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EFFECT OF SUPPORTING STRUCTURE STIFFNESS ON THE DRIVE TRAIN ASSEMBLY OF AN INDUCED DRAFT COOLING TOWER UNDER SEISMIC EFFECTS

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ABSTRACT

In a nuclear power project an induced draft cooling tower, as a safety-related structure and part of the main cooling system, has to perform satisfactorily under designated seismic effects. While the structural elements can be designed by conventional methods to ensure adequate safety, the seismic qualification of the mechanical components poses a challenge. The paper describes a methodology adopted for the seismic qualification of a typical Drive Train Assembly for the axial flow fan of an induced draft cooling tower, to ensure the structural integrity and functional operability of the assembly during Operating Base Earthquake and Safe Shutdown Earthquake conditions. This is achieved by performing a detailed finite element analysis of the rotating equipment assembly consisting of the electric motor, gear box and fan along with the drive shaft between the motor and the gear box.

The various components are modeled using beam elements, plate elements and spring elements to idealize the flexible connections and supports. The floor response spectra derived from a dynamic analysis of the overall structure under stipulated seismic acceleration spectra are the main excitation inputs into the system.

The results validate the adequacy of gaps for movement and the strengths of the couplings and bolts to withstand the applied loads. The assumed modeling and analysis methodology are seen to be acceptable procedures for seismic qualification of important components of the cooling tower.

Key words: Seismic qualification, mechanical components, finite element analysis

1. INTRODUCTION

The cooling tower is an integral part of the heat removal system in any power plant. It is used for dissipation of heat from various heat exchangers handling active process water. The process water cooling pumps circulate cooling water from cooling towers to process water heat exchangers continuously. It is essential that all systems of the cooling tower should remain functional during normal operating and accidental conditions under earthquakes. This condition is all the more important for a nuclear power plant where continued functioning of the circulating water system under earthquakes may be vital.

An Induced Draft Cooling Tower (IDCT) is a reinforced concrete flexible 3-dimensional framed structure supporting the rotating equipment on top of the structure with the heat exchange media located below. The main element of the Air Drive chain in an IDCT is the axial flow fan which is mounted on a gear reducer. This unit is connected through a long drive shaft to a drive motor located outside the fan enclosure. For proper performance of the cooling tower under a severe seismic event, the performance of this air-driving unit is of importance.

2. SEISMIC QUALIFICATION AND STRUCTURAL INTEGRITY

For certain important and sensitive projects such as Nuclear Power projects the functioning of the IDCT is of vital importance and it has to be functional under all foreseeable and probable critical events. The intent of the seismic qualification is to ensure the structural integrity and functional operability of the fan motor assembly inside the Cooling Tower cells during Operating Basis Earthquake (OBE) and Safe shut down Earthquake (SSE). The seismic qualification of the drive chain is one important step in the process of ensuring uninterrupted performance of the cooling tower during a seismic event. The equipment assembly is mounted on the structure through a rigid base frame and anchor bolts. The RCC supporting structure imparts seismic motion to the mechanical equipment assembly and its stiffness properties are also relevant. The floor response spectra at the fan supporting level vary according to the total stiffness of the structure which is a governing factor for imparting the seismic effects to the equipment assembly. The qualification of the structure and the rotating equipment, whether passive or active, is performed by detailed finite element analysis to assess their intended function in terms of their structural integrity as per the requirements of governing codes.

3. SYSTEM DESCRIPTION

The Mechanical Equipment system consists of the following items: Axial Flow Fan, Gear Reducer, Drive Shaft, Drive Motor. A typical assembly view is shown in Fig.1&2 and the equipment are described below.

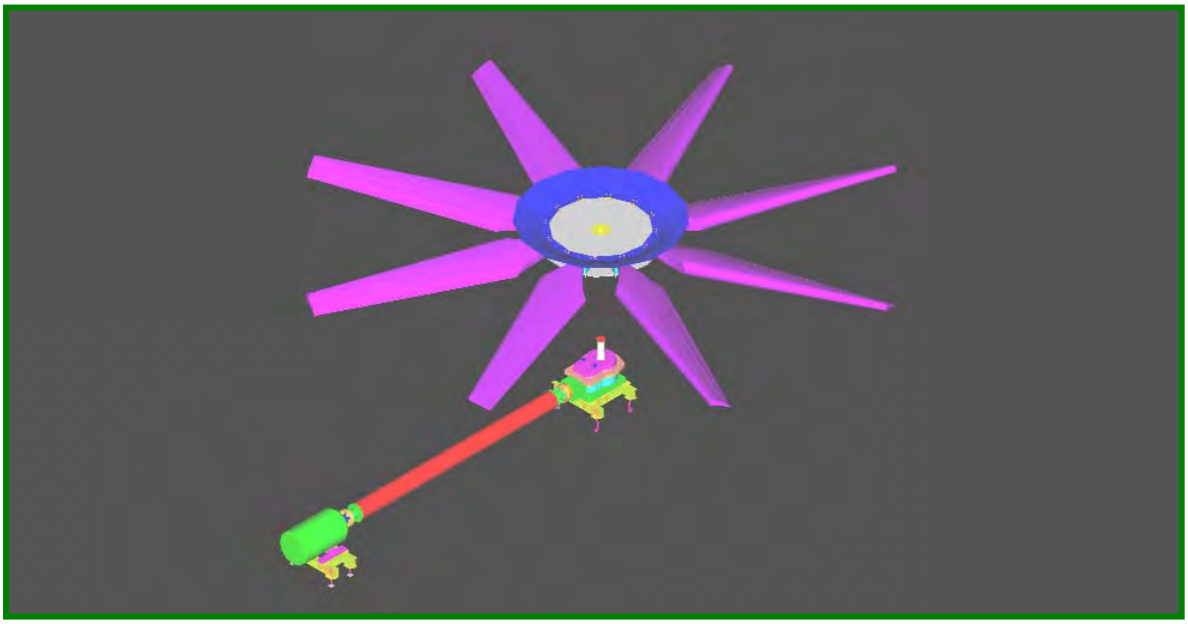

Fig.1. 3D View of Gearbox, Motor, Drive Shaft and Fan Assembly

3.1 <u>Axial Flow Fan</u>

Axial Flow Fan in a cooling tower is a large diameter, multi bladed, low speed rotating unit. The blades are made of Glass Fibre Reinforced Plastic (FRP) and the hub is made of galvanized steel. These blades are hollow inside and are of aero-profile shape. The blades are lightweight, corrosion resistant and of adjustable pitch type. The fan assembly is designed to lift a large amount of airflow against low resistance. Each blade can be mounted separately to the hub at the root location with the help of a blade clamp. SS304 Hardware is used to fix the blades to the hub using a blade clamp. The hub assembly is dynamically balanced and the blades are match moment balanced for smooth running of the fan unit. The clearance between the fan enclosure and fan blade tip is generally in the range of 35 to 50 mm. FRP Seal disc is provided on top of the hub to avoid recirculation or bypass of air through the fan. The fans are generally operated at 100 to 125 rpm with a natural frequency of about 5.0 to 5.5 Hz. Each blade weighs about 50kg with a total weight of the assembly of 400kg for an 8 bladed 9.0 m diameter.

3.2 Gearbox

The fan hub assembly is mounted directly on the output shaft of a double reduction bevel helical gear reducer through a flanged bush locked through a key. This unit is driven by an induction motor through a drive shaft. The drive shaft is connected to the input shaft of the gear reducer through couplings, which allow flexibility to a certain extent. The gearbox housing is made of cast iron grade FG.260. Input, intermediate and Output shafts are made of alloy steel while the gear teeth are made of case- hardened steel. The gear teeth on input shaft are of bevel type while the second stage teeth are of helical type. The gearbox is provided with lubricating oil, which by splashing lubricates while the gearbox is in operation. Two sets of taper roller bearings are provided at input, intermediate and output shafts mounted to the gearbox casing. The gearboxes are selected with a minimum mechanical rating of 2.0. The weight of the gearbox unit is about 750 kg.

3.3 Drive Shaft

Since the axial flow fan is of large diameter and since the motor could not be directly coupled to the gearbox, a long hollow floating drive shaft is provided to drive the axial flow fan. The drive shaft is made of stainless steel connected to end flanges. These flanges are connected to the motor output shaft at one end and to the gearbox input shaft at other end. The drive shaft is dynamically balanced in the shop as per ISO 1940 Gr. 6.3. The approximate weight of the drive shaft along with couplings is 170 kg and the critical speed is 2016 rpm. The rating of the drive shaft is generally two times the rating of the drive motor.

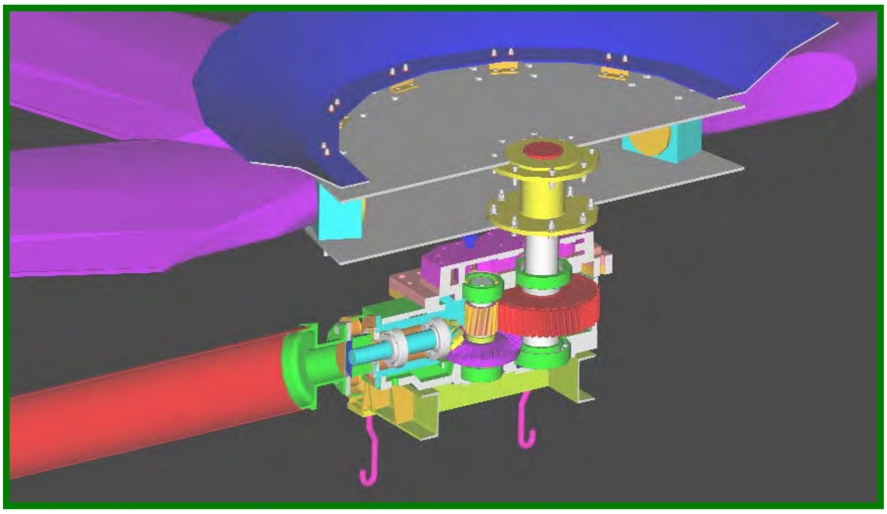

Fig 2. Sectional View of Gearbox and Fan Hub

3.4 Drive Motor

Each fan and gear assembly is driven by a three-phase squirrel cage induction motor installed horizontally outside the fan enclosure. The rotor shaft is mounted on two bearings resting on the stator. The stator / casing is fixed to the foundation through anchor bolts. The motor shaft rotates at a speed of 1480 to 1500 rpm and weighs approximately 600 kg (Stator – 360kg, Rotor-240 kg. approx).The Motor frame is made of cast iron and the Motor shaft of alloy steel (EN8).

3.5 Mounting / Fixing Arrangement

Both the gearbox and the motor are mounted on a hot dip galvanized base frame independently. The equipment are mounted on this base frame through bolts while the base frame is fixed to the structure through anchor bolts. Grouting is done between the base frame and structure after matching the centerlines of gearbox shaft, drive shaft and motor shaft.

4. ANALYSIS MODEL AND METHODOLOGY

4.1 General

A finite element dynamic analysis is performed to analyse the problem. The dynamic model of the assembly is developed in detail to the extent required for seismic qualification of the component parts. The effects of normal operating load conditions and the effects of imbalance in fan blades will be considered in the static and dynamic analysis. The seismic excitations due to SSE and OBE are derived at fan deck level from floor response spectra. The response spectrum method of seismic analysis is carried out on the model to assess the increase in stresses and displacements due to seismic effects in the fan assembly. The effect of unbalanced mass in the fan blade is considered in the analysis. Axial thrust load on the gearbox due to fan lifting the air required for cooling is also considered. The seismic effect is considered in the form of broadened Floor response spectrum at the deck level for the analytical model. Damping value of 3% for SSE is considered for purpose of the analysis.

4.2 The general steps involved in the qualification of the above equipment for structural integrity are;

(a) Preparation of the finite element model which represents the equipment adequately.
(b) Identification of the applicable loads / effects
(c) Determination the structural response for these loads in terms of forces, moments, displacements and stresses. The seismic response is determined by using response spectrum analysis / time history analysis and equivalent static analysis method.
(d) Combination of the seismic responses with operating stresses and displacements for various load combinations as specified.
(e) Comparison of the combined stresses and displacements with those that ensure compliance with design / codal requirements.

The general steps involved in the qualification of the equipment to meet functional responsibility are same as above. In addition, displacements of moving components are to be less than the clearances/gaps between the moving and stationary components like the RCC fan stack and the fan blades. The alignment of the shaft should be within the specified value. Reactions at the bearing locations are to be less than the specified bearing capacity.

The purpose of this analysis is to assess the increase in loads due to a seismic event at bearing locations, gear contact points etc. and also to determine the relative changes in translational and regular movements at these points. Based on this information, it is possible to assess whether the operating assembly fails due to overloading or ceases functioning during seismic events.

4.3 Basis of analysis

a All the components remain within limits of small displacement and linear elasticity and principle of superposition holds good.
b Frequency analysis is carried up to 33 Hz.

c Missing mass effects are accounted for.
d All components remain in contact with each other during a seismic event and gaps or openings are not considered in the analysis.
e The gyroscopic effects on the fan assembly due to rotations are neglected in this study and are not clubbed with seismic events.
f Loads are combined by SRSS method
g The electro magnetic coupling between motor rotor and stator is not considered as it is expected to be insignificant with respect to the overall response of the system.

Different systems are interconnected in transferring seismic motion from the base of the model to various effective components of the equipment assembly.

Since it is a linear model analysis, results of different load combinations are combined linearly for checking the adequacy of components.

4.4 Salient Features of the Idealization Model

- Software used : NISA
- Fan Assembly : Fan Blades as beam elements, Fan hub as plate elements
- Gear Box : Input and output shaft as beam elements, bearings as spring elements with associated stiffnesses, casing as plate elements, gear contacts as coupled displacements and base frame as beam elements
- Drive Shaft : Shaft as beam element and flanges as plate elements
- Motor : Stator and Rotor as beam elements, bearings as spring elements and base frame as beam elements
- Foundation bolts : as beam elements with lower end fixed inside the concrete foundation.

Different types of elements are used in the model to simulate the actual model to be nearest to the actual. The model of the assembly is developed for interconnection of parts of the rotating assembly for active transfer of seismic motion from base of the model to the effective components of IDCT fan assembly. The interfacing of equipment and structure i.e. foundation bolts are modeled as beam elements with their lower ends fixed to their foundations.

The stresses due to self weight, normal operating loads, maximum torque load and the efforts due to OBE and SSE are combined to check against allowable design stresses.

4.5 Floor response considered in the analysis

Two different floor response spectrums in X, Y and Z directions having two structural stiffness are considered in the analysis as shown in Fig. 3. The stiffness variation arises for the same structure having two different founding levels. The same ground motion is considered for both the cases for development of floor response spectra. These spectra were peak broadened to account for uncertainties in the analysis. The model considered is analysed for both the cases and salient results are analyzed.

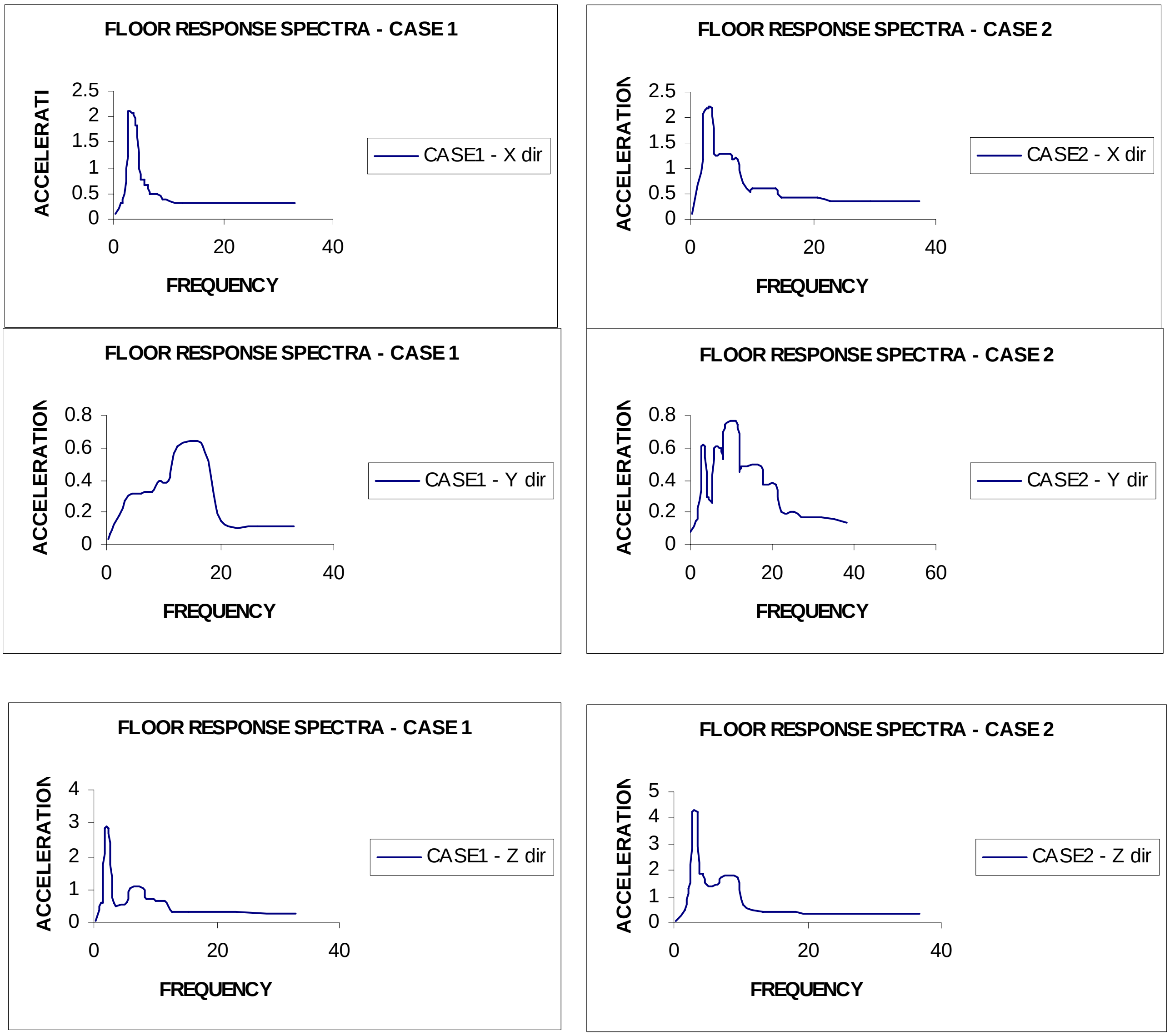

Fig. 3 : Floor Response Spectra

5. OBSERVATIONS

5.1 General

The assumed model has been successfully analyzed using a finite element software and results have been obtained in the form of mode shapes , frequencies of vibration in the various modes and stress resultants. Essentially, it is seen that the fundamental frequency of vibration of the mechanical assembly is well separated from the natural frequency of vibration of the structure and hence there is no danger of resonance. The frequency and mode shapes derived are generally seen to conform to expected patterns. The stress resultants obtained for the base connections of the mechanical assembly are within the acceptable safe capacities of the elements concerned. Similarly, the stress resultants derived for the couplings of the draft shaft assembly are also seen to be within permissible limits. With the above, the designer can derive sufficient confidence that the mechanical assembly is well capable of resisting seismic effects satisfactorily and that the cooling tower will function as required without any failure under the anticipated seismic events.

5.2 Mode Shapes

The observed mode shapes are shown in Fig. 4

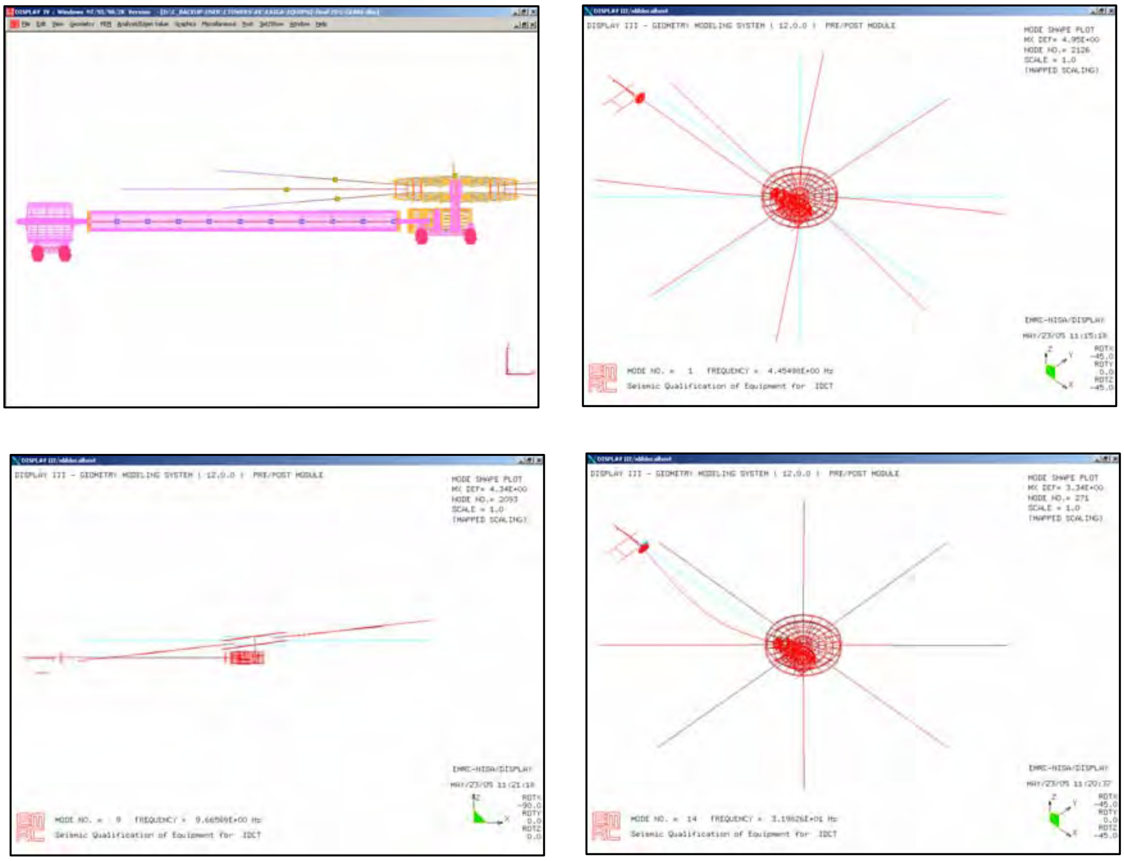

Fig. 4 Mode Shapes

5.3 <u>Salient Results for comparison</u>

Sl. No.	Description	Case 1	Case 2	Remarks
1	Horizontal Fan blade Tip Movement (mm)	17.30	38.15	To be checked for fan casing fouling
2	Relative movement of Gear teeth (mm)	0.019	0.038	To be checked for allowable limits
3	Axial thrust in bearings of Gearbox (kN)	21.05	34.73	To be checked for allowable limits
4	Radial thrust in bearings of Gearbox (kN)	23.30	24.03	To be checked for allowable limits
5	Max force in foundation bolts (kN)	8.50	11.91	To be checked for allowable limits

From the above table it is very clear that critical operating parameters listed above are sensitive to structural stiffness and ground motion

6. CONCLUSIONS

The paper describes the procedures used for the seismic qualification of an essential component, viz the air drive train assembly for an induced draft cooling tower for a nuclear power project. Though this is an unusual type of Engineering problem, the same requires a proper solution to ensure that the Cooling Tower is available for safe operations during anticipated severe seismic events. A finite element model has been assumed and the dynamic analysis performed using standard software. Innovative idealizations had to be worked out in the modeling of the complex elements without incurring very high computational difficulties. It is seen that the idealization, analysis methodologies and overall approach have yielded satisfactory solutions in order to establish the safety of the structure to the required extent.

It is seen that with this analysis, it is possible to assess the increase in loads at bearing locations, gear contact points and also to determine the relative changes in translational and regular movements at these points due to seismic events. Based on this information, it is possible to assess whether the operating assembly fails due to overloading or ceases functioning during seismic event.

The floor response spectrum generated from the support structure at the equipment support level is a critical input for such an analysis. Floor response changes with support structural stiffness. A study on the effect of IDCT structural stiffness (by changing the structural member stiffness) and its effect on the mechanical components is made for a typical case. This paper deals with a specific case study for better understanding of the behaviour of the whole system.

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