectangular four-node plate/shell elements. Eight elements were set along each horizontal side of the base mat; two elements were set along vertical axis.

NUMERICAL RESULTS

Three formats of the seismic response were studied. The first format was the acceleration spectra in the different nodes of structure. The second format was the maximal nodal soil-structure interaction vertical forces in the different base mat nodes. The third format was the maximal bending moments in the different elements of the base mat.

Fig.1 shows the horizontal accelerations spectra in the centre of the base mat due to the horizontal seismic excitation. These are the results for the building no.1 (without the internal walls) and soil foundation no.1 (homogeneous half space). Damping in oscillators for all spectra presented is 2%. The reason for the response spectra fluctuation is the in-plane shear in the flexible base mat. That is why the internal walls do not change the effect. We see the comparatively small impact of the base mat flexibility to the horizontal response of the base mat. The impact of the base mat flexibility to the motion of the roof is even less.

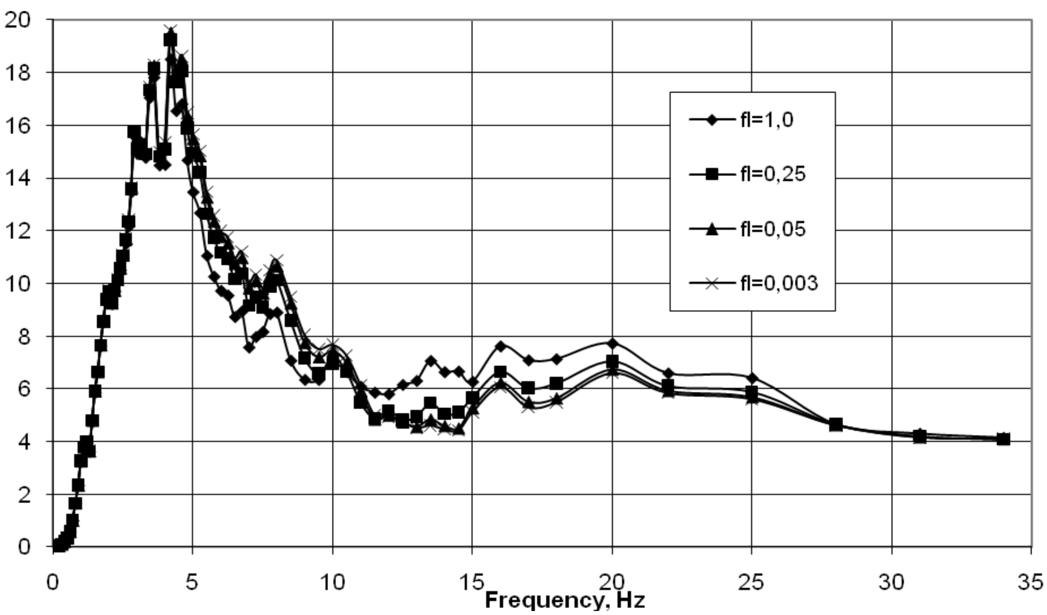

Fig.1: Horizontal accelerations in the center of the base mat due to the horizontal seismic excitation. Building no.1, foundation no.1

Vertical response accelerations show considerable dependence on the base mat flexibility. The greatest effect is in the centre of the room floor at the base mat itself. Let us consider the one-component vertical seismic excitation. Fig.2 shows the vertical accelerations spectra in the center of the room for building no.1 (in this case the center of the room is at the same time the center of the base mat) resting on the foundation number 2. Additional spectral peaks appear in frequencies 10…15 Hz shifting to the lower frequencies along with the flexibility increase.

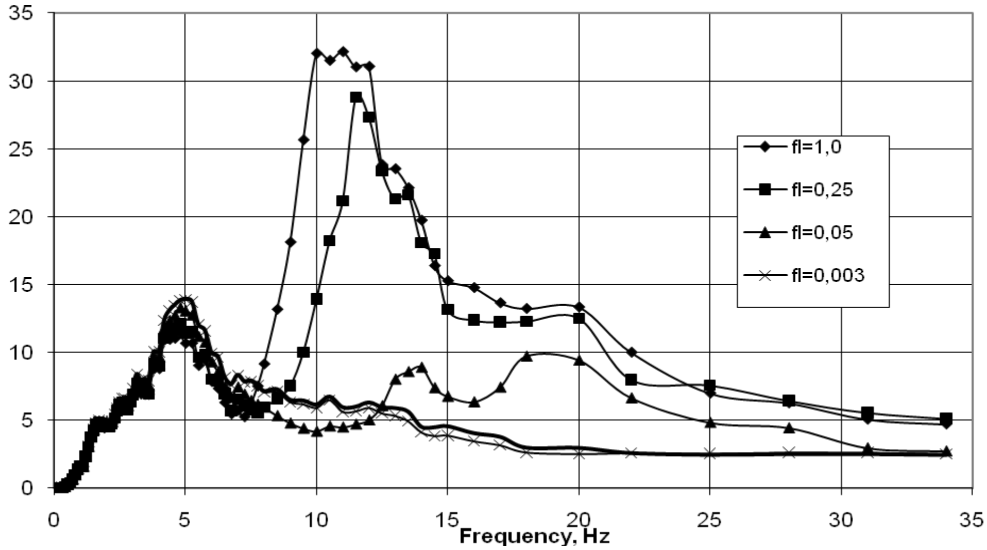

Fig.2: Vertical accelerations in the centre of the base mat (for building no.1, foundation no.2) due to the vertical seismic excitation

Fig.3 shows vertical accelerations in the different nodes of the base mat, including the center of the room for building no.2 (this time the center of the room is ¼ diagonal from the corner) resting on the foundation no.2.

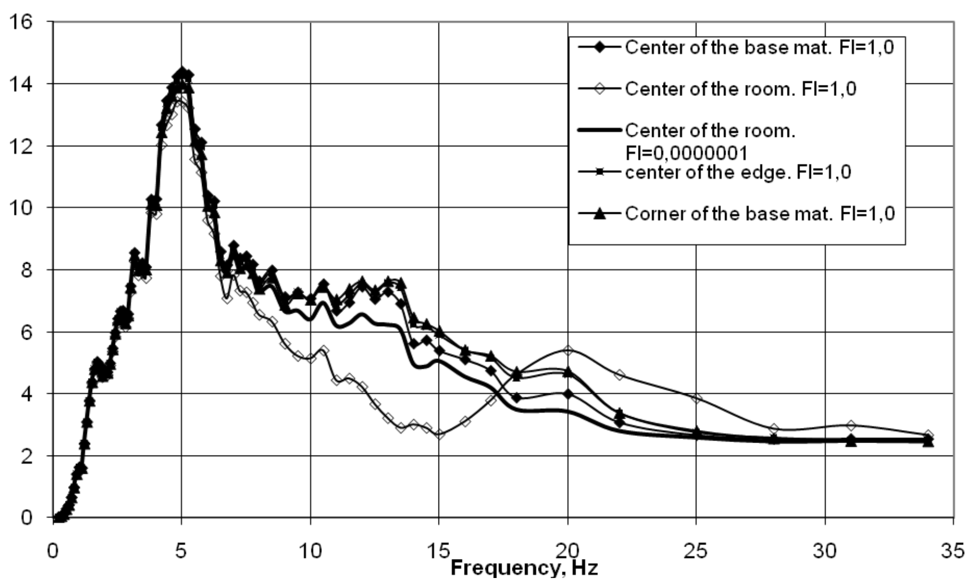

Fig.3: Vertical accelerations (for building no.2, foundation no.2) in the centre of the room and in some other nodes due to the vertical seismic excitation

As the fluctuations in the vertical accelerations are due to the bending of the mat, they strongly depend on the horizontal dimensions of the room and on the thickness of the mat. The comparison of Fig.2 and Fig.3 shows that the horizontal room size 15 m (unlike 30 m) for the mat thickness 2 m leads to the modest influence of the mat flexibility to the vertical response accelerations (excluding the very central part of the room).

As to the upper structure and the nodes at the base mat, reinforced by the walls, the influence of the base mat flexibility is really considerable only for the box-like structure no.1 and less considerable for the structure no.2 with the internal walls (the second case with real base mat module is more or less comparable to the first case with the base mat module 20 times greater than the real one). This effect is shown on Fig.4.

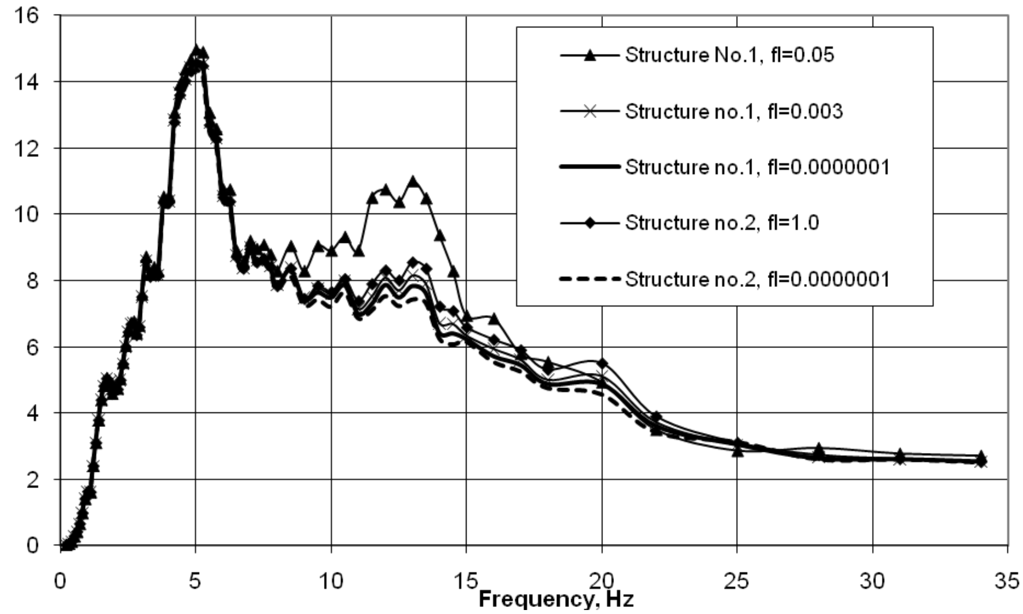

Fig.4: Vertical accelerations of the rigid roof due to the vertical excitation. Soil foundation no.2

Maximal soil-structure interaction forces for the vertical excitation show the concentration at the edges and especially in the corners of the base mat. However, in the different “internal” nodes in case of rigid mat they are almost flat. When the mat becomes flexible, the interaction forces increase in the nodes reinforced by the walls (both the external and the internal ones) and decrease in the rest of the nodes. Fig.5 shows maximal vertical interaction forces in the 25 nodes of ¼ of the base mat due to the vertical seismic excitation for building no.2 (with the internal walls). Var.0 denotes the results for building no.1 with rigid base mat. Fig.6 explains the order of counting these nodes.

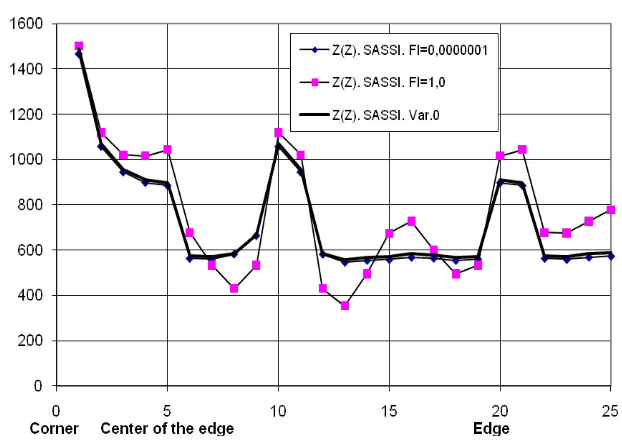

Fig.5: Maximal vertical interaction forces for foundation no.1 and building no.2 (Var.0 – for building no.1). The order of the nodes is explained in Fig.6

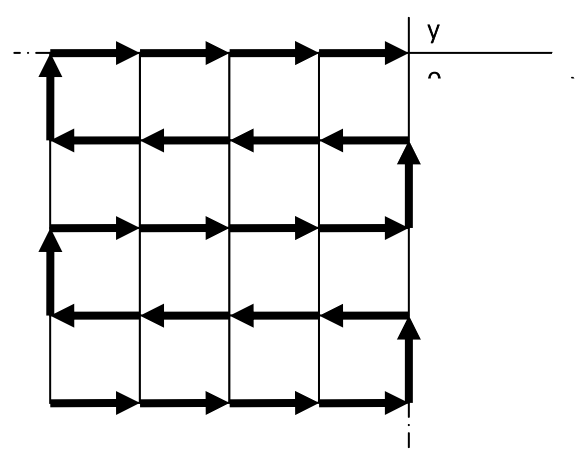

Fig.6: The order of the nodes in Fig.4

Maximal bending moments in the rigid base mat in the box-like structure no.1 in response to the vertical excitation are about two times greater than those in the structure no.2 with the internal walls. In the latter case the maximal moments are near the internal walls. When the mat becomes flexible, all bending moments decrease. Fig.7 shows maximal bending moments in the centers of 16 elements of ¼ of the base mat due to the vertical seismic excitation for building no.2 (with the internal walls) and foundation no.2 (layered soil). Var.0 denotes the results for building no.1 with rigid base mat. Fig.8 explains the order of counting these elements.

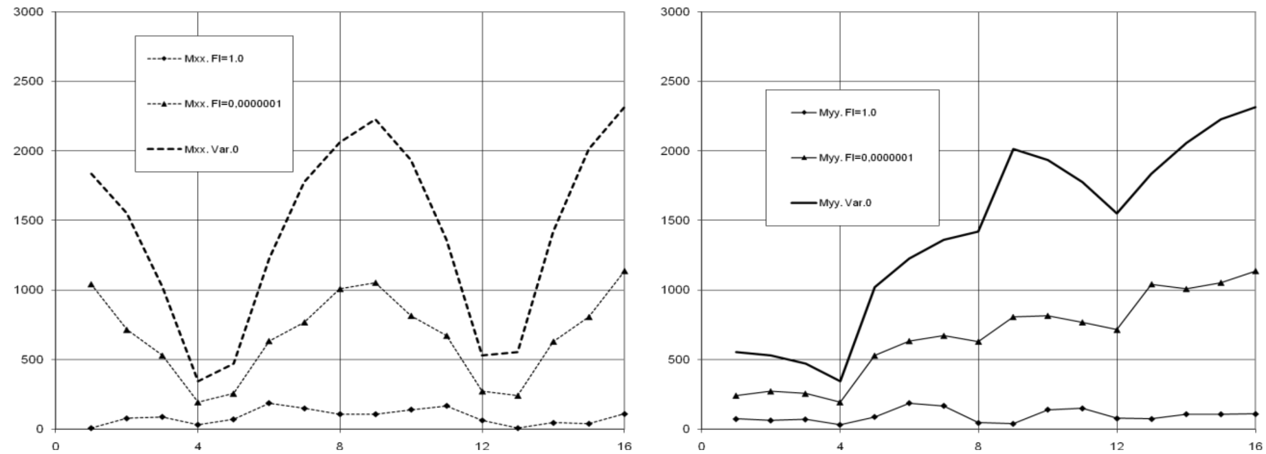

Fig.7: Maximal bending moments in the finite element centers of the base mat. The order of the elements is explained in Fig.8

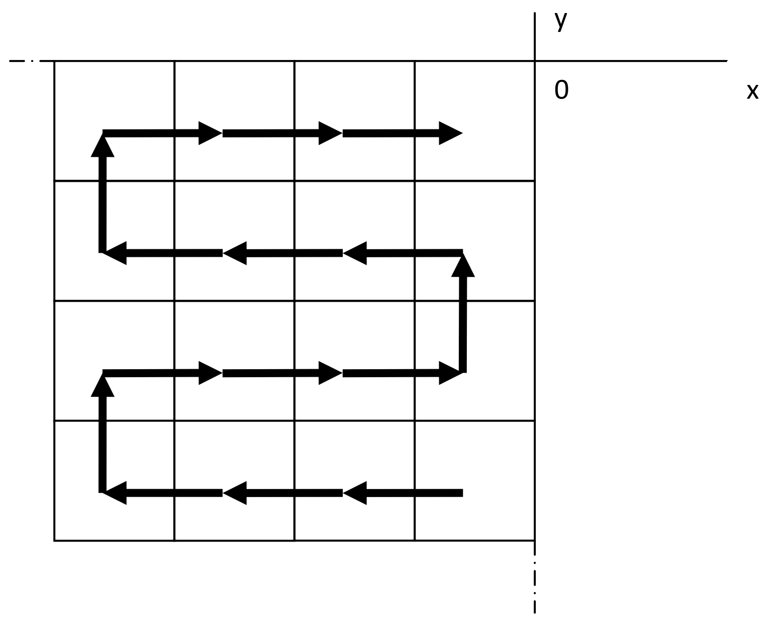

Fig.8: The order of the finite elements in Fig.7

CONCLUSIONS

1. Horizontal response accelerations show minor dependence on the base mat flexibility.
2. Vertical response accelerations show considerable dependence on the base mat flexibility. The greatest effect is in the centre of the room floor right at the base mat. As to the upper structure and the nodes at the base mat, reinforced by the walls, the influence of the base mat flexibility is really considerable only for the

box-like structure and less considerable for the structure with the internal walls (the second case with real base mat module is more or less comparable to the first case with the base mat module 20 times greater than the real one). Additional spectral peaks appear in frequencies 10…15 Hz shifting to the lower frequencies along with the flexibility increase.

3. Maximal soil-structure interaction forces for the vertical excitation show the concentration at the edges and especially in the corners of the base mat. However, in the different "internal" nodes in case of rigid mat they are almost flat. When the mat becomes flexible, the interaction forces increase in the nodes reinforced by the walls and decrease in the rest of the nodes.
4. Maximal bending moments in the rigid base mat in the box-like structure in response to the vertical excitation are about two times greater than those in the structure with the internal walls. In the latter case the maximal moments are near the internal walls.
5. When the mat becomes flexible, all bending moments decrease.

The main goal of the "wave" analysis presented in this first part of the report was to provide the benchmark solution for the further tests of different spring-dashpot models.

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