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UNIVERSAL SEISMIC QUALIFICATION OF HIGH VOLTAGE SF6 GAS INSULATED METAL-CLAD SWITCHGEAR EQUIPMENT

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SUMMARY

In order to upgrade the standard design of Gas Insulated Switchgear (GIS) plants to withstand seismic loading, firstly universal qualification criteria are developed that may allow to assess the safety of the equipment under any specific national seismic qualification criteria. For this, a Reference Normalized Safety Factor, based on the responses of the equipment to a seismic disturbance characterized by the Standard Envelope Floor Design Response Spectra, is established. Mathematical models of the upgraded GIS plant are analyzed using the most widely accepted dynamic seismic analysis procedures. The results indicate that the upgraded GIS plants can be qualified under severe seismic conditions.

INTRODUCTION

The fast expansion of the market for the high voltage, SF6 Gas Insulated metal-clad Switchgear (GIS) equipment, manufactured by SPRECHER ENERGIE AG (SE), Oberentfelden - Switzerland, in the countries located in the most seismically active regions of the globe, leads SE to conduct a research program for upgrading the seismic capability of GIS plants to a level that can satisfy the requirements of those countries. EMCH + BERGER BERN AG (E+B), Bern - Switzerland, has performed the necessary seismic qualification analysis on behalf of SE.

In the following sections, the seismic qualification activities performed on the B212-GIS plants, comprising the development of generalized seismic qualification criteria, the selection of appropriate seismic analysis methods and the results of the dynamic analysis performed are presented as a summary of the analysis report (Ref.1) submitted to SE.

B212 RANGE OF GIS PLANT ARRANGEMENTS

SE has developed a modular system to provide utmost flexibility in satisfying the wide-ranging requirements of different clients in the most economical fashion. The range of modular components has been carefully selected to permit virtually any desired switchgear layout by appropriate combination of modules. Desired layout is selected according to service conditions, and may be extended in stages as service conditions demand. B212-GIS plants can be arranged and operated as single or multiple bays. Modifications to the modular bay units can easily be achieved. With reduced space and footing area requirements, B212-GIS plants are comfortably housed in appropriate buildings, even underground.

DEVELOPMENT OF SEISMIC QUALIFICATION CRITERIA

Since, the B212-GIS plants are universal equipment for all types of power plants ranging from conventional to nuclear power plants, and SE has a worldwide market, it is desirable to seismically qualify the B212-GIS plants under all realistically probable combinations of local conditions and design requirements. This can only be achieved by developing universal seismic qualification criteria covering regulatory requirements, realistically enveloping all site and structure dependent factors, and also allowing to assess the margin of safety of the B212-GIS plants under specific conditions. Such universal seismic qualification criteria can be based on the following design principles:

- Analysis procedures follow the most widely accepted codes and regulations, such as IEEE Standards, USNRC Standard Review Plan and associated Regulatory Guides.
- A set of horizontal and vertical Standard Envelope Floor Design Response Spectra (SEFDRS), which realistically envelope all site and structure dependent factors, are employed as seismic loading.
- The equipment behaves linearly under seismic disturbances combined with dead load and other normal operational conditions.
- Quasi-ultimate load bearing capacities of the structural elements are determined considering that the maximum stress just reaches to the yield stress, however, not permitting any further plastic deformation.
- For the structural elements, Normalized Safety Factors (NSF) are calculated as the ratio of quasi-ultimate load bearing capacities to the maximum combined element forces.

The resultant minimum NSF calculated for all elements represents a Reference Normalized Safety Factor (RNSF) of the equipment under seismic loading defined by the SEFDRS. Once the RNSF of the equipment is determined, the seismic qualification of the equipment for a specific type of power plant and specific local conditions, e.g. site seismicity, foundation soil and support structure, can easily be achieved. For this, the RNSF is multiplied by the ratio of the corresponding ordinates of the SEFDRS and the Required Response Spectra (RRS) at the dominant frequency range, then the resultant Actual Safety Factor (ASF) is compared with the Required Safety Factor (RSF) specified by the regulatory authority of the specific country. In this context, the RSF is interpreted as the ratio of yield stress to the maximum allowable stress for the load combination including the seismic loading.

STANDARD ENVELOPE FLOOR DESIGN RESPONSE SPECTRA (SEFDRS)

For dynamic seismic analysis using the Response Spectrum method, earthquake loading is defined by horizontal and vertical Floor Design Response Spectra (FDRS), that can be developed by means of comprehensive dynamic analysis performed on the specific supporting structure, considering the site seismicity and local foundation soil conditions. Once the FDRS are developed for the floor where the equipment is located, the damping capacity of the equipment completes the necessary information required for the definition of the seismic loading.

Since, none of the design parameters involved in the development of the FDRS can be predetermined definitely, such a site and structure specific FDRS can not serve as a firm basis for a universal seismic qualification procedure as described in the previous section. What is needed is a sort of standard envelope FDRS which covers the probable range of variation of the design parameters in a realistic way. As a matter of fact, a methodology to develop such a SEFDRS is presented in (Ref.2), and the feasibility of its application is demonstrated. Applying this methodology with the following design parameters and assumptions, a set of SEFDRS is developed:

- Considering the trends in the development of the seismic qualification criteria in the U.S.A. (Ref.3), a ground motion with ah = 0.5 g is selected as the reference earthquake. Additionally, av = 0.33 g is assumed (2/3 of ah).
- A broad band DRS, such as given in USNRC R.G. 1.60, is selected to completely define the earthquake ground motion.
- The B212-GIS plants are usually installed either directly in the open air on simple basemats, or on the slab of the basement or the lower floors of low-rise buildings. Taking into consideration the effects of soil-structure-interaction and dynamic behaviour of the supporting structure, the following amplifications are assumed at the lower floor levels where the B212-GIS plants are installed:
  . For maximum horizontal acceleration : 1.5
  . For maximum vertical acceleration : 1.3
  Accordingly, the maximum floor accelerations become:
  . afh = 1.5 ah = 0.75 g
  . afv = 1.3 av = 0.43 g
- The B212-GIS plant mainly consists of large diameter pipes (250 to 300 mm) and steel support structures, all joined to each other by bolted connections and flanges. Considering the recommendations of USNRC R.G. 1.61, a damping ratio of 3 % is selected as an overall equivalent modal damping ratio for the B212-GIS plants.

The resultant horizontal and vertical SEFDRS developed using the procedure recommended in (Ref.2), are shown in Fig.1. These SEFDRS are used as the reference seismic input for the qualification analysis of the B212-GIS plants.

PRELIMINARY SEISMIC DESIGN ACTIVITIES

Among the wide variety of modular B212-GIS plant arrangements, firstly a representative critical arrangement is selected for the seismic qualification analysis. This arrangement shown in Fig.2, has all possible heaviest components, the most possible number of multiple busbars, long and flexible connection pipes, and air bushing outlets with adverse connections.

Preliminary upgrading investigations carried out on this selected plant arrangement have shown that the original B212-GIS plant which is designed only for dead loads and other operational condition, requires important modifications and /or additions to the supporting elements. Such modifications and additions to the main supporting frames are shown in Fig.3.

MATHEMATICAL MODEL OF B212-GIS PLANT

The structural system of the upgraded complete B212-GIS plant unit is idealized as a 3-D mathematical model consisting of concentrated masses and 156 beam finite elements (Fig.4). Each grid point of the model has six degrees of freedom, i.e., the whole model with 118 grid points, has totally 708 degrees of freedom. With the application of boundary constraints this number reduces to 648 .

In the case of multiple bay plants, the effects of interaction between the bays, i.e. the behaviour of the interconnection elements becomes of primary interest. Accordingly, the model of a 3-bay plant is achieved by combining 3 simplified unit models which are connected each other by means of detailed interconnection elements. This model shown in Fig.5 consists of 45 grid points and 84 beam elements and comprises totally 270 degrees of freedom.

RESULTS OF DYNAMIC SEISMIC ANALYSIS

50 modes are calculated for the single bay model covering a frequency range

up to 75 Hz, while 10 modes are found to be sufficient for the 3-bay model. Selected mode shapes are shown in Fig.6 and 7, respectively.

The results of the detailed dynamic seismic analysis carried out by using the response spectrum option of E+B's Program Package DYNAMIC, indicated that, the interaction between the bays does not cause high responses, except the struts between the busbars. Some of these struts experience slightly higher forces in the case of the multiple-bay model.

Detailed stress analysis are performed for the most critical element in each element group in order to determine the NSF for that group. The minimum of all NSF values, which is denoted as the RNSF, becomes the indicator to the seismic withstand of the equipment under SEFDRS. The RNSF for the B212-GIS plants is found to be 1.002 for a vertical pipe element. This characteristic value can be utilized to qualify the B212-GIS plants under any specific national seismic qualification criteria.

SAMPLE SEISMIC QUALIFICATION

In order to demonstrate the applicability of the procedures and results summarized in the previous sections, seismic qualification of the B212-GIS plants under Chilenian requirements is taken as an example.

CHILECTRA METROPOLITANA S.A. specifies the following seismic requirements for electrical and mechanical equipment and accessories (Ref.4):

- (2.2.2).....For lack of better information, the average spectrum, by G.W. Housner for El Centro, California, May 18, 1940 earthquake, may be used for the horizontal components. The same horizontal spectrum may be used for the vertical component, reducing the results by 50 % . A damping factor not greater than 2 % for the equipment shall be assumed.
- (4.2).......Allowable unit stresses for materials may be increased, but by not more than 1/3 when considering seismic action.

The first specification can be used to define the earthquake input, in terms of FDRS based on the average spectrum given by Housner for El Centro, May 18,1940 earthquake (Ref.5), following a similar procedure described above. The given earthquake has a peak horizontal ground acceleration ah = 0.33 g, which may create afh = 0.50 g maximum horizontal acceleration at the lower floor levels. With these assumptions, horizontal FDRS for 2 % damping is developed and shown in Fig.8 together with SEFDRS. Considering the dominant frequency band of 11 to 17 Hz, an average multiplication factor of 2.3 is determined as the ratio of ordinates of SEFDRS and FDRS. Accordingly, the ASF for the B212-GIS plants under Chilenian earthquake becomes ASF = 1.002 x 2.3 = 2.3 .

The second specification approximately corresponds to RSF = 1.3 , which is smaller than ASF. As a matter of fact, the ratio of ASF to RSF can be considered as an indicator to the reserved margin of safety of the B212-GIS plants under Chilenian requirements, ASF / RSF = 2.3 / 1.3 = 1.77 .

QUALIFICATION BY MEANS OF QUALITATIVE COMPARISON

Since some of the B212-GIS plant arrangements to be supplied by SE to Chile (Photo.1) have some structural differences than that of the referenced plant, the seismic qualification of these different plant arrangements is necessitated. The comparison of these different plant arrangements with the referenced plant shows that, these differences either cause only minor local vibrations not disturbing the overall behaviour of the plant, or they are some structural differences due to the space requirements, which are found to be adequate for seismic resistant design. Accordingly a qualitative comparison is found to be sufficient for the seismic qualification of these different B212-GIS plants. For this firstly, the criteria for the qualitative comparison are established (Ref.6), then the important structural differences in various plant arrangements are identified and the measures taken to satisfy the criteria are described.

The results of the qualitative comparison of the different B212-GIS plant arrangements with the referenced plant show that, all B212-GIS plant arrangements supplied by SE to Chile are as safe as the referenced plant arrangement and have not any critical structural element that may fail during earthquakes specified by CHILECTRA METROPOLITANA S.A., i.e. they are seismically qualified.

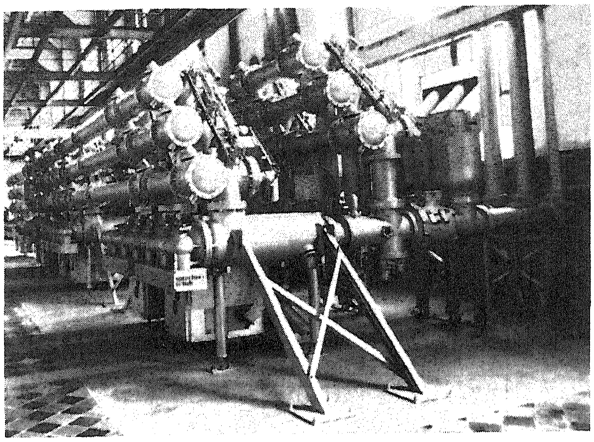

Photo. 1 B212-GIS Plant Arrangement at San Cristobal Substation in Santiago, Chile

CONCLUSIONS

A general design procedure has been developed for universal seismic qualificaton of equipment. For this purpose specific SEFDRS are developed. This universal design procedure is succesfully applied for the seismic qualification of the B212-GIS plants. The margin of safety determined under e.g. Chilenian conditions indicates that the B212-GIS plants can be qualified under even severer seismic conditions than in Chile.

ACKNOWLEDGEMENTS

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REFERENCES

1. Ermutlu, H.E., "Seismic Qualification of B212-GIS Plants", Emch + Berger Bern AG, Report No. 01'85'202, (1986).
2. Tsai, N.C. and Tseng, W.S., "Standardized Seismic Design Spectra for Nuclear Plant Equipment", Nuclear Engineering and Design, 45, 481-488, (1978).
3. Klopfenstein, A., Conway, B.J. and Stanton, T.N., "An Approach to Seismic Evaluation of Electrical Substations", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-95, No.1, 231-239, Jan./Feb., (1976).
4. Chilectra Metropolitana S.A., "Seismic Action on Electrical and Mechanical Equipment and Accessories", Annex to Technical Specifications No.41, (1985).
5. Housner, G.W., "Vibration of Structures Induced by Seismic Waves", in Shock and Vibration Handbook, ed. Harris and Crede, Chapter 50,McGraw-Hill, (1961).
6. Ermutlu, H.E., "Seismic Qualification of B212-GIS Plants - Addendum No. 1", Emch + Berger Bern AG, Report No. 01'85'202, (1986).

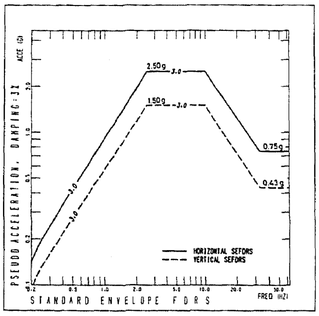

Fig. 1 Standard Envelope Floor Design Response Spectra

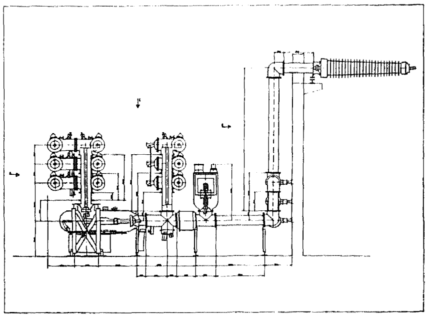

Fig. 2 General View of the Upgraded B212-GIS Plant

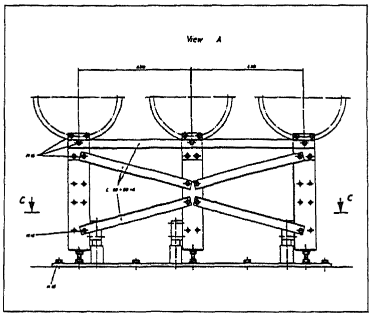

Fig. 3 Details of Upgraded Rear Footings

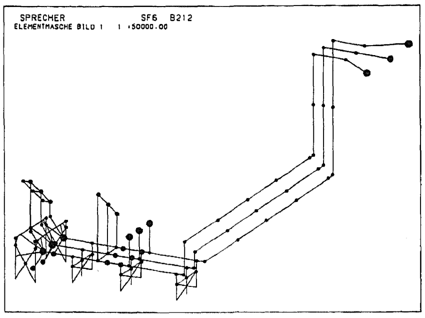

Fig. 4 Structural Model of B212-GIS Plant Unit

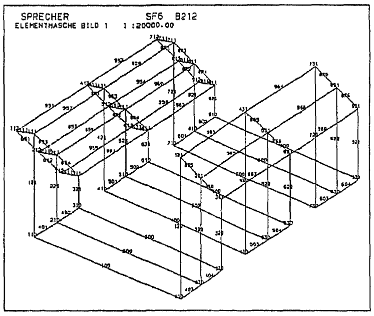

Fig. 5 Structural Model of 3-Bay Units

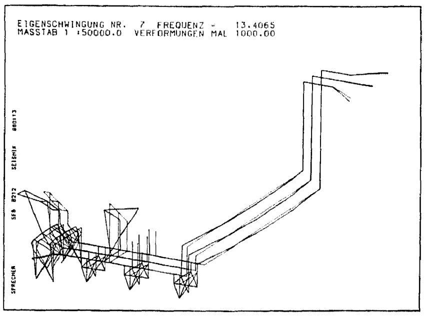

Fig. 6 Mode Shape of Single-Bay Model

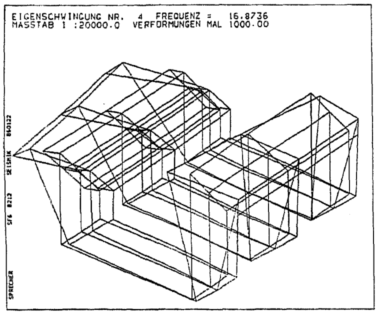

Fig. 7 Mode Shape of 3-Bay Model

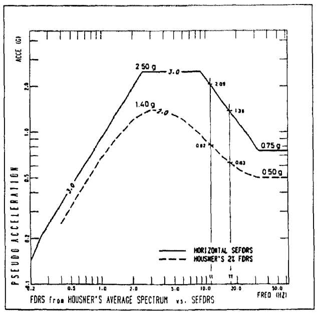

Fig. 8 Comparison of FDRS from Housner's Average Spectrum with SEFDRS