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DYNAMIC ANALYSIS OF STEAM GENERATOR INTERNALS FOLLOWING FEED WATER LINE BREAK / MAIN STEAM LINE BREAK

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ABSTRACT

Dynamic structural analysis of steam generator internal components was done for postulated accident events. The analysis was performed using simplified dynamic load factor method. Flow distribution plate was analysed using mode superposition method also.

1 INTRODUCTION

In order to evaluate the possible release of radioactivity in extreme conditions, some accident events are postulated and analysed during the design stage of Steam Generator (SG) of 500 MWe Indian Pressurized Heavy Water Reactor (PHWR). The most important of them are Feed Water Line Break (FWLB) and Main Steam Line Break (MSLB). In both these events there would be rapid depressurization of SG vessel and its internal components would experience rapidly time varying pressure and/or drag forces. It was assumed that FWLB and MSLB do'nt occur simultaneously. The radioactivity release can be due to failure of U-tubes (carrying radioactive heavy water), directly due to transient forces caused by FWLB/MSLB. It is also possible that after FWLB/MSLB the failure or excessive deformation of adjacent internals, may cause damage to U-tubes. Another important aim was to ensure the structural integrity of other internal components.

2 INTERNAL COMPONENTS OF SG MODELLED AND ANALYSED

Fig.1 shows the cut away view of SG along with the relative locations of these components. The moisture separators and flow distribution plate is fabricted from DIN17440-1.4550 and U-tubes from Incoloy-800. Remaining all components are fabricated, primarly from DIN17155-15Mo3, [1]. Internal components of SG modelled and analysed are listed below.

(a) Shroud Vessel-Separator Deck Plate-Separator Assembly
(b) Feed Water Ring Header Assembly
(c) Steam Drier Assembly
(d) Flow Distribution Plate Assembly
(e) Primary U-tubes

Finite element method was used for the analysis. Plate/shell and beam/pipe elements were used to model these components. Some of the components modelled are shown in Fig.2 through Fig.4. Flow distribution plate assembly is shown in Fig.4a, steam drier assembly in Fig.3 while Fig.2 shows feed water ring header assembly. The detailed modelling aspects of all the components are discussed in ref.[2]. The perforated flow distribution plate and steam plate in steam drier were modelled using well known concept of equivalent solid plate, [3]. In case of flow distribution plate where limit analysis could'nt be avoided (since, stresses based on elastic analysis were high), additional plastic constants were used in equivalent solid plate model inorder to accurately predict initiation and progress of plastic front, [4].

3 GENERAL ANALYSIS PROCEDURE

Analysis was done for the conditions leading to the accident of maximum potential. These are :

(a) 100% feed water line break at 100% power - for FWLB
(b) 100% steam line break at 0% power - for MSLB

These events are normaly classified as Level D service load, as per ASME Sec III NB, [5]. The dynamic structural analysis was done using simplified Dynamic Load Factor (DLF) method, [6]. In case of flow distribution plate, analysis was done using mode superposition method also. The assessment of structural integrity was done based on ASME Sec III Appendix F. Deflection was also checked in order to ensure that any component vibrating during the accident, should'nt interfere with adjacent components.

3.1 Analysis by Simplified DLF Method

DLF v/s structural natural frequency curve for a particular component can be obtained from its corresponding load function F(t), by solving Duhamel's Integral for the single degree of freedom (SDOF) system, [6]. Here load function F(t) implies pressure/drag force-time history. DLF is defined as -

$$DLF = Y(t)max/Yst \qquad \ldots (1)$$

Y(t)max is maximum response for SDOF system obtained from the solution of Duhamel's Integral and Yst is static response corresponding to maximum pressure in F(t). The load function F(t) is represented as F(t) = P.f(t). Where P is load factor corresponding to maximum magnitude of pressure or drag force in time history and f(t) is normalised load function with respect to P. Hence, peak value in load function f(t) gets normalised to unity and Yst is corresponding to P.

For a particular structural natural frequency and damping ratio Duhamel's Integral was solved to obtain response v/s time output, Y(t). Then eq.1 was used to calculate DLF value for the given natural frequency and damping ratio. This calculation was repeated for various values of natural frequencies while keeping the damping ratio constant. Hence, DLF v/s natural frequency curves were obtained for the given values of damping ratios. Fig.4c & 4b show pressure time history during MSLB and corresponding DLF curve for flow distribution plate.

If Yst is evaluated for load factor P then dynamic response can be estimated by multiplying Yst with spectral peak DLF value (see eq.1). The peak DLF value was chosen in order to eliminate the uncertainties involved due to approximations in time history calculations and structural modelling. This procedure will definitely yield the most upper bound values of dynamic response. The damping values used were corresponding to the operating basis earthquake given in ASME Sec III Appendices. In case when stresses are near the yield stress value then safe shut down earthquake damping values were used.

3.2 Analysis by Mode Superposition Method

As pointed out earlier that flow distribution plate (which is basically a perforated semi-circular plate) was analysed using mode superposition method also. The stresses calculated based on simplified DLF method were very high. However, it was qualified based on collapse load calculation by limit analysis, [5]. Mode superposition method is widely described in literature e.g. see ref. [7]. During the accident the internal components are submerged in water or steam. Hence, the effect of fluid forces has to be considered. This effect was taken into account by hydrodynamic added mass approach, [8]. In which the effective mass of the plate is increased by an amount equal to the hydrodynamic added mass and there by altering its natural frequency. Its added mass was evaluated using an empirical relation given in ref. [9]. There are always some uncertaintities involved in it since during the transients, added mass will change with time. In the present case the value of added mass considered was such that it will lead to conservative results.

For selecting the number of modes to be considered in the analysis, the magnitude of fourier coefficients of the given time history were evaluated at discrete frequencies. Fast fourier transform technique, [7], was used to evaluate the coefficients. The frequency at which the relative magnitude of these coefficie-nts becomes insignificant was chosen as the cutoff value.

3.3 Mode Superposition V/S Simplified DLF Method

Mode superposition method is more rigorous technique than simplified DLF method but there is some approximation in calculation of added mass value. If the components are modelled using plate/shell element then there is always the chance that numerical calculations may lead to many local modes of vibration, which will not significantly contribute to the overall response hence one has to evaluate many natural frequencies and mode shapes. Therefore, it is computationaly very expensive method specially when complicated structures are to be analysed. If the stresses induced in a structure are above yield stress then this method cannot be used. Analysis becomes more complicated for structures where geometrical nonlinearity is important. Whereas, in simplified DLF method one has to do static analysis and then multiply the results by peak DLF value. In static analysis geometrical and material nonlinearities can be easily incorporated. Above all DLF is computaionaly, very less time consuming. Needless to say that simplified DLF method will lead to conservative response and for more realistic results one has to adopt mode superposition method or other more rigorous techniques like direct time integration, [7].

4 RESULTS AND DISCUSSION

It was concluded that all the components are safe as per the ASME Sec III Appendix F allowable limits. The maximum primary stress values in components are given in Table 1. Structural integrity of flow distribution plate was ensured based on collapse load calculation by limit analysis since stresses based on elastic stress analysis were high. U-tubes will be safe hence, chances of radioactivity leakage during FWLB/MSLB are ruled out. In case of flow distribution plate the response based on elastic analysis by both the methods (simplified DLF and mode superposition) is nearly same. However, it may not always be true, in other situations simplified DLF method may lead to very conservative results.

5 REFERENCES

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TABLE 1. PRIMARY STRESSES (in Kg(f)/sqcm) IN SG COMPONENTS

COMPONENT	FWLB	MSLB	ALLOWABLE
Shroud Vessel	2585.2	1623.2	4002.6
Separator Deck Plate	170.3	2047.1	4002.6
Moisture Separator	326.6	509.1	3585.8
Steam Plate of drier	381.9	888.6	4002.6
Bottom Plate of drier	546.0	341.8	4002.6
Feed Water Ring Header	2358.8	255.5	4002.6
U-tubes	9.3	134.0	5298.3

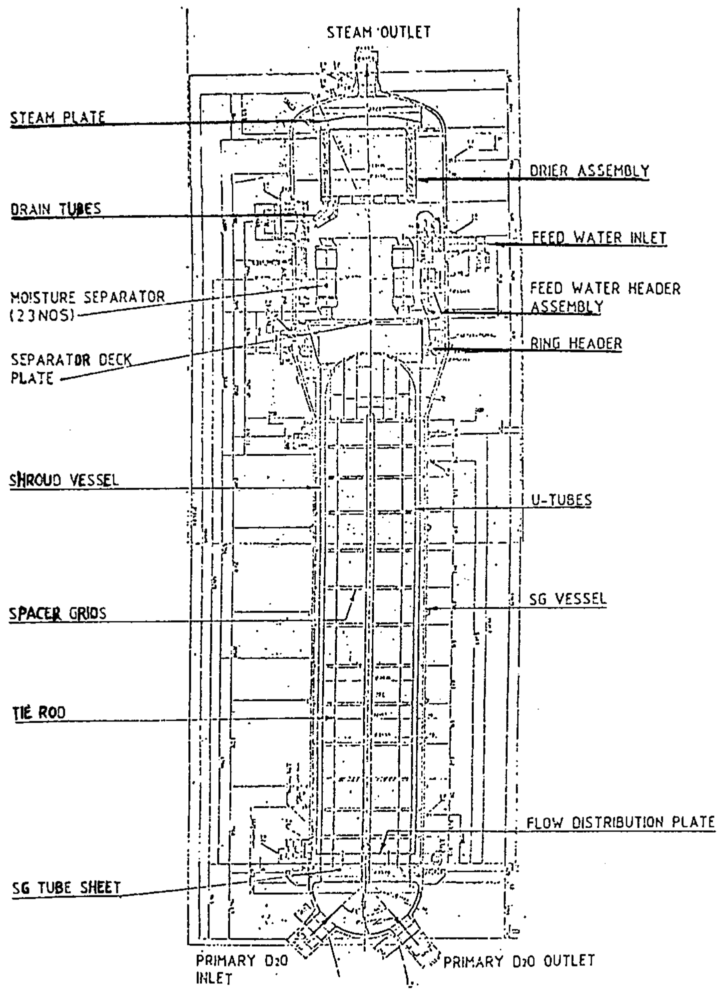

FIG.1: SECTIONAL VIEW OF STEAM GENERATOR.

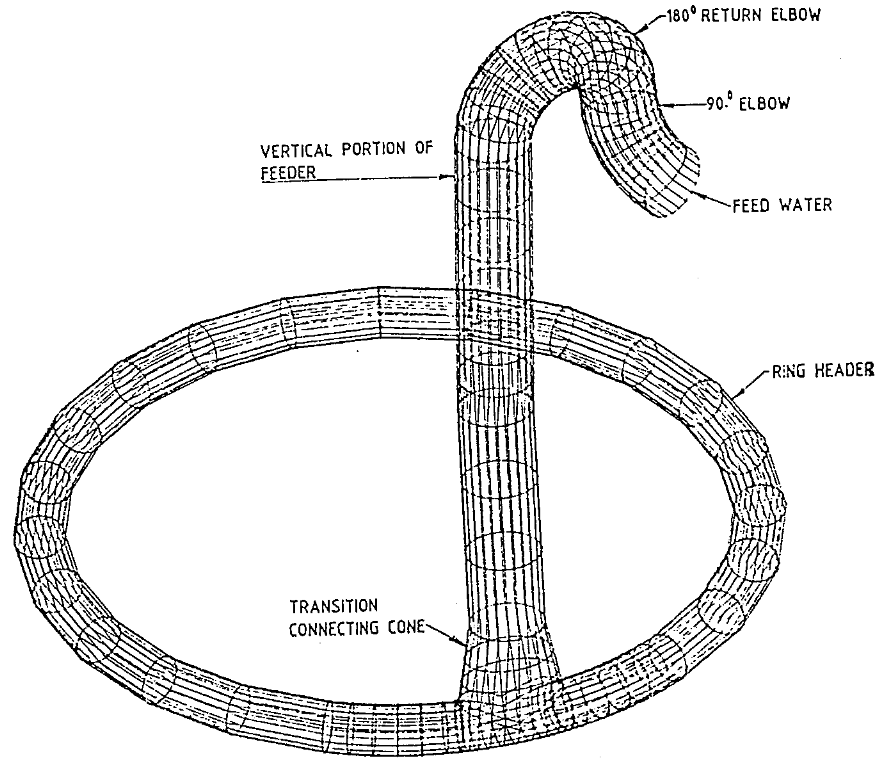

FIG. 2 : FINITE ELEMENT MESH OF FEED WATER RING HEADER

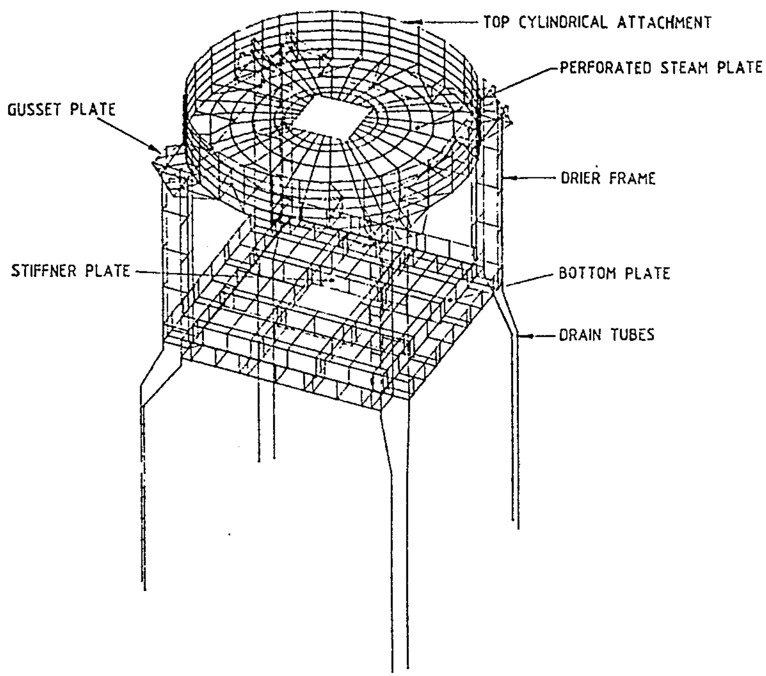

FIG. 3 : FINITE ELEMENT MESH OF STEAM DRIER ASSEMBLY

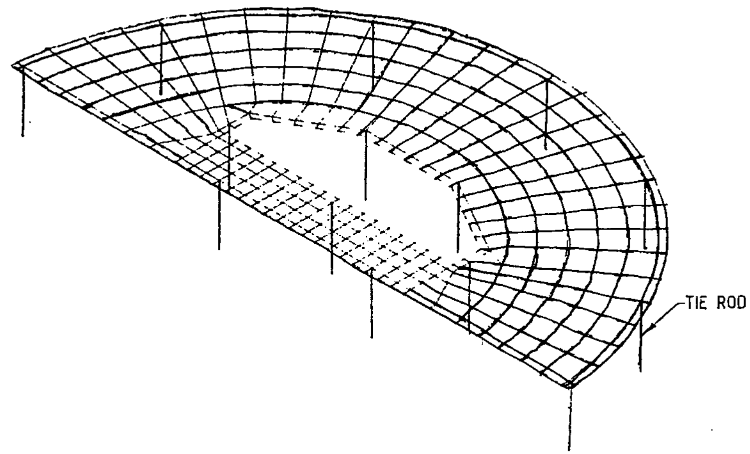

FIG. 4a : FINITE ELEMENT MESH OF FLOW DISTRIBUTION PLATE

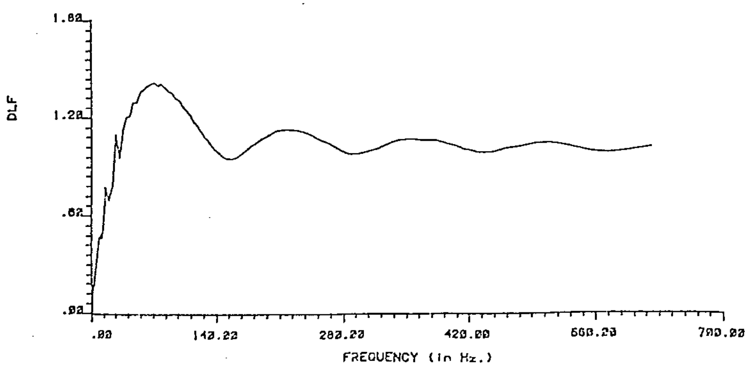

FIG.4b DLF CURVE FOR FLOW DISTRIBUTION PLATE - MSLB

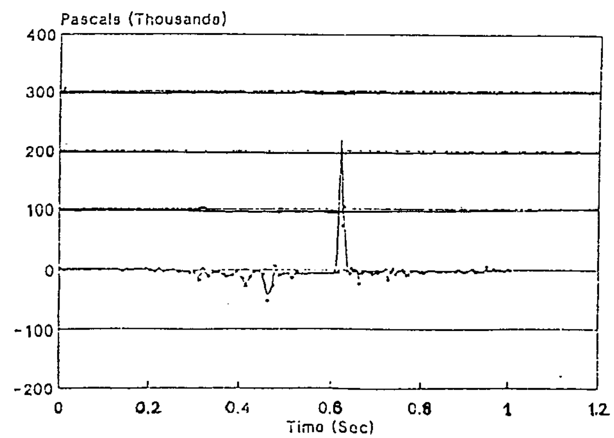

FIG.4c:Pr. TIME HISTORY ACROSS FLOW DISTRIBUTION PLATE-MSLB