SEISMIC QUALIFICATION OF SST AUXILIARY TRANSFORMER

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ABSTRACT :

The aim of the paper is to demonstrate the procedure and results of the seismic qualification of SST auxiliary transformer. The transformer is qualified for a maximum seismic excitation at Maritza East I Power Station site in Bulgaria. The seismic analysis is performed using the time history analysis. The method is chosen because of very strong soil-structure interaction and high level of the seismic input. Internal forces are derived for all important elements of the transformer. The seismic capacity is checked for critical cross sections in these elements.

KEYWORDS: Seismic qualification, dynamic analysis, power transformer

1. INTRODUCTION

The equipment for this seismic qualification is a SST auxiliary Transformer, Rated power 36/60MVA, Voltage level 20 kV, designed by “HYUNDAI Heavy Industries” – Bulgaria. There are several main parts of the transformer: the active part, transformer base, tank and cover, high and low voltage bushings, conservator and radiators. The general drawing is shown in Figure 1. The equipment is mounted on a railway carriages. The rails are installed on a massive reinforced concrete foundation.

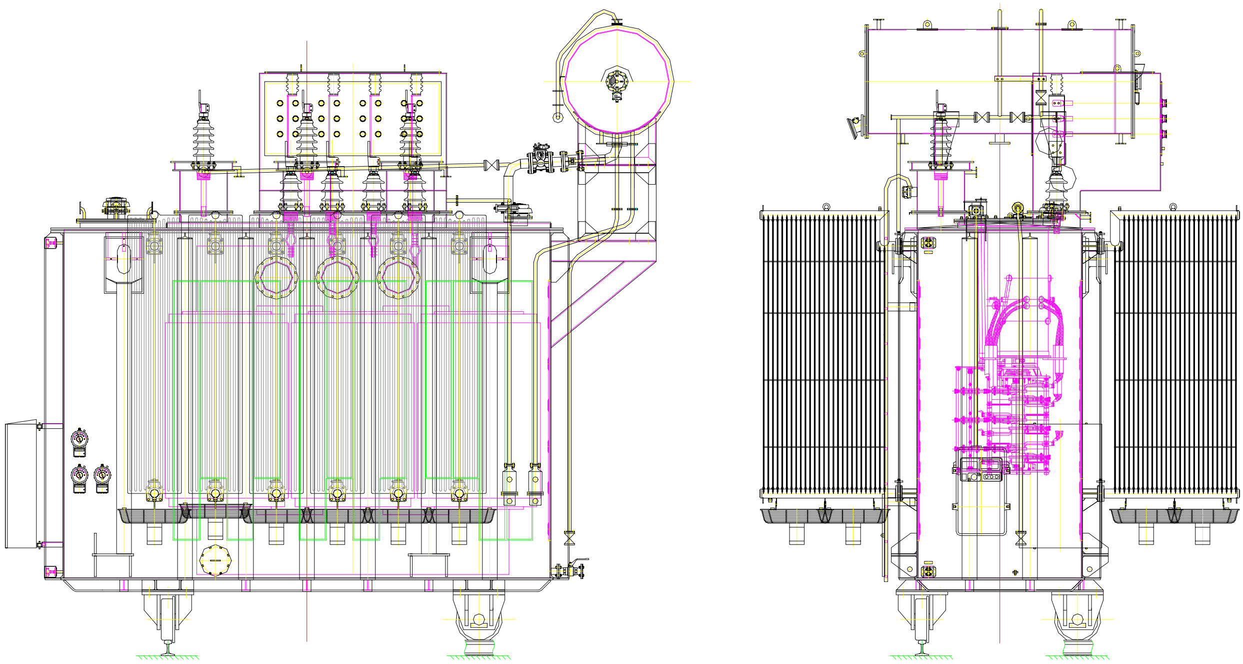

Figure 1 General drawing of the transformer

2. DEFINITION OF THE SEISMIC EXCITATION

The transformer is qualified for a maximum seismic excitation at Maritza East I Power Station site. Two different codes are used. The first one is the existing Bulgarian code: "Code for Design of Buildings and Structures in Seismic Regions" (CDBSSR) – 1987 year. The second one is the relevant document for European Union: "Eurocode 8: Design of structures for earthquake resistance EN 1998-1 (EC8) ". The seismic qualification is performed for a maximum seismic excitation, which corresponds with both requirements, listed above.

The earthquake motion at a given point at the surface is represented by an elastic ground acceleration response spectrum. The horizontal seismic action is described by two orthogonal components considered as independent and represented by the same response spectrum. The vertical seismic action is described by another response spectrum. The soil conditions at the site correspond to soil group III according to the Bulgarian code and ground type C according to the EC8. In Figure 2 are shown the horizontal response spectra for every soil type, according to both codes.

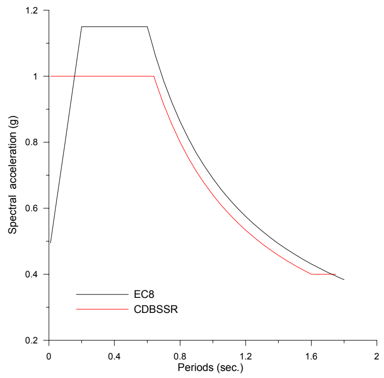

Figure 2 Comparison of spectra acc. EC8 and CDBSSR

The values of the design ground accelerations are:
- horizontal acceleration a_{gh}=0.4 g;
- vertical acceleration a_{gv}=0.4 g.

3. FINITE ELEMENT MODEL OF THE TRANSFORMER

The transformer is a very complex equipment and it is impossible all components to be included in the model. The seismic analysis is concentrated on several critical elements, which can be damaged during a strong earthquake. The following finite elements are used in the modeling:

- 3-D BEAM element with 6 degrees of freedom per node;
- 3-D QUAD element with 5 degrees of freedom per node.

The three-dimensional FE model consists of 1341 nodes, 733 beams and 1066 plane elements. A general view of the model is shown in Figure 3. The models are built using pre-processor FEMAP and computer code STARDYNE.

The transformer cover, tank and tank base are modeled by plane elements. The high and low voltage bushings are modeled by beam elements. The mass of the bushings is equally distributed along the element length. The radiators are modeled by beam elements. The mass is distributed in the three vertical elements. The mass of the ventilators is added to the radiators at the end of the transformer. The active part is modeled by beam elements. The FE model is shown in Figure 4. The mass is distributed in the nine vertical elements. The 12 small vertical elements are used to asses the shear forces from the inertial loads to the tank base of the transformer. The upper zone of the active part model is connected with small plane elements to the transformer cover.

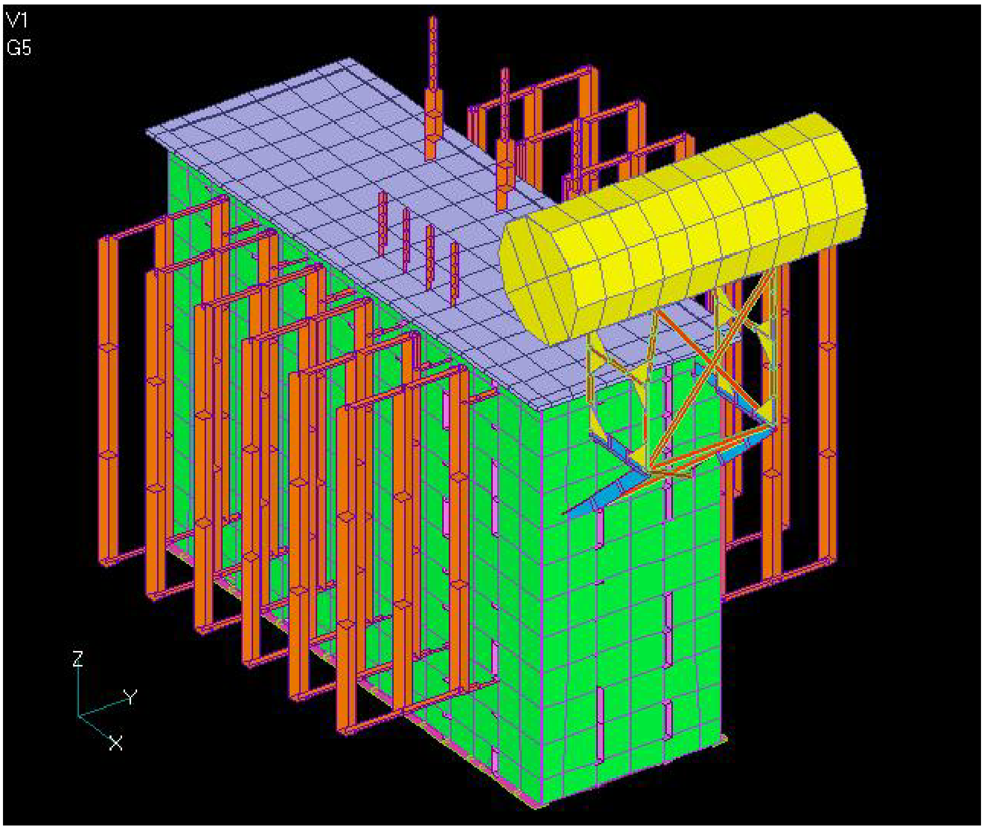

Figure 3 General view of the transformer model

The conservator is modelled by plane elements. In order to asses the internal forces in the supporting structure a modification is done. The supporting structure is modelled by beam elements and stiffeners (plane elements). The FE model is shown in Figure 5. The four railway carriages are modelled by beam elements.

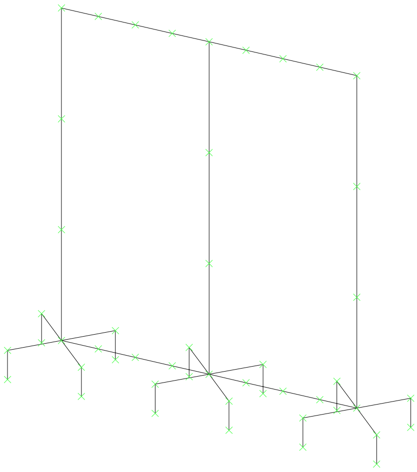

Figure 4 Active part - FE model

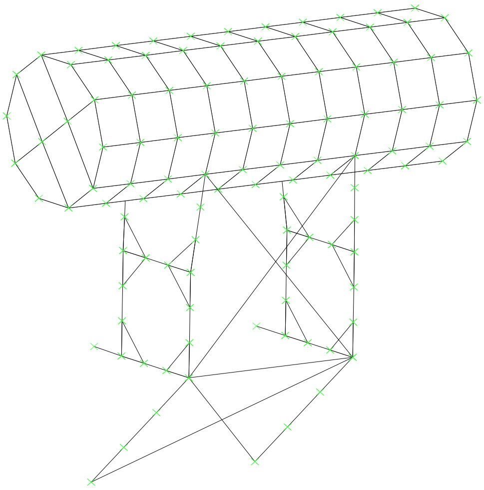

Figure 5 Conservator - FE model

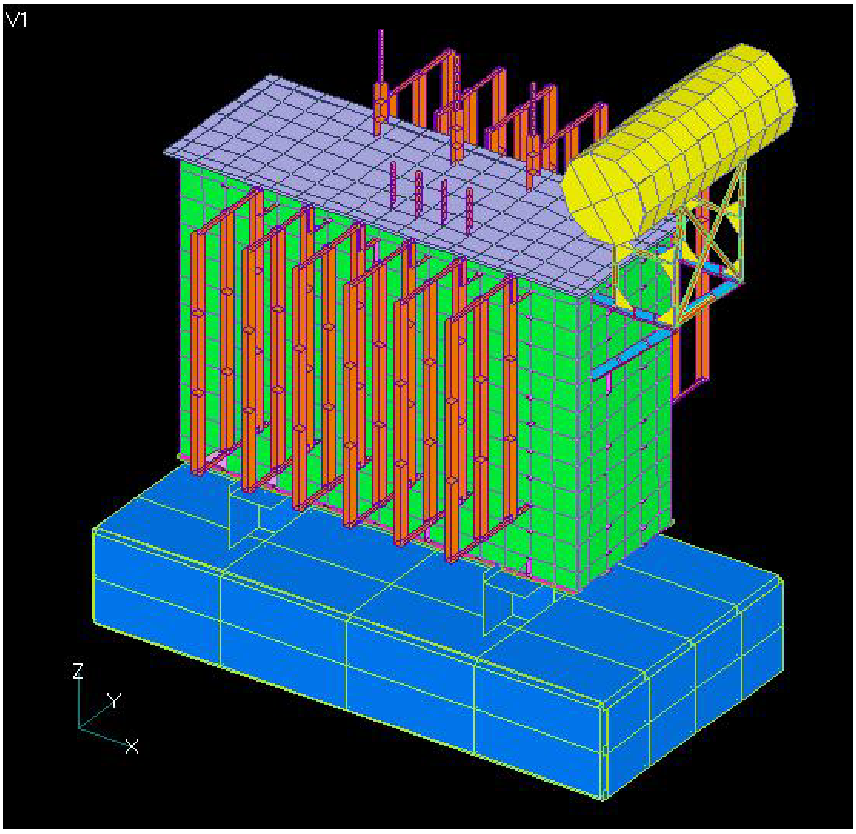

Figure 6 The complex FE model - transformer and foundation

The soil-structure interaction is modeled by spring elements. Using the methodology "elastic half space" (Prakash, 1986) the values of translational and rotational stiffnesses and the corresponding damping values are derived. The massive reinforced concrete foundation is modelled by rigid plane elements. The soil stiffness is calculated taking into account the embedment of the foundation. That's why the spring values are distributed in the nodes on the bottom of the foundation. The whole FE model - the transformer and the foundation is shown in Figure 6.

4. NATURAL FREQUENCIES AND MODES

The dynamic analysis is performed by computer code "STARDYNE". In Table 1 are summarised the first several natural frequencies. The first 10 modes are mainly the vibration of the radiators. Mode 1 is illustrated in Figure 7. The mode 13, shown in Figure 8, is global rotation around global X axis, but the conservator rotate around global Z axis. The conservator translates in global X direction in the next mode 14 – Figure 9. The influence of the soil-structure interaction can be seen in Figure 10. The main response is rotation of the whole model around global X axis.

Table 1 Natural frequencies of the model

№ Mode	1	13	14	15	20
Frequency (Hz)	4.953	5.962	7.090	7.561	12.849

The following conclusions can be drawn from the modal analysis:

- The dynamic analysis is performed. 99 natural modes are considered up to 34.4 Hz;

- The global response of the complex FE model is influenced very strong from the soil-structure interaction. In such cases the time history analysis is preferable, because it gives the possibility to take into account the soil damping more precisely.

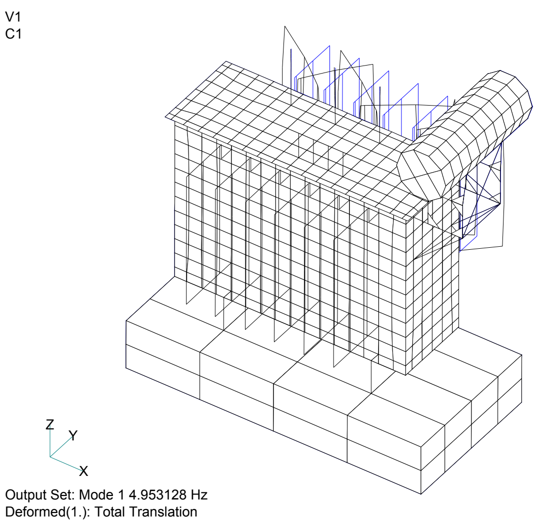

Figure 7 Mode number 1

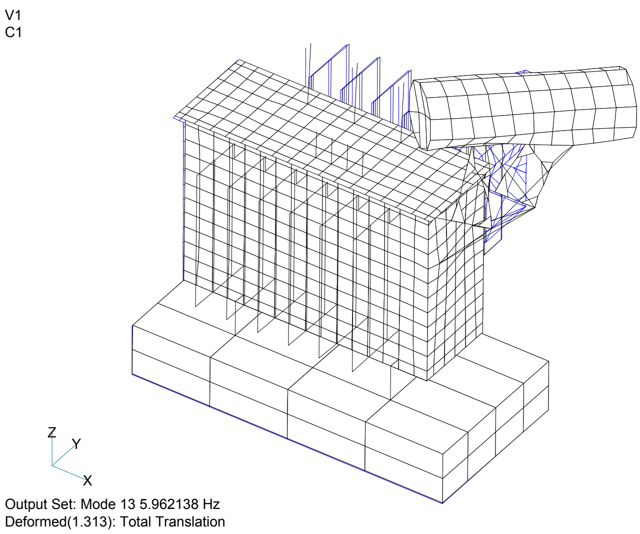

Figure 8 Mode number 13

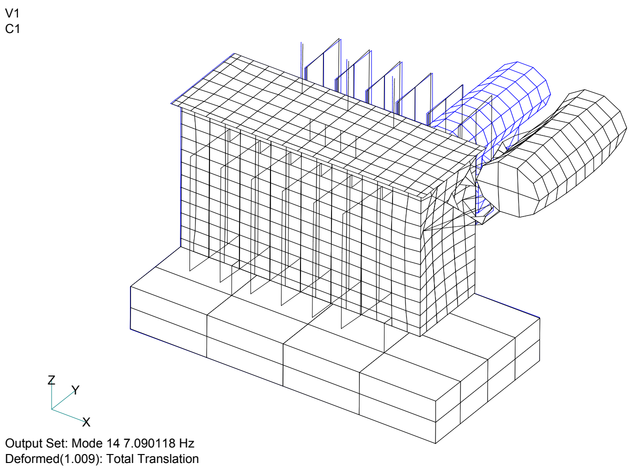

Figure 9 Mode number 14

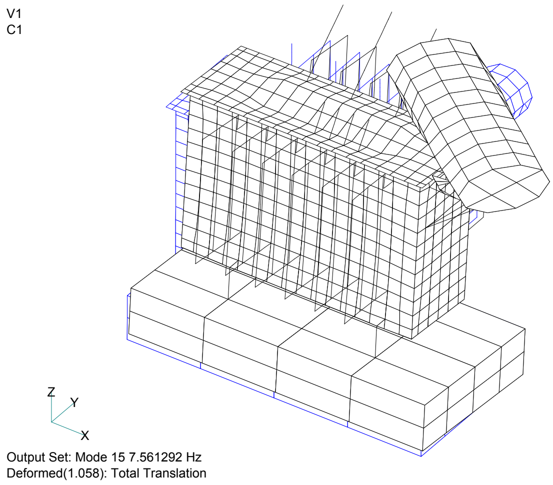

Figure 10 Mode number 15

5. SEISMIC ANALYSIS

Time history analysis is chosen for the seismic investigation. The computer code "STARDYNE" is used. It gives the possibility to use the "composite damping". The composite damping is calculated for every different mode and it is a function of material damping of the structure (transformer) and the soil damping. Generally the material damping depends on the intensity of the seismic excitation. Because the level of the ground acceleration is high the material damping for the transformer is assumed to be 0.04 of critical. The soil damping is assumed to be equal to this, calculated according (Prakash, 1986).

The seismic excitation is defined by acceleration response spectra, described in Item 2. In order to perform the time history analysis is necessary to generate 3 accelerograms, corresponding to two horizontal and one vertical direction. Three accelerograms are generated with duration 35 seconds. In order to approve that the accelerograms are appropriate a comparison is made between the generated and target spectra - Figure 11. The calculated spectra fitted the target ones very well.

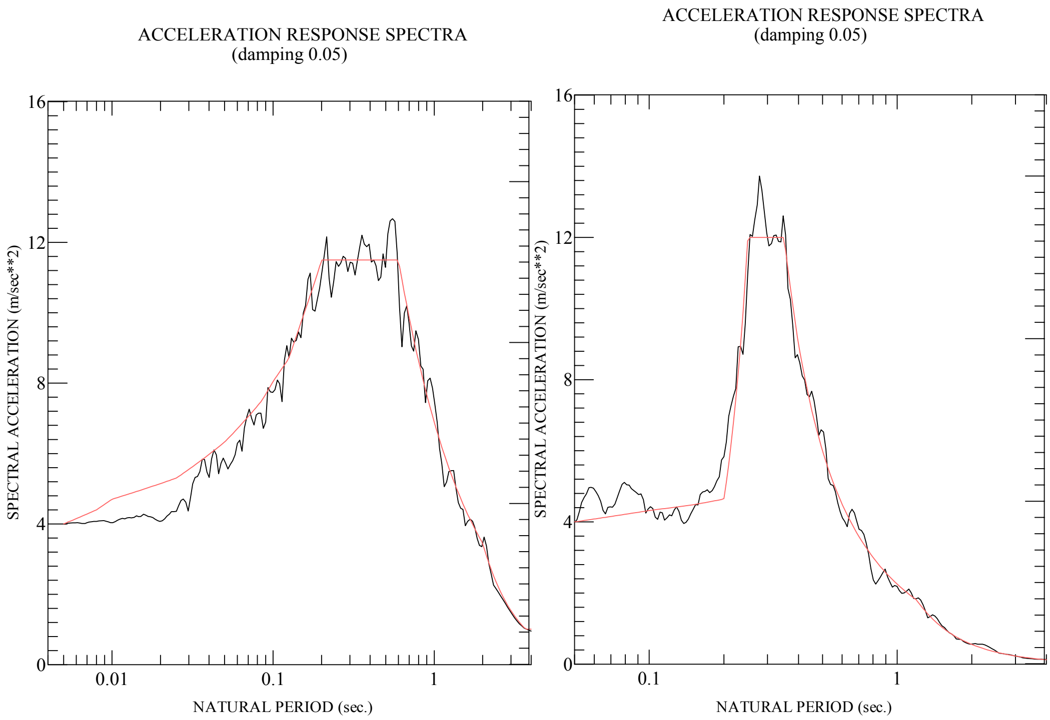

Figure 11. Horizontal and vertical direction - comparison between generated and target response spectra

The seismic analysis is carried out for two perpendicular horizontal directions as well as for the vertical direction. The seismic action is combined with permanent action under normal condition - dead load.

6. SEISMIC QUALIFICATION

The seismic qualification is done for the final values for the internal forces. The internal forces are bending moments and shear forces in two perpendicular directions and axial forces. When a tube cross section is considered a combined forces are used for the qualification:

$$M = [\,(M2)^2 + (M3)^2\,]^{1/2}$$

$$V = [\,(V2)^2 + (V3)^2\,]^{1/2}$$

Normal (tensile or compressive) and shear stresses are calculated for every critical cross section of the elements under consideration. The normal stresses are calculated from the action of axial forces and the bending moments. The maximum stresses are compared with the allowable (permissible) ones.

The critical cross section of the high and the low voltage bushings is the attachment to the transformer tank. The values of the seismic forces are compared with the values of the so called “cantilever test”. These values are determined from the producer of the bushings and usually is the maximum allowable shear force.

There are two critical cross sections for the radiators. The first one is the attachment of the radiators to the transformer tank. There are two stiffeners (one horizontal and one vertical) at the connection between tube section and transformer tank. In fact the joint cross section in one direction consists of one tube (outer diameter D = 89mm, thickness t = 4mm) and one stiffener (length = 9 cm, thickness = 10mm). The capacity is checked for tensile and shear stresses. The second critical cross section is the cross section of the header tube next to the flange connection. Usually the tensile stresses at this cross section are very high and they must carefully assess.

Generally for horizontal loads the active part (which is the heaviest part of the transformer) is fixed to the tank base and to the transformer cover. The active part is fixed to tank base by means of 4 nibs. Every nib is a tube with outer diameter D = 78mm and thickness t = 21mm. The active part is fixed to the transformer cover by 12 bolts with diameter 30 mm. The shear capacity of the nibs and bolts is checked.

As a result from the seismic qualification is turned out that the horizontal stiffness of conservator supporting structure is small. That's why additional bracing elements are recommended to increase the stiffness. The capacity check is done for the vertical, inclined and bracing elements separately. The critical cross section of the vertical conservator supports (steel section **L** 100/100/14) is above the stiffeners. They are checked for tensile and shear stresses.

The transformer is mounted on 4 railway carriages. The transformer is fixed to the one carriage by 4 bolts with diameter 30 mm. The shear capacity of the bolt is checked.

A special check is done for the overturning of the transformer. There are two possible positions of the wheels of the carriages. First position - the wheels are parallel to the longitudinal side of the transformer, which corresponds to the global X axis of the model. Second position - the wheels are parallel to the transversal side of the transformer, which corresponds to the global Y axis of the model. The value of the overturning moment at the first position is Mo=859.3 kNm. The corresponding value of the retaining moment is Mr=645.6 kNm. < 859.3 kNm. The overturning moment is bigger than the retaining moment. Therefore there is a real danger of overturning of the transformer at the first position.

The value of the overturning moment at the second position is Mo=1601 kNm. The corresponding value of the retaining moment is Mr=1154 kNm < 1601 kNm. The overturning moment is bigger than the retaining moment. Therefore there is a real danger of overturning of the transformer in the second position.

To fix the problem with the overturning of the transformer during earthquake, additional fixing devices are designed, which prevent the possible overturn of the transformer at seismic excitation.

7. CONCLUSION

Seismic analysis is performed for seismic qualification of SST auxiliary Transformer, Rated power 36/60MVA, Voltage level 20 kV, designed by "HYUNDAI Heavy Industries" – Bulgaria.

Three-dimensional finite element model is developed. This model gives the possibility to investigate the 3-D response of the complicated structure composed by parts different in stiffness, height and distribution in plan and takes into account the interaction between the transformer, foundation and soil.

The seismic analysis is performed using the time history analysis. The method is chosen because of very strong soil-structure interaction. The "composite damping" gives the possibility to account more realistically the damping in the soil during earthquakes.

Internal forces are derived for all important elements of the transformer. The seismic capacity is checked for critical cross sections in these elements.

After the analytical investigation is established that there is real danger of overturning of transformer at seismic excitation. Additional fixing devices are designed to fix the wheels against rotation and overturning.

REFERENCES:

Prakash J. (1986), Soil Dynamics.

ACKNOWLEDGEMENTS

The author gratefully acknowledge the good cooperation with the colleagues from “HYUNDAI Heavy Industries” – Bulgaria.