SEISMIC QUALIFICATION OF 1000 MW POWER EQUIPMENT

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ABSTRACT

This paper clarifies the seismic adequacy of installed equipment and electrical cable raceways in operating WWER 1000 type NPP:

The qualification approach is a combination of numerical analyses and GIP methodology in consideration of some specific features of WWER equipment, taking into account the as-built conditions and plant specific floor response spectra.

As result of the study the selected equipment is divided into 2 groups – equipment and cable raceways that are seismically qualified for Review Level Earthquake, equipment and cable raceways which require seismic upgrading.

Keywords: seismic adequacy, GIP methodology, cable raceways, heat exchangers, penetrations

INTRODUCTION

This paper reflects the methodology and results of a study aimed at clarifying the seismic adequacy of the equipment and cable raceways included in a preliminary developed Seismic Equipment List (SEL) and to outline the measures for qualification of non-qualified equipment.

SEL equipment and cable raceways are installed in the Reactor building – inside and outside of the containment and in the Diesel generator stations of the operating WWER 1000MW type Nuclear Power Plant.

All components and cable traces are safety related equipment, necessary for safe shutdown of the reactor and its maintenance sub criticality.

The equipment is required to maintain its function and integrity during and after the Review Level Earthquake with peak ground acceleration of 0.2g.

The SEL contains the following equipment:

- Motor operator valves – 143 items
- Fans – 24 items
- Chillers – 30 items
- Heat exchangers – 4 types
- Penetrations – 8 types
- Cable raceways – 797 groups grouped on the "system in the room" basis

The possible approaches for solving seismic qualification problems are analysis, testing, engineering judgment based on experience pertaining to the equipment behavior during past earthquakes, and combinations thereof.

For this study it was decided qualification by testing to be performed, since all other methods could not be applied because of difficulties in dismounting already mounted equipment.

The seismic qualification methods performed in this paper are: qualification by analysis, and engineering judgment based on seismic experience.

The heat exchangers and penetrations were qualified by analyses. All other components in the SEL were qualified by engineering judgment

As result of the study the selected equipment was divided into 2 groups – equipment and cable raceways which are seismically qualified for the Review Level Earthquake, and equipment and cable raceways which could be qualified after implementation of upgrading measures. The performed analyses did not outline equipment that needs to be replaced by seismically qualified one.

SEISMIC QUALIFICATION BY ENGINEERING JUDGMENT

The procedure used for seismic qualification of mechanical equipment and electrical cable raceways was based mainly on the Generic Implementation Procedure – GIP [1, 2]. This procedure is widely used as an indirect method of seismic adequacy evaluation of nuclear power plant equipment and is one of the approaches for assessing the nuclear power plant seismic margin. GIP uses the seismic walkdown as a procedure for collection of data on the so-built state of NPP equipment. Within GIP, the nuclear power plant equipment is divided into equipment classes and for evaluation of each equipment class the procedure defines certain specific evaluation criteria (a set of inclusion/exclusion rules named as “caveats”) and certain common evaluation criteria (seismic capacity spectra versus seismic demand spectra evaluation, anchorage examination and possible seismic interactions examination). GIP itself corresponds to the methodology EPRI NP-6041 [3]. Another more or less similar method exists in the USA which is based on the GIP DOE Seismic Evaluation Procedure [2]. The implementation of the GIP approach for WWER units was justified in the IAEA documents referred to herein as [4, 5].

It should be noted that all these procedures: SQUG GIP, GIP WWER and SEP DOE, are based on the same main principles and differ only in some details. For the practical implementation of the seismic walkdowns in our study the DOE SEP was chosen as a basic, being the most advanced procedure. However, in order to optimize the performance of this work, the general forms of Seismic Evaluation Work Sheets (SEWS) were additionally adopted from the GIP WWER procedure, to take into account some peculiarities of the WWER equipment.

All mentioned above sources provide a comprehensive description of the walkdown procedure for the respective equipment classes. In order to implement this procedure all components listed in SEL were classified into respective equipment classes (Table 1).

Table 1 List of Equipment Classes used for Plant Seismic Walkdowns

№	Class of Equipment	Qualification Procedure	Notes
8	Motor-Operated Valves	Experience Data	(1)
9	Fans	Experience Data	(1)
11	Chillers	Experience Data	(1)
23	Cable Trays and Conduits	Experience Data + Limited Analysis	(1)

Notes:

(1) walkdown results were documented in SEWS;

Generally the GIP procedure for the majority of the equipment to be evaluated consists of the following four major steps:

1. Selection of Seismic Evaluation Personnel.
2. Determination of Seismic Equipment List.
3. Screening Evaluation and Walkdown, focusing on:
    a. Capacity versus Demand;
    b. Anchorage;
    c. Seismic Interaction;
    d. Equipment Class Evaluations;
    e. Relay Functionality
4. Outlier Identification and Resolution

Since the first two steps have been identified before the study was started, the following subchapters are mainly focused on the features implemented in steps 3 and 4.

The purpose of the ***Screening Evaluation and Walkdown*** is to screen out from further consideration those items of equipment which meet certain generic, seismic adequacy criteria. The screening evaluation is based mainly on the use of seismic experience data. If the equipment does not pass the screens, other more refined or sophisticated methods for evaluating the seismic adequacy of the equipment may be used.

Capacity-versus-Demand Evaluation

Following the approach of GIP DOE [2] a seismic capacity of equipment is represented by a “Reference Spectrum” based on earthquake experience data. This spectrum can be compared to a seismic demand spectrum (SDS) defined in terms of an in-structure (floor) response spectrum (IRS/FRS). To meet the requirements of the implemented procedure, the seismic capacity spectrum should envelop the SDS over the entire frequency range of interest (typically 1 to 33 Hz). However, an exception could be made, if the spectrum envelops only the SDS for frequencies equal to, and higher than the conservatively estimated lowest natural frequency of the item of equipment being evaluated.

Within the frame of this study, in order to obtain a seismic demand spectrum, an envelope of corresponding FRS for three spatial directions has been used. The analysis of the Reactor and Diesel Generator Buildings floor response spectra shows that they exceed the Reference Spectrum in a narrow band of frequencies (up to 1 - 3 Hz, depending on the elevation, Fig. 1.).

In a few instances the SDS exceeds the Reference Spectrum also in the frequency region of 11 - 15 Hz by 1.2 times. For such cases all three directional components were plotted in the corresponding SEWS Figures, wherefrom it can be seen that only the vertical FRS component exceeds the Reference Spectra. However, according to the DOE procedure ([2], chapter 5.4.1, "Comparison of Equipment Seismic Capacity to Seismic Demand") for such comparisons, "the largest horizontal component of the 5% damped in-structure response spectra is used…".

However, from the Walkdown results it was recognized that most of the considered components (cable races and mechanical equipment) have their first natural frequency above 4 - 5 Hz. Taking this into account, a formal answer to the question "Capacity vs. Demand" was given in all SEWS as "NO", but in absence of other negative remarks for residual SEWS questions, the component was considered seismically adequate. The corresponding comments on this approach were included in the SEWS.

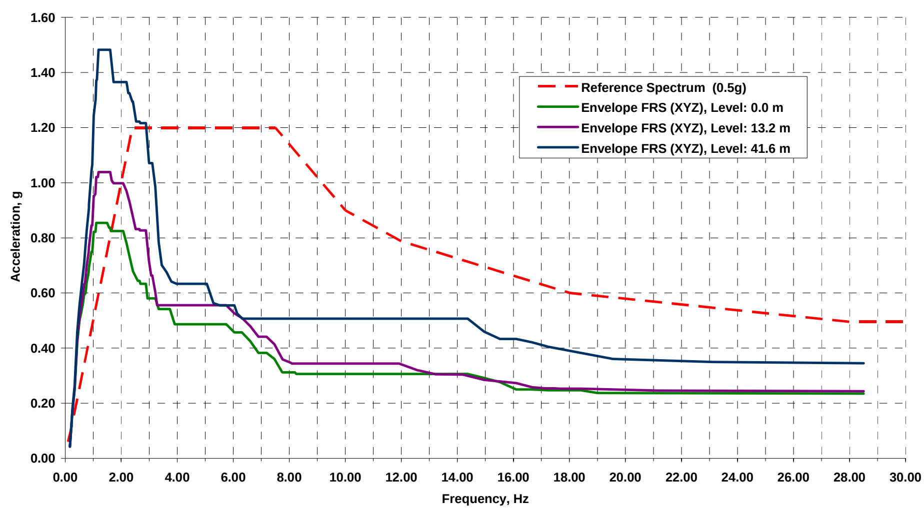

Figure 1. Reference Spectrum vs. FRS (Reactor Building)

Anchorage

The equipment anchorage capacity, installation and stiffness should be adequate to withstand the seismic demand at the equipment location. The walkdowns included inspection and visual check for correct location, adequacy of the weld joints, availability of bolts, nuts and washers where necessary, absence of defects in the concrete etc. All visible defects and deficiencies in the equipment anchorage were reported in the corresponding SEWS.

Seismic Interaction

The effect of possible seismic spatial interactions with nearby equipment, systems, and structures and interaction from water spray, flooding, and fire hazards should not cause equipment failure in performing its intended safety functions.

Seismic interaction is the physical interaction of any structures, piping, or equipment with a nearby item of equipment caused by relative motions from an earthquake. Components with fragile appendages (such as instrumentation tubing, air lines, and glass site tubes) are most prone to damage from seismic interaction. Inspection was performed in the area adjacent to and surrounding the equipment to identify any seismic interaction condition which could adversely affect the capability of the equipment to perform its intended function.

Generally, four seismic interaction effects were considered during Seismic Walkdown:

- proximity (impact of adjacent equipment or structures on safety-related equipment due to their relative motion during an earthquake);
- structural failure and falling of overhead or adjacent structures, systems, or equipment components);
- flexibility of attached lines and cables;
- flooding due to earthquake-induced failures of tanks or vessels

It should be noted that the decision on significance of the seismic interaction for the component seismic capacity in each case was taken on the basis of the SRT Judgment and Engineering Experience according to the GIP procedure general principles.

Equipment Class Evaluations

The equipment must be similar to the equipment of the earthquake experience equipment class or to the generic seismic testing equipment class and must also meet the specific requirements for that class of equipment in order to apply the seismic capacity defined by the earthquake experience Reference Spectrum. If equipment-specific seismic qualification data is used, then specific restrictions or requirements for that qualification data apply instead.

For example: among inspected Motor Operated Valves there were several instances, when the requirements for the valve operator cantilever length were not met. In such cases the following approach was implemented:

Since Floor Response Spectra for KNPP site are essentially lower than the Reference Spectra, a comparison of spectra provides much higher margin than the 30 % margin prescribed by DOE [2], so that for the length of valve's operator the following equation should be satisfied: $H \leq 1.3*HDOE$, where: H - Valve Operator Cantilever Length, HDOE - permissible length from the DOE Figure 8.2.2-3. Such evaluation was performed for all outlier cases and it was found that a resolution from the length scaling is applicable for the majority number of items ($H/HDOE \leq 1.3$), but for several valves this condition is not fulfilled. At the same time, according to DOE, the main concern related to these requirements (exceeding operator's length) is that longer operator lengths may lead to excessive stress in the valve yoke. In order to eliminate such possibility, it was recommended to restrain the valve operator in such cases. In several other instances valve's operator has already been restrained, thus the intention of this caveat also was met. Corresponding records with explanation for each specific case were included in SEWS as well.

Relay Functionality

This screening guideline is not applicable for the actual scope of the equipment's classes under consideration .

Outlier Identification and Resolution

Items listed in the SEL that do not meet the screening criteria contained in the Seismic Evaluation Procedure are considered as outliers (i.e., they lay outside the scope of coverage for the screening criteria) and should be evaluated further. An outlier may be shown to be adequate for seismic loads by performing additional evaluations such as the seismic qualification techniques. Methods of outlier resolution are typically more time consuming and expensive than the screening evaluations provided in the Seismic Evaluation Procedure. The most appropriate method of outlier resolution will depend upon a number of factors such as: (1) which of the screening criteria could not be met and to what extent, (2) whether the discrepancy lends itself to analytical evaluation, (3) how extensive the problem is in the facility and in other facilities, or (4) how difficult and expensive it would be to modify, test, or replace the subject equipment items.

The results of the walkdown were documented using Microsoft Access Data Base. All relevant photos were commented and linked to the corresponding components. Simultaneously any findings and observed seismic deficiencies were described and documented. Finally, Seismic Walkdown Sheets have been developed and collected for further reference.

The results of seismic qualification, depending on the further activities have been grouped into the following categories:

OK - component is seismically adequate;
EF - upgrading of "easy fix" type is needed;
NEF - upgrading of "not easy fix" type is needed;
AT - for seismic qualification of the component an additional analytical evaluation is required

Activities of type EF (“easy fix”) assume proposed future elimination of obvious component deficiencies (deviations from the original design) such as restoring lost bolts/nuts/washers, missing supports, insulation damages, etc. and/or component relatively easy fixing in-situ.

Activities of the "NEF" ("not easy fix") type as a rule are connected with elimination of possible seismic interaction effects, which may require changes in the existing system environment and/or its layout. As an alternative to the abovementioned, a special analysis could be performed to verify the sufficient component seismic capacity.

Recommendations of the "AT" (analysis) type as a rule were given in a situation when it was not possible to define measures providing seismic capacity by only a GIP walk down procedure, and a special, more sophisticated analysis should be performed to resolve the issue.

For a number of components such analysis may allow to avoid performance of "EF" and "NEF" type activities associated with some structural changes that could be much more expensive than the analysis itself. The final decision in these cases could be considered and approved on a cost effective basis.

The following figure shows the percentage distribution of the results of seismic qualification in terms of the proposed classification.

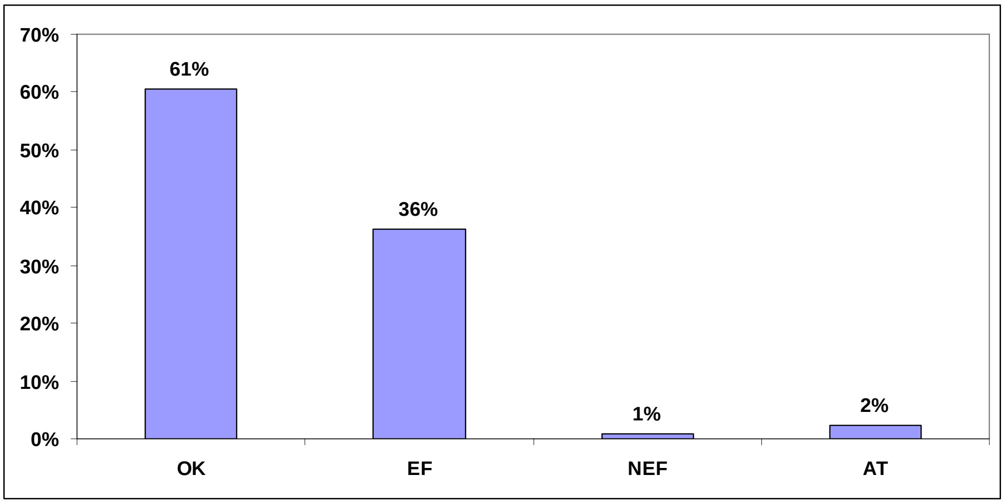

Figure 2. Results of seismic qualification with use of indirect method.

SEISMIC QUALIFICATION BY ANALYSES

Seismic qualification of Heat exchangers

In the list of equipment for seismic qualification by analyses two types of heat exchangers are included. They belong to two recirculation systems and are situated in the Reactor building on elevations -4.20m and +6.60m. These systems do not function under normal operating conditions. The heat exchangers are connected to ventilators and are used to cool the air in the rooms of the emergency core cooling system, the rooms of the ventilation boxes and the hermetic penetrations. For cooling both systems service water is used with temperature not more than 33ºC. The heat exchangers are arranged in groups by two supported by steel beams anchored in concrete foundation. The steel beams that support the heat exchangers are of different profiles and heights. Drawings of the supports anchorage in the concrete foundations are not available. This was one of the reasons to conclude that the heat exchangers could not pass the seismic qualification with the existing condition of the supports.

For the purposes of the analyses finite element models of the two types of heat exchangers were generated based on data collected mainly during walk-downs and from available drawings. The steel supports and part of the external pipes that convey the service water to and out of the heat exchangers were also included in the FE models. To account for the missing part of the external pipes different boundary conditions were imposed at the ends of these pipes. The most unfavorable boundary conditions were chosen for the analyses. The exchangers that are mounted on the highest supports and the configurations of external pipes with highest position were analyzed.

General view of the model is shown in Fig. 3

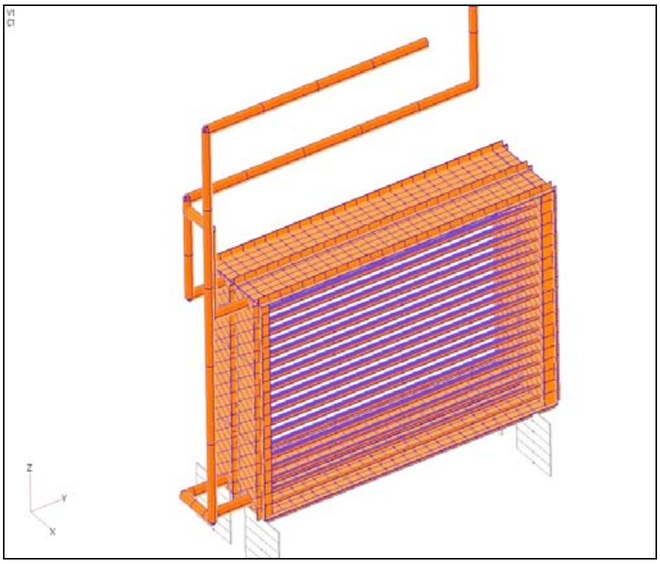

Figure 3 – General view of the model

The dynamic behavior of the heat exchangers was studied using Eigenvalue analysis followed by shock spectrum analysis. The dynamic loading was represented by floor response spectra in three directions. The RMS modal combination method was applied to calculate the response values. The first natural frequencies of the heat exchangers without the external pipes are: 10.067 Hz for the „small" type heat exchangers on elevation +6.6m, and 4.765 Hz for the „big" type on elevation -4.20. The weight of each of the „small" type exchangers in the group is 1.37 kN, and the weight of each of the „big" ones is 3.59 kN. The results show that the heat exchangers are relatively stiff structures and their first natural frequencies are below the maximum values of the floor spectra. The resulting stresses in the steel supports and connections between the steel supports and the equipment are low.

Presence of badly implemented connections between the heat exchangers and their supports, and even missing bolts between the heat exchangers and the supports were the next reasons to conclude that the heat exchangers cannot pass the seismic qualification. The main conclusion of the analyses for seismic qualification of the heat exchangers is that due to lack of data for the anchoring of the supports in the foundation and not adequate connection between the supports and the equipment, the heat exchangers at the present state cannot be qualified. In the next stage of the project upgrading the supports and connections thereof will be developed.

Seismic qualification of Penetrations

Eight penetration types in total were considered during the qualification process, with diameter of the main pipe varying from 50mm up to 600mm. The penetrations are grouped in types depending on the diameter of the corresponding pipes and the load conditions in terms of pressure and temperature of the transported fluid.

Numerical modeling and analysis procedure

The same modeling principles have been used for all penetrations. Shell finite elements are used for modeling the pipe type elements of the penetration corpus and the anchoring plates. For penetrations, where the transmission zone between the external and the internal pipe is very large and with varying pipe wall thickness and can not be modeled accurately with shell elements, solid finite elements are used to fill the gap between the external and the internal pipe. Solid finite elements are used also for modeling of the surrounding concrete, whose thickness is assumed to be four times the length of the anchor plates. The reinforcement in the concrete section is neglected during the modeling. The effect of the post-tensioning of the containment over the stress condition of the concrete is also neglected. Ideal contact between the steel elements of the penetration corpus and the concrete section is assumed. The fraction of the steel liner corresponding to the modeled zone is also included in the model and is subject to assessment during the penetration qualification. The boundary conditions are in the form of fixed translational degrees of freedom in all nodes on the external contour of the surrounding concrete. Linear static analyses are used for the seismic assessment of all penetrations. An example of penetration numerical model is presented in Fig.1.

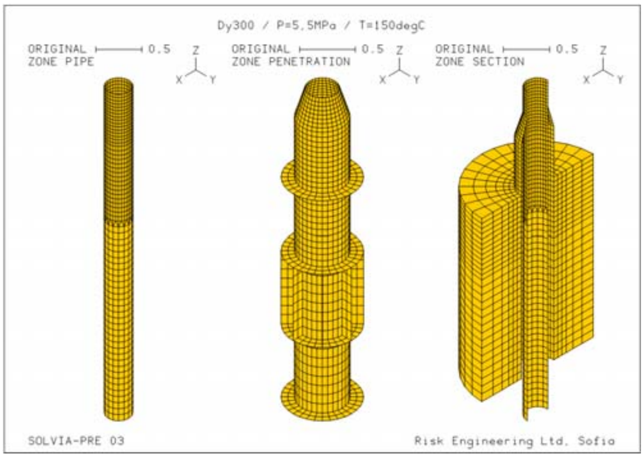

Figure 4: Numerical model of penetration for process pipe, with diameter 300mm.

Materials and allowable stresses

The penetrations are implemented using high-strength steel. The steel classes are in compliance with the Russian codes [7] for nuclear related components and the following steel types have been used: Steel 08X18H10T, Steel 20 and Steel 12X18H12T. The ultimate stress varies from 353MPa (Steel 20@350ºC) to 520MPa (Steel 08X18H10T@350ºC), depending on the steel type and temperature conditions. The allowable stresses are in compliance with the ASME Appendix F for stress category D [1].

The mechanical characteristics of the concrete are based on *in situ* and laboratory testing of concrete samples, performed in year 2008 for the needs of another project related to containment capacity assessment. The dynamic concrete tensile strength is derived from the measured compressive strength using the formulae of Rafael. The following strength characteristics are used: 49MPa compressive and 6,5MPa tensile strength for the penetrations through the base plate on level +13,20 and 40MPa compressive and 5,5MPa tensile for the penetrations through the cylindrical walls of the containment.

Loads and load combinations

In principle, the penetrations are analysed for the load combination of self weight, internal pressure on the internal pipe and a set of three forces and three moments corresponding to the reactions of the corresponding pipelines. The reaction loads are derived from the available analyses of the corresponding pipe lines for the combinations including earthquake loadings. Each loading set represent the loading conditions of one load combination for one safety system. Since there are three channels of each safety system and since one penetration type is generally used for several safety systems, the resulting load combinations could reach up to 164 for one single penetration type.

Capacity assessment

The penetration capacity is assessed through comparison of the Von Misses stresses in the penetration corpus obtained through the analyses and the maximum allowable stresses. Since, the welds are through the whole element thickness they are assumed, with equal strength, with the main steel material. Therefore, no additional verifications of the welds are performed. The capacity of the concrete section is verified through comparison of the obtained stresses, with the compressive and tensile strength.

Table 2: Results obtained for penetration to process pipe, with diameter 200mm

ZONE	ELEMENT	COMBINATION	STRESS	STRESS LIMIT	D/C
Process Pipe	9957	C30	308563	412000	0.75
Corpus	883	C85	152904	412000	0.37
Liner	12040	C74	5795	410000	0.014
Concrete [compression]	3659	C74	3321	49000	0.07
Concrete [tensile]	3650	C52	3299	6510	0.51

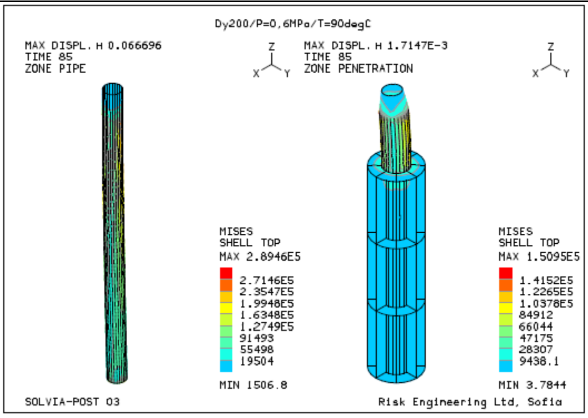

Fig.5: Analysis results of penetration for process pipe, with diameter 200mm – process pipe and corpus

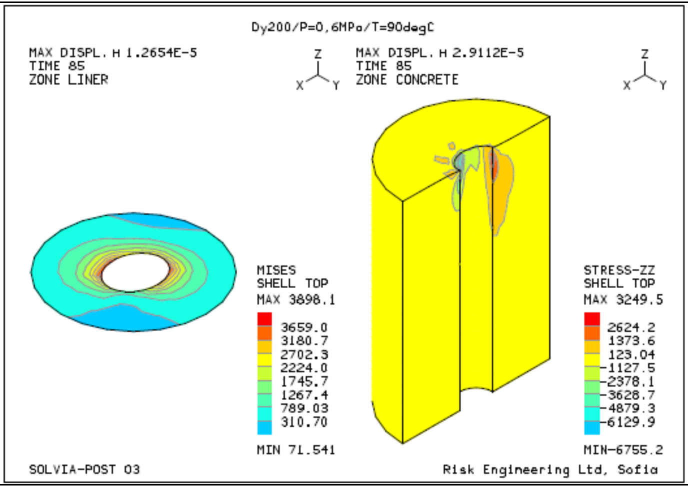

Fig.6: Analysis results of penetration for process pipe, with diameter 200mm – liner and concrete section.

CONCLUSIONS

Seismic qualification of safety shutdown equipment in operational WWER 1000 type NPP – Motor operated valves, Fans, Chillers, Cable traces, Heat exchangers and Penetrations was presented.

The equipment was qualified by engineering judgment based mainly on the Generic Implementation Procedure conformable to WWER peculiarity and numerical analysis.

The seismic input was determined on the basis of floor response spectra, considering the as-built conditions. For each component of SEL a conclusion was drawn regarding seismic adequacy. As a result 61%of the components qualified by engineering judgment were qualified, 100% of the penetrations. All Heat exchangers need upgrading of the supporting structures. For non-qualified components measures for seismic qualification were outlined.

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